Use of T-Port System for Pressure Injection Crack Fill of Concrete Structures

Laboratory Testing and Field Validation

Final Report

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INTRODUCTION

In service, cracks can develop in concrete due to mechanical and/or environmental loadings. The presence of cracks would not only reduce the strength and stiffness of concrete structures, but also permit the accelerated ingress of water and other aggressive agents causing cumulative deterioration. As a result, it is essential to restore the strength, stiffness, and water-tightness of structures, thus assuring a safe, serviceable, and durable structure. Repair of a cracked concrete structure is always a challenge facing the concrete professionals due to the fact that a long-lasting, aesthetically-acceptable, and structurally-sound repair is a combination of art and science.

Epoxy injection that has been practiced for many years is a successful method of strengthening cracked concrete structures, in which surface or socket-mounted ports and an injection gun or machine are typically used to inject the epoxy into the cracks. However, this system is typically time-consuming because the injection is normally performed port to port and capping of port is performed each time immediately after the injection. In the case of a manual injection, this process can be exhaustive.

Additionally, it is difficult to judge when the crack is completely filled in the conventional epoxy injection system. This is due to the fact that the epoxy flow along the crack is invisible. Typically, injection is stopped when the overflow through the adjacent ports is observed. However, the presence of epoxy in the neighboring ports does not necessarily indicate that all the crack space near the port is full.

A T-port system is specially developed by KPG Americas to facilitate the crack-filling process. This system mainly consists of T-ports, observation windows, and a gun or injection machine. The T-port utilizes a latex pod to temporarily receive and deposit the epoxy. Upon depositing the epoxy, the latex pod swells, and then generates a low pressure which is able to inject the epoxy into cracks. One of the great benefits of this system is that the epoxy can be deposited on multiple ports at a time, thus allowing simultaneous injection of epoxy. This significantly shortens the repair time. Refilling of port can also be performed when necessary. Consequently, this self-injection process enables the epoxy to slowly penetrate into every segment of cracks without worrying about whether the crack is full or not. In addition, the T-port injection is automatically achieved under a low pressure, which avoids the blow-out of cap seal and the formation of additional cracks, thus assuring a safe and sound repair.

Besides substantial labor and time savings, the T-port system also features leaking control and air relief during injection. The specially designed leak control valve is not only epoxy-tight, but also allows the free escape of air and water. This is particularly important for the overhead or horizontal crack fill because there is no concern about the leaking from ports and the air entrapment during injection, thus being able to achieve high quality crack fill.

Another important feature of T-port system is the use of observation windows to check the epoxy flow. In conventional crack fill methods, all crack surfaces are invisible after
capping and installation of injection ports. Consequently, the flow of epoxy during injection is imperceptible. With the installation of transparent observation windows, the crack surface becomes visible, thus providing a window of viewing the arrival and passing of epoxy flow during the injection process.

SCOPE OF WORK
The primary goal of this study was to conduct a field test for examining the reliability and the time and labor savings of epoxy injection by a T-port system. A variety of cracks (horizontal, vertical, and overhead) were selected from different concrete members such as retailing walls and joists/beams at the campus of Middle Tennessee State University (MTSU), Murfreesboro, TN. As a comparison, a conventional injection method was also evaluated.

Additionally, laboratory-cured specimens were used to aide in assessing the effectiveness of T-port system. A non-destructive testing method (Ultrasonic Pulse Velocity) was employed to evaluate the extent of crack fill. Specifically, cores were taken to visually examine how crack was filled. After visual examination, the splitting tensile test was performed to determine the quality of bond.

FIELD VALIDATION

Part I – Horizontal Cracks
A horizontal crack was chosen in a retaining wall with typical crack opening of 0.5 to 1mm as shown in Figure 1. The crack surface was thoroughly cleaned to remove debris and loose particles before cap seal and port installation.

