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Andrii Klym, Yaroslav Blikharskyy

INJECTION OF CRACKS IN A RC BEAM WITH EPOXY RESIN USING THE GRAVITY FLOW METHOD

Lviv Polytechnic National University,
Department of Highways and Bridges;
andrii.b.klym@lpnu.ua

The restoration of the load-bearing capacity of RC beams through crack injection is one of the most efficient and practical methods for executing repairs in the field of civil engineering. In the article, following an analysis of crack injection methods in RC structures, an economically viable method for injecting RC beams is proposed. The core approach of the proposed crack injection method involves the process of introducing epoxy resin into the crack, which occurs by gravity flow (without specialized equipment and pressure). The paper outlines a systematic process for preparing the crack in the RC beam for epoxy resin injection. The crack injection method was conducted comprehensively, including the restoration of the compressed concrete zone within the RC beam. The test results demonstrated the effectiveness of the crack injection method, as there were no new crack formations at the injection sites, and the load-bearing capacity of the RC beam was restored to 115%.

Key words: RC beam, damage, restoration, crack, epoxy resin, injection.

Introduction

RC is one of the most widely used building materials in the world (Bobalo et al., 2019; Vatulia et al., 2014; Verma et al., 2014; Karpiuk et al., 2020). It is known for its high strength, durability, and reliability. However, like any other material, RC can be susceptible to cracking (Golewski, 2023). It's worth noting that cracks in concrete and RC structures are quite common and can be considered a natural feature of concrete, even an integral part of its structure (Akram, 2021; Pathak and Vesmawala, 2022). Cracks in RC structures can lead to a deterioration in their strength, stability, and durability. In some cases, cracks can even result in structural failure. RC structures, despite their strength and long service life, are sometimes prone to deterioration or cracking due to various factors, such as loads, temperature fluctuations, reinforcement corrosion, and other operational influences (Carino and Clifton, 1995; Gupta and Akbar, 1984; Xia and Chen, 2023). Cracks can reduce the load-bearing capacity of the structure and pose a threat to public safety and the environment.

Research into the factors influencing crack formation in RC structures is discussed in these articles (Zhang and Li, 2023; Liu and Wang, 2023), where the authors present a case study of crack formation in a RC structure. They use a discrete element modeling method to study the impact of various factors, including loads, temperature variations, concrete properties, reinforcement, and defects in design or construction, which are almost the primary factors contributing to crack formation.

After reviewing prior sources, three main methods for repairing and reinforcing cracks in RC structures were identified: mechanical repair, chemical repair, and injection. Each method serves a specific purpose in restoring cracks, and factors influencing the choice of method are considered by the authors of this article (Li, Y. and Li, X., 2023) to make an objective and rational selection for crack repair. Let's delve into the most common and practical method for crack repair in RC structures, injection.

Injection of cracks in RC structures is a pivotal technology in the field of building repair and restoration, playing a crucial role in preserving and extending the service life of RC structures and buildings as a whole. Crack injection is an effective approach to address this challenging issue, as it can be performed on-site with minimal downtime. This method involves filling cracks with high-quality injection materials that not only restore the structural integrity but also prevent further crack propagation and safeguard against aggressive environmental influences. The significance of crack injection lies in its ability to restore the structure without the need for dismantling or replacement.

The implementation process of injection varies primarily based on the filling material, including cementitious solutions, polymer materials, and epoxy resins. Secondly, it depends on the method and equipment used, such as hydraulic (the most common), pneumatic, and electro-osmotic injection. The effectiveness of epoxy injection depends on the injection pressure, as described by the authors of the article (Kim et al., 2022). They assert that higher injection pressures, when delivering epoxy resin into cracks in RC beams, yield more efficient results compared to lower injection pressures. Injection remains highly effective in the restoration and repair of RC beams from cracks when various materials are employed. One of the modern materials used is nanocomposites, the research on their effectiveness is documented in the article (Al-Sulaimani et al., 2022). Depending on the specific approach required for restoration work, new methods and systems need to be introduced. Authors of the study conducted (Ma et al., 2019) investigated the effectiveness of crack repair in RC beams using a novel injection system based on fiber-reinforced plastic. Their findings revealed that this system provides more efficient repair than traditional injection methods.

