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Guidance Note – Anchorage of Steel Step Barrier on bridges

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March 2006

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Contents

1 Introduction

This guidance note summarises the anchorage requirements for the steel step barrier when used on structures.

Guidance is given for two cases as follows:

- Fixity is within the central reserve level make up material (e.g. asphalt or non-structural concrete) such that the fixings do not affect the deck structure
- Fixity is fully or partially into structural members forming part of the deck

The 'retrofit' anchor system comprises the following elements:

- A drilled cylindrical hole formed by rotary percussion or diamond drilling that contains the bonding agent and anchor
- An embedded metal internally threaded anchor
- A holding down bolt attachment that is engaged in the metal anchor

The anchorage will be required to comply with current UK Highways Agency (HA) design standards and specifications.

Failure of the anchor under loading will occur in one of the following modes dependent upon the individual strengths of the component items.

- Concrete cone failure, splitting failure or pull out failure
- Material failure of the embedded anchor
- Holding down bolt failure

The following variables affect the carrying capacity of these individual elements of the anchorage system for the proposed barrier system

- Strength of concrete support
- Length of embedment
- Size of fixing
- Grade and type of fixing (e.g. mild / stainless steel)
- Group action of multiple fixings
- Action of force in anchor (i.e. proportion of shear and tension)

It is proposed that the anchor design for the Steel Step barrier ensures that failure is always confined to the holding down bolt.

The guidance given in this document is of a general nature and cannot address every site specific situation that may arise.

The interpretation and use of the information herein is therefore the responsibility of the scheme designer, where the steel step barrier is to be adopted, taking due consideration of site specific conditions and restraints.

2 Design Data

2.1 Anchor fixings

Table 1 below summarises the anchorage requirement for different central reserve treatments. Each anchorage comprises a four bolt anchor group.

Central reserve construction	**Anchor type**	**Comment**
Asphalt construction	Grade 4.6 M24 bolts 340 mm long Penetration into asphalt 240 mm (NB Identical to the performance test)	There should be sufficient depth such that the anchor does not penetrate the deck. HA approval will be required to fix holding down bolt in asphalt – anchorage system will require testing to confirm capacity Alternatively form concrete plinth to receive anchor bolt assembly – anchor assembly to be in stainless steel.
Concrete plinth or strip	Use anchor designed in accordance with Section 3 Bolt M20 Grade A4-80 stainless steel	If plinth not part of bridge deck – reinforcement should be provided adjacent to the anchor points to avoid damage following impact (see Table 4). The plinth to be a minimum of 1m wide by 0.5m deep protruding typically 225mm on the traffic face. The plinth to be nominally reinforced in both faces away from the anchorage points.
Structural Concrete	Use anchor designed in accordance with Section 3 Bolt M20 Grade A4-80 stainless steel	To ensure deck has sufficient capacity check reinforcement provision. The anchor is to be fully within the structure

Table 1: Centre reserve treatments

2.2 Anchor design load

When an anchorage is partially or fully connected to a deck member, the nominal anchor design load should be as a minimum that appropriate to H2 containment (coach) as shown in Table 2. These values are obtained from an analysis of the maximum mean impact force that occurs in the anchor as a result of the impact collision.

Comparative values are also given for the coach and rigid HGV tests that are relevant to H2 and H4a containment.

Item	**Nominal**	**Car**	**Coach**	**Rigid HGV**	**Comment**
Test Reference	-	**TB11**	**TB51**	**TB71**	
Containment		**N2**	**H2**	**H4a**	
F (kN)	100.0	37.8	**106.4**	221.3	Mean impact load
N (kN)	77.5	29.3	**82.5**	171.5	Maximum unfactored tension load in anchor (based upon performance test)

Item	Nominal	Car	Coach	Rigid HGV	Comment
Test Reference	**-**	**TB11**	**TB51**	**TB71**	
Containment		**N2**	**H2**	**H4a**	
V (kN)	22.5	8.5	**24.2**	50.4	Maximum unfactored shear load in anchor (based upon performance test)
γ_{un}	1.10	1.10	**1.10**	1.10	Load factor to allow for variations in vehicle geometry
F_{nom} (kN)	88.8	33.6	**94.5**	196.4	Nominal anchor load $\gamma_{un}.(V^2 + N^2)^{0.5}$

Table 2: Anchor design loads

2.3 Design of anchor support, anchor and supporting concrete members

For conventional post and rail parapet systems, concrete supporting members are required to possess a reserve of strength above the ultimate capacity of up to three adjacent posts.

