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# NTNU/MTP REPORT

TITLE:

**HERØY F&U**

**WP2.A4 “Corrosion mechanism including effect of environmental parameters”**

**Summary of work and findings**

AUTHOR(S):

**Roy Johnsen**

CLIENT(S):

**Nordland Fylkeskommune and Statens Vegvesen**

|                                    |                                |                                  |   |
|------------------------------------|--------------------------------|----------------------------------|---|
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ABSTRACT:


This report contains a summary of results from literature reviews, inspections and two MSc thesis to investigate the effect of pH, chlorides, sulphate and oxygen on corrosion of tensile wires inside ducts in concrete bridges.

The following observations were done in the experimental work:

1. pH, chloride and sulphate are important environmental parameters for corrosion on tensile wires inside a duct.
2. A change of pH from 12.5/13 to <11, resulted in strong increase in corrosion on the wires.
3. Test in electrolytes simulating fluids inside a duct and exposed in contact with air, will react with the atmosphere and reduce the pH below 11.
4. The effect of oxygen on corrosion is not thoroughly examined and no clear conclusion can be drawn.
5. The possible effect of galvanic corrosion between wires without concrete and with concrete coverage needs to be further investigated.

The conclusion from the work is summarised in Chapter 3 and proposal for further work in Chapter 4.

|             |             |                         |                    |                 |
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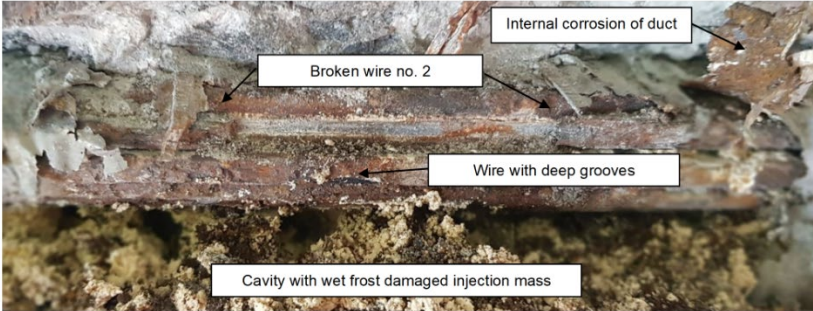
**REFERENCES ..... 16**

# 1 WORK PERFORMED BEFORE START-UP OF THE HERØY FOU PROJECT<sup>1-2,4</sup>

This report contains a summary of the work performed in WP2.A4. More details are given in the reports<sup>1-5</sup>.

## CHALLENGE ON HERØYSUND BRIDGE

### Corrosion of armor wires and ducts




Internal corrosion of duct

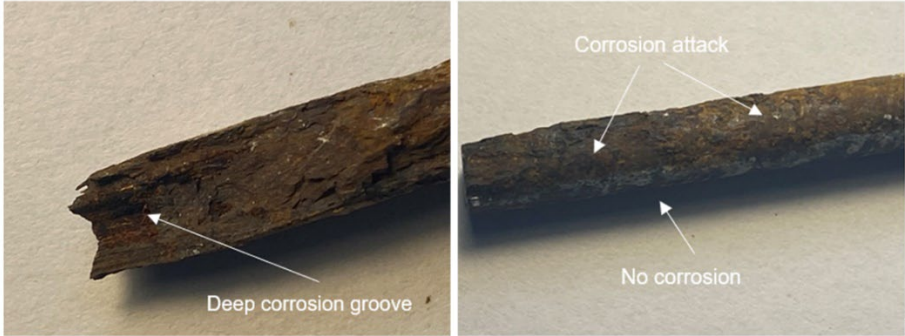
Broken wire no. 2

Wire with deep grooves

Cavity with wet frost damaged injection mass

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## FRACTURE IN WIRE



Deep corrosion groove

Corrosion attack

No corrosion

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## EARLIER INSPECTIONS

**Multiconsult 2017**

- Concrete coverage in areas where chloride content and potential measurements were done – 76 inspection points
- Chloride (Cl-) content 0.40-1.56 wt% (sement)

**Statens Vegvesen October 2019**

- During concrete repair, corrosion and voids were discovered inside cable ducts. No more details reported.

**SINTEF 2020**

- Analysis of injection mass from SSV – delivered in October 2019
- Chloride (Cl-) content 0.03-0.04% of dry mass

**Dekra 2020**

- Detecting voids inside tendon ducts (due to observations by SVV in October 2019)
- Documented a lot of missing grout
- Documented brakage in 3 wires (3SC) through drilling holes


RAPPORT  
**18-1069 HERØYSUND BRU**

OPPDRAAGSGIVER  
STATENS VEGVESEN REGION NORD

EMNE  
SPESIALINSPEKSJON


DATE / REVISJON: 23. desember 2017 / 00  
DOKUMENTNR: 73298-18-1000-1844-01

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 SINTEF

**Previngsrapport**

Laboratorieuundersøkelser av injiseringsmasse fra innsiden av kabelkanal for spennarmring på Herøysund bru


 MTRILLOSJØET Betonglaboratoriet Dato: 2020-09-13

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**REPORT**

**Herøysund bridge**

Locating voids in grouted tendon ducts with NDT  
REPORT: Ref: 7204-B-18452-V04.1

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## EARLIER INSPECTIONS, cont.