Polymeric materials, as described by the authors in the article (Sylovaniuk et al., 2015), are effective for injection and demonstrate improved load-bearing capacity in RC beams. However, these materials have limitations concerning crack width and length parameters. These limitations were addressed by the authors of the study outlined in the article (Zhang and Wang, 2023), who proposed their polymeric material-based injection method, capable of filling and strengthening cracks of various dimensions. The utilization of epoxy resin materials covers a wide range of possible injection applications and is widely used in the concrete industry. One of the most comprehensive studies using epoxy resins for crack injection in concrete was conducted in the article (Issa and Debs, 2007), where they employed concrete beams with cracks of varying widths and lengths, as well as two different types of epoxy resins. The research results demonstrated that crack repair in concrete using epoxy resins is an effective method. Epoxy resins ensure a secure filling of cracks while enhancing the strength and elasticity of the concrete. In their article (Saliah et al., 2021) assessed the effectiveness of epoxy resin injection for severely damaged RC beams using the "acoustic emission" method. The study revealed that RC beams repaired with epoxy resin can withstand higher maximum loads compared to other methods.

The unexplored issue of crack injection without specialized equipment and material delivery without pressure necessitates investigation, making this study on crack injection with epoxy resin without pressure, as presented in this article, both pertinent and essential. This research aims to demonstrate the viability of employing this crack injection method, its practicality in various situations, as well as its positive economic implications.

In this article, we will delve into various facets of crack injection in RC structures. We will analyze the fundamental principles of injection technologies, different types of injection materials, and their properties. Practical aspects of conducting injection work will also be examined, encompassing surface preparation, method selection, and quality control.

The purpose of this article is to scrutinize research on methods for injecting cracks in RC structures. Furthermore, the article introduces a proprietary method for injecting cracks in RC beams, subsequently subjected to experimental testing. The article's objective is to showcase the rationale and effectiveness of the proposed crack injection method.

Materials and Methods

The conducted research was carried out on RC beam from the university's testing laboratory was used. The RC beam has a geometric size of 2100×200×100 mm. The longitudinal reinforcement of the beam consists of rolled steel Ø20A500S in the stretched zone and 2Ø6A240S in the compressed zone. The transverse reinforcement is made in the form of U-shaped clamps Ø6A240S with a step of 75 mm (see Fig. 1).

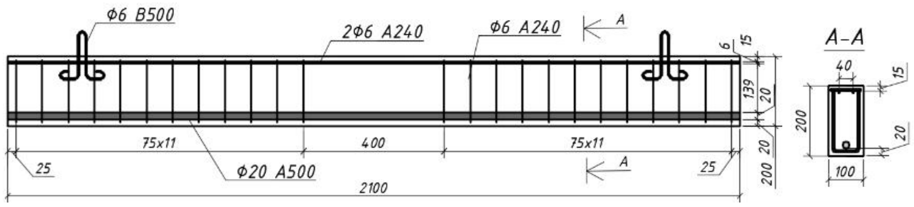


Fig. 1. The general view of reinforcement in the sample.

The RC beam was so designed to be installed on the stand, that its destruction is ex-pected to occur in the zone of pure bending by the normal sections (see Fig. 2). The constructive reinforcement was joined in the reinforcing cage with the use of contact welding in industrial conditions. The concrete was of C30/35 strength class.

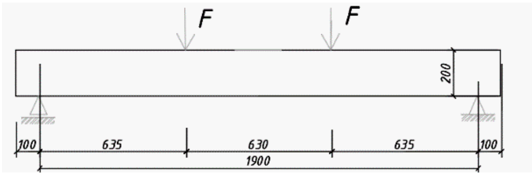


Fig. 2. The general view of the sample.

During overloading beyond the operational limits, RC beams lost their load-bearing capacity and were physically damaged, resulting in the complete destruction of the compressed concrete zone (see Fig. 3).

Fig. 3. The destruction of the RC beam occurred within the compressed concrete zone.

The formation of such cracks along the height effectively divides the RC beam into sections, creating hinges at these points. Therefore, to restore the RC beam, it is necessary to bond it along the crack in such a way as to eliminate the hinges, allowing the RC beam to function as a single continuous body. In this case, for practicality and feasibility, the decision was made to bond it using the epoxy resin injection method.

The injection was carried out in conjunction with the restoration of the compressed concrete zone. Initially, the damaged layer of the compressed concrete zone was cut with dimensions of 900x100x60 mm (see Fig. 4, a). Afterward, the RC beam was unloaded on the stand. Here is an illustration of through cracks along the height of the beam (see Fig. 4, b, c).

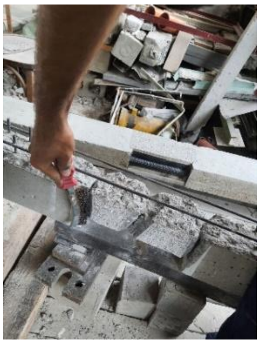
The injection bonding process requires preparing the crack and the RC beam itself for this stage. The first step involves removing all loose concrete fragments and elements that are movable and can be eliminated. The crack on both sides of the RC beam along the lateral surface is cleaned at a 45°-degree angle to prevent adhesive leakage during injection (see Fig. 5, a). The smooth cut surface should be brushed with a wire brush to enhance adhesion between the concrete and epoxy adhesive (see Fig. 5, b). After all dust-related work is completed, blow air holes and the crack with compressed air from a compressor to remove dust and small concrete elements (see Fig. 5, c).

