PSC연구모임 설정과제

1. 내부 PT텐던 안전성 여부
2. 하부구조의 PT텐던 점검 및 진단
3. 내부 PT텐던의 점검 및 천공부 보수방안
4. **내부 PT텐던 결함부 보수보강 방안**
5. 내부 PT텐던 부식방지 방안
6. 계측방안
7. 설계, 시공, 유지관리 지침 수립 등
8. 내부텐던 중대결함 발생 시 대처 시나리오

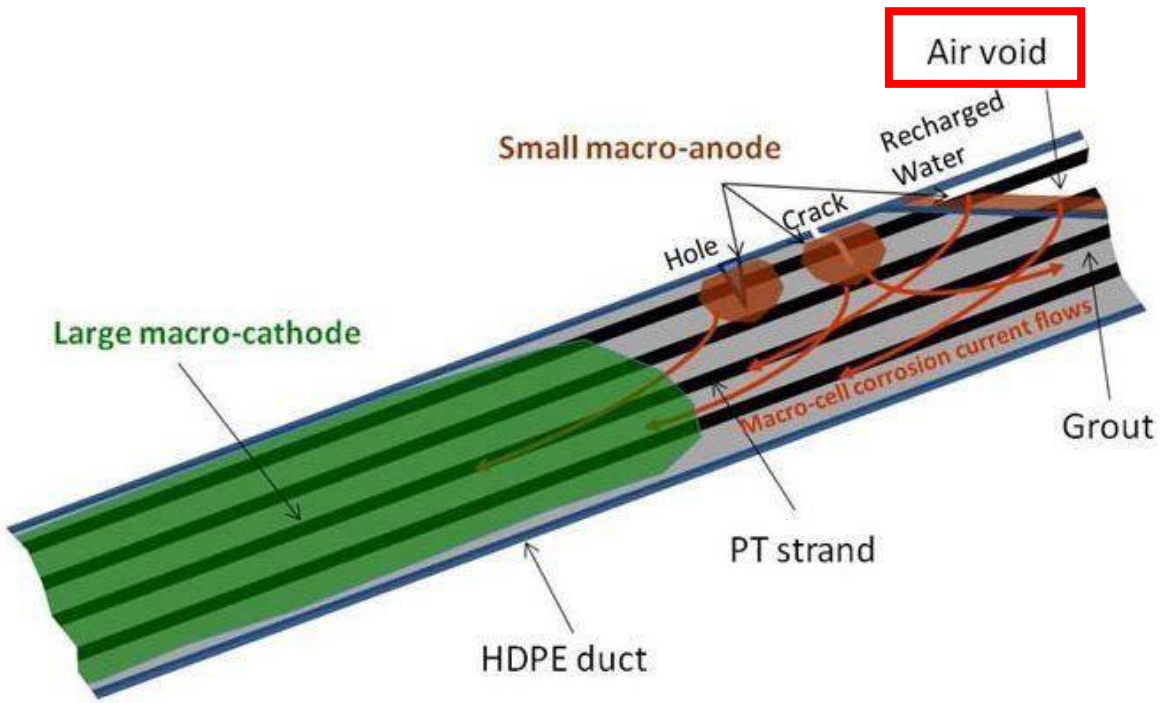
Varina-Enon Bridge 사례연구를 통한

결함부 그라우트 충진 보수의 적합성 고찰

목 차

Macro-cell 부식이론

Macro-cell corrosion mechanism in PT tendon



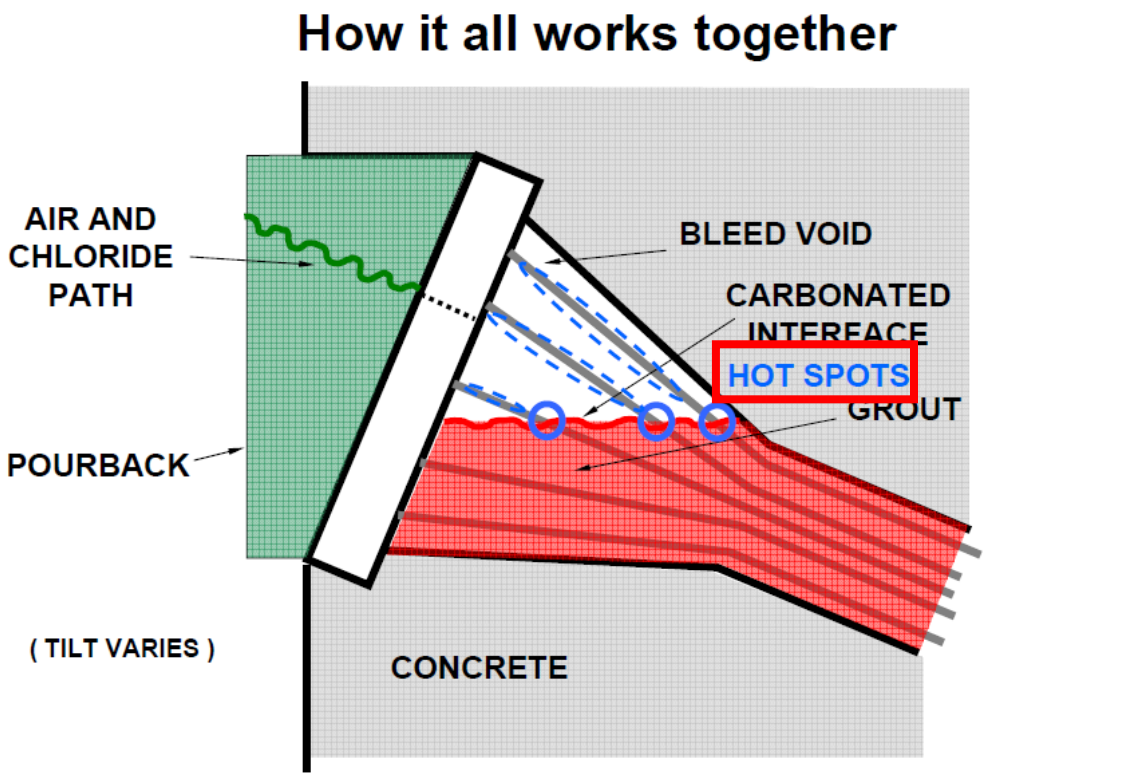
[Ref.] FHWA, Post-Tensioning tendon grout chloride thresholds, 2014

