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Experimental Study on the Crack Repair Techniques of Concrete Structures: A Case Study

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Abstract: A crack is a whole or partial split of either concrete or masonry into two or more portions caused by breaking or fracturing in concrete constructions. The bulk of fractures is caused by external forces higher than what the structure or its components can sustain acting on it. The most typical sign of degradation in concrete buildings is cracking. Once the fractured system has been assessed, an appropriate repair method that considers these reasons may be chosen. Selecting the best crack repair method may produce results that endure for a very long time while saving you a lot of time, money, and effort. The causes of cracks and several strategies for healing them are covered in this paper.

Keywords: Cracks, Epoxy Resin, CFRPs, Electrochemical methods, Bacteria

1. Introduction

Cracking is one of the most common flaws in reinforced concrete slabs and beams. The primary factors that lead to fractures include overloading, reinforcement corrosion or differential settling of the support, relatively high tensile stresses, forced deformations, plastic shrinkage, plastic settlement, and expansive reactions [7]. All of these elements have an impact on how long concrete constructions last. In recent years, buildings' upkeep and repairs have become crucial. To ensure the safety and usefulness of the structures, it is essential to repair deteriorating concrete structures. Numerous restoration techniques, including epoxy injection, route sealing, grouting, and electrochemical procedures, are available [2], depending on the nature of the cracks.

One more magnetic material for fixing is cementitious composites (ECCs), which have a broad scope of solidifying and breaking properties. It advances micro-cracks, protecting fixed structures from substances like chloride particles, water, and so on, as well as rigidity and cold execution. Notwithstanding, the conditions where these ECC benefits are accomplished should be made sense of in his solicitation [14].

Bonded overlay concrete has been a typical and generally involved fix system for the more significant part of a century with extraordinary adequacy. It has many purposes, including walkways, modern floors, and extension decks. Its allure comes from its convenience. Formwork can be restricted to unobtrusive vertical structures at the edge of the dike since it is introduced over a current substantial construction. The main aim behind a bonded overlay concrete substantial underlayment is to fix debased concrete or to develop the cross-area further and, consequently, the heap conveying limit of the construction. The reinforced liner fundamentally adds both burdens giving limit and primary unbending nature since it works solidly with the basic design. Water and dampness can't determine how to go along the surface due to the fortified layer. At last, a decent bond will want to scatter the break if the covering can't endure breaking because of unavoidable shrinkage, warm obstruction, or mechanical pressure [11].

Procedures might be chosen to achieve the following goals by carefully evaluating the reasons for cracking

- Restore and boost stiffness and strength
- Improve the durability and appearance of the concrete surface
- Improve the functional performance of the structures

The key to successfully repairing concrete cracks is to determine the source or cause of cracks, then select a recovery process or solution taking into account the reason. as well as a spacious sign of fractures in question will continue to be the "active" or "sleeping" cracks currently operating.[1]

Selection of repair methods for active and dormant cracks

The following are the best crack repair methods for active cracks

- Epoxy Injection
- Routing and sealing
- Stitching crack
- Drilling and Plugging
- Cement mortar grout [3]

2. Crack Repair Techniques in Concrete Structures

2.1 Epoxy Resin

The epoxy injection technique has been successfully used to patch fractures in concrete structures. Due to the lack of new concrete, this repair is the least expensive and invasive [8]. Sikadur 52, a low-viscosity, free-flowing, and quickly curing injection resin, is the most often used epoxy resin [5]. To expand the strength and malleability of epoxy, an adaptable relieving specialist, flexibility, and silica nanopowder were added, and two kinds of it were made: texture cover (FRP paste) and break fastener (break paste to tie materials). Epoxy tar, diluents, relieving specialist, silica nanopowder, flexibility, coupling specialist, and antifoaming specialist are utilized in FRP paste and break stick.[6]

2.2 Carbon Fibre Reinforced Polymers (CFRPs)

Using materials made of carbon fibre-reinforced polymer (CFRP), which is lightweight and robust in Spans, is beneficial when creating improvements in structural engineering. The utilization of superstructures as a retrofit approach is becoming progressively well-known. While having a great deal of knowledge of the program, using CFRPs for primary applications is gradually typical.