Sikadur-30 is a thixotropic structural two-component epoxy-based adhesive used for bonding construction materials. It possesses high mechanical strength and is used for repairing detachments and damages to the concrete of structural elements. This crack injection method will be performed without pressure, relying on gravity flow. To expel air from inside the crack, which may accumulate during the pouring of Sikadur-52 epoxy resin, holes are pre-drilled along the height of the beam's crack before dust removal, and tubes (packers) are inserted through which air will escape from the interior (see Fig. 6).

a

b *c*

Fig. 4. RC beam before injection preparation: a – appearance after cutting the damaged compressed concrete zone; b, c – appearance of through cracks after unloading.



a *b* *c*

Fig. 5. Crack preparation for injection: a – cutting the crack surfaces at a 45° angle; b – cleaning the smooth concrete surface with a stiff brush; c – blowing out dust and small particles with a compressor.

a *b*

Fig. 6. Preparation for the air venting stage: a – drilling holes for packers; b – installing packers.

After the work is completed, Sikadur-30 epoxy adhesive is mixed by combining components A and B for 3 minutes to obtain a uniform mass. This epoxy adhesive is applied to the sides of the RC beam (Sikadur®-30). To improve adhesion with concrete, the epoxy adhesive is brushed thinly onto the concrete surface (see Fig. 7, a) and then sprinkled with quartz sand for mechanical adhesion (see Fig. 7, b). Subsequently, the required thickness of epoxy resin is applied to the lateral surfaces of the RC beam (see Fig. 7, c).

a *b* *c*

Fig. 7. Crack chasing process on the beam's lateral surface: a – application of a thin layer of epoxy resin; b – sprinkling with quartz sand; c – appearance after completing the crack chasing with epoxy resin.

After 24 hours, when the epoxy adhesive has cured, you can proceed with pouring Sikadur-52 epoxy resin. Sikadur-52 Injection Type N is a two-component, solvent-free, low-viscosity injection liquid based on high-strength epoxy resin. Type N indicates its suitability for use at base temperatures ranging from +5°C to +30°C. The ratio of components A and B is 1:2. After 3 minutes of mixing and obtaining a yellow-brown adhesive liquid (see Fig. 8, a), you can gradually start pouring the epoxy injection liquid into the crack in the RC beam (see Fig. 8, b). Gradually filling the crack space with epoxy liquid, expelling all air from it, gradually close the holes (packers) from which epoxy liquid begins to flow out (see Fig. 8, c). The epoxy sets and gains strength instantly; on the first day, it reaches 80% of its strength, and after 7 days, it reaches 100% (for compression – 52 N/mm², for tension – 37 N/mm², for bending – 61 N/mm²) (Sikadur®-52 Injection Normal).

a *b* *c*

Fig. 8. Crack injection process: a – mixing the epoxy resin; b – injecting epoxy resin into the crack; c – sealing the packers and completing the crack injection.

Results and discussion

During the testing of the RC beam for its load-bearing capacity, at the point of characteristic failure within the compressed concrete zone, when the load-bearing capacity to withstand external loads was exhausted, the cracks on the RC beam appeared as follows (see Fig. 9).

During the experimental load-bearing capacity test of the RC beam, which had its compressed concrete zone restored, and the crack injection process was conducted, resistance to crack formation in the injection zone was observed over an extended period of loading.

Fig. 9. Appearance of cracks during the failure of the restored RC beam.

In the location where the crack was injected into the RC beam, where a hinge crack had previously existed, there was no new crack formation. This indicates the effectiveness of the injection method and the strong bonding of the two parts of the beam into a single, cohesive, and cooperative entity (Fig. 10).

In the course of testing, the restored RC beam withstood 27.3 kN/m of force applied at each loading ring, which is 13% more than its previous load-bearing capacity and 15% more than a similar RC beam that underwent testing.

Additionally, a key indicator of the effectiveness of the method of restoring the compressed concrete zone and crack injection in the RC beam is the minimal deflection under high loads. These actions signify the strong adhesion in the tensile zone of the concrete after injection, which counteracts tensile forces, as well as the excellent stability and strength of the restored compressed concrete zone thanks to the use of Sika MonoTop-4012 solution (Sika MonoTop®-4012).

It should be noted that there was no chipping or delamination at the interface between the Sika MonoTop-4012 restorative solution and the beam's concrete, and the adhesion and penetration of the restored compressed concrete zone were sufficient (see Fig. 10).