The HA requirement for parapet supports is as follows:

- Local effects - The nominal impact loads due to vehicle collision with a High level of containment parapets is defined in BD 37/01 Clause 6.7.1.1 (a) and (b)
- Global effects - is defined in BD 37/01 Clause .6.7.2.1

The design method for the Steel Step Barrier system and supporting concrete members is given in Section 3.

The design approach for the Steel Step Barrier will follow the principles of metal parapet design[1]. The holding down bolt is assumed to be the element that fails first. The anchor (i.e. the part of the anchorage system embedded in concrete) and any supporting concrete element is required to have a reserve of strength that exceeds the bolt capacity.

2.3.1 Holding down bolt capacity

The ultimate capacity of M20 stainless steel bolts are given in Table 3.

Effect	Coarse threaded M20 bolt	Fine pitch threaded M20 bolt
Tensile strength R_y	*600 N/mm²*	*600 N/mm²*
Effective area $A_{s,nom}$	*245 mm²*	*272 mm²*
Material factor γ_m	*1.2*	*1.2*
Bolt capacity = $A_{s,nom} x R_y / \gamma_m$	*122.5kN*	*136.0kN*

Table 3: Single holding down bolt capacity

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[1] BS 6779-1:1998 Highway parapets for bridges and other structures – Part 1: Specification for vehicle containment parapets of metal construction.

3 Anchorage system design

Design Step	Design
1. Design of the holding down bolts (Attachment system)	
a) Take the theoretical lateral impact force on the barrier for the H2 test (TB11) calculated in accordance with EN 1317 as the nominal design load for the attachment system (i.e. holding down bolts). The calculations for the determination of the lateral impact force should use the most onerous combination of assumed vehicle parameters (b, c and z)	P_{lat} =106.4 x 1.1 = 117.0kN (see Table 2) NB 1.1 factor to allow for variation in vehicle parameters to give most onerous value
b) Apply an ultimate load factor (γ_{fl}) of 1.2 to this nominal design load. (γ_{f3} may be taken as 1.0)	H_{ult} = 117.0 x 1.2 = 140.4kN
c) Calculate the ultimate tensile and shear forces in the holding down bolts considering the force to be applied at 600 mm above the base of the barrier and to a single bolt group.	For H = 100kN, N = 77.5kN ; V = 22.5kN ; $F_{nom} = (N^2 + V^2)^{0.5}$ = 80.7kN (see Table 2) Hence for H_{ult} =140.4kN, F_{ult} =140.4/ 100 x 80.7 = 113.3kN
d) Design the holding down bolts using a material factor (γ_m) suitable for the bolt material. (normally 1.2)	Bolt capacity M20 A 4-80 Stainless Steel, $P_a = 600 \times 245 \times 10^{-3} / 1.2$ = 122.5kN – (see Table 3)
e) The bolt capacity should not exceed the required capacity by more than 15%.	$(P_a – F_{ult}) / F_{ult}$ = 8.1% < 15% - Hence OK
f) Check that the bolt capacity is not less than that of the bolts used in the Performance Test for the barrier.	For tested system, f_y = 240N/mm^2, A_s = 353mm^2 (Grade 4.6, M24) $P_b = 240 \times 353 \times 10^{-3} / 1.2$ = 70.6kN; $P_b = 0.58 \times P_a$ **Hence M20 A4-80 stainless steel bolts OK**
2. Design of the anchorage (embedded metal element and supporting concrete)	
a) Take the ultimate tensile capacity of a holding down bolt as its nominal design load.	Estimated maximum load in anchor or attachment for H2 containment P_{H2} = 94.5kN (see Table 2) Bolt capacity M20 A 4-80 Stainless Steel

