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THE TECHNOLOGY OF CRACK REPAIR BY POLYMER COMPOSITION

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Introduction. During the inspection of buildings and structures and development of design documentation for restoration works it was found that there is a need to provide recommendations or to develop solutions for repair work. These repair works either are not regulated by standards or may be technically or economically inefficient.

Problem Statement. The most common defect of the tension zone in reinforced concrete beams, floor slabs or roof slabs are cracks. Injection technology is normally used to repair it. However, in case of large number of small cracks, this technology is time consuming.

Purpose. Development of a new technology for repairing the tension zone of reinforced concrete beams, floor slabs or roof slabs with a large number of small cracks. This will ensure maximum filling of cracks with polymer compositions with their subsequent bonding.

Materials and methods. A number of factors that may affect the technology of filling cracks with polymer compositions have been identified from the analysis of scientific and technical literature. A special device ‘tray’ was produced for experimental research. It was attached to the lower zone by a system of ties or props. A repair mix to fill the cracks was fed into the tray under pressure. By means of changing the experiment conditions the strengthening level of previously destroyed samples were set.

Results. As a result, it was found that the maximum filling of cracks with the polymer composition is achieved within the 5-10 minutes of repair mix supply at a pressure in the system in the range of 0.5-0.6 atmospheres (atm). The maximum strengthening of the repaired structures under the re-applied destructive force was achieved at the conditions of repair work with a structural temperature of 20 ± 2 °C and dry state of the structure.

Conclusions. The technology of repair with polymer compositions of the cracks located on the lower surface of horizontal reinforced concrete structures has been developed. It was established that in the presence of small cracks on the structure (the width is up to 0.2 mm) the developed technology is most effective, in case of widths from 0.3 to 0.8 mm it is advisable to use injection technology whereas for widths larger than 0.8 mm the hybrid technology should be applied.

Keywords: reinforced concrete structures, cracks, polymer compositions, influence factors, soak technology.

During the inspection of buildings and structures and development of design documentation for restoration works it was found that there is a need to provide recommendations or to develop solutions for repair work. These repair works either are not regulated by standards or may be technically or economically inefficient. The analysis of scientific and technical literature indicates insufficient study or lack of research on a particular method of structural restoration work. Therefore, the theoretical and experimental research have been carried out. It was aimed to verify the effectiveness of existing design and technological solutions and, if possible, to develop similar solutions or to improve existing or to develop new solutions.

1. Problem statement

During the process of inspection of horizontal reinforced concrete structures of floors and roofs in the form of flat, ribbed and hollow slabs and beams it was found that one of the most common defects are cracks on the lower surfaces of structures. These cracks often appear along the bottom steel reinforcing bars.

Such defects often occur as a result of non-compliance with the technology of concrete works such as lack of proper attention to concrete in hot or winter conditions, smaller than standard protective layers, early remove of formwork etc. Moreover, cracks on the structures of floors (roofs) appear in the process of non-compliance with the rules of operation of building or structure [1, 2]. In particular, the influence of factors that occur during the operation of the building can provoke cracks on the surface of building structures. Such factors are overload, excessive dynamic influences, climatic influences that do not correspond to the design solutions, etc.

The appearance of cracks on the surface of building structure has a negative effect on its service life. This is due to the decrease of bonding between the reinforcement and concrete. Thereafter, air or moisture enters the reinforcement through a crack and it corrodes. Due to the increase in corrosion volume the stress in the concrete around the reinforcement increase and further breakdown of its fragments is possible. This reduces the cross section of the reinforcement and, hence the load-bearing capacity of structure.

