CAPITA

11 September 2014

Appendix A

Cambridgeshire Guided Busway

Report on Guideway Defects and Corrective Measures

Cambridgeshire Guided Busway
Cambridgeshire County Council v BAM Nuttall Ltd.

Report on Guideway Defects and Corrective Measures

Instructed	:	Tony Cort / Robin Sanders
	:	
For	:	BDB
	:	Cambridgeshire County Council
Date	:	11 September 2014
Ref	:	CS/059090

This document is for use solely in connection with dispute resolution and/or legal proceedings. It sets out the present state of knowledge and understanding of relevant facts and matters and the independent views of the authors, not Capita. Although there is no reason to expect any current opinion to change, it could do so if, for example, new evidence comes to light, or after considering the issue(s) in more detail or after discussions between respective party's expert(s).

Drafted : Tony Cort and Robin Sanders

Checked : Claire Clark/Fiacra Feehan-Fitzgerald

CONTENTS

INTRODUCTION

Instructions

1. This report is for issue to elected members of Cambridgeshire County Council ('the Council'). It has been prepared by us, Messrs Tony Cort and Robin Sanders, as independent engineering experts instructed by the Council's solicitors Bircham Dyson Bell ('BDB'). Details of our qualifications and experience are provided in Appendix A.

2. This report has been prepared to inform elected members of our opinions with respect to specific notified Defects on the superstructure (i.e. the elements of the guideway above the foundations) on the entirety of the guideway and notified Defects on the foundations on the northern section of the guideway, i.e. between St Ives and Milton Road, Chesterton. This report:

   (i) describes the Defects we are considering in outline;

   (ii) summarises the reasons why it is necessary that something is done about the defects;

   (iii) explains what, in our opinion, will happen to the guideway over time if nothing is done to correct the Defects;

   (iv) explains what, in our opinion, are the options available to the Council to correct the Defects, covering both pre-emptive repairs, reactive repairs when the effects of Defects manifest themselves and both pre-emptive and reactive work that will, in part or in whole, alleviate or reduce the effects of the Defects;

3. Mr Cort has prepared the sections of the report that discuss the notified Defects and options for corrective measures to the guideway structure above the foundations, as described in §8 - §15 below and those foundations supported on screw piles; Mr Sanders discusses the notified Defects and options for corrective measures to the foundations that lie directly on ground at the base of shallow (up to 2.975m deep) foundation excavations.

BACKGROUND

4. BAM Nuttall Ltd ('BNL') contracted with the Council to design and then build the bus guideway network to the north and south of Cambridge. The contract defines the design standards, which are generally those published by the UK Highways Agency, that were to be used and it specified performance and serviceability criteria that had to be meet by the constructed work, all in a document called 'Works Information'. In broad outline, BNL was required, as part of its obligations to:

   (i) submit designs in accordance with the design standards and any agreed deviation, for acceptance by Council's representatives;

(ii) undertake construction work to form the guideway in line with those designs so that the completed construction would meet the performance and serviceability criteria set by the Council in the contract; and

(iii) apply to the Council for approval of any proposed deviation from the design standards given in the contract.

5. Amongst its various roles the Council's Supervisor had a duty to notify BNL of aspects of its design or constructed work that it considered were not in accordance with:

(i) the design;

(ii) any applicable law; or

(iii) that, as constructed, would not meet the specified performance and serviceability criteria specified in the Works Information.

6. These notified elements of constructed work are called Defects. Until such time as it is agreed by the Project Manager that they are not Defects, or work is undertaken to correct or remedy the Defects to ensure the guideway performs in accordance with the Council's requirements as defined in the contract, they remain Defects. Each notified Defect is given a unique numerical reference number by the PM.

FUNDAMENTAL ELEMENTS OF THE GUIDEWAY

7. The guideway is formed of three principal elements

(i) the foundations;

(ii) the concrete elements which should provide a stable running surface ('guiderails') and guidance for the buses; and

(iii) the supports between these two elements, which are formed of bearings and shims.

8. The guiderails are made of concrete and have upstands on the outer edges which keep the buses on the track. The guiderails are kept apart by spacer beams that are bolted to the guiderails, thereby forming a series of 'ladders'. The arrangement is shown in the photograph below.

Figure 1. Photograph of a section of the guideway showing the spacer beams and foundation pads.

9. Most of the ladders are 15 metres long and are supported at each end and in the centre by foundations. The rails rest on plastic (high density polyethylene) shims, which in turn rest upon elastomeric (rubber) bearing pads. These sit directly on a raised upper surface of the foundation pads or pile caps, see §16 below for the distinction between these.

