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The Assessment of the Fatigue Life of Corroded or Damaged Reinforcing Bars

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Standards

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The Assessment of the Fatigue Life of Corroded or Damaged Reinforcing Bars

June 2014

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Summary:

This Advice Note provides criteria for the assessment of the fatigue life of corroded reinforcing bars, and bars which have sustained mechanical damage.

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VOLUME 3 ROAD STRUCTURES: INSPECTION AND MAINTENANCE

SECTION 4 ASSESSMENT

PART 3

NRA BA 38/14

ASSESSMENT OF THE FATIGUE LIFE OF CORRODED OR DAMAGED REINFORCING BARS

Contents

Chapter

1. INTRODUCTION

General

1.1 The purpose of this Advice Note is to give guidance to engineers on the assessment of the remaining fatigue life of corroded or damaged reinforcement in an existing structure. At present there are no requirements in National Roads Authority Standard NRA BD 44 on fatigue because these are considered as serviceability criteria and the emphasis of the Standard is on determining the safe load carrying capacity of the structure at the ultimate limit state. However, where a structure is of relatively recent construction and designed in accordance with BS 5400, part 4, the assessment of the remaining fatigue life can be relevant particularly when it has suffered deterioration or damage to the reinforcement.

1.2 The assessment requirements in this Advice Note are based on experimental evidence from tests on corroded and damaged bars, which indicates that, even after allowing for the loss of section, a shorter fatigue life is obtained compared to the unaffected bars. This is because the jagged nature of corroded bars results in higher stress concentrations and a reduction in fatigue resistance. Results from these tests have been used to develop the criteria in this Advice Note for assessing the remaining fatigue life of affected bars. Appendix A gives methods of measurements of cross-sections of typical corroded reinforcing bars.

1.3 This document should be read in conjunction with BS 5400: Part 10: 1980, The Code of Practice for Fatigue [(3)] (hereinafter referred to as Part 10) and the implementation documents, NRA BD 9 and NRA BA 9.

1.4 The symbols referred to in this Advice Note are as defined in Part 10.

Scope

1.5 Guidance is given in this Advice Note on the fatigue classification of corrosion damage to reinforcing bars with advice on estimating the extent of damage to the cross-section. The fatigue performance of mechanically damaged reinforcement is also considered. To determine the actual fatigue life of reinforcement, a simplified method has been given which should cover most cases. A more rigorous method using clause 8.4 of Part 10 may also be used. The document is applicable to mild steel and high yield bars of a diameter ranging from 6mm to 50mm.

1.6 Welded reinforcing bars and mechanically connected bars are not covered by this Advice Note.

Application

1.7 Application of the guidelines in this document will depend on a number of factors which are outlined in the following paragraphs. The agreement of the National Roads Authority should be sought before undertaking a fatigue check on reinforcement subjected to corrosion or mechanical damage.

1.8 Fatigue assessments will be appropriate only for bridges constructed after 1968 and which have suffered corrosion or damage to the reinforcement. However, older structures containing affected reinforcement may also be assessed for fatigue if, for example, their repaired condition would appear to be adequate for an extensive future life.

1.9 In assessing the remaining fatigue life, allowance should be made for the fatigue history of the bridge. This should take the form of a reduction in the fatigue life, based on an estimate of the period of time that corrosion of the reinforcement has been known to be present (Paragraph 3.13).

1.10 Certain types of bridge elements are subject to stress ranges due to local loading, which could cause a fatigue failure under normal traffic loading. In such cases, the deterioration of any reduction in fatigue life due to corroded or damaged reinforcement would be extremely important. For example, in half-joints the occurrence of high stress ranges in areas of localised corrosion could create major durability problems; hence these joints are particularly susceptible to fatigue failure.

1.11 The extent of corrosion or damage in an element will influence the decision on checking the fatigue life. Where the loss of cross-section of reinforcement is such that replacement is required for other reasons, for instance, to maintain the load carrying capacity of the element, then a fatigue check is not necessary. Where the performance of an affected element is otherwise acceptable, a shortened fatigue life may influence the decision on retaining or replacing the reinforcement. In such cases, an assessment of the fatigue life may be appropriate.