It has been gotten about structural designing, and considerably fewer CFRPs have been utilized to fix an assortment of designs [13]. In recent years, the Use of Carbon Fibre Reinforced Polymer (CFRP) materials in woven and laminated forms to retrofit these corroded R.C. structures. CFRP material is lightweight, corrosion-resistant, and has high tensile strength [21]. They can also quickly bond to concrete surfaces without scaffolding or large jacks and with minimal support. The CFRP system can also be used in areas where traditional procedures would be difficult to apply due to limited accessibility. As a result, CFRP repair technology makes upgrades more accessible and saves money [17].

Figure 1. Carbon Fibre Reinforced Polymers

2.3 Using Micro bacteria

The utilization of bacterially created calcium carbonate accelerates as another option and harmless to the ecosystem technique for break recuperating has been proposed. Gollapudi quickly offered this remarkable crack fix technique utilizing eco-accommodating natural cycles in 1995. A few boundaries impact microbial CaCO3 precipitation, including focus broke up inorganic carbon, pH, calcium particle fixation, and the presence of nucleation destinations. The initial three parts are given by bacterial digestion, while the bacterial cell divider fills in as the nucleation site [1].

Microbes, explicitly B. subtilis, were chosen for this examination since they meet the essential boundaries to make due in brutal conditions. Whenever Gram-positive microorganisms are presented with antagonistic conditions, they can deliver spores. This spore arrangement safeguards the life form against high mechanical pressure and antacid conditions, making it a great decision. Individuals from the class Bacillus can deliver spores that can stay lethargic for over 200 years [22].

A spectrophotometer with a frequency of 600 nm was utilized to gauge an amount of 0.5 ml of the precise arrangement. The clear was supplanted with 0.5 ml of the bacterial account after the instrument perused the clear, and the 600 nm frequency was reused [19]. Bacterial arrangements (microorganisms in a culture tank), created and handled in a controlled microbial science lab to guarantee spore creation, are regularly used to bring these microscopic organisms into processes in different substantial blends [23]

Figure 2. Bacillus subtilis spore powder

2.4 Using Electrochemical Method

The electrochemical technique is one of the handling headings to fix breaks. Examinations show it is doable to utilize electric flow to repair cracks in built-up concrete, particularly in unambiguous circumstances where other average rebuilding techniques are ineffectual. Tests are in progress to decide the practicality and advantages of utilizing electroplating innovation to fix supported substantial breaks, as well as the effect of this strategy on the mechanical and mechanical properties of the gatherings. Important primary parts [16]. Electrodeposition is another cycle used to fix supported significant breaks in marine and earthbound conditions. This methodology applies a present thickness for a brief time frame, generally half a month [18]. The utilization of current flow in the electrodeposition strategy enjoys a few upper hands over the utilization of direct flow, including lessening focus predisposition, wiping out hydrogen delicacy, diminishing blending portion, acquiring electrically stored layers that have high immaculateness and thickness, and working on the actual properties of the coating [24].

2.5 Using Bonded Overlays

Bonded overlay concrete has been a typical and generally involved fix system for the more significant part of a century with extraordinary adequacy. It has many purposes, including walkways, modern floors, and extension decks. Its allure comes from its convenience. Formwork can be restricted to unobtrusive vertical structures at the edge of the dike since it is introduced over a current substantial construction [25]. The main aim behind a bonded overlay concrete substantial underlayment is to fix debased concrete or to develop the cross-area further and, consequently, the heap conveying limit of the construction. There are various options, including those listed below, and the overlay attributes depend on the kind and quality

- Portland cement mortar and concrete
- Silica fume mortar and concrete
- Polymer concrete
- Steel fibre-reinforced polymer
- SIFCON[11]

3. CASE STUDY

"Repair of the Deira–Shindagha tunnel in Dubai" [1]-

A sea arm separates Dubai from the Arabian Gulf, and in 1975 a 561-meter-long tunnel was constructed to bridge Dubai Creek. The concrete was cast on-site with sulphate-resistant Portland cement, porous limestone, coarse aggregate, beach sand with occasional chloride fractions, and tap water. The ratio of free water to cement varied and might reach 0.6.

