VOLUME 1 HIGHWAY STRUCTURES: APPROVAL PROCEDURES AND GENERAL DESIGN

SECTION 3 GENERAL DESIGN

PART 4

BA 40/93

TACK WELDING OF REINFORCING BARS

SUMMARY

This Advice Note gives guidelines for the use of Tack Welding and the Assessment of Fatigue Strength of Tack Welded Reinforcing Bars.

INSTRUCTIONS FOR USE

This is a new document to be incorporated into the Manual.

1. Remove existing contents pages for Volume 1 and insert new contents pages dated July 1993.

2. Insert BA 40/93 into Volume 1 Section 3.

3. Archive this sheet as appropriate.

THE HIGHWAYS AGENCY BA 40/93

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

Tack Welding of Reinforcing Bars

Summary: This Advice Note gives guidance on the use of tack welding and the checking of fatigue strength of tack welded reinforcing bars.

This Advice Note provides advice on specification requirements for use in public purchasing contracts. It does not lay down legislative requirements for products and materials used in highway construction in the United Kingdom.

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

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Contents

Chapter

1. INTRODUCTION

General

1.1 This Advice Note gives guidelines for the use of tack welding and the assessment of fatigue strength of tack welded reinforcing bars. It is based on the findings of two desk studies on the tack welding of reinforcing bars and the fatigue of unwelded reinforcement (see bibliographies 1 and 2).

1.2 Tack welding of reinforcing bars can be used in specified locations and should always be carried out under carefully controlled conditions. Good quality tack welds can improve the construction process and lead to improvements in the quality of location of reinforcing steel and of cover. However in some situations tack welds, even of good quality, can drastically reduce the fatigue strength of reinforcement; while poor quality tack welds can lead to substantial loss of strength and embrittlement, as well as to shorter fatigue lives.

1.3 Contracts including the tack welding of reinforcing bars will normally incorporate the Specification for Highway Works (MCHW 1). In such cases products conforming to equivalent standards and specifications of other member states of the European Community and tests undertaken in other member states will be acceptable in accordance with the terms of the 104 and 105 Series of Clauses of that Specification. Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect regarding which advice should be sought.

Scope

1.4 This Advice Note is applicable to both reinforced and prestressed concrete members. A `deemed to satisfy' rule with a limitation on maximum stress range is provided for the calculation of fatigue life (see paragraph 4.2). Sample design calculations for fatigue strength of shear links with tack welding are given in Annex A.

1.5 Any reference in this Advice Note to a British Standard is to that Standard as implemented by the appropriate Departmental Standard.

Implementation

1.6 This Advice Note should be used forthwith on all schemes for the construction, improvement and maintenance of trunk roads, including motorways, currently being prepared or under construction provided that, in the opinion of the Overseeing Department, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Department.

2. ENGINEER'S APPROVAL FOR THE USE OF TACK WELDING

2.1 The Specification for Highway Works (MCHW 1) Clause 1716 allows the use of tack welding provided that the Contractor can demonstrate to the Engineer that the fatigue life, durability and other properties of the concrete member are not adversely affected by the welding. In addition to the guidelines given in Clause NG 1716 of Notes for Guidance on the Specification for Highway Works (MCHW 2), the Engineer should adopt the following requirements and procedures when considering the Contractor's proposals.

2.2 The use of tack welding for reinforcing bars should be limited by the guidelines set out in Chapter 3.

2.3 The fatigue strength of tack welded reinforcing bars should be assessed in accordance with Chapter 4 and should be submitted to the Engineer for approval before commencing tack welding.

2.4 Before commencing tack welding the welding procedures for shop and site tack welds should be submitted to the Engineer for approval in accordance with the requirements of BS 7123 Specification for Metal Arc Welding of Steel for Concrete Reinforcement[5].

2.5 Before and periodically during welding operations, welding approval procedure tests should be carried out in accordance with BS 7123.

2.6 Sample tack welded joints should be provided for use as a comparison with production joints during inspection.

2.7 Tack welding may reduce yield strength and therefore the engineer should be satisfied by means of load tests, if necessary, that the yield strength of the reinforcing bars is not reduced by tack welding. Cold worked bars are particularly vulnerable to loss of yield strength.

3. GUIDELINES FOR THE USE OF TACK WELDING

General

3.1 Typical weldment forms for tack welds at cruciform joints and lap joints between reinforcing bars are shown in Figure 3/1.

3.2 Tack welding should comply with the requirements of BS 7123.

3.3 Electrodes used should be of mild steel as required in BS 7123 with hydrogen controlled electrodes or MIG/MAG welding.