![Figure 1 – A horizontal crack in a retailing wall selected for this study](image)

Capping materials were prepared by mixing two component adhesives (Miracle Bond MB 1450 from Adhesive Technology Corp.) in a 1:1 proportion by volume as shown in Figure 2 until a uniform gray paste was achieved.
After the capping materials were evenly mixed, cap seal and port installation were followed. For a conventional surface-mounted port, the bond achieved by the adhesive that was applied on the bottom of base was generally insufficient to resist the high injection pressure (Figure 3a). Additional capping materials were needed to apply on the port base (Figure 3b). This helped to strengthen the base and avoid blowout or leaking during injection. Consequently, an increase in the capping time and the capping material was anticipated.

However, the T-port base with a guide circle made it easy to receive the viscous capping paste (Figure 4a); while a higher bonding area and a better bond helped to attain strong adhesion between the port and the substrate (Figure 4b), thus reducing the risk of failure in the process of injection. Obviously, this saved the capping materials and reduced the capping time.
The ports were mounted on the crack surface at a space of approximately 8” (Figure 4a). The rest of crack surface was fully sealed with the capping paste. For the T-port system, an observation window was often set up between two adjacent ports (Figure 4b), making it possible to check the passage of epoxy flow during the injection. Apparently, this assisted in assessing the extent of crack fill.

After the capping paste was hardened, the port was connected to a KPG injection machine (pump) or an injection gun and a low viscosity resin (CRACKBOND LR-321 manufactured by Adhesive Technology Corp.) was delivered to the ports. For a conventional port, injection was only performed on one port at a time, thus requiring longer time to finish. When a manually operated gun is used, this process can be labor-intensive (Figure 5a) and the injection pressure can vary significantly. A high pressure was likely to break the cap seal; while a very low pressure would slow down the injection and reduce the penetration depth. Another disadvantage of the conventional port system was the difficulty of determining when to stop the injection. In general, the injection gun or machine was disconnected from the port when refusal of epoxy was arbitrarily
determined or overflow of epoxy occurred from the adjacent ports. However, this did not assure that the crack had been completely filled. This was particularly true when the interior part of crack was very small, which required slow permeation of epoxy to reach full saturation. After the rejection of epoxy was felt, the port was capped. The process was continued at the next port until all ports were finished. As a result, the conventional epoxy injection was a laborious process that involved a high risk of blow off and incomplete crack fill.

Conversely, a T-port system not only allowed the direct transmission of epoxy to the crack, but also stored the epoxy at the pod for further self-injection. At the beginning of T-port injection, a part of epoxy was directly transferred to the crack through the port and there was little accumulation at the pod. However, as the injection proceeded, the crack space that was easily accessible was nearly full. The epoxy started to accumulate at the pod as shown in Figure 5b, generating a bubble.

Approximately 40 cc can be stored at the pod (Figure 6a). The bubbling of pod created a low pressure of 40 to 60 psi that allowed slow permeation of epoxy to the remaining crack areas (typically hairline cracks). Obviously, this automatic injection process significantly reduced the injection time and labor at each port as there was no need to wait until each port was completed. After the epoxy was adequately deposited, the injection machine was then detached from the port (Figure 6a). The injection to the other ports was continued until all ports were adequately bubbled. Consequently, a concurrent self-injection of multiple ports occurred, which undoubtedly accelerated the injection process. Based on the observation in this study, more than 50% of injection time and labor could be saved.

Besides time and labor savings, the T-port system was more likely to achieve high-quality crack fill. This was because the self-injection T-port provided unlimited continuing supply of epoxy that was able to gradually permeate into the areas with hairline cracks. Also, the specially designed valve of T-port allowed the free escape of air thus reducing air entrapment during injection. Without air-releasing, the advance of epoxy front would compress the retained air resulting in a pressure build-up of air phase. When this accumulated pressure balanced the injection pressure, epoxy front would stop, leading to incomplete fill of crack. As a result, the air-free injection of T-port was always preferred to achieve full saturation of epoxy. Moreover, the T-port injection was a non-
aggressive process because the self-injection was constantly under a constant low pressure. This eliminates the risk of blow-out. When the crack was filled, the T-port injection would stop automatically. This excluded the concerns of not knowing when to stop the injection. Therefore, T-port injection was a worry-free process. The only thing that needed to do after initial injection was to confirm whether a refill of pod was necessary.