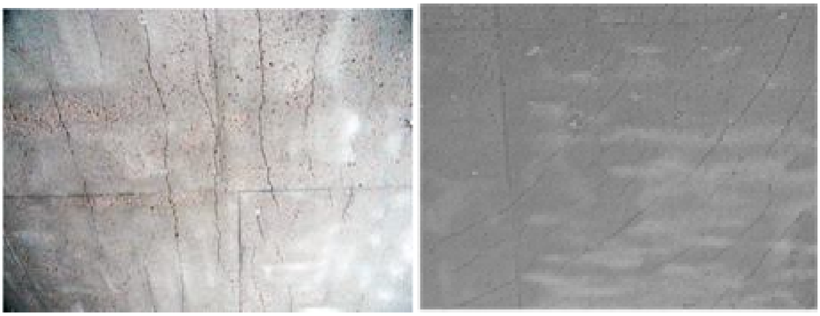
In case of single cracks on the edges of ribbed slabs (Fig. 1) and/or the surface of hollow floor (roof) slabs they can be repaired using the classic technology of injection of composite or cement-polymer mixtures by packers [3, 4].

A completely different situation arises at the presence of large number of adjacent (150-250 mm) cracks (Fig. 2) on the lower surfaces of horizontal structures (in most cases are flat floor slabs).

The problem is that such cracks usually have a width from 0.05 to 0.5 mm, and most injection materials used in conventional injection are not able to completely fill the cracks. In this case, repair of a large number of cracks by classical technology is useless and expensive.

On the result of the problem analyzing it was decided to develop a new technology to repair the building structures with a large number of small cracks on the lower surfaces. The main goal in the development of such technology was to ensure complete filling of cracks (even in their tops) with the penetration of polymers around the reinforcement. This is to bond the reinforcement with concrete as well as restore and improve their adhesion. At the same time, it was assumed that the developed technology will not involve the destruction (drilling) of existing structures and will have time consuming, cost and duration of work lower than the classic injection technology.

Fig. 1. Single cracks along the reinforcement on the edges of the ribbed floor slab



(a) (b)

Fig. 2. Cracks at the tension zone of reinforced concrete floor slabs:
(a) – longitudinal cracks; (b) – enveloping cracks around the columns

In accordance with the research method of effectiveness of the latest and new design and technological solutions to restore the serviceability of building structures [5, 6, 7] a number of theoretical and experimental researches aimed to develop a new technology for crack repair have been performed.

The working hypothesis of the research was that cracks on the lower surface of structures should be repaired by soaking with a high-flowing polymer composition supplied under the pressure through a special 'tray' which fit tightly to the surface of structure.

Among the large number of injectable composite materials presented on the market the material 'Consolid 1' produced by 'COMPOSITE' LTD was chosen [8]. This composition met the established criteria. It is a high-flowing composition of the increased viscosity which glues together small cracks in concrete, gives hydrophobicity to porous surfaces, glues reinforcement to concrete, preserves and protects reinforcement from atmospheric influences, increases frost resistance, dedusts, increases surface durability in 3-5 times, increases abrasion resistance in 2-3 times as well as provides resistance to aggressive influences. The depth of soak depends on the porosity of structure surface and its processing. The main characteristics of the polymer composition are given in Table 1.

Table 1

Characteristics of the polymer composition 'Consolid 1'

№	Main characteristics	Description
1	Viability at the temperature 20±2 °C, min	90
2	Density at the temperature 20±2 °C, g/cm3	1,02–1,07
3	Relative viscosity at the temperature 20±2 °C, s	10
4	Temperature of work with material, °C	from -5 to +50
5	Operating temperature range, °C	from -60 to +300

2. Research methods

The system for feeding the composite mixture was first designed and then produced. The developed system for laboratory research had the form (Fig. 3) of a metal tray [9] with a flat bottom and sides of 5 mm high [10] on which a special rubber seal was glued. When it is pressed to a flat surface it creates a closed sealed space (Fig. 4). In addition, the system incorporated a container for the polymer composition, a compressor to create pressure, rubber hoses and valves.