The concrete structure was constructed in parts with a rubber water stop at expansion joints and construction joints. Bituminized cork and a Neferma strip were utilized to fill the space between the dilation joints. The tunnel's exterior was covered with Bitu-Then sheets intended to prevent the entry of water and salt. A latex-cement (P.C.) coating was applied on the concrete inner wall with an aesthetic function.

Repair Techniques-

- Stop leakage- Epoxy injection agent was injected into the concrete around the rubber water stop in the joints. This appeared to stop the majority of the leakage effectively.
- Elimination of the impacted concrete and chloride-contaminated.This happened up to 50 mm behind the reinforcement, but it had to be limited to the reinforcement level in structurally critical sites.
- Cleaning or replacing steel reinforcement bars.

- Coating the cleaned reinforcement with an epoxy barrier coating and replacing the rebars with new rebars illustrate the cleaning and coating operation of the ramps' concrete walls.
- Replace the concrete that was removed. The initial application consisted of a polymer-modified shotcrete with blast furnace slag cement CEM III/B as the cementation's binder. Later, silica fume substituted the polymer for operational reasons.
- With the same shotcrete, the reinforcement cover was extended by 20 millimetres.
- A coating was placed that prevented oxygen from reaching the reinforcement. A 4000 m oxygen-diffusion resistance was required for the coating system. Generally, it is impossible to prevent oxygen from entering concrete during repair work. In the actual case of the underwater tunnel, however, it is conceivable if combined with additional measures.
- The coating system included two epoxy layers and a polyurethane topping. The topcoat was more resistant to ultraviolet light, which was a need for the tunnel and ramps, and could bridge cracks. Before applying the coating, the surface is sanded using an equalization slurry comprised of epoxy.

4. Experimental Studies

4.1 Epoxy Injection Technique

Six full-scale, 2.8-meter-long one-way reinforced concrete slabs were used to study how various repair methods affected the structural response of one-way slabs. Cast, cured, and tested components are 1.2 m broad and 0.2 m thick. Five high-yield deformed steel bars with a diameter of 10 mm and a characteristic strength of 460 N/mm2 make up the steel reinforcement. The concrete used has a 28-day compressive strength cube of 30 N/mm2. As illustrated in Figure 3, a two-line load is applied to the central part of each specimen during testing. Except for the control slab, which is stressed till failure, all the slabs are initially loaded to 2/3 of their projected ultimate load capacity or when the specimens begin to show indications of cracking. [5].

Figure 3. Test setup

Under a total load of 37.4 kN, two flexural fractures measuring 0.60 mm in width each were seen at the centre third of the slab. This restoration technique uses 200 mm-diameter injection nipples along the crack's route. The injection nipples were secured in place, and the surface of the fissures was sealed with Sikadur30. Sikadur52, a low-viscosity epoxy that is free-flowing, quick to cure, and based on a two-component solvent-free epoxy resin, is used to plug the fracture. Its properties include 1.1 kg/L density, 25 N/mm2 tensile strength after seven days, and 40 MPa compressive strength after 24 hours at 20 C. Sikadur52 puts width limitations on cracks between 0.2 and 5 mm. The crack was filled with Sikadur52 by injecting it from one end until it began to seep out of the other nip. Epoxy resin was injected into the cracks until they were filled.

Figure 4. Cracks in slab

In the beam, to make the test simpler, concrete mortar tests are ready. In the wake of eliminating the cast, the specimens are lowered for about three months to fix. After cutting the middle part, they are relieved at room temperature for one more month. The width of the counterfeit break is set to 1 mm, and epoxy pitch is infused into the break. To fix the epoxy tar, it is held at 20 degrees Celsius for 24 hours and then at 50 degrees Celsius for 24 hours [7].