Additionally, the use of observation window in T-port system provided an easy way of checking the epoxy flow in cracks during injection. As can be observed in Figure 6b, the presence of epoxy at the observation window was an indication of continuous unobstructed epoxy flow in the crack. Effective crack filling could be anticipated.

![Figure 6](image)

Figure 6 – Close up view of T-port and observation window: (a) T-port with epoxy deposit (bubbled), and (b) observation window with epoxy flow clearly shown

After the epoxy was cured (typically overnight), the port and cap seal were removed by heating, chipping, or grinding (Figure 7a) and a final finish after grinding can be seen in Figure 7c.

![Figure 7](image)

Figure 7- Removal of injection port and cap seal and final finish of repair surface: (a) heating, chipping, and grinding; and (b) close up view of final finish of repaired crack
Part II – Vertical Cracks

The field validation test was also conducted on vertical cracks in a structural wall (about 10’ high and 1.5’ thick) with vertical cracks of approximately 0.5 mm wide as shown in Figure 8a. The cracks were observed to go through the whole thickness of wall. Two similar cracks were selected for comparison. One was for conventional ports (Figure 8b) and the other one was for T-ports (Figure 8c). The port installation and cap seal were performed following the same procedures as described in Part I. The crack surface on the other side of wall was purposely left open to check the penetrability of epoxy. Epoxy injection was performed from the bottom port to the top port using a cartridge gun. Shortly after the injection, presence of epoxy was observed on the opposite side of wall (Figure 8d) indicating that both systems were highly penetrable. However, the T-port system was observed to be faster and easier. Besides a slight savings on capping materials, substantial time and labor savings (more than 50%) were expected. Again, there was no need to watch over the T-port. The only thing for the T-port was to deposit the epoxy as soon as possible and assured a refill when needed. Another advantage of T-port system in this application was that leaking from the other side of wall was adequately compensated as a result of the continuous supply of epoxy from the pod, thus leading to a better crack fill.

Figure 8 – Epoxy injection on vertical cracks: (a) vertical crack in the front face of wall; (b) T-port application; (c) conventional port application; and (d) vertical crack on the back face of wall (note the presence of epoxy shortly after injection).
In addition, the comparison between conventional port and T-port was performed on a thick retailing wall (8’ tall and 3’ wide) with various vertical cracks of approximately 1 mm opening as shown in Figure 9a. Similarly, two comparable cracks were selected to simplify the comparison. Procedures for capping, port installation, and epoxy injection (Figure 9b and Figure 9c) were same as what was described in Part I. The crack surface on the top of wall was partially sealed with the capping paste so that the overflow of epoxy from top of wall could be viewed. Again, T-port system proved to be faster and easier than the conventional injection system for the crack fill. Specifically, it was observed that the overflow at the top of wall (nearly 1’ above the top port) occurred shortly after the injection of the top port (Figure 10). This again indicates that the T-port self-injection system has high penetrability.

Figure 9 – Tests on vertical cracks in a retailing wall: (a) a typical vertical crack; (b) epoxy injection after port installation; and (c) close-up view of T-port and observation window during epoxy injection (note – the observation window filled with epoxy)

Figure 10 – Arrival of epoxy at crack surface on top of wall
Part III – Overhead Cracks

Overhead cracks occurred in concrete beams or suspended slabs as a result of overload or under design. The repair of overhead cracks is always a challenge due to the fact that they are difficult to access. In this study, a reinforced concrete beam (2’ high and 1’ wide) with severe flexural cracks was selected to verify the performance of the two injection systems (i.e. T-port vs. conventional). The crack opening was approximately 0.5mm as shown in Figure 11a. The cap seal and port installation followed the same procedures as above (Figure 11b).

