SANDBERG

**63555/X/01**

# HOLDING DOWN BOLT FAILURE INVESTIGATION

## ARMY AND NAVY FLYOVER

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This report comprises:
6 Pages of text
Appendix A

To: [redacted]

18 October 2018

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# ARMY AND NAVY FLYOVER

**Instruction** Sub-Contract 100840.NC.B1659, undated, referring to failure of holding down bolts on the B1659 Army and Navy Flyover.

## 1 INTRODUCTION

1.1 During inspection of the support columns for the Army and Navy Flyover at Chelmsford concern was raised over the condition of some of the holding down bolts. Further inspection revealed that some of the bolts had failed completely at a level which appears to correspond with the grout below the mounting flange, which is attached to base of the column.

1.2 Following this discovery two of the failed bolts, complete with the grout tubes in which they were secured to the foundation, were removed from the base of the north column of Trestle 7. These samples were forwarded to Sandberg for an investigation into the nature of the failure.

1.3 These samples were submitted to the Sandberg Metallurgy Department for the investigation.

## 2 BACKGROUND

2.1 The Army and Navy Flyover is a lightweight structure for vehicle traffic and is supported by a series of steel columns. At their bases the columns are anchored by a series of holding down bolts which are mounted in the foundation beneath the column.

2.2 The holding down bolts are secured in a ‘U’ shaped structure which is set in the concrete foundation. At the base of the U is flat bar, which provides restraint to the bolt heads. Vertical sides of the U are formed from steel tubes, which had been filled with grout, to secure and protect the main length of the bolts.

2.3 Where the bolts project from the foundation there is a gap, which appears to be intended to permit adjustment of the column height, before they pass through the mounting flange at bottom of the column. These bolts were then secured by nuts and washers on top of the mounting flange. It is understood that the space under the mounting flange was filled with grout.

2.4 Failures are reported to be within the grout beneath the mounting flange.

## 3 LABORATORY INVESTIGATION

### 3.1 Sample Receipt

3.1.1 Samples received were the ends of two failed bolts and a U section formed of two steel tubes joined by a flat steel bar. Within the tubes were the other part of the failed bolts, still embedded within the grout filling in the tubes.

3.1.2 Each of the samples were given a unique individual laboratory reference numbers before the following schedule of testing was conducted.

| Met Dept Sample Ref | Site Ref | Sample description |
|---|---|---|
| MY 774 | B1659 T7-NC-W 52157/303 | Failed bolt and nut in grout filled tube |
| MY 775 | B1659 T7-NC-E 52157/302 | Failed bolt and nut in grout filled tube |

### 3.2 Visual Examination

3.2.1 Samples were examined visually under bright light conditions taking particular note of the surface condition on the bolts. The fractured ends which had detached from the bolts are shown in Photographs 1 and 2, presented in Appendix A. It is of note that the exposed threads, i.e. above the mounting flange, had been coated with paint and were in relatively good condition.

3.2.2 Where the threads pass through the width of the flange there was evidence corrosion, in the form of dark brown deposits which were firmly adhering to the bolt. Towards the lower end of these sections, where the bolts passed through the grout, the corrosion was associated with a major loss in cross section.

3.2.3 Examination of the grout tube samples confirmed that the holding down bolts had been inserted from the underside of the plate and passed through the length of the tube. Failure of the bolts was beyond the end of the grout within the tube, Photograph 3.

3.2.4 To examine the condition of the bolts within the grout, the steel tubes were sectioned and removed, Photograph 4. From the discolouration on the grout columns it would appear that the grout had been filled in stages.

3.2.5 Grout was removed by crushing to expose the bolt shanks, Photograph 5. The shanks of the bolts were noted to be unaffected by corrosion in the area that had been within the grout tubes.

3.2.6 Examination of the markings on bolt heads, Photograph 6, confirmed that these were strength Grade 8.8, M24 diameter bolts. It was not possible to identify the manufacturer from the ‘CM’ marking.

## 3.3 **Fractography**

3.3.1 Ends of the samples were carefully cleaned in inhibited acid to removed the bulk of the corrosion products so that the surfaces could be examined using low power microscopy.