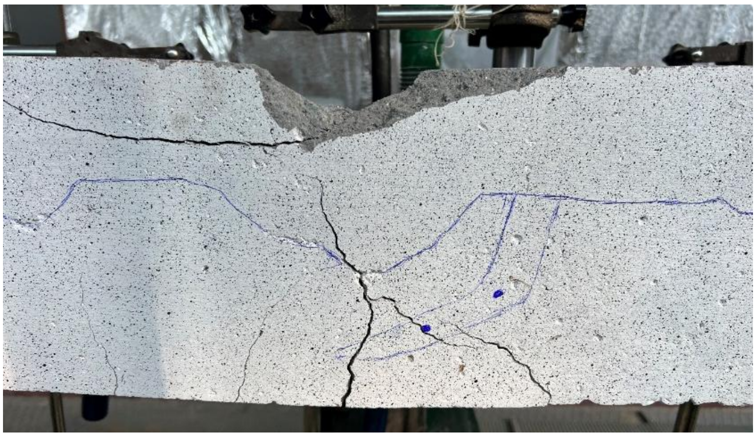


Fig. 10. Comparative view between formed cracks and the boundary solution Sika MonoTop-4012 and Sikadur-30, Sikadur-52.

Conclusions

Concrete cracking is a random process that is highly variable and influenced by numerous factors. However, one process is certain: the longer the crack, the higher the induced stress concentrations. The presence of cracks in the structure gradually reduces its strength as the crack size increases. Consequently, the structure becomes susceptible to failure when its strength becomes so low that it cannot withstand normal loads.

In this study, the injection method was applied without specialized equipment for pressurized epoxy resin delivery, which helped reduce costs. However, this approach limited the injection to wide and through cracks since it cannot effectively fill fine cracks beyond the main injected crack (unlike pressurized injection throughout the entire beam, which might result from previous external loading). This method is used only in specific situations and where its implementation is feasible.

Nevertheless, we achieved success by restoring the load-bearing capacity of the damaged RC beam to 15% higher than its previous load-bearing capacity, confirming the effectiveness of the injection method, which is simple, practical, and efficient. During testing, no new cracks formed at the injection site, but new cracks did appear in weaker areas, leading to damage and a reduction in load-bearing capacity. Thus, the primary objective of eliminating the hinge in the RC beam at the point of through cracking was achieved, and the restoration of the load-bearing capacity of the RC beam was economically justified with a 15% margin compared to the previous testing of an undamaged sibling RC beam.

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А. Б. Клим, Я. З. Бліхарський
Національний університет “Львівська політехніка”,
Кафедра автомобільних доріг та мостів

ІН’ЄКТУВАННЯ ТРІЩИНИ ЗАЛІЗБЕТОННОЇ БАЛКИ ЕПОКСИДНОЮ СМОЛОЮ МЕТОДОМ САМОПЛИВУ

Тріщини у залізобетонних балках несуть суттєву загрозу соціальні безпеці і навколишньому середовищі, через деякий час експлуатації чи навіть у ранньому віці, в притул до повної втрати несучої здатності і руйнування. Відновлення несучої здатності залізобетонних балках способом ін’єктування тріщин є одним із найбільш дієвим та практичним способом реалізації ремонту в сучасних тенденціях. Сьогодення технологічного прогресу дозволяє удосконалювати матеріали для ін’єктування, а також процес заповнення тріщин цими матеріалами. Але при цьому такий підхід із застосування спеціалізованого обладнання призводить до дорогого ремонту пошкоджених залізобетонних балок, що не завжди є раціонально у використанні. Тому у статті після проведення аналізу методів ін’єктування тріщин в залізобетонних балках та конструкціях було запропоновано економічно-доцільний метод ін’єктування залізобетонних балок, що дозволив би запобігти необхідності дорогого ремонту. Основний підхід запропонованого методу ін’єктування тріщини полягає у процес подачі епоксидної смоли в тріщину, що відбувається самопливом (без спеціалізованого обладнання і тиску). У роботі також наведено послідовну процес підготовки бічної та внутрішньої ділянки тріщини залізобетонної балки до ін’єктування епоксидною смолою. Метод ін’єктування тріщин був проведений комплексно із відновленням стиснутої зони бетону залізобетонної балки. Результати випробовування показали ефективність методу ін’єктування тріщини, так як не було новоутворення тріщин в місцях ін’єктування. А також ін’єктування тріщин комплексно із методом відновлення стиснутої зони бетону розчином Sika MonoTop – 4012 було досягнуто відновлення несучої здатності пошкодженої залізобетонної балки на 115%, що на 15% більше від попереднього випробовування непошкодженої балки близнюка.

Ключові слова: залізобетонна балка, пошкодження, відновлення, тріщина, епоксидна смола, ін’єктування.