### SVV and NTNU August 2020

- Drilled holes in three different locations – selected from the Decra results with indication of missing grout.
- Several holes in the concrete drilled to expose the cable duct and wires
- Injection mass (SINTEF analysis), part of broken wire from two positions collected and photos taken.

### SINTEF 2020

- Analysis of injection mass
- Low chloride content in solid 0.035% and pH 13

|   |                             |  |                             |
|---|-----------------------------|--|-----------------------------|
|  |                             | <b>NTNU/MTP RAPPORT</b>  |                             |
| Institutt for Maskinteknikk og Produksjon (MTP)                                   |                             | TITTEL<br><b>HERØYSUND BRU</b><br>Korrosjon av spennarmering i betongbruer |                             |
| Adresse: Richard Stoklands vei 2b<br>8059 Gjøvik                                  |                             | FORFATTERE<br>Roy Johnsen  |                             |
| Telefon: +47 90 00 12 73<br>Faks: +47 72 00 41 20<br>E-post: info@ntnu.no         |                             | KUNDE<br>Statens Vegvesen  |                             |
| RAPPORT NO.<br>90599200-01  | KLASSEBETEGNING<br>90599200 | PROSJEKT NO.<br>90599200   | ANTALL SIDEVERDIER<br>46/14 |

|   |  |  |  |
|---|--|--|--|
|    |  | <b>Prøvsrapport</b>  |  |
| SINTEF Consumer<br>Postboks 476 Postveien<br>1507 Sandnessjøen<br>Sandnessjøen, 18<br>Nordland +47 20010000<br>info@sindef.no<br>Handelsregister<br>NO 90 90 90 90 90 |  | Undersøkelser av injiseringsmasse fra kabelkanal til Herøysund bru |  |
|   |  | Dato: 2020-11-30   |  |

## 2020/Location 1, Kabelbane 2 (close to 2SA-2)



### Analysis of injection mass:

- Cl: 0.035%
- Moist: 21%
- pH: 13 (measured with pH paper)

### Corrosion observations

- Corrosion on wires – indication of more attacks in the bottom
- Injection mass covers the gap and partly the surface of the wires
- Part of the duct volume not filled with injection mass
- Consists of injection mass varies from dry to frost damaged

## 2020/Location 3, Kabelbane 2 (close to 2SA-2)



### Analysis of injection mass:




- Cl: 0.037%
- Moist: 44% (wet)
- pH: 13 (measured with pH paper)

### Corrosion observations

- Serious corrosion on wires, more in the bottom
- One broken wire found (investigated)
- No external corrosion on duct
- «Damaged» injection mass



## 2020/Location 2, Kabelbane 2, but North side of the bridge






Analysis of injection mass:

- Cl: ?
- Moist: ?
- pH: ?


Corrosion observations

- Serious corrosion on wires, more in the top
- Sroius corrosion of the duct
- Injection mass partly covered the wires and the gap between the wires
- One wire cut and analysed in the lab

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## FRACTURED WIRES

### From inspection August 2020 – Inspection point 3





Corrosion observations

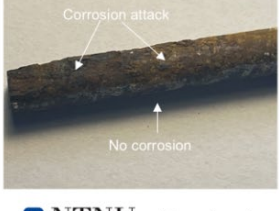
- Fracture in wire no. 2 from top
- Corrosion on the wire on both side of the fracture
- Min. wire diameter close to the fracture 2.9 mm
- Only part of the wire diameter exposed to corrosion
- At fracture: 30-35% of the cross section intact

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## FRACTURED WIRES

### From inspection August 2020 – Inspection point 1









Corrosion observations

- No fracture had occurred in this wire
- Deep corrosion grooves in the wire – oval form with length 5-15 mm, depth 1.5 mm and width 3-4 mm
- All grooves were on the same side of the wire, while the rest of the wire surface was without and serious attacks.

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# MÅLØY BRIDGE

**Corrosion observations**

- Serious corrosion attacks on wires
- Fracture occurred in several wires
- Lack of injection mass
- Investigation of 3 fractured wires documented
  - Areas with and without corrosion
  - Deep corrosion attacks close to the fractures
  - Fracture region showed cup and cone with remaining wall thickness 1 mm and depth 6 mm (see photo)
- Internal and external corrosion on the duct
- **SEM: Indication of high local content (3-13 wt%)**

**Analysis of injection mass:**

- Cl: ~ 0.18%
- Sulphate (SO<sub>3</sub>): 1.19-1.44 wt% (inj.mass)
- pH: ?