3.3.2 The end of sample MY 774 was completely corroded, however, there were still some features remaining which would be consistent with the presence of a fracture. This would indicate that after a major loss in cross section due to corrosion the bolt had failed mechanically. The mode of failure could not be positively determined due to the level of corrosion but may be consistent with a tensile action. Following failure the bolt had remind in-situ and many of the features associated with the fracture had been destroyed by further corrosion.

3.3.3 The end of sample MY 775 had also been subject to severe corrosion. In this case there was still evidence of a metallic fracture face, Photograph 8. The area of final fracture was estimated to be around 25-30 % of the original cross section.

## 3.4 Metallography

3.4.1 Sections were taken through the failed ends of the bolts and prepared for metallographic examination.

3.4.2 Section through MY 774 shows major corrosion around the end of the bolt where it failed, confirming the absence of any fracture features, Photomacrograph 1, presented in Appendix A.

3.4.3 Similar corrosion is present on the section through MY 775 but the end of the sample is more sharply defined, Photomacrograph 2. The profile of the fracture would be indicative of shear rather than tensile failure.

3.4.4 The section through MY 775 was mounted in Bakelite and prepared to a 1 µm finish and then etched in 2 % Nital for a more detailed examination of the matrix, shown in Photomicrograph 1. This was a primarily pearlitic matrix with fine equi-axed grain structure, delineated by fine ferrite grains, typical of a normalised medium carbon, i.e. 0.3-0.4 % C, steel.

3.4.5 Examination of the section through the fracture face confirmed the presence of deformation at the surface, Photomicrograph 2. This would be consistent with failure under a shearing action.

## 3.5 Hardness

3.5.1 Vickers hardness testing was carried out to BS EN ISO 6507-1:2005, using a 10 kg load, the results of which are presented below.

| | Value 1 | Value2 | Value 3 | **Ave HV10** |
|---|---|---|---|---|
| Bulk | 266 | 268 | 262 | **265** |
| Thread | 247 | 253 | 243 | **248** |

3.5.2 From BS EN ISO 898-1, the minimum hardness for strength Grade 8.8 bolts is 255 VPN. Results for the core of the bolt is towards to the lower end of the hardness range but above the lower limit.

## 3.6 Tensile Testing

3.6.1 A tensile sample was machined as per the requirements of BS EN ISO 898-1:2013 from a bolt section removed from the grout tube. This specimen was then tensile tested in accordance with BS EN ISO 6892-1:2016. Results of this testing are presented on Test Certificate 63555/M/1 presented at the end of Appendix A.

3.6.2 From these results it is apparent that to the current standard the strength properties would be below the lower specified limit. Without knowing when these bolts were manufactured it is not possible to confirm whether or not they may have complied with the standards that were applicable at that time.

## 4 DISCUSSION

4.1 From the results of the testing discussed above it is apparent that the failure of the bolts is consistent with corrosion in the part of the shank which passed through the grout under the mounting plate.

4.2 Mounting mild steel in grout would normally be expected to provide a measure of protection, based on the alkalinity of the grout, provided that it is in full contact with the steel and that it remains reasonably dry.

4.3 Where the grout is not fully in contact with the steel and in particular if there is a gap in which moisture can enter then the protection will be less effective.

4.4 For situations such as these columns in the vicinity of carriageways that are salted in winter, periodically the ingress of moisture is likely to draw in chlorides. These chlorides will be expected to increase the rate of corrosion. Due to the catalytic nature of the chloride it is not consumed by the corrosion process and the effect will be experienced over extended periods as it will not readily be removed from the confined space inside the grout.

4.5 If these are original holding down bolts then it may be that the original installation had provided some protection but that this had been lost over time, possibly due to service conditions and/or poor grout installation. Once the protection of the seal with the grout has been lost this will then exacerbate the problem by retaining moisture against the exposed bolt sections which have little or no inherent corrosion resistance.

## 5 CONCLUSIONS

5.1 Failure of the holding down bolts appears to be associated with a major loss in cross section as a result of corrosion.

5.2 This corrosion has occurred in the section of bolt below the mounting flange where it passes through the grout layer.

5.3 The initial failure, sample MY774, appears to have been tensile in nature although due to the corrosion this could not be confirmed definitively. Following failure the bolt has remained in-situ and further corrosion has taken place obscuring the details of the fracture face.