Implementation

1.12 This Advice Note should be used in all future assessments of structures or structural elements containing corroded or damaged reinforcing bars.

2. EFFECT OF CORROSION ON FATIGUE LIFE

General

2.1 The σ_r-N relationships for the different classes in Part 10 have been established from a statistical analysis of σ_r-N results from a large number of tests. A similar analysis was not possible for corroded bars because of the limited scope of the tests. As a result the σ_r-N values given in Figure 2.1 for corroded bars have been taken as lower bound to the test data. These may be used with the equations given in clause 11.2 of Part 10 (Paragraph 3.8).

2.2 Corrosion of reinforcement can result from a number of effects such as carbonation and chloride attack. The fatigue life of a corroded bar is significantly affected only when there is a substantial loss of cross-sectional area. This is unlikely to occur with carbonation which generally involves a loss of surface material rather than the loss of large areas of cross-section. Chloride attack however can cause deep pits involving substantial loss of cross-section and consequently a reduction in fatigue life. Localised corrosion, such as this, can occur in either isolated locations or over long sections of a bar. Generally, an assessment of reduced fatigue life should be considered where there is localised corrosion resulting in a significant loss of cross-sectional area. In determining the stress in a corroded or damaged bar any loss of cross-section should always be taken into account.

2.3 A detailed description of corrosion in reinforcement is given in the NRA Advice Note NRA BA 35, 'Inspection and Repair of Concrete Road Structures'

Classification of Corroded Bars

2.4 The evidence from tests on reinforcement subject to corrosion indicated that the reduction in fatigue life is related to the loss of cross-section. Based on the results of these tests, a classification has been adopted in Table 2.1 which defines the degree of corrosion, either minor or major, by the percentage loss of cross-sectional area. This classification will be used to define the 'detail class' when assessing the fatigue life of a bar in accordance with Part 10.

Classification / Detail Class	**Requirement**
Minor corrosion	Less than or equal to 25% of cross-section lost
Major corrosion	More than 25% of cross-section lost

Table 2.1 Classification of Degree of Corrosion

2.5 To determine the extent of corrosion, measurements of the cross-section of a bar should be taken at the position under investigation. Appendix A outlines the procedure for such measurements with suggested methods for determining the percentage area lost due to corrosion.

2.6 The classification of a bar should be based on the worst case of corrosion if more than one position is being considered.