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# REPORTS (input to the SVV-NTNU Herøy project)

**NTNU/MTP RAPPORT**

**HERØYSUND BRU**  
Korrosjon av spennarming i betongbruer

Forfatter: Roy Johnsen

Stad: Statens Vegvesen

Prosjekt nr.: 6056200-02

Utskrift nr.: 40/14

**NTNU/IPM REPORT**

**Corrosion testing of tensile wire**

Forfatter: Roy Johnsen

Stad: Statens Vegvesen

Prosjekt nr.: 6056200-02

Utskrift nr.: 14/4

**NTNU/MTP RAPPORT**

**Korrosjon av spennarming i betongbruer**  
Oppsummering av resultater fra eksperimentell arbeid ved NTNU

Forfatter: Roy Johnsen

Stad: Statens Vegvesen

Prosjekt nr.: 6056200-03

Utskrift nr.: 10/0

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## 2 SUMMERY OF OUTCOME FROM MSc PROJECTS

### 2.1 MSc student Bettina Horn Myhre<sup>3</sup>

# MSc PROJECT

## Bettina H. Myhre 2021-2022


**Objective**


Examine how pH, chloride (Cl<sup>-</sup>), sulphur and oxygen affect the stability of the oxide/passive layer and corrosion properties on prestressed tendons in injection mass

**Parameters**

|                   |   |   |
|-------------------|---|---|
| ○ pH:             | 12 – 14                                   | } Based on values from SINTEF analysis of samples from the bridge |
| ○ Chloride:       | 0.01 – 0.6 wt%                            |   |
| ○ Sulfat:         | 0 – 20.000 ppm (0-20 g/l)                 |   |
| ○ Temperature:    | Room temperature                          |   |
| ○ Oxygen content: | i) Saturated (7-8 ppm), and ii) < 100 ppb |   |

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Faculty of Engineering  
Department of Mechanical and Industrial Engineering

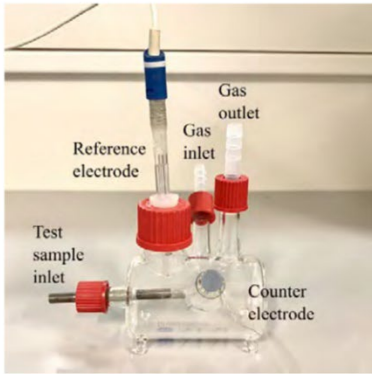
Bettina Horn Myhre

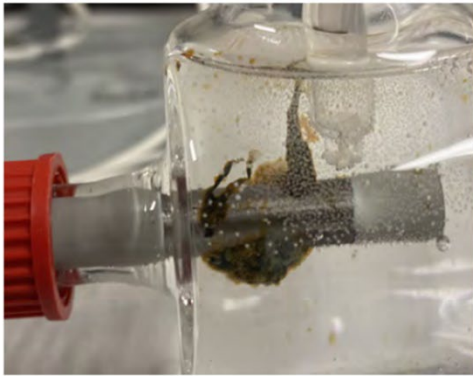
**Effects of chloride, sulfate and pH on the corrosion of tensile wires in grouted tendon ducts in Herøysundet bridge**


Master's thesis in Materials Science and Engineering  
Supervisor: Roy Johnsen  
Co-supervisor: Andreas Erbe, Mette Geiker  
June 2022


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## TEST SET-UP

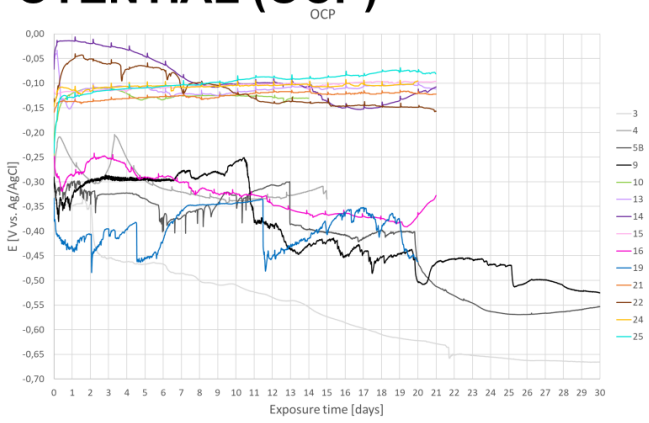






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## DEVELOPMENT OF CORROSION POTENTIAL (OCP)