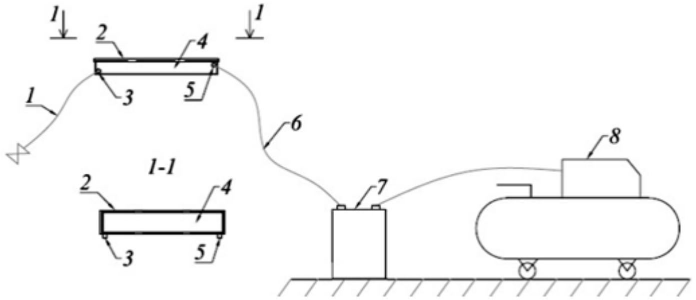


Fig. 3. 'Tray' device: 1 - rubber hose with valve; 2 - rubber seal; 3 – outlet valve for air release and liquid drainage; 4 - tray; 5 - the inlet valve for feeding the liquid in a tray; 6 - rubber hose; 7 - container for composite liquid; 8 – compressor

The effectiveness control of the developed method was performed in the following order:

1. The experimental reinforced concrete samples were produced.
2. The cracks on the lower surface of samples were artificially created by means of the force produced by the hydraulic press and the destructive force was set.
3. The surface of the samples with cracks was soaked with a polymer composition.
4. Using a hydraulic press the destructive force of the samples with glued cracks was set after 48 hours.

The research was considered as an effective when the strength of the samples with glued cracks was not less than 80% of the initial values.

The device 'tray' was attached to the lower tension zone of reinforced concrete samples by means of system of ties at the process of experimental laboratory research (Fig. 4). The injection repair mixture was fed into 'tray' through the inlet valve while an excessive air was released through the outlet valve. Thereafter, the outlet valve was turned off whereas the polymer composition continued to be injected under the low pressure (0.5-0.6 atm.) during the 5-10 minutes.

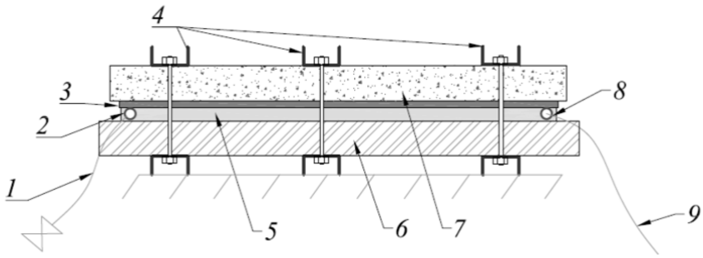


Fig. 4. 'Tray' device under the working condition: 1 – rubber hose with valve; 2 – outlet valve for air release and liquid drainage; 3 – rubber seal; 4 – ties; 5 – tray; 6 – steel channel; 7 – reinforced concrete lintel; 8 – the inlet valve for feeding the liquid in a tray; 9 – hose for feeding the liquid in a tray

3. Research results

First of all, a series of researches were performed. The aim was to establish the width and depth of crack in reinforced concrete structures for which the developed technology will be effective. As a result, it was found that samples with glued cracks with a width of up to 0.33 mm have a destructive force of about 80% of the original values before soaking while the samples with glued cracks with a width of up to 0.25 mm have a destructive force close to 95-98%. (Fig. 5) [11].

It should be noted that in the samples before soaking there was a noticeable breach of the adhesion between reinforcement and concrete. Due to this, cracks were also developed along the reinforcement. However, the soaking of samples with polymer composition provided complete bonding of cracks with width up to 0.25 mm and ends of cracks with width up to 0.8 mm. (Fig. 6). At the same time the reinforcement and concrete were getting bonded and when determing the destructive force after the soaking of samples, cracks were formed in another place but not where they were before gluing.

Subsequently, a number of researches were performed to establish the impact of technological factors on the technology of repair work. The chosen factors are those that can have a significant impact on the technology of work in natural conditions. Such factors are humidity and temperature of the structure as well as the width of the cracks.

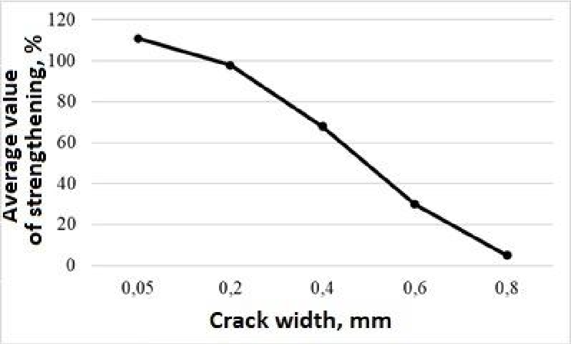


Fig. 5. Change in the average value of strengthening with change in the width of the crack