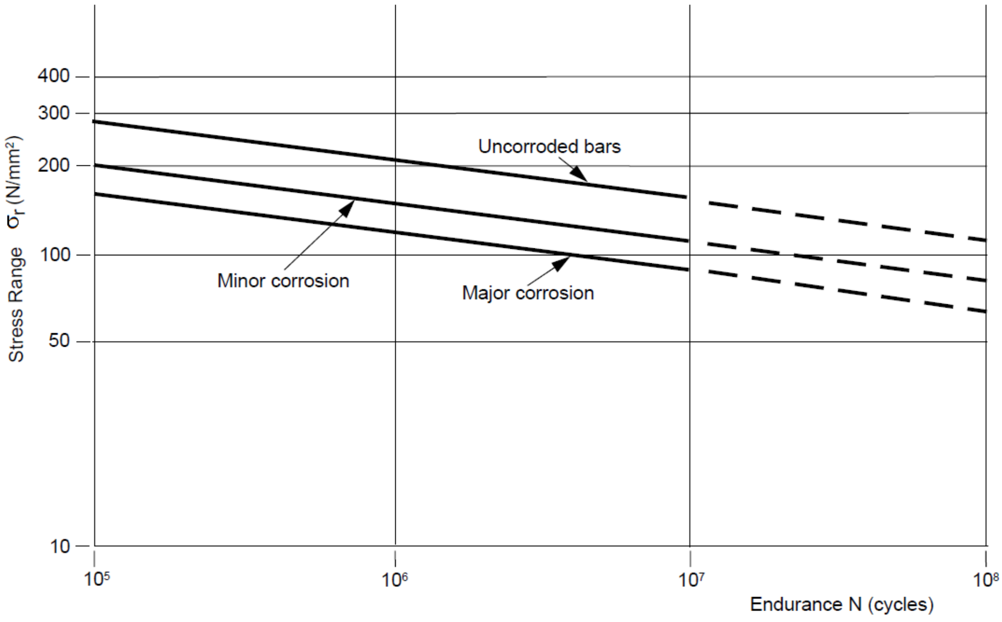

Figure 2.1 Design σ_r-N Curves

3. FATIGUE ASSESSMENT

Methods of Fatigue Assessment

3.1 Fatigue assessments may be carried out using either the simplified method given in 3.3 below or, when a more accurate assessment is needed, a rigorous analysis using the vehicle spectrum method of clause 8.4 of Part 10. In using these methods some additional criteria specified in this Advice Note would also need to be considered. The simplified procedures in 8.2 and 8.3 of Part 10 are not suitable for assessing the fatigue life of corroded reinforcement.

3.2 The detail classes given in Table 2.1 identify two levels of fatigue performance for which design data have been derived. To determine the fatigue life of a corroded or damaged bar, a detail class appropriate to the level of corrosion, i.e. major or minor, should be chosen.

Simplified Method

3.3 The simplified method of assessing fatigue life gives limiting stress ranges corresponding to 20 and 120 years of fatigue life. As it covers a number of different situations the method is inherently conservative. Therefore, if the check shows that the fatigue life is below the required value, the Assessment Engineer should use the more rigorous method specified in paragraph 3.8 which uses clause 8.4 of Part 10. The procedure for the simplified method is as follows:

3.4 The maximum and the minimum stresses in the reinforcing bar should be calculated for the 40 tonne assessment live loading using the actual cross-sectional area of the corroded bar. Any pattern of live loading consistent with NRA BD 21 (including zero live load) may be used to derive these stresses. In calculating these stresses, partial load factors should be taken as unity.

3.5 The stress range should be taken as the algebraic difference between the maximum and the minimum of these stresses and should be used with the loop lengths to determine the actual fatigue life for major and minor corrosion from Figure 3.1.

3.6 A linear interpolation should be carried out when the calculated fatigue life falls between the curves in Figure 3.1.

3.7 In using Figure 3.1, L is the influence line loop length which is defined in Figure 12 of Part 10 and, in the case of simply supported decks, falls into one of the following categories:

a) Longitudinal Steel – L is the length of the longitudinal span

b) Transverse Steel - L is the length of transverse span e.g. span of deck between adjacent beams.

c) Shear Links - L is the longest distance from the link to the end of the span.

Rigorous Method

3.8 As an alternative to the simplified method, the Vehicle Spectrum method of Part 10 may be used.

3.9 In determining the actual fatigue life using clause 8.4 of Part 10 the values of m and K_2 for use in the equations in clause 11.2 appropriate to the level of corrosion, should be obtained from Table 3.1.

Detail Class	**m**	**K_2**	**σ_o (N/mm^2)**
Minor corrosion	9.0	0.49×10^{26}	119
Major corrosion	9.0	0.61×10^{26}	95

Table 3.1: σ_r-N Relationships and constant amplitude non-propagating stress range values for bars up to 16mm diameter

3.10 Figure 2.1 gives the design σ_r-N curves for the two detail classes. The design curve for uncorroded reinforcement is also included for comparison purposes. The design curves and the values in Table 3.1 relate to bars of 16mm diameter. For corroded or damaged bars above 16mm diameter the stress range, σ_r, should be reduced by 25% (4).

3.11 In using clause 8.4 of Part 10, the condensed load spectra given in Appendix 1 of NRA BA 9 may be used as an alternative to Tables 13 and 14 of Part 10, but the assessed fatigue life resulting from it will be more conservative. The number of repetitions, and the stress range σ_r which takes into account the loss of cross-section, should be evaluated for each vehicle designation. The actual fatigue life is calculated on the basis of cumulative damage due to the total vehicle usage.

3.12 Where structures are subject to a non-standard load spectrum or non-standard vehicle flows (see clause 7.2 of Part 10) the advice of the National Roads Authority should be sought on the appropriate criteria to be adopted.