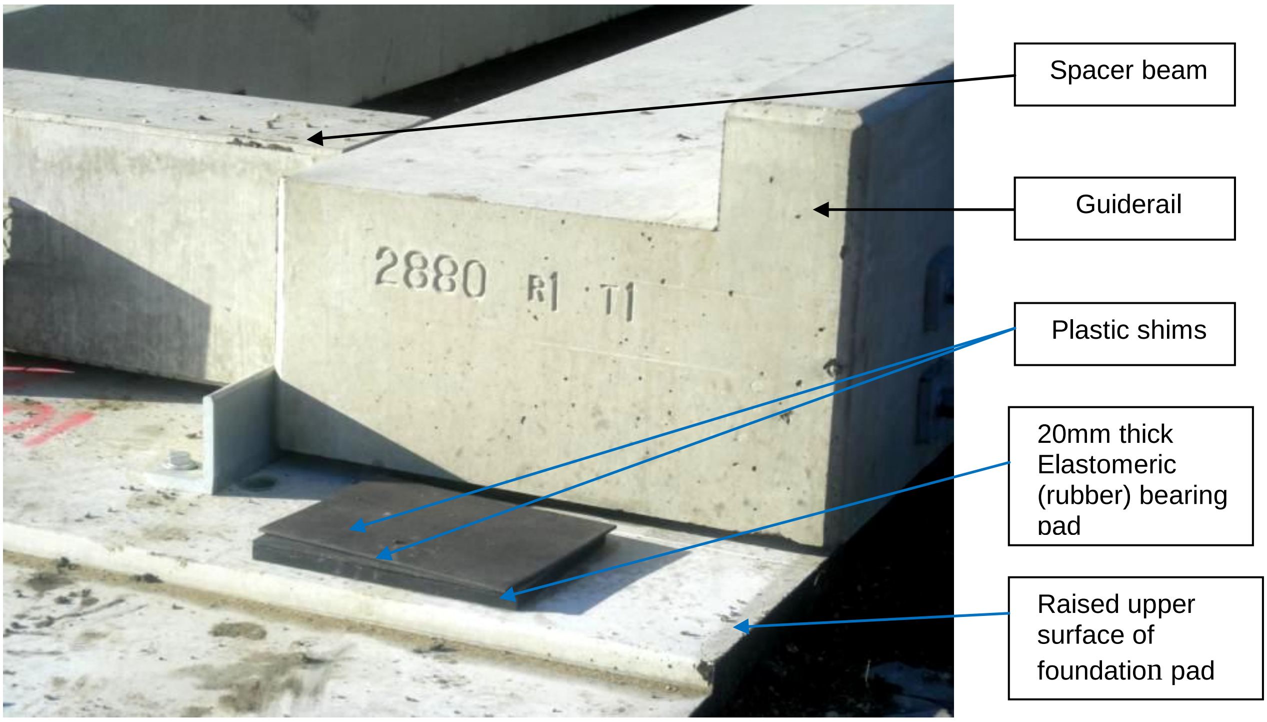


Figure 2. Photograph of a part of the guideway during construction, showing a spacer beam, guiderail, shims, bearing pad, and foundation pad.

10. The shims are the only part of the guideway structure that are designed to be removed or added to allow limited vertical movement between the foundations and guideway ladders. The shims are of various thickness so that small, millimetre scale adjustments can be made to ensure the continuity of bearing between the guideway ladders and the foundations.

11. The elastomeric (rubber) bearing pads are present to provide uniform seating of the beams and to permit the ends of the guiderails to rotate without damage occurring to the concrete. Such rotation occurs when buses pass along the guiderails causing them to move downwards slightly, and when one foundation of a guiderail moves vertically relative to the next foundation – the design was supposed to allow for 25mm of such differential movement of the supports.

12. BNL's design included for there to be 10mm of shims in place on construction and permitted a maximum of a further 25mm to be placed if necessary. Limited exploratory excavations to examine the bearings and shims along the site, where no previous adjustments have been made, have shown that the depth of shims present is variable where shallow foundations are present. We believe this reflects corrections to the level of the guideway undertaken by BNL prior to handover to the Council. The depth of shims occasionally exceeds BNL's design limit of 35mm as can be seen in the photograph below.

Figure 3. Photograph of a foundation pad upon which there are more than 35mm of shims.

13. Alternate joints in the ladders are designated as 'fixed' and the guiderails at these locations are designed as touching end-to-end. At these locations both ladders were 'fixed' by brackets positioned against the spacer beams and bolted to the foundation pads or pile caps. These brackets are intended to provide restraint to longitudinal movement of the ladder units under a braking force of about 24 tonnes.