✓ 텐던의 정착부, 덕트 최상단은 블리딩 등에 의해 대규모 공극이 발생할 가능성이 높음

- 회색부분: 작은 규모의 양성전위 (macro-anode)
  - ▶ 공극 및 균열부에서 공기, 수분, 염화물 등에 노출
  - ▶ 중성의 습한상태
- 초록부분: 큰 규모의 음성전위 (macro-cathode)
  - ▶ PH가 높은 염기성 환경과 건조한 상태

✓ 대규모 공극에 의하여 발생하는 큰 전위차는 양성(Anode)인 부분에서 부식을 급격하게 발생시킴

Macro-cell 부식이론



Aggravation by Galvanic Coupling

- The bulk grout-void interface is electrochemically coupled to the rest of the passive strand and anchor metal.
- After passivity breakdown, oxygen reduction at those large surfaces can intensify corrosion at the steel emergence point.

✓ 공극으로 기인하여 부동상태가 깨지게 되면 산소 환원에 의한 HOT SPOTS에서 부식이 집중됨

[Ref.] FDOT, Mechanism and Detection of Corrosion in PT Tendons in Florida Bridges, 2006

신구 그라우트의 전위차로 인한 부식?

Varina-Enon교 사례

- ✓ 1990년 7월 준공, 28경간, 상부구조 480개 텐던
  - 박스내 8개(6개 Draped) 외부텐던, 19개 강연선/텐던,
- ✓ 2001년 상당수의 텐던에서 공극 발견, Slightly corroded*
- ✓ 2003 & 2004년 HPG로 공극 진공그라우팅(VG) 보수실시
  - 대략 55%의 텐던에 대하여 진공그라우트 보수
- ✓ 2007년 보수 후 3~4년 만에 파단 발생
  - 1개 텐던 파단, 1개 텐던은 소선 2가닥(혹은 3가닥) 파단

  ⇒ 2개 텐던 교체
- ✓ 중차량(57톤 이상) 제한 및 텐던 교체보수

* PTI, VDOT Experience with grouts and grouted PT tendons

▸ VDOT News - Richmond

RELEASE: IMMEDIATE RICH-0726

CONTACT: Dawn Eischen (804) 524-6179 May 24, 2007
Richmondinfo@VDOT.Virginia.gov

VDOT Posts Weight Restriction for the Varina-Enon Bridge
Affects only specially permitted loads

CHESTERFIELD/HENRICO COUNTIES—During a routine inspection of the Varina-Enon Bridge, the Virginia Department of Transportation (VDOT) found evidence of corrosion in one of six steel strands located inside the bridge along the southbound approach span. As a precaution, specially permitted loads over 57 tons (115,000 lbs.) will be restricted from driving over the bridge at I-295 south until repairs are completed. The northbound side of the bridge is not affected by this restriction.

"The bridge is structurally sound and can withstand normal traffic loads," said VDOT Richmond District Structure and Bridge Engineer Gary Martin, P.E. "This weight restriction only affects trucks carrying overweight loads, which are required to have a permit and adhere to a designated route." The Virginia Department of Motor Vehicles (DMV) is responsible for issuing permits and routing vehicles around restricted structures for both weight and clearance.

VDOT is posting signs and using variable message boards to communicate these restrictions to truckers. In addition, the DMV is contacting special permit holders to give them route instructions. Drivers carrying loads over 57 tons that had planned to use I-295 south over the Varina-Enon Bridge should call the DMV's hauling permit section at (804) 497-7135 for further instructions.

VDOT inspects all bridges every two years. In fact, the last inspection for the Varina-Enon Bridge was in 2005. At that time, there was no evidence of corrosion in any of the steel strands.

"Routine bridge inspections are a critical part in maintaining structural safety," said Martin. "In this case, we were able to identify a potential weakness before it became a more serious problem."

Over the next few weeks, VDOT and contractors will make repairs to the bridge. Other than the posted weight restriction, I-295 south travelers will experience periodic lane closures during repairs.

The 17-year old, cable-stayed bridge spans the James River and connects Chesterfield and Henrico counties. The southbound side carries approximately 17,000 vehicles per day.

Tweet

[R

Information in VDOT news releases was accurate at the time the release was published. For the most current information about projects or programs, please visit the project or program Web pages. You may find those by searching by keyword in the search Virginia DOT box above.

신구 그라우트의 전위차로 인한 부식?

공극 충진보수 영향관련 의혹 제기

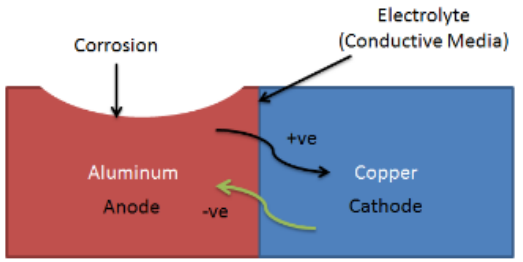
✓ Texas Transportation Institute 보고서

2.2.2.4. *Varina-Enon Bridge, Virginia, US*

The Varina-Enon cable-stayed, post-tensioned, segmental concrete bridge over the James River near Richmond, Virginia (Figure 2-7), was opened to traffic in 1990. One of the external tendons in this bridge failed in 2007 (after 17 years of service). Figure 2-8 shows the failed tendon. This tendon failure draws special attention because of the fact that the failure occurred at approximately 3 to 4 years after the voids in the tendon/duct were grouted or repaired. This repair work included filling voids inside the ducts using a high-performance grout. Hansen (2007) reported that the location of tendon failure was at the interface between the existing Class A or B grout and newer Class C repair grout. This failure indicates a critical need for research into the influence of new repair grouts on tendon corrosion, especially at the interface between existing and repair grouts. This interface could possibly generate a galvanic corrosion cell. However, the validity of this argument needs to be investigated. It was also observed that many tendons were not completely sealed during the original construction. This likely enabled moist air from the environment to enter the voided ducts and accelerate corrosion of the exposed tendons.