Fatigue Life

3.13 The methods outlined above determine the total fatigue life of the affected reinforcement. Therefore in order to predict the remaining fatigue life of the reinforcement, an allowance has to be made for the number of years corrosion is estimated to have been present. This value, based on knowledge of the condition of the structure in previous years, should be deducted from the total fatigue life, determined as above, to obtain the remaining fatigue life. As evidence of corrosion in embedded reinforcement may not be apparent for some time, an engineering judgement is necessary to determine this allowance period.

Mechanically Damaged Bars

3.14 Mechanical damage to bars can introduce high stress concentrations with a loss of cross-sectional area. As a consequence, the fatigue performance of a bar is reduced. In such cases an assessment of the reduced fatigue life may be based on the method for corroded bars, using the cross-sectional area at the damaged section to determine the classification from Table 2.1.

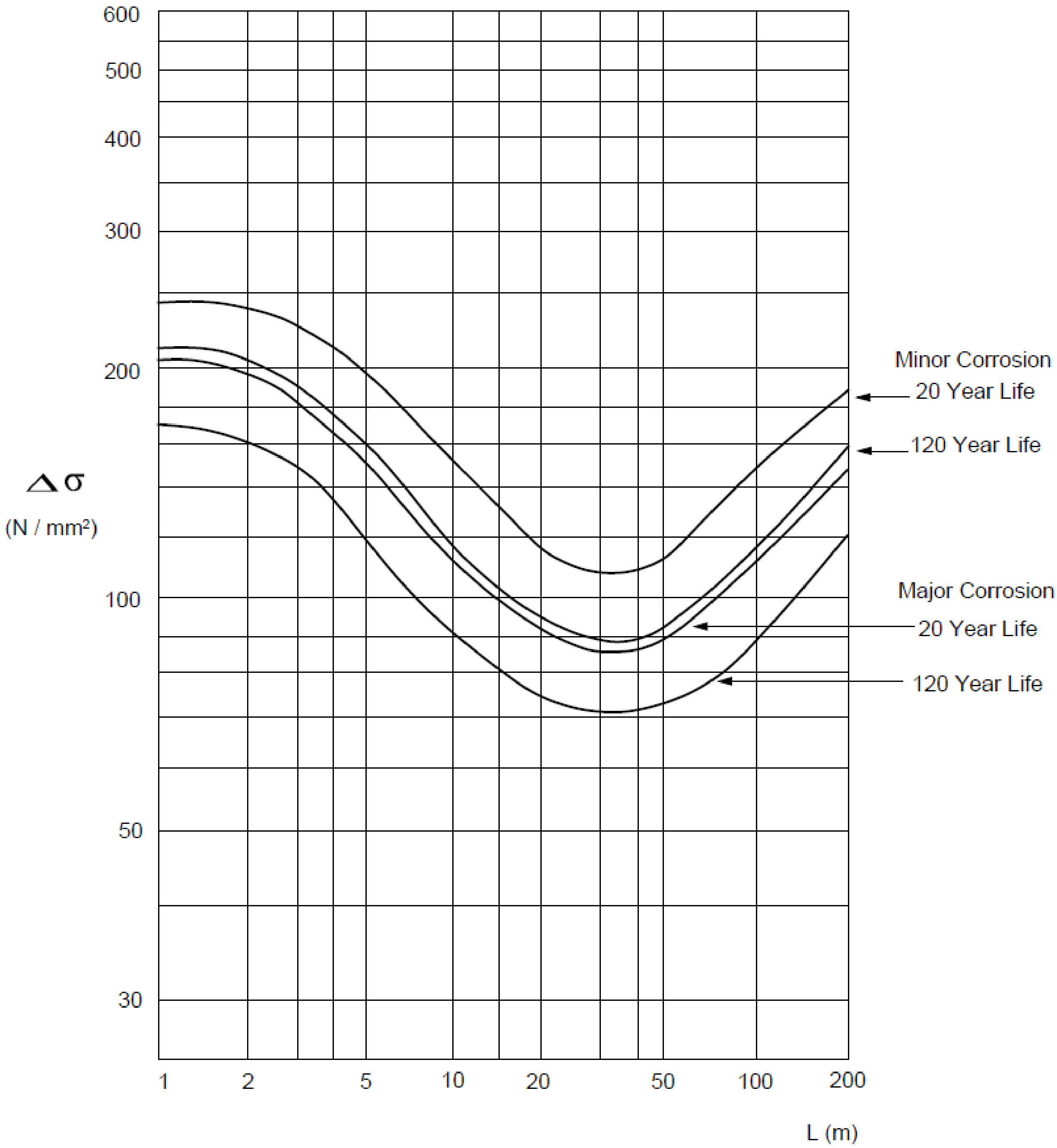

Figure 3.1 – Stress Limits for 40 Tonne Assessment Loading for Major and Minor Corrosion

4. REFERENCES

4.1 NRA Design Manual for Roads and Bridges

NRA BA 35	The Inspection and Repair of Concrete Highway Structures.
NRA BD 21	The Assessment of Highway Bridges and Structures.
NRA BD 44	The Assessment of Concrete Highway Bridges and Structures.
NRA BD 9	Use of BS 5400: Part 10: 1980
NRA BA 9	Use of BS 5400: Part 10: 1980

4.2 BS 5400: Steel, Concrete and Composite Bridges. Part 10: Code of Practice for Fatigue. BSI, 1980.

4.3 BS 5400: Steel, Concrete and Composite Bridges. Part 4: Concrete Bridges. BSI, 1990.

4.4 Durability of Concrete Bridges, G P Tilly. Highways and Transport, February 1988.

5. ENQUIRIES

5.1 All technical enquiries or comments on this document or any of the documents listed as forming part of the NRA DMRB should be sent by e-mail to infoDMRB@nra.ie, addressed to the following:

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APPENDIX A - CROSS-SECTION MEASUREMENT