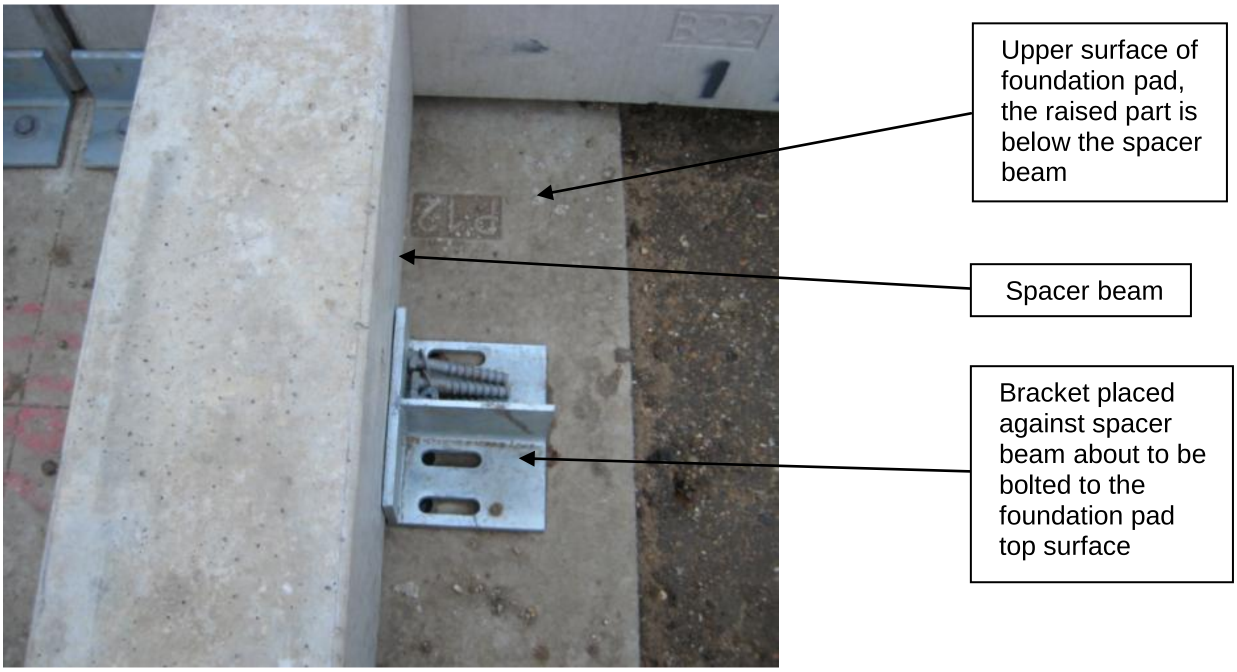


Figure 4. Photograph of a 'fixed' joint longitudinal restraint bracket

14. The other joints between the fixed joints are not 'fixed'. They were designed to allow longitudinal movement arising from temperature changes which cause expansion and contraction of the ladder units. These joints are called 'free' joints.

15. The beams are restrained laterally (across the direction of bus travel) by brackets that are placed against the guiderails at every joint.