[Ref.] Effect of voids in grouted, post-tensioned concrete bridge construction

- 텐던 파단이 기존/보수 그라우트의 경계면에서 발생
- 경계면에서 보수 그라우트가 텐던의 부식에 미치는 영향에 대한 연구가 필요함
- Galvanic corrosion cell의 발생시켰을 가능성이 있으나, 이러한 주장의 입증은 추가 조사가 필요함



<Galvanic corrosion cell>

신구 그라우트의 전위차로 인한 부식?

공극 충진보수 영향관련 의혹 제기

✓ Texas Transportation Institute 보고서 – Moratorium 언급

In late 2007, a PT bridge in Virginia experienced failure of a tendon. The tendon had been recently repaired (i.e., grouted), and it was believed that the failure could be a result of galvanic cells formed by the different grout environments. The State of Virginia placed a moratorium on repairing PT bridges, and TxDOT delayed repairs pending the findings from Virginia Department of Transportation. Unfortunately, the potential corrosion of strands

[Ref.] Effect of voids in grouted, post-tensioned concrete bridge construction

TTI보고서 외 Galvanic corrosion cell 관련자료

ASCE 매거진

✓ Tendon failure raises questions about grout in post-tensioned bridges, 2007

Forensic Engineering: Tendon Failure Raises Questions about Grout in Posttensioned Bridges

by Brett Hansen, Associate Editor; Civil Engineering Magzine, ASCE World Headquarters, 1801 Alexander Bell Drive, Reston, VA.,

Serial Information: *Civil Engineering—ASCE*, 2007, Vol. 77, Issue 11, Pg. 17-18

Document Type: Editorial

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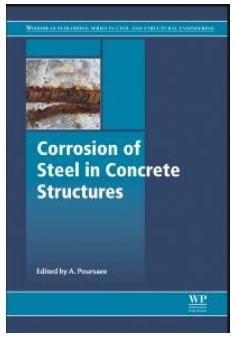
TTI보고서 외 Galvanic corrosion cell 관련자료

Corrosion of Steel in Concrete Structures

1) K. Lau, Florida International University
2) I. Lasa, FDOT



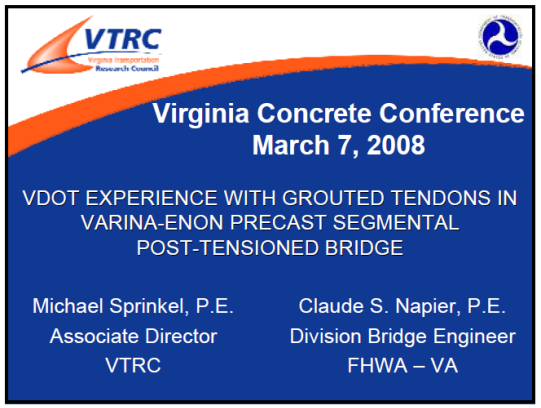
Concerns about corrosion development in steel strands after repair of void spaces with dissimilar grout materials may be particularly relevant for tendon systems containing deficient grout materials. Corrosion failure of an external tendon in the Varina-Enon Bridge in Virginia in 2007 has often been cited, as the tendon failure occurred less than 4 years after repair of a void space (Hansen, 2007). In the absence of grout degradation and other tendon deficiencies, complete repair of the void space with dissimilar materials can be expected not to produce any significant corrosion development if both materials yield high-pH environments where the steel should maintain its passive behavior. Moderate levels of polarization in the anodic region due to coupling of the steel in the dissimilar grouts should not cause significant enhanced corrosion rates if the repair is made in such a way that it prevents moisture accumulation and external exposure. Voids created by bleed water and grout segregation could lead to localized grout deficiencies such as carbonation and enrichment of aggressive chemical species, where steel depassivation can occur and the condition can be aggravated by macrocell development. Laboratory testing of repair void spaces filled with repair grout in field-extracted external tendons containing some form of grout segregation indicated corrosion activity after placement of the repair material (Lau et al., 2013b,c; O'Reilly et al., 2012). Removal of deficient grout prior to repair remains a challenge.

- 블리딩과 그라우트 재료분리로 유발된 공극은 부분적 그라우트 결함을 유발하고 macrocell을 발달시킴
- 공극이 보수 그라우트 (이질적 그라우트)로 보수가 잘 되었다면 급격한 부식이 발생하지 않았어야 함.
- 현장에서 추출한 재료 분리된 그라우트의 외부텐던을 시험실에서 보수 그라우트로 충진 (Lau, 2013년)
  ⇒ 부식 활동 (Corrosion activity) 관찰
- 보수에 앞서 결함 그라우트의 제거가 과제로 남아있음

[Ref.] Corrosion of prestress and post-tension reinforced-concrete bridges, 2016, Pages 37-57