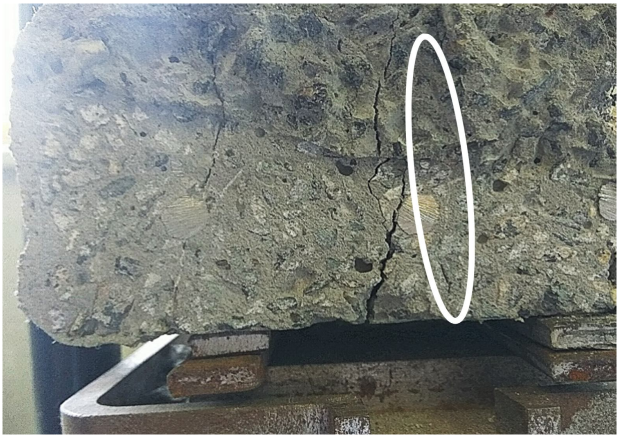


Fig. 6. New crack formed parallel to the glued (glued crack is marked)

According to EN 1504-5: 2013 [12], four states of humidity of structures can be distinguished: dry, damp, wet and with active water flow. According to the properties of composition 'Consolid 1', it is not suitable to eliminate active water leaks. Thus, experimental researches were planned to be performed with three states of humidity of structures with cracks, namely dry, damp and wet. As mentioned earlier, the repair of cracks in reinforced concrete structures can be affected by their temperature. The research was planned to be performed with three temperature regime, namely + 20°C, – 10°C and – 20°C.

The experimental research program included nine series. The established variations of humidity and temperature of the structures are presented in the Table 2.

Prior to the experiment, the surfaces of all samples were processed. The surfaces were cleaned of dust, dirt, and cement laitance. In addition, the samples were greased on all sides, except the side to be soaked, with acrylic putty to avoid seepage of the repair mixture through the cracks.

Table 2

Variations of humidity and temperature of the structures

Humidity of structure	Temperature of structure, ^oC		
	+ 20	– 10	– 20
dry	№ 1	№ 4	№ 7
damp	№ 2	№ 5	№ 8
wet	№ 3	№ 6	№ 9

The humidity state of the structures was modeled in accordance with EN 1504-5: 2013 [12]. Thereafter, the samples were kept for two days at a temperature of 20 ± 2 ^oC and a relative humidity of 60 ± 5 % [13]. After that, according to the described above technology, the samples were soaked with a polymer composition using a tray. After the soaking, all samples were placed in the conditions in which they were before soaking. This means the samples from the freezer were returned back after the soaking to the appropriate temperature and left there for 4 days.

Thereafter, destructive force was re-applied. The visual inspection of the destroyed structures shown that cracks with a width of up to 0.5 mm were completely glued together. Moreover, in some places, cracks parallel to the glued ones appeared on the samples during re-application of force. Some cracks with a width of larger than 0.5 mm were not fully filled with repair mixture. The research results are given in Table 3.

Table 3

The value of the destructive forces applied to reinforced concrete samples before and after their soaking

Number of research	The average value of the destructive force before gluing 2F1, kgf	The temperature of the Sample before gluing t, ^oC	Humidity of cracks	The average humidity of the samples, %	The average value of the destructive force after gluing, 2F2, kgf	The ratio of the average value of the destructive force after and before gluing (F2/F1)	Reduction of destructive force after gluing, %
1	4160	+ 20	dry	10,5	4085	0,9820	1,80
2	4105	+ 20	damp	17,5	3900	0,9501	4,99
3	4125	+ 20	wet	26,7	3755	0,9103	8,97
4	4140	– 10	dry	11,3	3480	0,8406	15,94
5	4065	– 10	damp	19,3	2310	0,5683	43,17
6	4100	– 10	wet	20,2	2115	0,5159	48,41
7	4135	– 20	dry	10,9	3500	0,8464	15,36
8	4095	– 20	damp	19,8	2390	0,5836	41,64
9	4110	– 20	wet	20,7	1555	0,3783	62,17

According to the Table 3, humidity of concrete samples and their temperature significantly affect the value of re-applied destructive force after crack repair.