4.2 Carbon Fibre Reinforced Polymers (CFRPs)

A beam with a cross-section of 150x300mm and a length of 3350 mm was manufactured for testing. The beams are supported and loaded in flexural loading under two points loading circumstances after 28 days of cure. The fractures in unrepaired beams were tested. [15]. Three half-scale models of the inner floor column connections are exposed to a rising lateral load routine daily while being subjected to the ground load of the floor slab and beam, equivalent to dead load + 30% live load. Damaged specimens are fixed to the plate surface with an epoxy-based crack sealant and gravity-fed CFRP sheet and then subjected to the same loading technique [20].

Figure 5. CFRPs in beams

4.3 Use of Electrochemical Method

Four rebars were employed as reinforcement in the 900x150x150 mm cast beam, and the concrete's top layer was 20 mm thick. Counterfeit breaks are formed in the lowest portion of the shaft and the pillar's focal point. With break widths of 0.4, 0.6, 0.8, and 1.0 mm, the crack depths were set at 3,7,11, and 15 mm. Examples were projected, recovered after one day, and alleviated after 27 days in a typical alleviating environment. The R.C. radiates were then subjected to the electrochemical statement. [4]

5. Results and Discussions

The initial cracking loads for slabs are shown in fig 5. The repaired specimen using epoxy injection techniques shows 35% increased cracking stresses compared to controlled slabs [5].

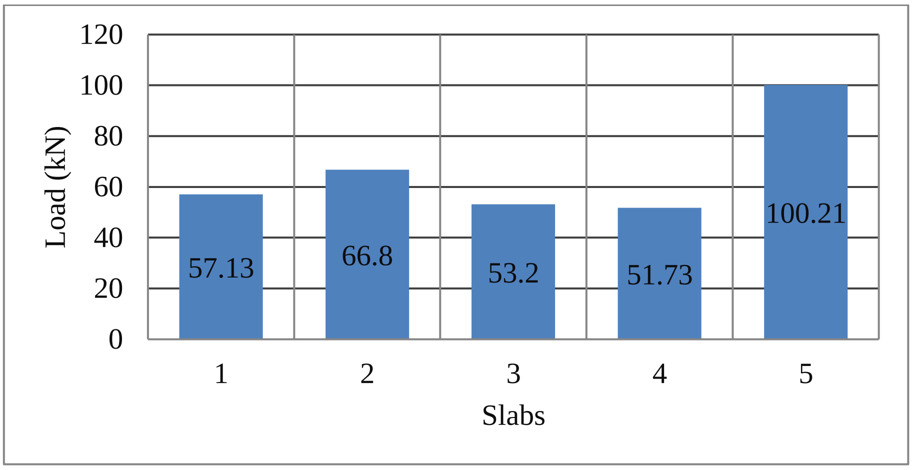

Figure 6. Cracking loads for slabs

Fig. 6 displays the control slab and various reinforced concrete slab specimens' first cracking loads (S1). All rehabilitated concrete slabs, except for S5, exhibit higher cracking loads than the control slab. Cracking loads in the restored specimens utilizing grout pouring, epoxy injection, and section expansion procedures are 35% higher than in the control slab. In comparison, adding a layer of Ferro-cement raises the cracking load by 17.8%. Reinforcing the slab by putting CFRP at its soffit does not strengthen the initial cracks; instead, it further widens the breach. Except for specimen S3, where the cracks were sealed with epoxy, all of the repair techniques used in this study can be demonstrated to be successful in restoring the damaged slab's ultimate capacity. However, the strength loss is just 8.6% compared to the control slab. The slabs S5 and S6, which were repaired using CFRP and section expansion, respectively, have ultimate load capacities of 77.4% and 130% greater than those of the control slab. The increase in maximum strength for slab specimen S5 is equivalent to that reported by Toong and Li [5], despite the comparatively low ratio of CFRP strip area to the total cross-section utilized in this experiment.

There are no notable differences in pressure debasement to 30,000 cycles for a displacement of 0.001 mm for beam fractures. Regarding the temperature swing, higher temperatures increase weakness disappointment, and the manner of disappointment in epoxy injection techniques changes from mortar to connect blow [9].