3.4 Acceptance levels during acceptance trials and production should be in accordance with BS 7123. Hardness in the heat affected zone should not exceed 350 HV 30 as given in BS 427[(6)].

3.5 Tack welds are permitted at bends, so long as the bend is made before welding (see paragraph 3.11).

3.6 The ambient temperature has no effect on tack weldability of either hot rolled or cold worked reinforcing bars (but see paragraph 3.10). It is also unaffected by normally rusted bar surfaces.

3.7 The design of tack welded assemblies should take account of any transportation requirements including location of lifting points for safe handling.

Limitations

3.8 Tack welding should not be used in cruciform joints of bars 8 mm and less in diameter, unless the damage ratio (Miner's Sum) is less than 0.1 (see fatigue strength check in Chapter 4 and sample calculations in Annex A).

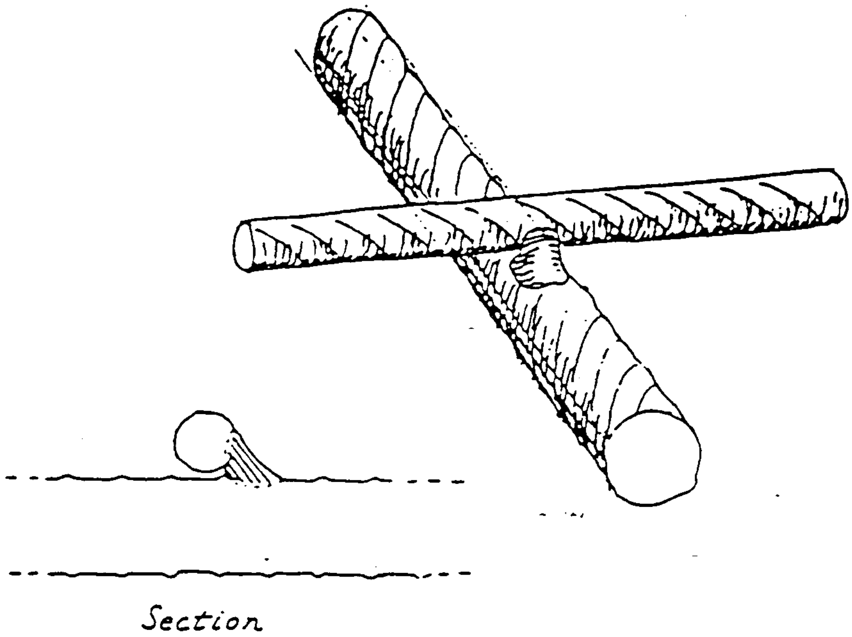
3.9 Tack welding should not be used in reinforcing bars which form part of a deck slab spanning between longitudinal and/or transverse members and subjected to the effect of concentrated wheel loads in a designated traffic lane.

3.10 Tack welding to steel bars with a carbon content exceeding 0.30% or a carbon equivalent value exceeding 0.42% should not be carried out without preheating. (Note: BS 4449[(7)] allows grade 460 steel bars to have carbon equivalent values up to a maximum of 0.51%.) When using steel bars with high carbon equivalent values, the practicality of attaining reliable preheating should be considered, especially when there is a large number of tack welds to be carried out.

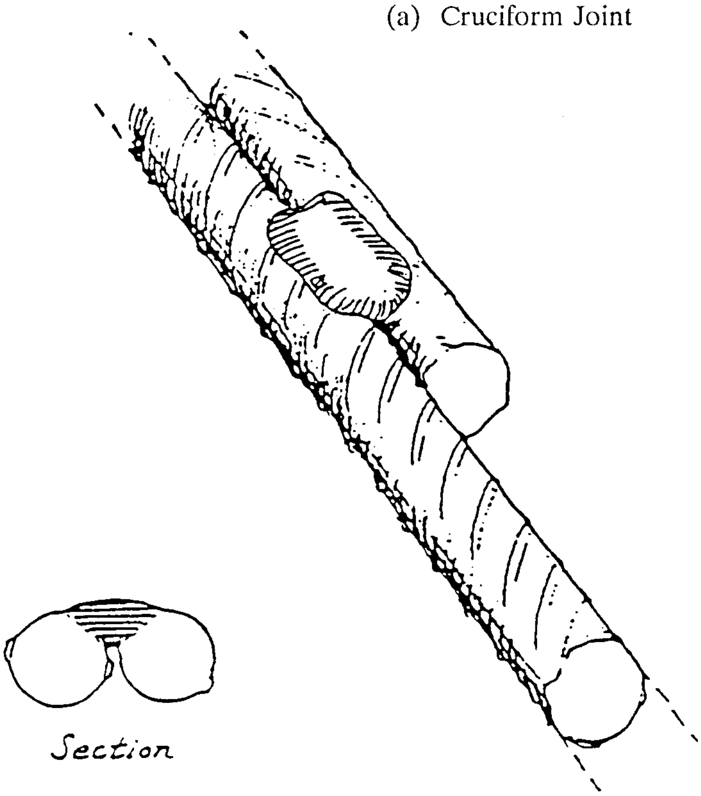
3.11 Tack welding should not be undertaken in rain, snow or high winds, or on wet surfaces, or on surfaces at a temperature below 0°C as indicated by BS 7123.