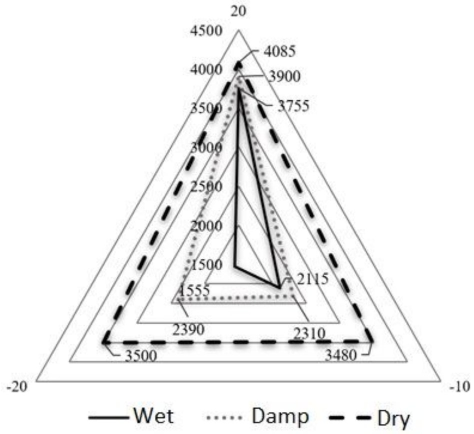


Fig. 7. The dependence of the average value of the destructive force after crack repair by composition ‘Consolid 1’ under the influence of temperature and humidity of the samples

Based on the obtained results, a three-dimensional dependence of the destructive force of the samples after their repair was produced. It depends on two technological factors of humidity and temperature of the samples (Fig. 7).

According to the dependences (Fig. 7) it is established that at repair of dry samples, temperature of structures influences not essentially values of the destructive forces applied to samples after crack repair in relation to the values applied to the samples before crack repair. This is 98% for samples repaired at a temperature of +20°C, 84% for samples repaired at a temperature of -10°C, 85% for samples repaired at a temperature of -20°C.

It was found that the increase in the humidity of the structure significantly affects the value of the destructive forces applied to the samples after their repair in relation to the values applied to the samples before crack repair.

For samples with damp cracks, the value of destructive forces after their repair was 95% for samples repaired at a temperature of +20°C, 57% for samples repaired at a temperature of -10 °C and 58% for samples repaired at a temperature of -20°C.

For wet samples with cracks, the value of destructive forces after their repair was 91% for samples repaired at a temperature of +20°C, 52% for samples repaired at a temperature of -10°C and 38% for samples repaired at a temperature of -20 °C.

Further researches established influence of width of cracks in a reinforced concrete structure on a method of their repair. The 4 series of crack gluing were considered [14]. They are the soaking with the composition 'Consolid 1' (№ 1); injection with the composition 'Edmock injection' (№ 2); combined method with pre-soaking by the composition ‘Consolid 1’ and immediately followed by injection with the composition 'Edmok injection' (№ 3); combined method with pre-soaking by the composition 'Consolid 1' and subsequent injection by the composition ‘Edmok injection’ with a technological break of 25 minutes (№ 4).

The use of the polymer composition ‘Edmock injection’ [15] is due to the increase in the width of crack in the researched samples. ‘Edmock injection’ is a composition with low viscosity for injecting cracks in structures that might be operated in various conditions including a humid environment. It is applied to glue cracks, waterproofing, anticorrosive protection of structures as well as has good adhesion to concrete and steel and high chemical resistance.

The main characteristics of the polymer composition are given in Table. 4.

Table 4

Characteristics of the polymer composition 'Edmok injection'

№	Main characteristics	Description
1	Viability at the temperature 20±2 °C, min	20
2	Relative viscosity at the temperature 20±2 °C, s	2–5
3	Temperature of work with material, °C	from 0 to +65
4	Operating temperature range, °C	from -60 to +150

According to research, it can be stated that the width of cracks in concrete structures affects the method of their repair. It is established that cracks with a width of up to 0.25 mm are most expedient to repair by the technology of soaking with the composition ‘Consolid 1’ (№ 1). The polymer composition penetrates the concrete body in the contact zone to a depth from 1 mm to 3 mm and increases its surface strength.

The method of repairing cracks by injecting the composition ‘Edmok injection’ (№ 2) is the most effective in repairing cracks from 0.3 mm to 0.7 mm. It is not effective for repairing cracks up to 0.3 mm because the high density of the composition does not allow it to penetrate into the depth of the gap. After experiment, the samples were visually inspected and the type of adhesive fracture was established by analogy with the types of adhesive bonding in accordance with DSTU B B.2.6-178: 2011 [16] and EN 1542: 1999 [17]. It should be noted that as a result of gluing of cracks in concrete the cohesive connection of samples (destruction along the concrete body) was obtained.