The beams are non-stationary radiation that has been put through testing up until one mm-wide fracture starts to show. This damage (due to fracture) was remedied on the specimens using CFRPs. Spokes that have undergone inspection following a repair are considered fixed. The primary break of each column seems to be 1050 mm from the focal length at the level of the second extreme. This demonstrates that support steel manufacturing begins in a nearby region. The results are made utilizing regular grades even though each layer comprises three R.C. spokes with indistinguishable cross-sectional parts and complicated supports. [12].

Then, SEM and XRD were used to look at these instances for micro-bacterial conditions. The ASTM C 39 test protocol is used to determine the compressive strength of cement. The self-recuperating limit is evaluated using a normal of five cases, whereas compressive strength is estimated using a normal of three test examples. Tetrahedrons and pyramidal shapes can be seen in bacterial cement, proving that calcite is present. It implies that the holes in the concrete mix are stuffed with calcite that has been conserved, which affects the significant's stability and toughness [10].

Following the completion of the ultrasonic measurements, samples with corrected, standardized fractures were sawed to produce cross-sections. Crystal formation at both fracture faces indicates that the untreated specimens show signs of autogenous healing during the water permeability test. After the water permeability test, no crystals were seen on the specimens with repaired fissures. Following is an explanation for this: The water flow rate for the untreated samples was so high that it took the whole test setup's top compartment to dry up between two measurements. As a result of coming into touch with the environment, the concrete's surface began to carbonate; turning Ca (OH)2 into CaCO3 crystals. Because bacteria were not resistant to the high pH in concrete, no CaCO3 crystals were seen using the microscope that was employed. However, as can be seen, the fissures are filled when the bacteria are immobilized in sol-gel. Due to the large grain size of the grout, it just covers the samples' surfaces and does not fill in the fissures.

In contrast, using epoxy led to the complete sealing of 10 mm and 20 mm deep fissures. The gel matrix cracked following sol-gel treatment alone or sol-gel+BS+CaCl2 treatment. The gel shrinks as it becomes more challenging, which causes cracking. Immediately following the filling of the cracks with silica gel and bacteria, samples treated with B.S. in sol-gel+CaCl2, Ca(NO3)2, or Ca(CH3COO)2 were put in urea-calcium solution. The fractures were filled once bacteria began to precipitate CaCO3 during immersion. However, only fissures that were 10 mm deep could be filled. The ultrasonic readings also demonstrated this. While 10 mm deep cracks treated with B.S. in sol-gel+ CaCl2, Ca(NO3)2, or Ca(CH3COO)2 worked almost as well as cracks treated with epoxy, 20 mm deep fractures were only filled when the epoxy was used.

6. Conclusion

In light of this research, one may draw the following conclusions: The rehabilitated buildings had ultimate loads and cracking that was on par with or even higher than the control slab. The flexibility and strength performances of the repaired slabs constructed using grout, epoxy injection, and Ferro-cement layers were comparable to those of the control slab. In other words, the usual reinforced concrete design for concrete slabs may be securely adopted using these restoration processes. CFRP and section expansion repair methods demonstrated increased strength-related structural performance for the broken slabs. However, compared to the control slabs, these slabs perform less ductility. One may also conclude that all forms of restoration, at the very least, successfully restore the structural integrity of fractured reinforced concrete slabs. Water permeability decreased due to the biological treatment used to seal cracks. However, it was shown that using autoclaved bacteria instead of living bacteria also caused the water flow to drop. This supports the Theory that the sol-gel matrix's capacity to patch cracks accounts for most of the decrease in water permeability. Only when active bacteria were present in the fracture healing material did a TGA study reveal the presence of CaCO3 crystals. The crystals' precipitation may improve this repair material's durability within the gel matrix. This biological therapy's effectiveness was assessed using visual inspection and ultrasonic transmission measures. After treating a fracture with B. sphaericus immobilized in silica gel, the ultrasonic pulse velocity increased, demonstrating the success of crack bridging. Visual examination of the cracks revealed that this treatment filled them. The employment of this biological repair technique is highly sought since the mineral precipitation brought on by microbial activity is unpolluted and organic. However, further research is required to determine how long this fracture-mending method will last.

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