3.12 Reinforcing bars should not be bent after tack welding.

Figure 3/1: Weldment Forms for Tack Welds for Locating Reinforcing Steel.



(a) Cruciform Joint



(b) Lap Joint

4. FATIGUE STRENGTH OF TACK WELDED REINFORCING BARS

4.1 Where it can be shown that the reinforcing bars near the tack weld will not be intersected by a crack in the concrete, the fatigue strength of the reinforcement need not be checked. For shear reinforcement, if the tack welds are not in the region where diagonal cracking could occur, no fatigue check is required. For longitudinal reinforcement in beams, if the tensile stress in the concrete at ultimate limit state is below $0.24(f_{cu})^{½}$, where f_{cu} is the characteristic concrete strength as defined in BS 5400 : Part 4[(3)], the concrete can be assumed to be uncracked and no fatigue check is required.

4.2 The tack welded reinforcing bars may be deemed to satisfy the fatigue check if the maximum stress range in the bars at serviceability limit state in accordance with BS 5400: Part 4 does not exceed $110 N/mm^2$.

4.3 Where the conditions in either paragraph 4.1 or 4.2 above are not met, the fatigue strength of tack welded reinforcing bars should be assessed in accordance with the following paragraphs.

4.4 The fatigue damage arising from tack welding may be calculated by the vehicle spectrum method of Clause 8.4 of BS 5400: Part 10: 1980[(4)] using the σ_r-N curve given for Class D details, which is given by:

$$N \sigma_r^m = K_2 \quad \text{with } m = 3 \text{ and } K_2 = 1.52 \times 10^{12}$$

4.5 Alternatively, either of the simplified methods of Clauses 8.2 and 8.3 of BS 5400: Part 10: 1980 for Class D details may be used as a conservative check of the fatigue resistance of tack welded reinforcing bars.

4.6 In calculating the stress in the longitudinal reinforcement in beams, the tensile strength of the concrete should be ignored and elastic stress distribution within the section should be assumed.

4.7 The methods of Clauses 8.2 and 8.3 of BS 5400: Part 10: 1980 are based on the assumption that the stress range is linearly proportional to the vehicle weight. In using one of these methods, the stress σ in the shear reinforcement in beams due to shear force V should be taken as:

$$\sigma = \frac{V\ s_v}{A_{sv}\ d}$$

where s_v, A_{sv} and d are the spacing of the links, the cross-sectional area of the links and the effective depth to tension steels respectively as defined in BS 5400: Part 4.

4.8 In calculating the stress in the shear reinforcement using the method of Clause 8.4 of BS 5400: Part 10: 1980 or the deemed to satisfy rule in paragraph 4.2 above, it may be assumed that 70% of the ultimate shear strength of the concrete is available at the serviceability limit state to resist shear. Therefore the stress σ in the shear reinforcement should be taken as:

$$\sigma = \frac{(V - 0.7V_c)\ s_v}{A_{sv}\ d} \qquad \text{but not less than zero}$$

where V_c is the ultimate shear strength of the reinforced or prestressed concrete member at the section calculated to BS 5400: Part 4.

NOTE: In calculating the stress range σ_r, the dead load and superimposed dead loads must be included in both the maximum and minimum shear forces to determine σ_{max} and σ_{min}. This is because of the effect of the $0.7V_c$ term which does not necessarily cancel out in the calculations (see sample calculations in Annex A.)

4.9 Sample calculations for the fatigue strength of shear links with tack welding are included in Annex A to illustrate in detail the use of this Advice Note using assessment methods given in BS 5400: Part 10: 1980.

5. REFERENCES AND BIBLIOGRAPHIES

References

1. Specification for Highway Works. HMSO (MCHW 1).

2. Notes for Guidance on the Specification for Highway Works. HMSO (MCHW 2).

3. BS 5400: Part 4: Steel, Concrete and Composite Bridges: Code of Practice for Design of Concrete Bridges. British Standards Institution, 1990.
[implemented by BD 24 (DMRB 1.3.1)]

4. BS 5400:Part 10: Steel, Concrete and Composite Bridges: Code of Practice for Fatigue. British Standards Institution, 1980.
[implemented by BD 9 (DMRB 1.3)]

5. BS 7123: Specification for Metal Arc Welding of Steel for Concrete Reinforcement. British Standards Institution, 1989.