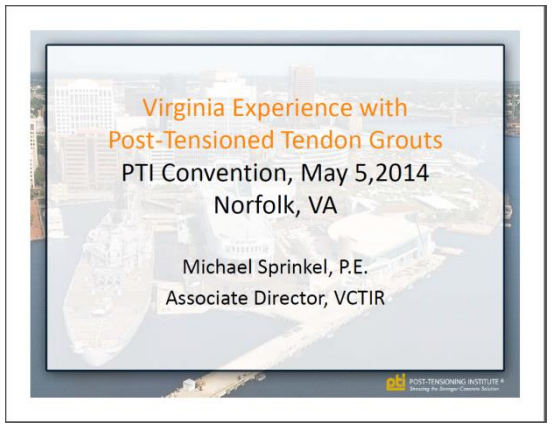
VE Bridge관련 VDOT(VTRC)의 발표자료

<Michael Sprinkel>

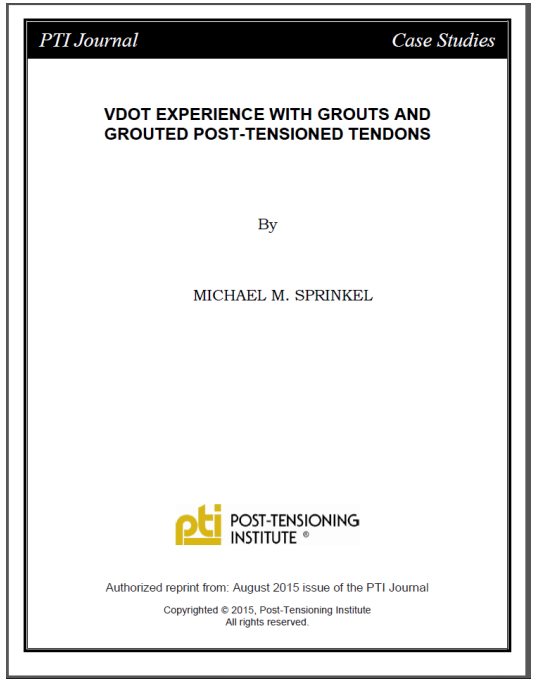


<2008년 VCC 발표자료>

<2013년 VCC 발표자료>

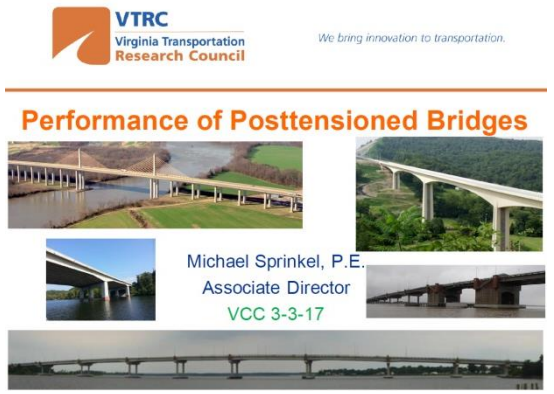


<2014년 PTI 발표자료>



<2015년 PTI 저널 기고자료>

<2016년 Bridge D&E 기고자료>



<2017년 VCC 발표자료>

<2018년 VCC 발표자료>

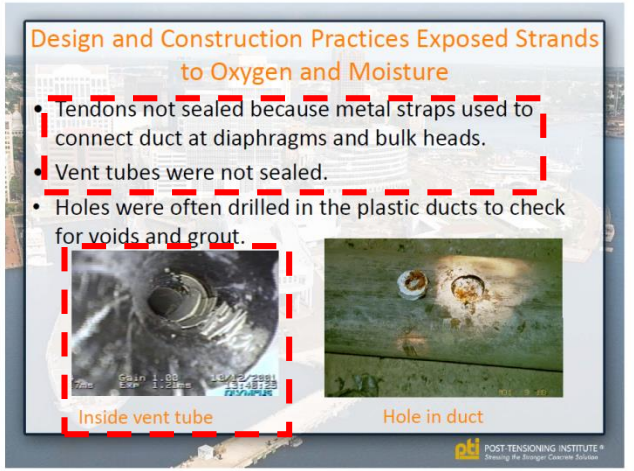
VDOT 발표자료 내용 요약

2001년 이전: Water-cement grout 사용

✓ Varina Enon Bridge (1990)

- 텐던 기밀성 떨어짐 (덕트 연결시 메탈 스트랩 사용) ⇒ VG가 잘 됐을지??
- 에어벤트가 밀폐되지 않음
- 1995년 이전 그라우트(w/c≤0.42)는 약 4%의 블리딩 유발

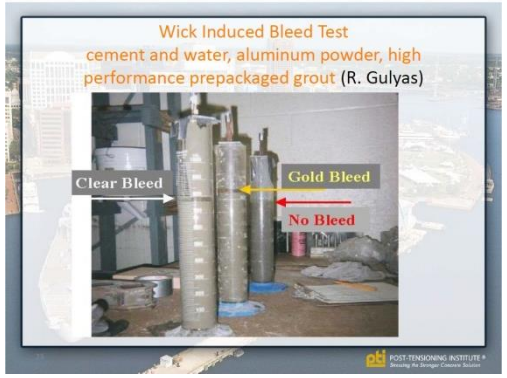
▶ 150ft(45.7m)텐던에서 6ft(1.8m)의 공극 유발 ⇒ 약 55% VG 충진



<2014년 PTI 발표자료>

bleed and segregate after being pumped into a tendon. A wick-induced bleed test indicates that bleeding in grouts used prior to 2001 was approximately 4%. In a typical 150 ft (45.7 m) long tendon in the Varina Enon Bridge (Fig. 4), 4% bleeding can cause 6 ft (1.8 m) of void at the high points in the draped tendons and a void along the top of a horizontal tendon (Fig. 5). Six of the eight tendons in

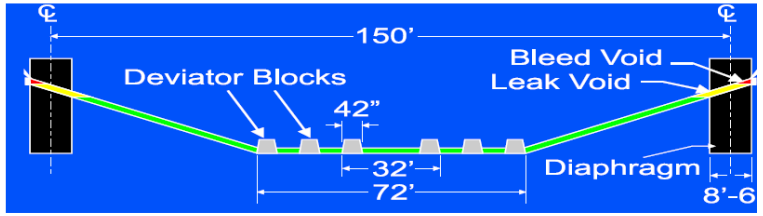
<2015년 PTI 저널>



Typical Grouted Condition of Draped prior to 2001 (1)

- Grout bleeds and segregates leaving 2 voids, each approximately 2 per cent of the tendon length.
- For 150-ft tendon two 3-ft voids with un protected strands at anchors is typical (red in figure).
- **Questions:** Do voids affect service life? Should voids be vacuum grouted? Vacuum grouted with what?
- **Preservation:** NDE methods can not be used to evaluate the condition of the strands. Install acoustic emission monitoring system to detect wire breaks.

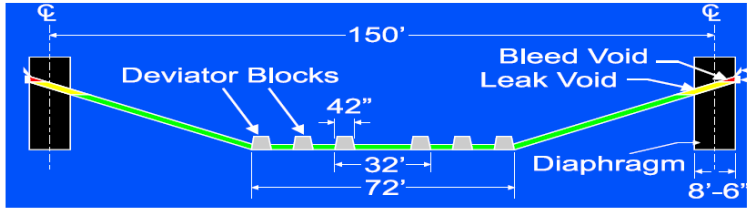
삭제이유?