The research results of the next series of samples (№ 3) indicate that the lack of technological break between injections of compositions 'Consolid 1' and 'Edmok injection' in cracks of structures has a negative impact on the quality of their repair. This is due to the foaming of compositions that appear at their contact in the point of injection to the crack. It makes impossible further filling the gap with repair mixture. As a result, the gap was filled with the composition ‘Edmock injection’ by an average of 15-30% and the destruction of such samples was adhesive.

Experimental researches of the last series of samples (№ 4) establish the feasibility of the proposed technological break between the injections of the compositions 'Consolid 1' and 'Edmok injection'. It was found that a technological break of 25 minutes allows the first composition to seep into the body of concrete but this time is not enough for its polymerization. Therefore, in the areas of contact of 'Edmock injection' with soaked 'Consolid 1' (meaning the liquid stage) was foaming of compositions. As a result, the destruction of the samples was at the junction of the concrete with the mixture and along the concrete body.

On the basis of the received dependences the technology of repair of cracks in reinforced concrete structures by their soaking with polymeric compositions was developed. Technical and economic calculations and their comparison with injection technology were performed to confirm the expediency of its use. As a result, the developed technology was tested at three sites.

An example of the application of the technology is the repair of the structures of the underpass in Kyiv (Ukraine). During the inspection of structures the water leakage through the structures of the floor slabs and walls was found. Detailed inspection of structures using a digital microscope allowed to find a large number of small cracks on the structures with a width of up to 0.1 mm (Fig. 8).

Fig. 8. Cracks in the structure (large scale)

To ensure the maximum effect from the repair work the soaking of the surfaces of the slabs was performed at a temperature of 15–23 ^{o}C and a relative humidity of 60 ± 5%. The surface to be repaired was cleaned of dust and dirt. Depending on the location plane (horizontal or vertical) the soaking device (tray) was placed so that the outlet valve for air release was located in the highest position of the device whereas the inlet valve for feeding the liquid in a tray was in the lowest position. Props and struts were applied to fix the tray in the design position (Fig. 9).

(a) (b)

Fig. 9. Use of the 'tray' system during repair works:
(a) - on a lateral surface of the slab edge; (b) - on the lower surface of the slab edge

The repair mixture was poured into the prepared container and pumped into the tray with compressed air during 5-10 minutes. After soaking of one zone the remained polymer composition was drained from the tray and moved to other areas to be soaked.

There was heavy rainfall for two months after the repair. However, a visual inspection of the repaired structures shown that the surface with microcracks and cracks with a width of up to 0.5 mm remained dry.

4. Conclusions

The obtained research results indicate the efficiency of repair of cracks with a width of up to 0.2 mm in reinforced concrete structures by soaking with the composition 'Consolid 1' using a system of trays. The repair of cracks with a width from 0.3 to 0.8 mm should be performed by injecting the composition ‘Edmok injection’ by classical technology.

Repair of cracks with larger than 0.8 mm should be performed by hybrid technology which consists in pre-soaking by the composition ‘Consolid 1’ and subsequent injection after 24 hours with the composition ‘Edmok injection’.

The application of the developed technology at three sites and further monitoring for a long time (from 6 months to 4 years) allows to confirm the effectiveness of its use to repair small cracks.

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ДОСЛІДЖЕННЯ ТЕХНОЛОГІЇ РЕМОНТУ ТРІЩИН ПОЛІМЕРНИМИ КОМПОЗИЦІЯМИ

Вступ. У процесі виконання робіт з обстеження будівель та споруд, або розробки проектної документації на проектно-відновлювальні роботи, направлені на відновлення експлуатаційної придатності будівельних конструкцій, виявлено, що є потреба у розробці рішень на ремонтні роботи, які не регламентуються нормативною документацію, або, в конкретних випадках, запропоновані способи можуть бути технічно або економічно не ефективними.