5.4 The second bolt, MY 775, has failed more recently and the fracture face could be cleaned to reveal an area with a more metallic appearance. This failure was also associated with large loss in cross section due to corrosion. In this case, however, the final fracture was associated with an element of shearing action.

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18 October 2018

File: 18.10.18 63555.X.01.X.01 Bolt Failure Report - SCC Final.wpd

**APPENDIX A**


Photograph 1 End of failed holding down bolt, sample MY 774, showing coated threads above the mounting plate and corroded threads below the level of the mounting flange, in an area that would be surrounded by grout.

Photograph 2 End of failed holding down bolt, sample MY 775, showing coated threads above the mounting plate and corroded threads below the level of the mounting flange, in an area that would be surrounded by grout.

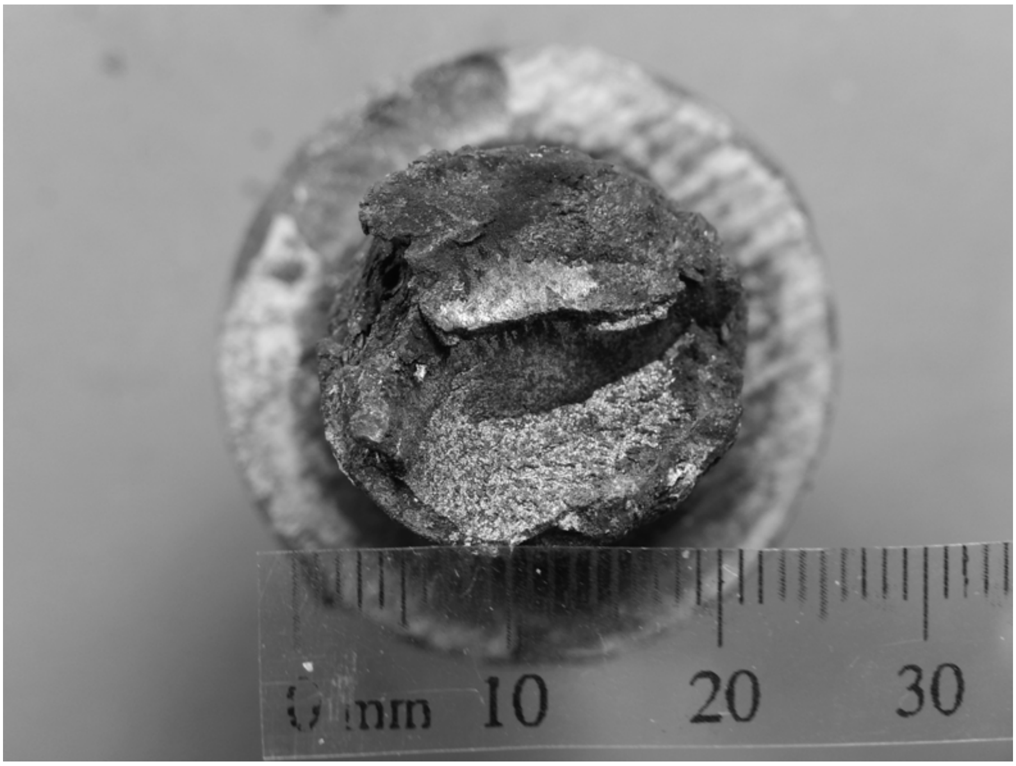

Photograph 3 Metal tube filled with grout surrounding the holding down bolts. Bolts had been inserted from the underside, such that the threads were uppermost to engage with flange under column.

Photograph 4 Metal tubes removed exposing grout fill. Grout in tubes appears to have been filled in two goes, with an interface between the separate fill materials.