<2017년 VCC 발표자료>

Typical Grouted Condition of Draped Tendons (1)

- Grout bleeds and segregates leaving 2 voids, each approximately 2 per cent of the tendon length.
- For 150-ft tendon two 3-ft voids with un protected strands at anchors is typical (red in figure).
- **Preservation:** NDE methods can not be used to evaluate the condition of the strands. Install acoustic emission monitoring system to detect wire breaks.



<2018년 VCC 발표자료>

VDOT 발표자료 내용 요약

- ✓ Varina Enon Bridge의 기존 그라우트 상태
  - 파단된 텐던은 높은 수분율(water contents) / 흡수율(absorption) 함유
  - 파단된 2개 텐던의 물시멘트비(w/c)가 0.6을 초과하는 것으로 추정 (PTI 기준치 최대 0.45)

Given that we estimated the w/c ratio for grout in two tendons of the Varina Enon bridge exceeded 0.6 and the PTI specification allows a maximum w/c of 0.45 we batched mixes with w/b ratios that ranged between those recommended by the manufacturers and 0.65.

<2014년 PTI 발표자료>

2001년 이후: Prepackaged Grout

- ✓ Preapproved Product List: 승인 그라우트 목록
  - Sika300PT, Masterflow 1205, Euco cable PTX
- ✓ Varina Enon Bridge 공극충진 보수 시행 (2007년)
- ✓ US460 Bridge (2012년 Mock-up 테스트 시행)

2017년 이후: Flexible filler

Preapproved Products List: Cable Grouts
Approved List No. 62 (Now Screening Qualification List)

- SikaGrout 300PT: Sika Corp. (Removed from List until a new grout formulation is approved.)
  - Shelf Life: 6 months – properly stored
  - Paper bag – plastic liner
- Masterflow 1205: BASF Construction Chemicals, LLC
  - Shelf Life: 9 months – properly stored
  - Paper Bag – plastic liner
- Euco Cable Grout PTX: Euclid Chemical Co.
  - Shelf Life: 1 year – in original unopened container
  - Plastic Container

<2013년 VCC 발표자료>

VDOT 발표자료 내용 요약

✓ VE교 사용 그라우트(Prepackaged grout)재료의 적합성 추론

The next effort involved working with grout suppliers to develop a high-performance grout (HPG) with low permeability that would not bleed and segregate. The first grout to be developed and approved by VDOT is referred to as Grout 1. By work order, Grout 1 was used to grout the tendons in the segmental bridge on the Smart Road in 2001. This bridge was the first in the world to be grouted with a high-performance grout. VDOT approved prepackaged Grout 2 later in 2001 and by work order Grout 2 was used to grout approximately the last 60% of the bridge spans on the 895 project. Finally, in 2001, VDOT approved prepackaged Grout 3. VDOT had accomplished the goal

3개 HPG 승인 (Grout 1, 2, 3)

480 tendons with grouted PT strands. The voids confirmed the need to implement the use of high-performance grouts. In 2003 and 2004, contracts were awarded to grout the voids in the Varina Enon Bridge. Grouts 1 and 2 were used.

VE교 보수는 2003년에 Grout 1, 2 사용

In 2010, tendons in Florida and Texas that had been grouted with Grout 2 were found to have voids; segregated grout; grout with high chloride content; and grout that was not set, called soft grout.[1] It was obvious that lab tests used to approve HPG needed to be improved. In 2012, FHWA published a sampling protocol for DOTs to use to identify tendons with grout that contained unacceptable levels of chloride.[2]

Grout2 문제 발생 in Florida & Texas
– HPG 승인 Lab test 개선 필요

The implementation of HPG seemed to be going well until, in 2011, the supplier of Grout 2, the most-used HPG, announced that the grout contained chlorides that were in the cement in the prepackaged grout. Despite test reports indicating acceptable levels of chlorides, the problem had gone undetected for approximately 10 years. The grout had

Grout 2 제조사의 염화물 함유 공표

and little testing was done. Later, the Texas DOT reported chlorides as well as soft grout in pier bends grouted with Grout 2, and Florida reported similar problems with tendons grouted with Grout 2.

TxDOT, FDOT의 Grout2 사용한 교량에서 문제점 발견
– 높은 염화물, soft grout

Preapproved Products List: Cable Grouts
Approved List No. 62 (Now Screening Qualification List)

- SikaGrout 300PT: Sika Corp. (Removed from List until a new grout formulation is approved.)
  - Shelf Life: 6 months – properly stored
  - Paper bag – plastic liner
- Masterflow 1205: BASF Construction Chemicals, LLC
  - Shelf Life: 9 months – properly stored
  - Paper Bag – plastic liner
- Euco Cable Grout PTX: Euclid Chemical Co.
  - Shelf Life: 1 year – in original unopened container
  - Plastic Container

Grout 2 = Sika 300PT일 가능성?

[Ref.] PTI Journal, VDOT Experience with grouts and grouted Post-Tensioned tendons, 2015

VDOT 발표자료 내용 요약

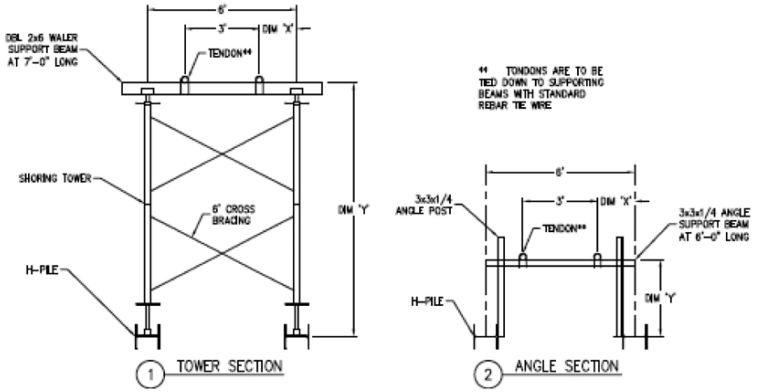
✓ US460 Bridge (2012년 Mock-up 테스트 시행)