OCP




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## SAMPLES AFTER EXPOSURE

| Samples <sup>1</sup> | Percentage of Area Corroded [%] |                              |
|----------------------|---------------------------------|------------------------------|
|                      | After OCP/LPR                   | After OCP/LPR + Polarization |
| 4 <sup>2</sup>       | 90-95                           | x                            |
| 3                    | 50-55                           | 95-100                       |
| 5B                   | 20-25                           | 95-100                       |
| 9                    | 10-15                           | x                            |
| 19                   | 0-5                             | 25-30                        |
| 14                   | 0-5                             | 0-5                          |
| 25                   | 0                               | 5-10                         |
| 25 <sup>3</sup>      | 0                               | x                            |
| 15                   | 0                               | x                            |
| 15 <sup>3</sup>      | 0                               | x                            |
| 21                   | 0                               | x                            |
| 22                   | 0                               | x                            |
| 10                   | 0                               | x                            |
| 13                   | 0                               | x                            |
| 16                   | 0                               | x                            |
| 24                   | -                               | -                            |

| betonno | pH   | Cl <sup>-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) | SO <sub>4</sub> <sup>2-</sup> (mg/l) |
|---------|------|------------------------|--------------------------------------|--------------------------------------|
| 1       | 12   | 0,4                    | 14,8                                 |                                      |
| 4       | 12,5 | 0,1                    | 0,36                                 |                                      |
| 9       | 12,5 | 0,1                    | 0,36                                 |                                      |
| 14      | 12,5 | 0,1                    | 0,36                                 |                                      |
| 19      | 12,5 | 0,1                    | 0,36                                 |                                      |
| 21      | 12,5 | 0,001                  | 0,001                                |                                      |
| 22      | 12,5 | 0,001                  | 0,001                                |                                      |
| 25      | 12,5 | 0,001                  | 0,001                                |                                      |
| 10      | 12,5 | 0,1                    | 0,36                                 | 0,208001200**                        |
| 13      | 12,5 | 0,1                    | 0,36                                 | 0,208001200**                        |
| 16      | 12,5 | 0,001                  | 0,001                                | 0,317720                             |
| 24      | 12,5 | 0,001                  | 0,001                                | 0,317720                             |
| 25      | 12,5 | 0,001                  | 0,001                                | 0,317720                             |

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## CONCLUSIONS

### Bettina H. Myhre

1. The chloride content is most important for initiation of corrosion, however, in combination with pH is also important.
2. pH 12.5 combined with 0.36 g/l chloride result in corrosion. However, at 0.036 g/l chloride and pH 12.5 corrosion is not initiated.
3. Addition of sulphate (Na<sub>2</sub>SO<sub>4</sub> eller MgSO<sub>4</sub>) did not effect initiation of corrosion (with the tested comcentrations).
4. Effect of oxygen not documented through the test program.

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## 2.2 MSc Student Christopher Andresen Bjerk<sup>5</sup>

Christopher Andresen Bjerk

**Corrosion of prestressed tensile wires on the Herøysund bridge**

Effect of pH, chloride, and sulfate

Master's thesis in Materials Science and Engineering  
 Supervisor: Roy Johnsen  
 Co-supervisor: Mette Geiker, Karla Hornbostel  
 June 2024



Norwegian University of Science and Technology

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## 2.2.1 Results from inspection on Herøysund Bridge<sup>3, 5</sup>

**1SA** moisture = 10.2%, injection mass: 13.7%

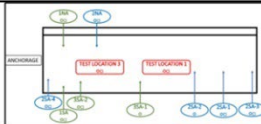



**Corrosion observations**


- o Filled up with injection mass
- o Only **surface corrosion** seen on wires and inside duct

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**2SA-1/2** moisture = 25% (1)




2SA-1 Light surface corrosion




2SA-2 Severe corrosion 0.25 m away




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**2SA-1/2** moisture = 25 (1)



2SA-1 Light surface corrosion



2SA-2 Severe corrosion 0.25 m away




**Corrosion observations 2SA-1**

- o No corrosion on duct outside, but some rust on the inside
- o Brow rust on the top wires (surface)
- o Injection mass covered the gap between the wires.
- o Injection mass was lacking on the top
- o Two wires could be moved

**Corrosion observations 2SA-2**

- o Lack of filler for the upper part (1/3) of the wires
- o Serious corrosion on wires in the part without injection mass
- o **One wire was broken**
- o On another wire, ~40% of the cross section was corroded away in a length ~ 100 mm
- o The internal surface of the duct was corroded

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## 2SA-3 $Cl^- = 0.07\%$ , moisture = 10.2%, injection mass: 1



### Corrosion observations

- Injection mass between the wires, but lacking in the top
- Surface rust, but production marks could be seen
- Internal corrosion of the duct on the top, and also further down

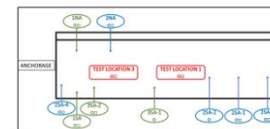
## 2SA-4 $pH = 12.44$ (PW), $Cl^- = 0.039\%$ , moisture = 45.1%, injection mass: 2