Design Step	Design
	$F_u = 600 \times 245 \times 10^{-3} = 147.0$kN >>$P_{H2}$ Design for bolt capacity
b) Apply an ultimate load factor (γ_{fl}) of 1.5 to this nominal design load. (γ_{f3} to be taken as 1.0).	$P_d = F_u \times 1.5 = 147 \times 1.5 = 220$kN N.B. ensure bolt fails first by providing material safety factors to anchorage elements
c) Set this as ultimate design load for the anchor.	Minimum required design resistance of anchorage **P_k = 220kN**
d) Check chosen anchor performance (both a cast in cradle and a drilled in bonded anchorage are considered)	Anchorage design checks – Case 1 – cast in cradle anchorage (i.e. New Build Construction) e.g. From Fixing Centre Limited **SSR 170 M20 x 150mm x 300mm x 400mm depth** (Drawing Ref. FCL 487) **R_d = Design resistance per socket = 255kN ≥ P_k Hence OK** – Case 2 – drilled in bonded chemical anchor (i.e. Retrofit Construction) e.g. From Fixing Centre Limited SSR-VDI Chemical Anchor Socket **– M20 x 40mm x 320mm**
Utilise material factor of $\gamma_m = 1.6$	Performance checks **a) Bond** Bond resistance - 9 N/mm^2 for SSR-VDP capsules $R_{k1} = 9 \times \pi \times 40 \times 320 \times 10^{-3} / 1.6 = 226.2$kN > P_k **b)Anchor strength** $A_{\mathbf{anc}} = \pi.\ (D^2-d^2)/4 = \pi.(40^2-20^2)/4 = 942$ mm^2 R_y = 600 N/mm^2 γ_m = 1.2 $R_{k2} = 942 \times 600 \times 10^{-3} / 1.2 = 471.2$kN > P_k
`Utilise material factor of $\gamma_m = 1.6$	**c) Concrete cone resistance** Cone resistance – single anchor, 320mm deep In C20/C25 concrete = 425kN Factor for C40/C50 concrete = 1.2 Cone resistance = 425 x 1.2 = 510kN Factors affecting cone resistance Group factor for anchors at 150mm centres at standard depth of 205mm = 0.67 Factor for increased depth (320mm) = 0.5 + 320 / (4 x 205) = 0.89 Factor for concrete cone resistance at 320mm depth ,f_{cr} = 0.67 / 0.89 = 0.75 $R_{k3} = 0.75 \times 510 / 1.6 = 239.1$kN > P_k Hence bond governs anchorage system capacity **R_k = 226.2kN > P_k – hence OK** **NB Assumes anchorage capacity not affected by anchor centre to concrete edge distance**

Design Step	Design
3. Design of the supporting structure for Local effects	
a) Design the supporting structure in accordance with the principles of BD 37/01 Clause 6.7.	Minimum yield stress of bolt = 600N/mm^2 Lever arm = 300mm A_{snom} = 245mm^2 (M20 bolt coarse threaded)
b) The nominal design loads for local effects shall be: - The calculated ultimate moment of resistance of the holding down bolt group plus; - an associated shear force equal to the ultimate moment of resistance of the bolt group divided by 0.3m. **Note:** This assumes the impact force to be applied at a level of 300mm above the base of the barrier which is analogous to the lower rail of a post and rail parapet as required by BD 37/01.	For push-pull failure, $M_{nom} = 2 \times 0.3 \times 600 \times 245 \times 10^{-3}$ = 88.2kNm S_{acc} = 88.2 / 0.3 = 294kN
c) Load factors for local effects are to be as stated in BD 37/01 for barriers of High Containment level	From BD 37/01 Clause 6.7.1.4 - High level of containment γ_{fl} = 1.40 at ULS, 1.15 at SLS
d) Apply the above loads to a single bolt group at the level of the underside of the steel step barrier.	Gives : $M_{des}=1.4 \times M_{nom}$ = 88.2 x 1.4 = 123.5kNm $S_{des}= 1.4 \times S_{acc}$ = 294 x 1.4 = 411.6kN The required area of reinforcement, A_s can be approximated as: $A_s = M_{des} / (0.87 \times f_y \times 0.9 \times d)$ Where A_s = area of reinforcement in mm^2 f_y = reinforcement yield stress (typically 460N/mm^2 for high yield reinforcement) For an effective depth of concrete member of 500mm, for the example given above, this equates to $A_s = 123.5 \times 10^6 / (0.87 \times 460 \times 0.9 \times 500)$ =686 mm^2 3 No T20 bars or 4 No. T16 bars would be sufficient for the bending effects only The provision of additional shear reinforcement in accordance with BS 5400:Part 4, Clause 5.3.3.2 would increase this by: $A_{sv} = S_{des} / 2(0.87 \times f_y)$ A_{sv} = 514mm^2 resulting in a total reinforcement area of 1200mm^2 Since the shear force will be taken in both