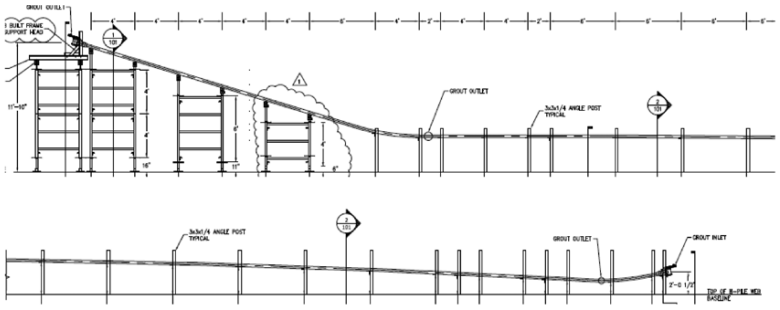
In 2012, a cast-in-place segmental bridge was being constructed on US-460 in the western part of Virginia next to the Kentucky/Virginia state line. The contractor was proposing to use Grout 2 and the decision was made to require a mockup to compare the performance of Grouts 2 and 3. The mockup was done to simulate the

US460교 건설시 시공사가 Grout2 사용 제안

In 2012, VDOT did a mockup by work order to identify a suitable grout for use in the US 460 segmental bridge project near Grundy, VA. The mockup determined that Grout 3 was suitable for use because the tendon was properly grouted. Grout 2 bled and segregated and left voids and soft grout at the high points in the tendon in the mockup and was rejected for use.

목업 테스트로 Grout 2,3성능 비교 ⇒ Grout2 Rejected






Grout 2 tendon has void along top.


Grout 2 outlet end cap has void and soft grout.

Grout2


Grout 3 tendon is fully grouted.


Grout 3 outlet end cap fully grouted.

Grout3

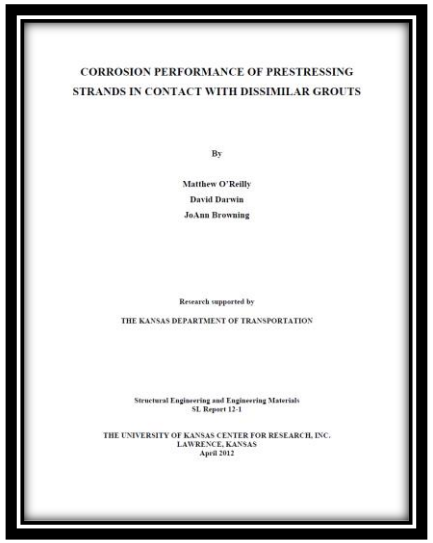
VDOT 발표자료 내용 요약 정리

- ✓ 기존 저품질의 Water-cement Grout는 부식 유발
  - 블리딩, 재료분리, 높은 수분율 함유, 많은 공극 유발
    - ⇒ 텐던의 약 55%를 진공그라우트 충진
  - 텐던의 기밀성이 떨어지는데 진공그라우트로 잘 충진 되었을지 의문?
- ✓ 보수 그라우트(Prepackaged HPG)의 재료적 적합성 추측
  - VE교에서 보수로 사용한 grout2를 US460의 목업테스트결과 Rejected
  - Sika300PT(Grout2)가 사용되었을 가능성
- ✓ 파단의 원인으로 Macro-cell부식 매커니즘을 명시하고 있지 않음
  - 가능성에 대하여 언급
- ✓ 횡방향 텐던 파단 발생 (2017년 5월)
  - 2개 cable stay 경간의 Transverse deck tendon

Transverse Tendon Failure May 2017

Transverse Tendon Failure May 2017

보수 그라우트 영향 (Dissimilar Grout) 관련 연구내용



CORROSION PERFORMANCE OF PRESTRESSING
STRANDS IN CONTACT WITH DISSIMILAR GROUTS

By

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Research supported by
THE KANSAS DEPARTMENT OF TRANSPORTATION

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April 2012

Kansas DOT, 2012

Corrosion performance of prestressing strands in contact with dissimilar grout

CORROSION OF POST-TENSIONED TENDONS WITH DEFICIENT GROUT

FINAL REPORT
Project BDV29-977-04
(800002803)

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Florida DOT, 2016

Corrosion of post-tensioned tendons with deficient grout

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보수 그라우트 영향 관련 KDOT 연구내용

KDOT, Corrosion performance of prestressing strands in contact with dissimilar grout, 2012

✓ 연구 배경

- KDOT에서 점검시 발견한 PT교량 텐던 내 공극을 충진할지, 아니면 공극 상태로 남겨둘지 의사결정에 대한 고민
- 일반적인 공극 충진은 Prepackaged anti-bleed grout를 사용하나, 이것이 오히려 급격한 부식을 초래한 많은 사례가 있음
- 보수 그라우트로 인한 이질적 환경에 따른 전위차로 급격한 부식이 발생했을 가능성

✓ 연구 목적

1) 보수 그라우트(Second grout)가 강연선 부식에 대한 보호를 할지 아니면 부식을 가속화 할지에 대한 결정
2) 공극을 미충진 상태로 남겨둘 때 혹시 모를 결과에 대한 확인

INTRODUCTION

Inspections of post-tensioned bridges by the Kansas Department of Transportation have revealed voids in strand ducts due to bleeding and shrinkage of older portland cement grouts (PB Americas 2010). The Kansas Department of Transportation is faced with a decision whether to fill these voids or to leave them ungrouted. As long as the voids remain dry, the strands typically appear intact with some surface rust. However, field observations indicate that severe corrosion occurs in cases in which water or water containing chlorides comes in contact with the strands.

The usual approach to filling voids in post-tensioning ducts involves using prepackaged anti-bleed grouts. Unfortunately, in a number of cases, the repair operations appear to have led to rapid corrosion of the re-grouted strands. A likely cause of the rapid corrosion is a difference in electrical potential in the strands caused by differences in environment provided by the dissimilar grout.