6. BS 427: Method for Vickers Hardness Test and for Verification of Vickers Hardness Testing Machine. British Standards Institution, 1990.

7. BS 4449: Carbon Steel Bars for the Reinforcement of Concrete. British Standards Institution, 1988.

Bibliographies

1. Study of Tack Welding of Reinforcing Steel. Report for Transport and Road Research Laboratory by Edmund Hambly Ltd, May 1989.

2. Fatigue of Unwelded Reinforcing Bars. Report for Transport and Road Research Laboratory by Edmund Hambly Ltd, September 1989.

6. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:-

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SAMPLE CALCULATION FOR THE FATIGUE STRENGTH OF SHEAR LINKS WITH TACK WELDING

Introduction

A.1 The M5 beams considered in the following calculations have been used in a manner that makes them borderline with respect to the existing rules for shear of prestressed concrete in BS 5400: Part 4: 1990. The dimensions of the web are at the lower limit acceptable for maximum shear to Clause 6.3.4.5, while the reinforcement provided is at the lower limit for longitudinal shear to Clause 7.4.2.3 and close to the lower limit for shear reinforcement to Clause 6.3.4.4. It is unlikely that tack welds would be used in the web region of M-beams. However it is shown in the fatigue calculations that with tack welds on the reinforcement the shear links are within the limit by the rigorous vehicle spectrum method, but not sufficient to satisfy simpler methods of assessment. It is considered unlikely that beams will be designed to be so borderline with respect to current rules in BS 5400: Part 4, and so they should in general have a greater reserve of strength against fatigue than shown here.

Beam Design to BS 5400: Part 4: 1990 Section 6.

A.2 Consider conditions at 0.5m from the support of a simply supported deck of 18m span constructed of M5 beams at 1.5m centres. The forces on the section under design loads are found to be:-

Dead load	V = 150kN
Superimposed dead load	V = 30kN
Live load:	
45 units HB with HA adjacent	V = 400kN
HA loading	V = 230kN
SFV (4 x 80kN)	V = 80kN
Minimum	V = 0

Each of the M5 beams has the following properties:

$b = 160$mm
$h = 1120$
$d = 960$mm
$V_c = 460$KN at ULS
$A_{sv}/s_v = 1292\text{mm}^2$ (Links 12 mm dia at 175 centres).

Fatigue Calculations Using Vehicle Spectrum Method

A.3 The results of a fatigue analysis according to Clause 8.4 of BS 5400: Part 10: 1980 are shown in the table below.

1 Vehicle designation	2 No of vehicles in 120 years	3 Max shear on section V_{max}	4 Max shear taken by links $V_{max} - 0.7V_c$	5 Max stress in links σ_r	6 No of repetition to failure N	7 Fatigue damage (Miner's sum) D = n/N
	n	kN	kN	N/mm^2		
18GT-H	2400	610	288	232	0.12×10^6	0.0200
18GT-M	7200	350	28	23	$625. X 10^6$	-
9TT-H	4800	540	218	175	$0.29 X 10^6$	0.0165
9TT-M	9600	340	18	16	$3.65 X 10^9$	-
7GT-H	7200	390	68	54	$9.52 X 10^6$	0.0008
7GT-M	16800	310	00	0	-	-
7A -H	4800	340	18	16	$3.65 X 10^9$	-
5A -H	67200	280	00	0	-	-
5A -M	3480000	270	00	0	-	-
					Miner's sum =	0.0373

Stress histories were calculated for each of the vehicles in BS 5400: Part 10: 1980, Table 11 travelling over the bridge in one lane. Only the heaviest vehicles are listed in the table, as the lighter vehicles do not cause fatigue damage of the shear links. Vehicles travelling in other lanes have very little effect on the shear force in the beam under consideration, and have therefore been ignored.

Column 2 list the numbers of each vehicle occurring in the 120 year design life of the bridge. These are derived from BS 5400: Part 10: 1980, Table 1 and Table 12 for the slow lane of a motorway.

The shear force, V_{max}, in column 3 is the maximum total shear force under the relevant vehicle, dead load and superimposed dead loads with $\gamma_{fL} = \gamma_{f3} = 1.0$.

The maximum shear force carried by the shear links is shown in column 4. 70% of the ultimate shear strength of concrete is taken into account (See paragraph 4.8).