### Corrosion observations

- «Wet» injection mass covering the wires and the volume between wires
- Light surface corrosion on wires, but production marks could be seen
- Slight corrosion on the inside of the duct

## 3SA-1



### Corrosion observations

- No injection mass
- Some shallow surface corrosion (production marks could be seen)
- Indication of local corrosion attacks on wire(s) in the bottom of the duct
- Internal corrosion of the duct



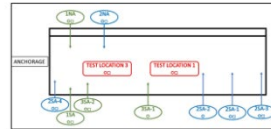
### 3SA-2 $\text{pH} = 13.76$ (PW), moisture = 10.8%, injection mass: 2



#### Corrosion observations

- Bitumen tape covering the outside of the duct (?)
- Shallow corrosion on the duct under the Bitumen tape
- Internal corrosion of the upper part of the duct
- Brown rust on the upper wire, but no/shallow attacks were seen (rust layer due to corrosion of the duct?)

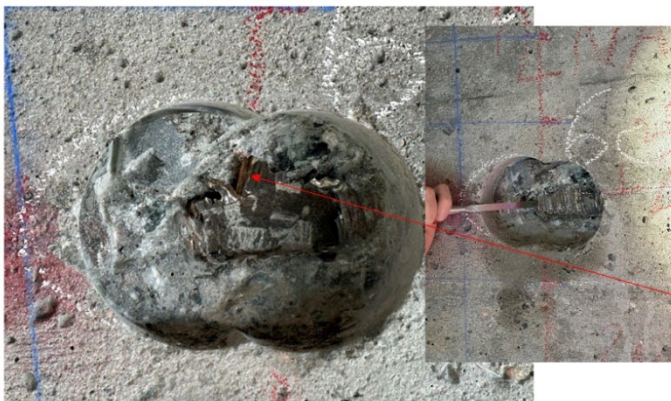
### 1NA moisture = 9.2%, injection mass: 1



#### Corrosion observations

- Completely filled with injection mass
- No corrosion observed (wires and duct)

### 2NA $\text{pH} = 14.1$ (PW), $\text{Cl}^- = 0.061\%$ , moisture = 10.2%, injection mass: 1



#### Corrosion observations

- Completely filled with injection mass
- No corrosion observed on wires
- Indication of corrosion on duct

| Post-tensioned components | Visual Observations after removal of concrete | Test Locations per Year           |    |    |              |      |      |                                |       |       |             |       |       |       |        |     |     |
|---------------------------|---|-----------------------------------|----|----|--------------|------|------|--------------------------------|-------|-------|-------------|-------|-------|-------|--------|-----|-----|
|                           |   | Prior Inspections, Appendix B,C,D |    |    |              |      |      | Recent Inspections, Appendix A |       |       |             |       |       |       |        |     |     |
|                           |   | 2017                              |    |    | January 2020 |      |      | August 2020                    |       |       | August 2023 |       |       |       |        |     |     |
|                           |   | NA                                | NA | NA | TL-1         | TL-2 | TL-3 | 1SA                            | 2SA-1 | 2SA-2 | 2SA-3       | 2SA-4 | 3SA-1 | 3SA-2 | 3SA-16 | 1NA | 2NA |
| Wire                      | Wires adhered to filler material              |                                   |    | ✓  | ✓            | ✓    |      |                                | ✓     | ✓     | ✓           | ✓     | ✓     | ✓     |        | ✓   | ✓   |
|                           | Surface corrosion                             |                                   |    |    | ✓            | ✓    |      | ✓                              | ✓     | ✓     | ✓           | ✓     | ✓     |       | ✓      |     |     |
|                           | Non-uniform and pitting corrosion             |                                   | ✓  |    |              | ✓    |      |                                |       | ✓     |             |       | ✓     |       |        |     |     |
|                           | Wire breakage                                 |                                   | ✓  |    |              |      | ✓    |                                |       | ✓     |             |       |       |       |        |     |     |
|                           | Presence of loose wires                       |                                   |    |    |              | ✓    |      |                                |       | ✓     |             |       |       |       |        |     |     |
| Duct                      | No corrosion                                  |                                   |    | ✓  |              | ✓    |      |                                |       |       |             |       |       |       |        | ✓   | ✓   |
|                           | Internal corrosion                            |                                   |    |    | ✓            |      | ✓    | ✓                              | ✓     |       | ✓           | ✓     | ✓     |       |        |     |     |
|                           | External corrosion                            |                                   |    |    |              |      |      |                                |       |       |             |       |       |       |        |     |     |
|                           | Both internal and external corrosion          |                                   | ✓  |    |              | ✓    |      |                                |       | ✓     |             |       |       | ✓     |        |     |     |
| Filler Material           | Fully grouted                                 |                                   |    | ✓  |              |      |      | ✓                              |       |       |             |       | ✓     | ✓     |        | ✓   | ✓   |
|                           | Presence of voids                             |                                   | ✓  |    | ✓            | ✓    | ✓    | ✓                              |       | ✓     | ✓           | ✓     | ✓     |       | ✓      |     |     |
|                           | Moist grout                                   |                                   |    |    |              |      | ✓    |                                |       | ✓     |             | ✓     |       |       |        |     |     |
|                           | Frost damaged                                 |                                   |    |    | ✓            |      | ✓    |                                |       |       |             |       |       |       |        |     |     |
|                           | White injection mass                          |                                   |    |    |              |      |      |                                | ✓     | ✓     | ✓           | ✓     |       |       |        |     |     |
| Mild steel                | Corrosion                                     |                                   |    | NA | NA           | ✓    |      | NA                             | NA    | NA    | NA          | NA    | NA    | NA    | NA     | NA  | NA  |
|                           | No signs of corrosion                         |                                   |    |    |              |      | ✓    |                                |       |       |             |       |       |       |        |     |     |