The dual goals of this study are to (1) determine if using a second grout will provide improved corrosion protection for the prestressing strands or result in accelerated corrosion and (2) determine the possible consequences of leaving the voids unfilled. To accomplish these goals, this research is designed to measure the effect of the differences in the environment provided by different grouts and to compare the level of corrosion caused by filling the voids with an anti-bleed grout to that resulting if the strands are not re-grouted but are subjected to water or water containing chloride.

보수 그라우트 영향 관련 KDOT 연구내용

KDOT, Corrosion performance of prestressing strands in contact with dissimilar grout, 2012

✓ 연구방법

– 포틀랜드 시멘트 그라우트, 석고(Gypsum) 그라우트?
4개의 상용화된 Prepackaged 그라우트로 보수했을 때의 영향 연구

▶ Sika300PT, Sika300PT w/FerroGard(부식방지혼화제), Euco cable PTX, NA-50

✓ 연구 결론

1) 노출 강연선을 보호되지 않은 상태로 방치하는 것은
급격한 부식 초래 할 수 있음

2) 황산이온 함량이 증가함에 따라, 상용 Prepackaged grout에서의
강연선 부식은 증가한다.

3) 포틀랜드 시멘트 그라우트와 prepackaged anti-bleed 그라우트는
물과 염분에 노출된 강연선보다 부식 손실이 현저히 낮다.
Prepackaged grout와 포틀랜드 시멘트 그라우트에서 측정된 가장 높은 부식은
높은 황산염 농도에서 발생했다.

1. Leaving prestressing strands unprotected from the elements has the potential to result in rapid corrosion of the exposed strands.
2. The gypsum grout has a significantly lower pH than any of the other grouts tested. It also has a higher sulfate content than all but one of the grouts. Gypsum will cause accelerated corrosion of strands when used in conjunction with portland cement grout or any of the commercially prepackaged grouts tested.
3. Corrosion of strands in commercially available prepackaged grouts increases as the sulfate ion content of the grout pore solution increases.
4. When paired with portland cement grout, the prepackaged anti-bleed grouts evaluated in this study resulted in corrosion losses significantly below those observed for strands exposed to salt or water. The highest corrosion measured for a prepackaged grout in conjunction with portland cement grout occurred for the grout with the highest pore solution sulfate content.

보수 그라우트 영향 관련 KDOT 연구내용

KDOT, Corrosion performance of prestressing strands in contact with dissimilar grout, 2012

✓ Recommendations

1) 강연선의 물과 염화물에 노출은 급격한 부식을 발생시키므로 PT덕트에서의 공극은 anti-bleed 그라우트로 충진 되기를 추천

2) anti-bleed 그라우트는 부식을 가속시킬 수 있는 기존 그라우트와의 환경적 차이를 최소화 할 수 있는 재료를 선택

3) 상용 Prepackaged 그라우트를 사용할 때, 염기도와 함께 황산이온 농도가 모니터 되어야 함

RECOMMENDATIONS

1. Because exposure of strands to water or chlorides can cause rapid corrosion, it is recommended that voids in post-tensioning ducts be filled with an anti-bleed grout.
2. The anti-bleed grout should be selected to minimize environmental differences with the existing grout that could result in accelerated corrosion of the post-tensioning strands. In addition to pH, the sulfate ion concentration of the commercial grout pore solution should be monitored. For repairs to ducts containing portland cement grout, the four commercially available grouts evaluated in this study provided significant reduction in corrosion compared to strands exposed to salt or water. The use of grouts with high gypsum content should be avoided in post-tensioning applications.

보수 그라우트 영향 관련 FDOT 연구내용

FDOT, Corrosion of post-tensioned tendons with deficient grout, 2016

✓ 연구 배경

- Prepackaged low-bleed 그라우트로 시공된 FDOT의 Ringling교에서 높은 수분, 높은 황산염 농도, 낮은 염화물 농도, 높은 염기도의 재료분리된 그라우트에서 파단이 발생

> Recent corrosion failures of post-tensioned (PT) tendons in the Ringling Causeway Bridge (and corrosion development of PT tendons elsewhere in Florida) utilizing pre-packaged low-bleed specified grout products have spurred the need to evaluate what mechanisms were involved to cause the failure and to determine to what extent the problem is in PT tendons with similar materials. Severe corrosion was accommodated by segregated grout that was characterized as having high moisture content, low total chloride content, high free sulfate concentrations, and high pore water pH. Accumulation of bleed water and grout void formation,

✓ 연구내용

- 결함 그라우트에서의 PT텐던 부식영향 연구

▶높은 수분의 결함 그라우트에서의 부식 영향

▶높은 염기도 내의 황산이온의 부식유발 영향

▶높은 황산이온 농도에서의 부식유발 영향

▶염화물과 황산염 결합에 의한 영향

1. Identify the characteristics of deficient grout associated with steel corrosion, including grout conditions formed when cast in presence of enhanced moisture presence.

2. Identify the role of sulfates in alkaline solutions and its possible adverse effects on steel corrosion activity.

3. Identify the behavior of steel in deficient grout with enhanced sulfate concentrations.

4. Identify the combined effect of enhanced chloride content and free sulfate content in deficient grout on corrosion initiation and identify practical threshold limits.

보수 그라우트 영향 관련 FDOT 연구내용

FDOT, Corrosion of post-tensioned tendons with deficient grout, 2016

✓ 연구 결론

- 그라우트 제조사 spec.의 15% 초과하는 높은 수분율은 결함을 촉진
- 결함 그라우트에서는 황산염의 농도가 높다
- 결함 그라우트에서의 높은 황산염 농도는 외부 유입 없이도 축적되며 낮은 농도의 황산염 또한 재료분리를 유발한다
- 낮은 농도의 염화물도 황산염이 존재할 때는 부식을 유발시킨다
- 염화물 단독으로 결함 그라우트의 부식 민감성을 평가하기엔 충분치 않다
- 그라우트 재료분리에서의 염화물과 황산염의 축적되는 경향은 그라우트 재료 시험에 중요한 부분으로 고려되어야 한다

- High moisture content promotes grout deficiency. The effect from excess admixed water (15%-20% above manufacturer's recommended limit) was more significant than grout pre-hydration after up to 7 days of grout powder pre-exposure in 100% relative humidity.
- High sulfate concentrations can be accumulated in deficient grouts without external sulfate sources. Even low concentrations of sulfates in well hydrated grout may locally aggregate due to segregation.
- Additions of 0.08 and 0.2% chloride by cement in itself did not initiate corrosion of steel in any of the segregated grout layers. Corrosion developed in deficient grout materials with similar low-level additions of chlorides (0.03 to 0.18% of total grout mass) when combined with as low as 2,000-ppm sodium sulfate in its mix water. The enhanced sulfate addition apparently had effect to initiate corrosion in presence of low-level chlorides.
- The enhanced sulfate additions apparently had adverse effect in the corrosion development of steel in grouts with low level chlorides indicating adverse effects of combined low level chlorides and sulfate presence. The finding would suggest that assessment of corrosion susceptibility of deficient grout by chloride content alone would not be sufficient.
- Propensity for chloride and sulfate accumulation in grout segregation should be considered as part of robustness testing of grout materials.