The minimum shear force V_{min}, is that due only to dead and superimposed dead loads:

$$V_{min} = 150 + 30 = 180kN$$

This is less than $0.7V_c = 0.7 \times 460 = 322kN$, so the minimum shear force carried by the links is zero. (The dead and superimposed dead loads must be included in both maximum and minimum shear forces, because the effect of $0.7V_c$ is that they do not necessarily cancel out.)

Since the minimum shear force carried by the link is zero, the maximum stress ranges listed in column 5 may be calculated
directly using the maximum shear forces in column 4, ie

$$\sigma_r = (V_{max} - 0.7V_c)s_v/A_{sv}d$$

For example the maximum stress range due to the 18GT-H is

σ_r = (610 - 0.7 x 460)/(1292 x 960)
= 232 N/mm^2

The values of N appropriate to the maximum stress ranges are listed in column 6, and are calculated using the σ_r-N equation for Class D details:

$N\sigma_r^3 = 1.52 \times 10^{12}$

Column 7 lists the damage done by the maximum stress range for each type of vehicle. Some vehicles cause a stress history with more than one peak, so other smaller stress ranges not shown in the table must also be taken into account in the calculation of total fatigue damage. Vehicles for which the shear force V_{max} is less than $0.7V_c$ are considered not to cause any fatigue damage.

The total damage over the 120 years is found to be the Miner's Sum of 0.0373. This is well below unity, so tack welds on these shear links are an acceptable detail for fatigue.

Fatigue Calculation Using Simplified Method of Clause 8.2 of BS 5400: Part 10: 1980

A.4 The simplified methods based on stress calculations for a single SFV can only be used if the stress ranges due to heavier vehicles are linearly proportional to the vehicle weights. The resistance from the concrete is ignored in this case and the stress range in the shear links may be calculated using the following formula without taking the effects of dead load and superimposed dead loads into account.

$$\sigma_r = \frac{(V_{max} - V_{min})\ s_v}{A_{sv}\ d}$$

Due to the single SFV, (V_{max} - V_{min}) = 80kN. Hence, with $\gamma_{fL} = \gamma_{f3} = 1.0$, σ_r = 80/(1292 x 960) = 65N/mm^2

In this example the base length of the influence line is taken as L = 18 -0.5 = 17.5m.

It can be seen from Figure 8(a) of BS 5400: Part 10: 1980 that for this value of L the limiting stress range σ_H is 31N/mm^2 for Class D details. Hence the design does not pass this simple conservative check. In order for it to do so σ_r would have to be reduced to 31N/mm^2 by increasing the area of reinforcement by a factor of over 2.

The reduced fatigue strength predicted by this method is due to the effects of $0.7V_c$ which have been ignored. It has been necessary to adopt a more conservative approach in this case because of the inherent simplification used in the method.

Stress Checks by Simple `Deemed to Satisfy' Fatigue Design Rule

A.5 The deemed to satisfy rule is based on the serviceability limit state loading criteria in accordance with BS 5400: Part 4; ie maximum stress range for HA loading with γ_{fL} = 1.20 and γ_{f3} = 1.0. Dead load and superimposed dead loads must be included in the stress calculations.

In this case, the minimum shear force, V_{min}, is that due to dead load and superimposed dead loads with the appropriate values of γ_{fL} and γ_{f3} at SLS, ie

$$V_{min} = 150 \ x \ 1.0 + 30 \ x \ 1.2 = 186kN$$

This is less than $0.7V_c$ = 0.7 x 460 = 322KN, so the minimum shear force carried by the links is zero.

The maximum shear force, V_{max}, is that due to HA loading, dead load and superimposed dead loads with the appropriate values of γ_{fL} and γ_{f3} at SLS.

$V_{max} = 230 \times 1.2 + 150 \times 1.0 + 30 \times 1.2 = 462$ kN

Since the minimum shear force carried by the links is zero, the stress range in the links can be calculated directly using the maximum shear force ie:

$$\sigma_r = \frac{(V_{max} - 0.7V_c)s_v}{A_{sv}\, d}$$

$$= \frac{(462 - 0.7 \times 460)}{1292 \times 960}$$

$$= 113\text{N/mm}^2$$

This exceeds the limiting stress range of 110N/mm^2 given by the deemed to satisfy rule and would require a slight reduction in the stress due to loads to satisfy the rule. The effect of $0.7V_c$ has been included in the calculation of the reinforcement stress range for this check. The deemed to satisfy design rule, in this example, is less conservative than the fatigue check using BS 5400: Part 10: 1980 Clause 8.2 (described in paragraph A.4), where the effect of $0.7V_c$ is ignored.