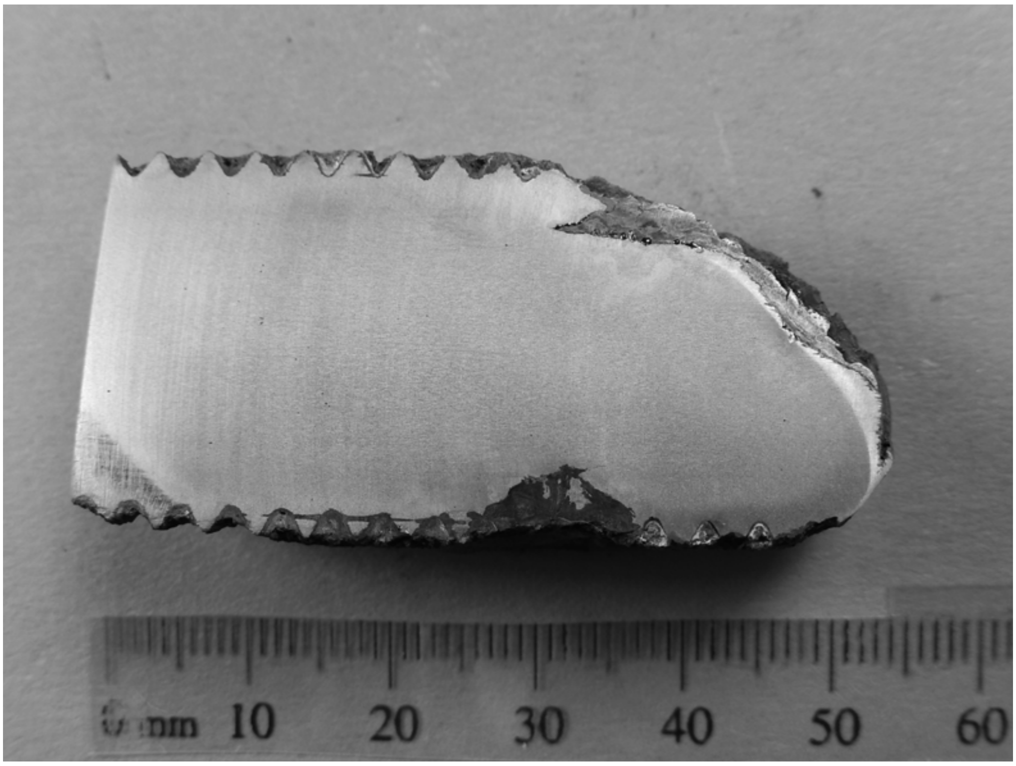
Photograph 5 Grout removed to expose shanks of holding down bolt. There was no evidence of corrosion or section loss of the bolts over the length within the grout tubes.

Photograph 6 Head of bolt showing size, 'M24', grade '8.8', and manufacturer's mark, 'CM'.