Design Step	Design
	longitudinal and transverse directions, the provision of a mesh of T16 bars at 100mm spacing or T20 bars at 150mm spacing within an area at 250mm from the centre of the anchorage in both directions would also provide the necessary required resistance.
4. Design of the supporting structure - Global effects	
a) The nominal design loads for global effects shall be: A single horizontal load equal to the theoretical lateral impact force on the barrier to cause failure of the bolt – subject to this force exceeding the comparative value for the H2 test (TB51) calculated in accordance with EN 1317 applied as a point load 600mm above base of at the top of the barrier.	For the TB51 test, estimated impact load P_{lat} =106.4 x 1.1 = 117.0kN (see Table 2) NB 1.1 factor to allow for variation in vehicle parameters For failure of bolt, Bolt capacity M20 A 4-80 Stainless Steel, P_a= 600 x 245 x 10^{-3} = 147.0kN For impact load = 100kN, Max anchor forces are: N = 77.5kN; V = 22.5kN ; (see Table 2) Hence impact load to cause tensile bolt failure = 147/ 77.5 x 100 = 190kN (> 117kN) **Hence global design force = 190kN**
This load may be distributed at a rate of 1 in 1 from the load application position through the height of the barrier.	Load width distribution = 2 x 0.6 = 1.2m
b) Load factors for both local and global effects are to be as stated in BD 37/01[2] for barriers of High Containment level.	From BD 37/01 Clause 6.7.1.4 - High level of containment γ_{fl} = 1.40 at ULS, 1.15 at SLS P_{des} = 190 x 1.4 = 265kN For a structure with bearings, BD 37/01 Clause 6.11 requires a skidding load of 300kN to be accommodated. HA Longitudinal loading due to traction or braking is 250KN plus 8kN/m – or 330kN for a 10m span bridge (Clause 6.10) Any bridge with vulnerable bearings will have a minimum capacity of 300kN – the largest envisaged impact force should be capable of being tolerated therefore
5. Barrier vertical loading	For design checks on the structure, the vertical load of the steel step barrier (unfactored) is 1.5kN/m. The weight of any concrete supporting plinth will be in addition to this.

Table 4: System design

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[2] BD 37/01 – Loads for Highway Bridges

3.1 Anchor specification in hardened concrete

Specification requirements for the anchor system are summarised in Table 5.

Item	Requirement
Threaded anchor	*Stainless steel designation 1.4401 or 1.4436 to BS EN 10088-1 or equivalent.*
Holding down bolt	*Holding down bolts, studs and nuts shall be stainless steel grade A4-80 to BS EN 1SO 3506-1 and BS EN ISO 3506-2.*
Minimum concrete cube strength for parent concrete (f_{cu})	*30 N/mm^2* *(NB If product test certificate is based on a higher concrete strength then the higher value shall apply)*
Anchor Performance	*Design to ensure that holding down bolt is the item that fails first*
In-situ testing of anchor – test load	*Criteria for failure is tensile yielding of bolt –* *Set test load to be 90% of yield capacity of bolt* *For M20 A 4-80 Stainless Steel Bolts* *= 90% x 600 x 245 x10^{-3} = 130kN*

Table 5: Anchor specification requirements in hardened concrete