A1. To evaluate the loss of cross-sectional area for classification purposes it is necessary to determine the nominal and actual cross-section of the bar. Where drawings are available the specified nominal diameter may be used to calculate the nominal area. In the absence of such information measurements at the undamaged and damaged sections of the bar will be required to calculate the nominal and actual areas.

A2. Prior to any measurements of the bar, all rust and loose concrete should be removed from a suitable length and the bar should then be cleaned down to bright metal. Areas of slight pitting which have a negligible effect on the surface may be ignored.

A3. Where the nominal diameter is determined from the sample bar, two measurements of the width of the bar at 90° to each other should be taken at an uncorroded section. The nominal area should then be based on the average of the measurements.

A4. To calculate the actual cross-sectional area, measurements should be taken at the position of worst corrosion or mechanical damage on the sample length. The method of measurement of this area will depend on the shape of the area lost.

a) Where the actual cross-section is as shown in Figure A1 the actual cross- sectional area may be taken as $\pi xy/4$ where x and y are measured at 90° to each other and either x or y records the minimum width.

b) Figures A2(i) and A2(ii) show a deeply pitted form of damage where measurements of the depth and width of the damaged area may be taken. From these measurements the loss of cross-sectional area can be determined.

c) Figure A3 illustrates an irregular boundary of damage which is not covered by either section (a) or (b). Since measurements are difficult in this case an approximation may be made in evaluating the loss of cross-sectional area.

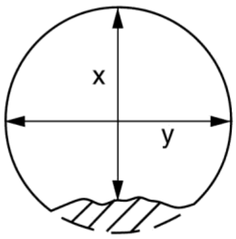


Figure A1

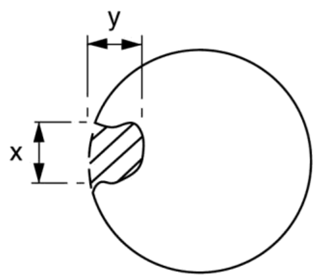


Figure A2(i)

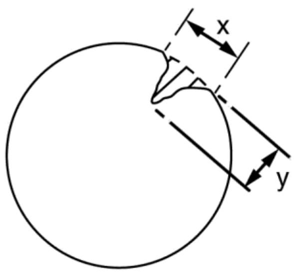
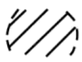


Figure A2(ii)

Figure A3



Damaged Area

Figure A - Measurements to Determine Cross Sectional Area of a Corroded Bar

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