Evaluation of Injection Pressure Retention and Crack Filling Performance According to Injection Methods

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1. Introduction

Concrete structures in nuclear power plants can develop cracks due to a variety of internal and external factors such as material shrinkage during construction, curing imbalance, thermal loads during operation, foundation settlement, repeated vibrations, movement of heavy equipment, and deterioration caused by radiation exposure. These cracks can significantly compromise the structural performance by reducing watertightness, accelerating rebar corrosion, and degrading seismic resistance. Therefore, precise and reliable crack repair technologies are essential.

Conventional crack repair methods generally rely on low-pressure manual injectors such as rubber-band or spring-type devices. However, these methods are often characterized by insufficient initial injection pressure and rapid pressure loss over time, which frequently results in incomplete resin delivery to the crack tips and the formation of internal voids. Such limitations hinder the long-term durability and performance of the repaired structures.

In this study, we aim to experimentally evaluate the injection pressure retention and crack filling performance of the T-PORT system, a core component of the TPS method (Designated as Construction New Technology No. 822), and assess its applicability for crack repair in nuclear power plant structures.

2. Experimental Method

2.1 Time-Dependent Injection Pressure Measurement

This experiment was designed to quantitatively evaluate and compare the time-dependent pressure retention characteristics of three different crack injection methods. The methods examined include the Rubber-Band Manual Injector, designated as Case A; the Spring-Type Manual Injector, designated as Case B; and the T-PORT System, designated as Case C. Each method was tested under identical conditions to assess differences in injection pressure behavior over time.

All devices were filled with the same two-component low-viscosity epoxy resin to their maximum injection capacity. A precision digital pressure gauge was installed between the injection port and the specimen to continuously measure injection pressure at 1-second intervals from the start to the end of injection. The measurement continued until the resin was depleted or the internal elastic recovery of the device was completed. The collected pressure data were then analyzed to compare the pressure retention characteristics of each system.

Table I. Comparison of Device Configurations by Injection Method

Category	Rubber-Band (Case A)	Spring (Case B)	T-PORT System (Case C)
Structure			

2.2 Crack Filling Performance Evaluation

To assess the qualitative and quantitative filling performance of each method, actual cracks measuring 0.3 mm in width were identified in in-service structures rather than laboratory specimens. After applying each injection method, cylindrical core samples (50 mm diameter) were extracted from the center of the repaired cracks. The cores were then cut and polished to visually inspect the depth of resin penetration, completeness of crack filling, and the presence of voids.

3. Results and Discussion

3.1 Injection Pressure Retention Performance

Injection pressure retention is a key parameter for delivering resin to the full depth of the crack. Figure 1 shows the time-dependent pressure changes for each injection method.

In Case A (Rubber-Band Method), the resin was injected with a single rubber band applied to a 40 cc syringe. Preliminary tests showed that 1–2 rubber bands produced negligible pressure, while 3, 4, and 5 bands generated 0.5, 0.75, and 1.0 kgf/cm² respectively. Since 1–2 bands are commonly used in field conditions, the experiment used one band, resulting in approximately 30 seconds for the 40 cc resin to discharge. However, the injection pressure was too low to overcome the internal flow resistance, and no significant pressure was recorded on the gauge. The resin was expelled solely by the minimal elastic tension of the rubber band, leading to ineffective delivery into deep crack regions.

Case B (Spring-Type Injector) applied an initial pressure of 1.5 kgf/cm² through linear spring compression, but the pressure rapidly dropped to 0.8 kgf/cm² within 2 seconds and further to 0.01 kgf/cm² by 17 seconds. The injected resin volume was 20 g. The pressure decay pattern indicated insufficient resistance to resin flow, resulting in incomplete filling in deeper crack zones.

In contrast, the T-PORT system (Case C) demonstrated stable pressure behavior. It began at approximately 2.2 kgf/cm² and maintained 1.7–1.8 kgf/cm² for over 30 seconds. Due to the recovery force of the elastic storage tube, the pressure increased again in the final stage, reaching up to 2.7 kgf/cm². The total injection time was approximately 45 seconds, attributed to the larger resin volume of 44 g—more than double that of the spring-type device. This time difference reflects resin quantity, not system performance.

As shown in Fig. 1, the T-PORT system maintained the most consistent injection pressure throughout the process, while both the rubber-band and spring-type methods exhibited rapid pressure loss, potentially leading to filling failure near the crack tip.

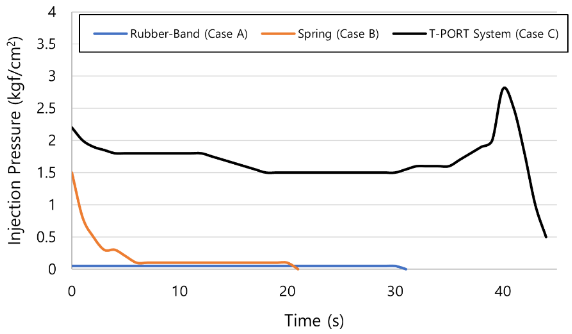

Fig. 1. Comparison of injection pressure variation over time by injection method

3.2 Crack Filling Performance

The qualitative evaluation results of crack filling for each injection method are summarized in Table II. After each injection, core samples were extracted from actual 0.3 mm-wide cracks in the structure and visually analyzed.

In Case A, resin remained only near the surface of the crack, with most of the internal regions unfilled. Incomplete filling and voids were observed, and in some cases, surface fracturing occurred during coring—indicating insufficient pressure to drive the resin deep into the crack.

Case B showed partially filled cracks with visible voids, suggesting inadequate resin continuity due to rapid pressure loss.

In contrast, Case C (T-PORT System) achieved continuous and complete crack filling, with no visible voids and full penetration to the crack tip.

Table II: Comparison of Core Cross-Sections After Crack Filling

Category	Rubber-Band (Case A)	Spring (Case B)	T-PORT System (Case C)
Crack Filling Evaluation			

4. Conclusion

This study experimentally demonstrated that the T-PORT system, a core component of the TPS method, provides significantly better injection pressure retention and crack filling performance compared to conventional manual injection systems.

Unlike conventional systems where pressure is applied only at the beginning and rapidly dissipates, the T-PORT system maintains a consistent and effective injection pressure throughout the entire process. This enables deeper resin penetration and continuous filling, even in narrow and deep cracks.

Moreover, the system's ability to sustain relatively high injection pressures makes it particularly suitable for thick concrete structures such as those in nuclear power plants, where resin flow resistance is greater. As a result, the T-PORT system is a promising technical alternative to overcome the limitations of traditional low-pressure injection methods.

Future research should involve field application tests on actual nuclear power plant structures and long-term durability evaluations including adhesion strength and crack reappearance prevention.

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