보수 그라우트 영향 관련 FDOT 연구내용

FDOT, Corrosion of post-tensioned tendons with deficient grout, 2016

✓ **보수 그라우트 영향관련 연구**

- 기존 그라우트가 균질하고 단단하며, 건조한 조건에서 보수 그라우트 충진했을 때 부식은 미미함
- 텐던에 습윤이 유입되어 보수 그라우트재와 혼합될 수 있는 조건에서 상대적으로 큰 부식활동이 관찰됨. 여기서 과다한 습윤에 황산염 농도가 증가 되었을 때 큰 부식 전류가 측정됨
- 2개의 상용 보수 그라우트로 실험 결과 부식 양상의 차이가 존재, 두 제품의 부식활동 차이의 원인은 연구범위를 벗어나 논의되지 않음
- 수분이 축적된 그라우트는 보수 후 부식 활성도를 높일 수 있다
- 결함 그라우트(양극)는 보수 그라우트에 충진된 강연선(음극)과 매크로셀 형성으로 인해 부식이 증가할 가능성이 있다. 부식을 유발하는 황산염 이온의 역할에 대한 추가 연구가 필요

As expected, negligible corrosion activity was observed for the tendon repair condition where the pre-existing grout was relatively homogenous, hardened and in relatively dry condition. Marked indication of relatively greater corrosion activity was observed in conditions

condition. Marked indication of relatively greater corrosion activity was observed in conditions where moisture was introduced into the tendon and allowed to intermix with the repair grout material. There, somewhat greater corrosion currents were measured when the excess moisture contained enhanced sulfate concentrations. Correspondingly in those cases, a

material was observed; however, there was differentiation in behavior for experiment subsets utilizing different repair grout materials. The cause of the differences in behavior between the two grout products was not elucidated and was further complicated by the conditions of the as-received grout sections. Two possible scenarios were posed to explain the differentiation in

dissimilar grout materials without major corrosion development. However, grout conditions with accumulated moisture may continue to support enhanced corrosion activity after repair.

Unmitigated deficient grout may support corrosion activity with possibility of enhanced corrosion due to macrocell formation between local anodic locations and strand in the repair grout. Further assessment of the pore water chemistry and the role of sulfate ions on corrosion initiation was recommended. Evaluation of the effectiveness of available repair grouts to

결론 (Conclusion)

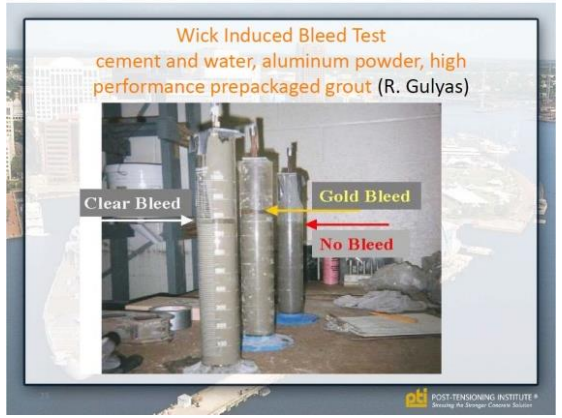
1) 현장배합 물-시멘트 그라우트는 **심지효과로 인한 블리딩**으로 포물선 배치된 텐던의 최상단부에서 공극을 유발시키는 **재료적 한계**가 있음 (VDOT)

2) 블리딩으로 발생한 텐던내 공극을 방치하는 것 보다 **충진하는 것이 부식에 유리**하나 새로운 재료로 충진하는 것은 **이질적인 환경을 조성**할 수 있으며 이는 **부식을 유발**할 수 있음 (KDOT, FDOT 연구)

3) 따라서, 이질적인 환경을 최소화 할 수 있는 기존 그라우트와 유사한 성질의 그라우트재로 보수가 필요하며 특히, 기존 결함이 있는 그라우트를 제거하는 것이 향후 과제이나 이 모두는 **현실적으로 쉽지 않음** (FDOT 연구)

4) **상용 Prepackaged grout로 공극 충진 보수**는, **높은 황산염 농도**에서 **급격한 부식을 유발**하였다는 연구결과 (KDOT 연구)

5) Prepackaged Grout의 재료적 문제점 확인 필요
   - **Sika300PT grout 로 시공**한 **FDOT의 Ringling(2003) , 공용 7~8년만에 파단 발생**



제언 (Recommendation)

1) 재료적 한계에 의하여 발생하는 공극을 충진해야 할지, 어떤 자재로 충진할지에 대한 의사결정 필요

2) 장기적으로 공극 충진 보수를 위한 국내의 Anti-bleeding Prepackaged Grout 개발 필요성이 있음

- 현장배합 물-시멘트 그라우트는 재료적 한계

3) Prepackaged Grout의 현장 적용을 위한 승인시험은 현재의 시험실 기준만으로는 검증이 부족하기 때문에 개선 전까지는 현장 재현시험 (목업테스트)을 통하여 재료를 검증할 필요가 있음 (VDOT사례)

4) 재료분리 그라우트에서 황산염의 축적 매커니즘 규명이 필요 (세계적으로 연구 진행 중)

- 재료분리된 soft그라우트에서 높은 황산염의 존재와 함께 급격한 부식에 따른 파단

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