## OBSERVATIONS – FOR DISCUSSION

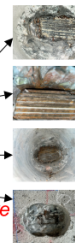
### From the literature

The following elements are important for initiation of corrosion

- pH, chloride content, sulphide, oxygen, temperature, humidity

### Observations from Herøysund Bridge

- **2SA-4**, pH= 12.44 (PW), Cl<sup>-</sup> = 0.039%, moisture = 45.1%, injection mass: 2 → *minor corrosion*
- **2SA-3**, Cl<sup>-</sup> = 0.07%, moisture = 10.2%, injection mass: 1 → *minor corrosion*
- **3SA-2**, pH= 13.76 (PW), moisture = 10.8%, injection mass: 2 → *minor corrosion*
- **2NA**, pH=14.1 (PW), Cl<sup>-</sup> = 0.061%, moisture = 10.2%, injection mass: 1 → *no corrosion*
- **Location 3 (2020)**, pH=13, Cl<sup>-</sup> = 0.037%, moisture = 44% (wet) → *serious corrosion + wire fracture*
- **Location 1 (2020)**, pH=13, Cl<sup>-</sup> = 0.035%, moisture = 21% (dry) → *serious corrosion*



## HOW CAN WE EXPLAIN THE CORROSION ATTACKS ON THE HERØYSUND BRIDGE?

- Lab tests in simulated pore water have documented that pH and chloride content are two important parameters
- Observations and analysis from the bridge show that similar pH, chloride content and moisture give different results:
  - 2SA-3 and 2SA-4 *Minor surface corrosion*
  - Location 1 and 3 *Serious corrosion attack*
- What can be the reason for the observations?
  - Local variation in injection mass quality (coverage, humidity, ...)
  - Can other information from the SINTEF reports contribute in explaining the reason (pore water composition, TGA output, XRD)?
  - Local galvanic cells



## 2.2.2 Results from experimental work<sup>5</sup>

# MSc Student Christopher – 2023/24

### OBJECTIVES

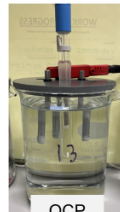
- How do different pH, chloride, and sulfate concentrations affect the corrosion of tensile wires?
- How does oxygen affect the corrosion behavior of tensile wires?
- How does the carbonation of a solution affect the corrosion behavior of tensile wires?
- Are the corrosion properties of steel embedded in concrete different from steel that is not in concrete in a given solution?
- If a steel sample and a steel sample embedded in concrete were connected and placed in the same solution, would it be possible to observe a galvanic effect?
- Can the corrosion observed in the tension wires on the Herøysund bridge be explained by the findings from the executed test program?

## LONG TERM EXPOSURE TEST

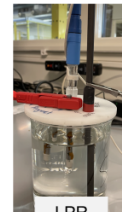
| Solution | Starting pH | Cl <sup>-</sup> [M] | SO <sub>4</sub> <sup>2-</sup> [M] |
|----------|-------------|---------------------|-----------------------------------|
| M1       | 12.5        | 0,005               | -                                 |
| M2       | 13          | 0,005               | -                                 |
| M3       | 13          | 0,01                | -                                 |
| M4       | 13          | 0,02                | -                                 |
| M5       | 12,5        | 0,005               | 0,01                              |
| M6       | 12,5        | 0,005               | 0,1                               |
| M7       | 12,5        | 0,005               | 0,2                               |
| M8       | 13          | 0,05                | -                                 |
| M9       | 13          | 0,1                 | -                                 |
| M10      | 13          | 0,02                | 0,2                               |
| M11      | 12,5        | 0,005               | 0,1                               |
| M12      | 12,5        | 0,005               | 0,005                             |
| M13      | 12,5        | 0,005               | 0,007                             |
| M14      | 13          | 0,02                | 0,05                              |
| M15      | 13          | 0,02                | 0,1                               |
| M16      | 13          | 0,01                | 0,1                               |
| M17      | 12,5        | 0,005               | -                                 |
| M18      | 12,5        | 0,01                | 0,01                              |
| M19      | 13          | 0,02                | 0,01                              |
| M20      | 13          | 0,01                | 0,05                              |
| M21      | 13          | 0,01                | 0,2                               |
| M22      | 13          | 0,005               | 0,1                               |