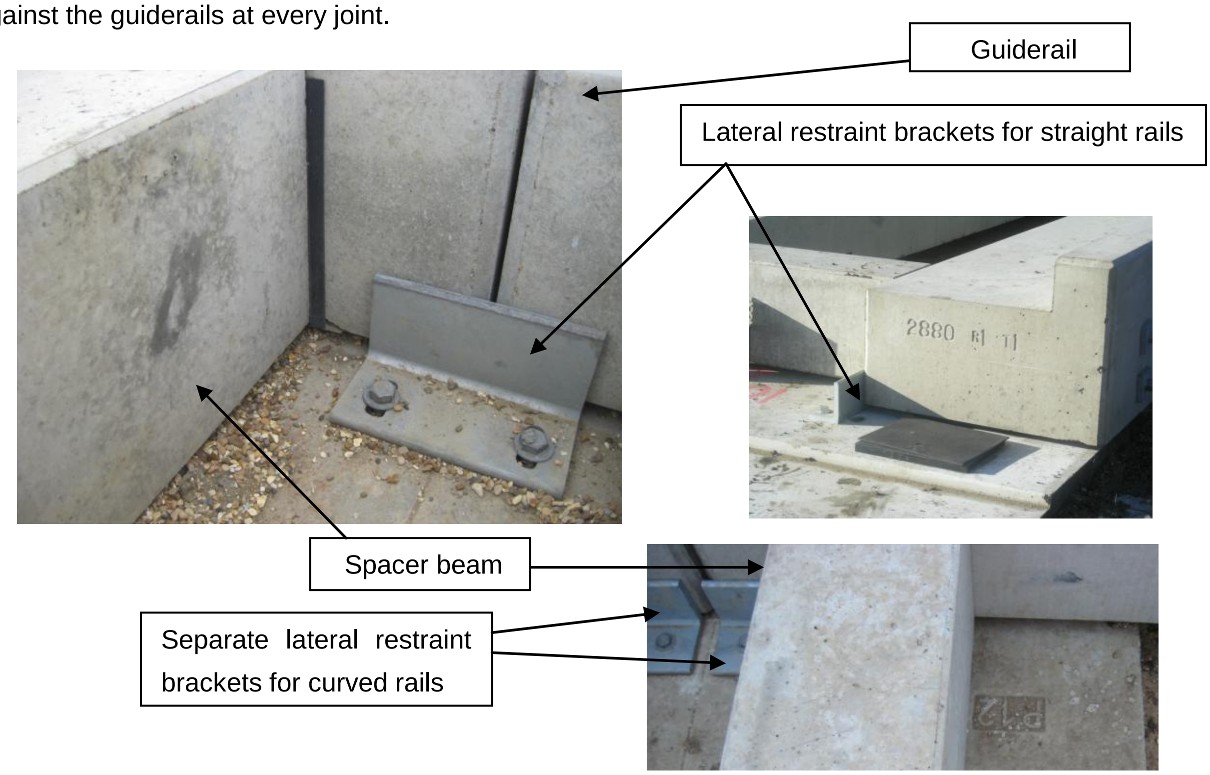


Figure 5. Photographs of lateral restraint brackets

16. There are three different types of foundations:

(i) small concrete pads ('pile caps') connected to and supported by square concrete piles driven to a depth to provide support to the guideway;

(ii) pile caps connected to and supported by narrow steel cylinders with a helix screw section on their lower part, screwed into a depth of ground to provide support to the guideway;

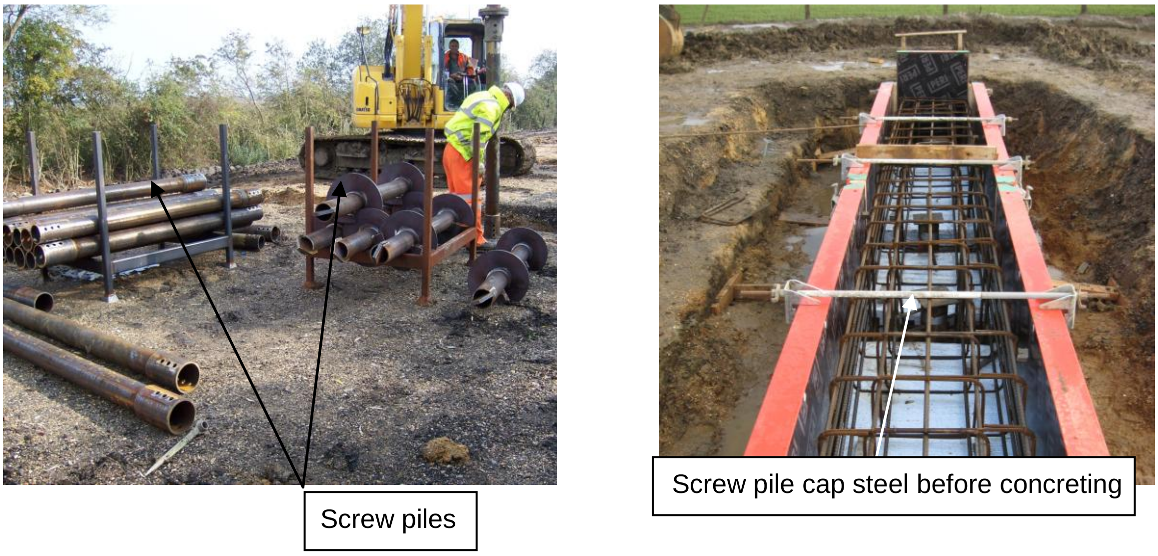


Figure 6. Photograph of screw piles prior to installation (left) and a screw pile cap before it is filled with concrete.

(iii) precast 300mm thick concrete pads with a plan area of 3m x 2m placed on 100mm of sand blinding.[1] These are referred to as 'shallow or spread foundations' in the Defect Notifications.