After curing of cap seal, injection was performed from port to port with a cartridge gun. For conventional ports, epoxy was transported to the crack by direct injection (Figure 12a); while T-ports initially used direct injection and deposit, and then self-injection to deliver the epoxy (Figure 12b). Based on the observations, T-port system was more convenient and saved time. No capping was required for the T-port after injection; whereas the conventional port needed to be capped immediately after injection to prevent leaking.
LABORATORY TESTING
The inspection of epoxy penetration into cracking by the T-port system was performed through the laboratory testing in this study. Special attention was paid to the effectiveness of air relief of the system during injection. Lab specimens (24”x12”x6”) were prepared using a normal structural concrete with a water-to-cement ratio of 0.4. The mixture proportion was Cement: water: sand: crushed limestone (NMSA=0.5”) = 1: 0.4: 2: 1.8. After 14 days curing, the specimens were fractured under the flexural loading. The width of cracking varied approximately from 1 mm to 3mm as shown in Figure 13a. Two T-ports were mounted on the surface of crack with one near the bottom and the other one on the top. An observation window was installed at the surface of crack approximately 8” away from the bottom port. The remaining crack surface was completely sealed with capping materials as shown in Figure 13b. After the curing of capping materials (overnight), the epoxy was injected through the bottom port until the overflow was observed at the top port.

A non-destructive testing method (Ultrasonic Pulse Velocity) was used to evaluate the penetration of epoxy into the fracture of concrete. Fully injected cracked concrete was anticipated to have similar transit time as the sound concrete; while locations with unfilled cracks would display longer transit time. In this test, a meter was connected to a pair of 54 kHz transducers that were coupled to the opposite sides of specimen using petroleum jelly as shown in Figure 14. One transducer was used as the pulser while the other was used as the receiver and the time that it took the wave to transmit across the specimen (in milli-seconds) was recorded. The UPV was measured every 2 inches from the bottom to the top of specimen before the epoxy injection and after the epoxy had cured. For each location, significant difference in transit time (20-100 milli-seconds) was observed before and after epoxy injection. The pulse velocity was then calculated by dividing the distance between the transducers by the transit time. An average increase of approximately 20 ft/min. in velocity was found in this study. This implies that the crack was effectively filled with epoxy by the T-port injection system.
It is commonly recognized that the best method of determining the efficiency of injection system is to examine the in-place penetration and the quality of bond. In this study, cores were taken from the cracked slab after the injected epoxy was hardened (Figure 15a). They were then visually examined to assess the penetration depth of epoxy and the extent of crack fill. As can be seen from Figure 15b, the crack was completely filled with epoxy suggesting that T-port was a reliable injection system.

After visual examination, splitting tensile test was conducted on the core to determine the quality of bond (Figure 16). A newly fractured section was observed when the specimen failed revealing that high quality bond was achieved by the T-port injection system.
As a comparison, the gravity feed method was conducted in this study. A pond was established at the crack surface on the top of specimen. The rest of crack surface was sealed by the capping materials as shown in Figure 17a. After the cap seal was cured, the epoxy was poured into the pond and then drained into the crack by gravity. This process continued until the refusal of epoxy from the crack. After the epoxy hardened, two cores were taken from the cracked areas of specimen (one near the pond and the other far away from the pond). Surprisingly, the core taken far away from the pond was observed to fall apart during the coring operation. Through the visual examination of broken sections, it was seen that the old fracture was only partially filled with epoxy. This can be attributed to the air entrainment during gravity feed since there was no air escape as a result of cap seal. The entrapped air stopped the epoxy front leading to unfilled cracking.

Figure 16 – Splitting tensile test for cored sample

Figure 17 – Crack repair by gravity feed: (a) cracked slab with cap seal and gravity feed reservoir; and (b) partially filled crack section
CONCLUSIONS

Laboratory results, as well as the field validation, have shown very conclusively that T-port injection is a better system of delivering adhesives into fractures of concrete. The system is especially more advantageous for large areas of cracked concrete where it is not economical to repair by conventional pressure injection methods (port to port). The main benefits of T-port system include:

- Fast injection – T-port injection can be preceded at a time to as many ports as desired, thus allowing simultaneously self-injection that substantially shortens the injection time. Fast injection means early completion and resulting cost savings.
- Easy injection – The epoxy can be quickly and easily deposited into the T-port and the rest of process is automatic, which leads to minimal labor demand and cost savings.
- High quality – The T-port self-injection process provides unlimited time that allows slow penetration of epoxy to hard-to-access areas of crack. It also allows the free air relief and compensates unexpected leaking during the injection. All lead to a high quality crack fill.

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