### Goals

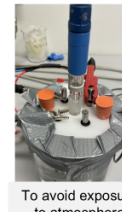
- To determine how the OCP (corrosion potential) developed over time for a given sample in different solutions.
- Determine the corrosion rate after a long exposure time (3 - 5 weeks) with LPR measurements.
- Determine through visual examination whether corrosion has occurred and, if so, identify the areas affected after a long exposure time (3 - 5 weeks).



OCP



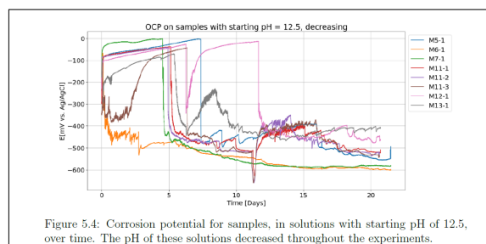
LPR



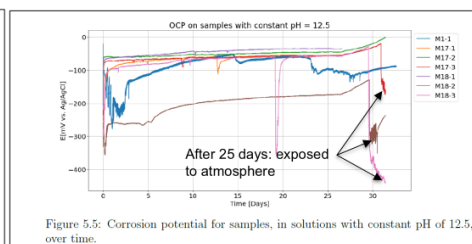
To avoid exposure to atmosphere

## LONG TERM EXPOSURE TEST

### Observation: Lowering of potential with time



At the end: pH 10-11



At the end: pH 12.5



(a) Sample M5-1



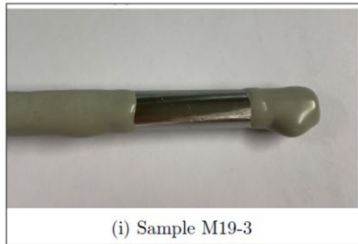
(i) Sample M7-3



(c) Sample M6-2



(m) Sample M9-1



(i) Sample M19-3



(o) Sample M21-3



(k) Sample M20-2

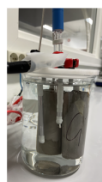
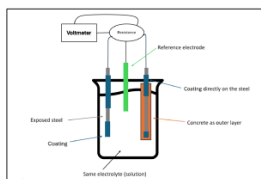


(p) Sample M22-1

## GALVANIC COUPLING

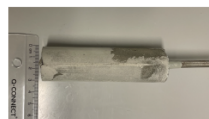
### Steel embedded in concrete coupled to steel

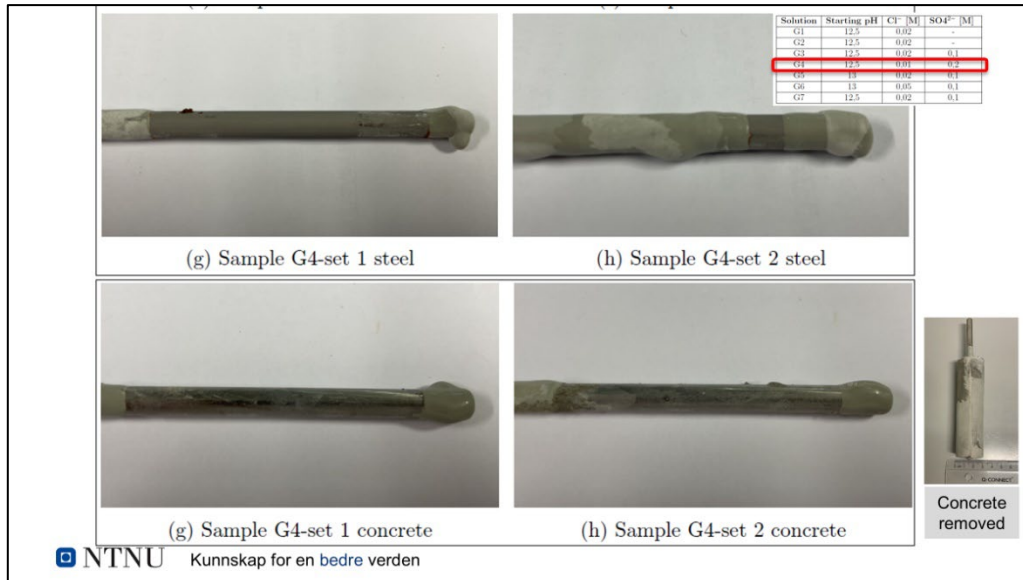
| Solution | Starting pH | Cl <sup>-</sup> [M] | SO <sub>4</sub> <sup>2-</sup> [M] |
|----------|-------------|---------------------|-----------------------------------|
| G1       | 12,5        | 0,02                | -                                 |
| G2       | 12,5        | 0,02                | -                                 |
| G3       | 12,5        | 0,02                | 0,1                               |
| G4       | 12,5        | 0,01                | 0,2                               |
| G5       | 13          | 0,02                | 0,1                               |
| G6       | 13          | 0,05                | 0,1                               |
| G7       | 12,5        | 0,02                | 0,1                               |