Проблематика. Найбільш поширеним дефектом розтягнутої зони залізобетонних балок, плит перекриття або покриття є тріщини. Зазвичай, для їх ремонту використовують технологію ін'єктування. Однак за великої кількості дрібних тріщин дана технологія є трудомісткою.

Мета роботи. Розробка нової технології ремонту розтягнутої зони залізобетонних балок, плит перекриття або покриття з великою кількістю дрібних тріщин, що забезпечить максимальне заповнення тріщин полімерними композиціями з їх подальшим склеюванням.

Матеріали та методи. З аналізу науково-технічної літератури було встановлено ряд чинників, що можуть впливати на технологію заповнення тріщин полімерними композиціями. Для проведення експериментальних досліджень було виготовлено спеціальний пристрій «лоточок», що кріпився до нижньої зони системою затяжок чи підпірок. У лоточок під тиском подавали ремонтний розчин, що заповнював тріщини. Змінюючи умови проведення експерименту встановлювали значення зміцнення попередньо зруйнованих зразків.

Результати. У результаті встановлено, що максимальне заповнення тріщин полімерною композицією досягається через 5-10 хв подачі ремонтного матеріалу при тиску у системі у межах 0,5-0,6 атм. Максимальне зміцнення конструкцій, що підлягали ремонту, при повторному прикладанні руйнівного зусилля досягалося за умов проведення ремонтних робіт за температури конструкцій 20 ± 2 оС та їх сухому стані вологості.

Висновки. Розроблено технологію ремонту тріщин на нижній поверхні горизонтальних залізобетонних конструкцій полімерними композиціями. Встановлено, що за наявності на конструкції дрібних тріщин (з шириною розкриття до 0,2 мм) ефективною є розроблена технологія просочення тріщин та тіла конструкції полімерною композицією, за ширини розкриття до від 0,3 до 0,8 мм – доцільно використовувати технологію ін'єктування; за ширини розкриття від 0,8 мм – комбіновану технологію.

Ключові слова: залізобетонні конструкції, тріщини, полімерні композиції, вплив чинників, технологія просочення.

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THE TECHNOLOGY OF CRACK REPAIR BY POLYMER COMPOSITION

Introduction. During the inspection of buildings and structures and development of design documentation for restoration works it was found that there is a need to provide recommendations or to develop solutions for repair work. These repair works either are not regulated by standards or may be technically or economically inefficient.

Problem Statement. The most common defect of the tension zone in reinforced concrete beams, floor slabs or roof slabs are cracks. Injection technology is normally used to repair it. However, in case of large number of small cracks, this technology is time consuming.

Purpose. Development of a new technology for repairing the tension zone of reinforced concrete beams, floor slabs or roof slabs with a large number of small cracks. This will ensure maximum filling of cracks with polymer compositions with their subsequent bonding.

Materials and methods. A number of factors that may affect the technology of filling cracks with polymer compositions have been identified from the analysis of scientific and technical literature. A special device 'tray' was produced for experimental research. It was attached to the lower zone by a system of ties or props. A repair mix to fill the cracks was fed into the tray under pressure. By means of changing the experiment conditions the strengthening level of previously destroyed samples were set.

Results. As a result, it was found that the maximum filling of cracks with the polymer composition is achieved within the 5-10 minutes of repair mix supply at a pressure in the system in the range of 0.5-0.6 atmospheres (atm). The maximum strengthening of the repaired structures under the re-applied destructive force was achieved at the conditions of repair work with a structural temperature of 20 ± 2 ^{o}C and dry state of the structure.

Conclusions. The technology of repair with polymer compositions of the cracks located on the lower surface of horizontal reinforced concrete structures has been developed. It was established that in the presence of small cracks on the structure (the width is up to 0.2 mm) the developed technology is most effective, in case of widths from 0.3 to 0.8 mm it is advisable to use injection technology whereas for widths larger than 0.8 mm the hybrid technology should be applied.

Keywords: reinforced concrete structures, cracks, polymer compositions, influence factors, soak technology.

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