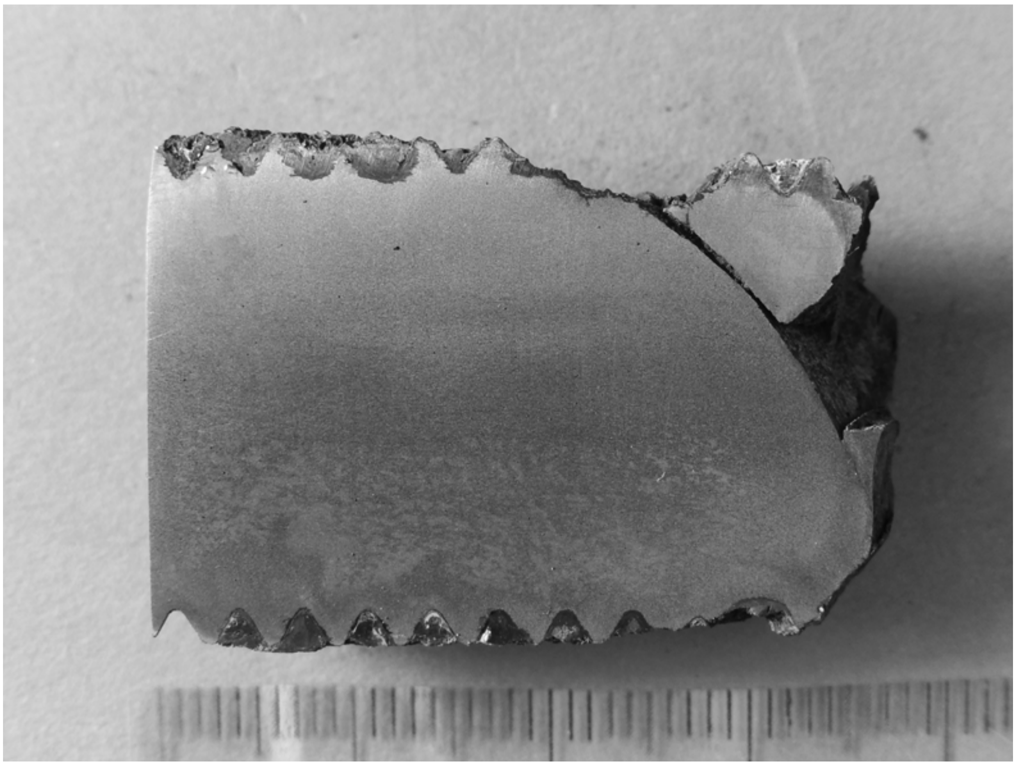

Photograph 7 End of sample MY 774 showing complete loss of section due to to corrosion. There was no evidence of fracture on this sample.



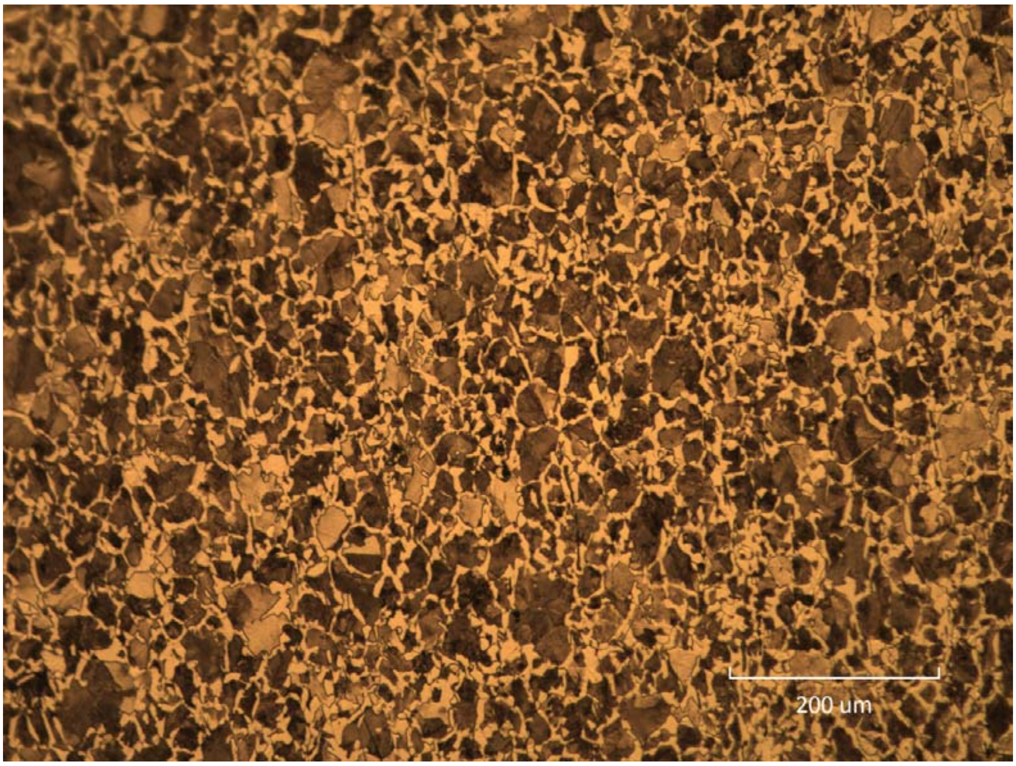

Photograph 8 End of sample MY 775 showing large loss in cross section due to corrosion. Final fracture associated with bolt failure was around 25-30 % of the original cross section.




Photomacrograph 1
Section through MY 774 showing loss of cross section due corrosion in the area which had been in the grout under the flange at the base of the column. There was no uncorroded that could be associated with failrue under load.