#### GOALS

- To determine how the OCP (corrosion potential) developed over time for a coupled pair of samples. This includes one sample embedded in concrete and one sample directly in contact with the solution.
- To determine if there is a current between two samples, one in concrete and one directly in contact with the solution.
- To determine if there are any corrosion differences between an exposed area ratio between the concrete sample and the other sample if the ratio is 1:1 or 10:1, concrete:non-concrete.
- After a longer time of exposure, examine the sample surface to see if corrosion occurred and if it did, where.






### 3 CONCLUSIONS

1. At a lower pH (12.5) the solution became more corrosive compared to at a higher pH (13).
2. *At a pH of 12.5 and no sulfate, corrosion initiated with a chloride concentration of 0.005 M. In solutions with a pH of 13 and no sulfate, a threshold between 0.02 and 0.005 M chloride was observed, where corrosion did not occur and where it did occur.* It was also observed that with increasing chloride concentration at both pH levels, the corrosiveness increased.
3. *At a pH of 12.5 and a chloride concentration of 0.005 M, the addition of a small amount of sulfate had a significant impact, making the solution more corrosive. At a pH of 13 with the same chloride concentration, a much larger amount of sulfate was required to achieve the same increase in corrosivity.* At both pH levels, it was observed that the corrosion properties did not change significantly beyond a certain concentration of sulfate.
4. With a *combination of chloride and sulfate in the solution*, it was observed that the corrosivity increased further compared to when only chloride was present.
5. For most of the samples where corrosion was seen, it primarily occurred at the interface between the coating and the exposed steel.
6. *The effect of using sealed and open containers was significant. Open containers led to carbonation of the solution* (decrease of the pH) and oxygen supply. Both factors led to a more corrosive solution.

### 4 FURTHER WORK

There are still uncertainties related to give a clear explanation of the reason(s) for the corrosion failures on the wires. Based on the executed work in the two MSc thesis projects, the follow proposal for further work is given:

1. From the long-term exposure experiments, it was seen that corrosion was initiated at the interface between the coating and the exposed steel. This might be because of crevice corrosion and needs further investigation.
2. To gain a better understanding of the galvanic experiments conducted, it is recommended to measure OCP and take LPR of freely exposed samples equivalent to those tested in the galvanic experiments and in the same solutions. This will help assess the effect of the measured galvanic current.
3. For a better understanding of the condition of the samples from the galvanic experiments, it is recommended to measure the anodic and cathodic polarization curves at the end of the tests on the same samples and solutions as in this project. This will give more insight into whether the samples are in a passive or active state.

|   |   |   |       |            |
|---|---|---|-------|------------|
|  | <i>Department for Mechanical and Industrial Engineering</i> |   | Date: | 02.01.2025 |
|   | Client:   | Nordland Fylkeskommune and Statens Vegvesen       | Rev.: | 01         |
|   | Title:  | Herøy FOU – WP2.A4 – Summery of work and findings | Page: | 16 of 16   |

4. Another suggestion for future research is to thoroughly explore the existing literature on galvanic coupling in prestressed reinforcement, given the limited information available. Based on these findings, it should be determined if the galvanic experiments should be modified and conducted over different time periods to produce more field-relevant results for galvanic couplings.

## REFERENCES

- /1/ Roy Johnsen; HERØYSUND BRU – Korrosjon av spennarmering i betongbruer. Rapport nr. 90599200-01 for Statens Vegvesen. Dato: 26.06.2022
- /2/ Roy Johnsen: Corrosion testing of tensile wire. Rapport nr. 90599200-01 for Statens Vegvesen. Dato: 05.09.2022
- /3/ Bettina Horn Myhre: Effects of chloride, sulfate and pH on the corrosion of tensile wires in grouted ducts in Herøysund bridge. MSc thesis NTNU, June 2022.
- /4/ S.Shama, C.Bjerk, M.R.Geiker and R.Johnsen: Summey of inspections and investigations on post-tensuioning components of Herøysund Bridge, Norway (2017-2023).
- /5/ Christopher Andresen Bjerk: Corrosion of pre-stressed wires on the Herøysund Bridge – effect of pH, chloride and sulphate. MSc thesis NTNU, June 2024.