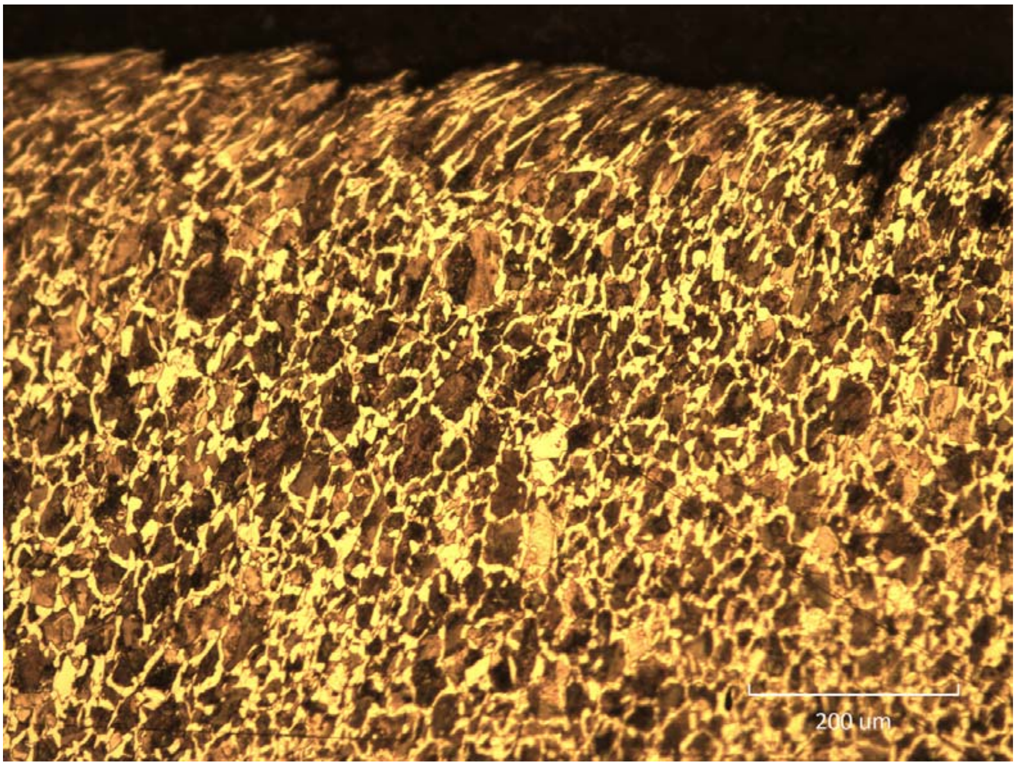


Photomacrograph 2
Section through MY 775 showing loss of cross section due corrosion in the area which had been in the grout under the flange at the base of the column. The area of the fracture was small compared to the original cross section.




Photomicrograph 1 Etched in 2 % Nital X160

Matrix of the bulk material showing fine grains of equi-axed pearlite delineated by fine grains of ferrite typical of normalised steel. The percentage of pearlite would indicate that it was medium carbon, i.e. 0.3-04 % carbon, material.




Photomicrograph 2 Etched in 2 % Nital X160

Matrix of the steel at the fracture face showing evidence of deformation that would be consistent with failure in shear.

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## TENSILE TEST CERTIFICATE
## BS EN ISO 6892-1:2016 B

| | | | |
|---|---|---|---|
| **Certificate:** | 63555/M/1 | **Order Ref:** | 100840.NC.B1659 |
| **Samples Received:** | 28 September 2018 | **Tested By:** | NAF |
| **Test Date:** | 4 October 2018 | **Test Procedure:** | M10/3/3 |
| **Client Details:** | Topbond Plc. | | |

| **Specimen Reference** | | **Area mm$^2$** | **0.2% Proof** | | **Ultimate Tensile** | | **Elongation %** |
|---|---|---|---|---|---|---|---|
| **Met lab Ref** | **Sample Ref** | | **Load kN** | **Stress N/mm$^2$** | **Load kN** | **Stress N/mm$^2$** | |
| MY 799 | Bolt Sample<br>Head markings<br>“M24 8.8 CM” | 317.9 | 204.0 | 642 | 259.5 | 816 | 15.5 |
| Specification:<br>BS EN ISO 898-1:2013<br>Property Class 8.8 | | | | 660 min | | 830 min | 12 min |

**Comments:** Sample was tensile tested as reduced section test piece in accordance with BS EN ISO 898:2013.

For Sandberg LLP

Date: 18 October 2018

**Neale Fetter - Assistant Manager Metallurgy Department**