17. Depending on the underlying ground strength, the presence of tree roots and the BNL adopted design approach for estimating the potential future depth of tree roots influence on the ground, many of these 'shallow' foundations were placed in excavations which extended below the blinding. These excavations were filled with a compacted sand and gravel (Class 6N) fill[2] below the blinding.

[1] Blinding is a layer of sand or fine gravel for filling the gaps in the surface of the ground.

[2] Each type of fill is given a classification, or code number, in the Highways Agency's Design Manual for Roads and Bridges. This is a standard that the designer, BNL, was obliged to comply with.

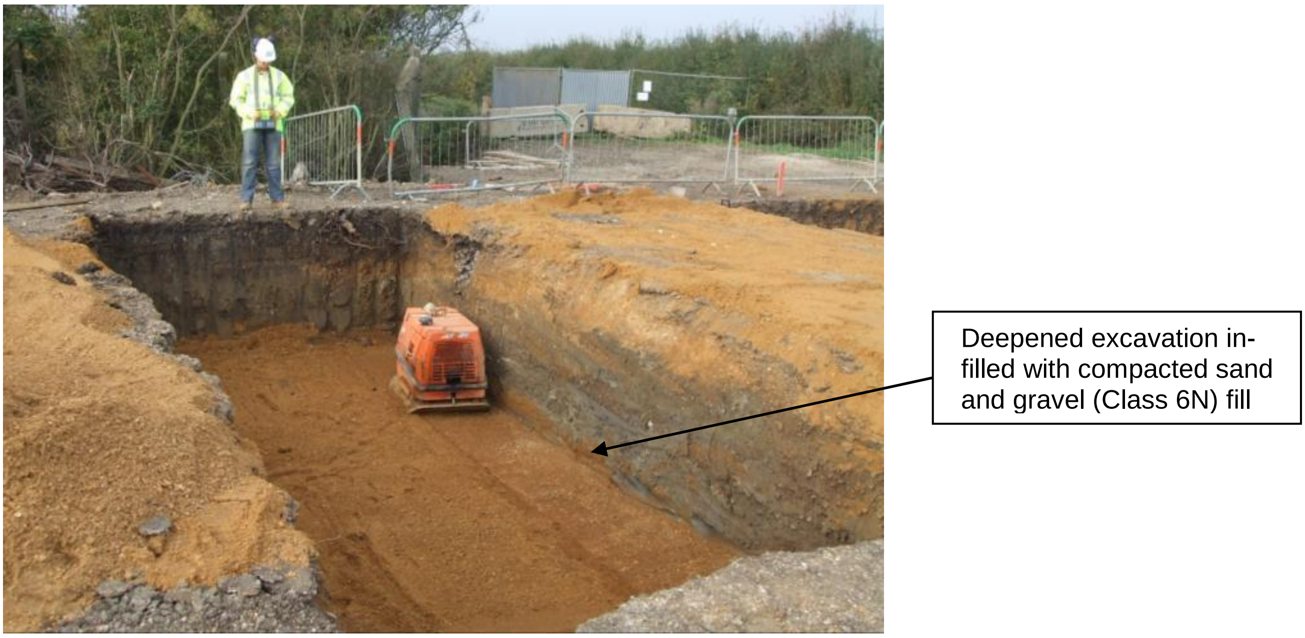


Figure 7. Photograph of an excavation for a shallow foundation that has been filled with Class 6N fill

18. The foundation pads were then placed on the blinding as shown below.

Figure 8. Photograph of a foundation pad being placed.

19. The foundation arrangements are shown in photographs B1 and B2 in Appendix B (beginning on page 62).

20. Drainage of the foundations is shown on the drawings as consisting of cross drains which connect into side trenches/drains running along the sides of the guideway and acting as soakaways whereby the water can infiltrate the ground.

THE NOTIFIED DEFECTS EXAMINED

21. We describe each of the defects we have examined briefly below. The first two Defects are addressed by Mr Sanders; the remaining Defects are addressed by Mr Cort.

Defect 016 & 16a

22. Defect 16 and 16a relate to defects in the design and construction of the shallow foundations. Defect 16a records BNL's failure to design and construct the 'shallow' foundations in accordance with the Works Information. Its design used a methodology that was a reduction in the design standard approach and it failed to adequately consider the impact of 'existing' trees (that is to say those that were in existence at the start of construction), and the impact of trees that it removed. Further it ignored the impact of new trees it planted. BNL failed to resolve comments on this, specifically its design approach to the depth of foundations, prior to commencing construction of that element of the design.

23. In constructing the foundations, BNL thus failed, for the majority of foundations, to install them in accordance with the Works Information with regard to the impact of trees in shrinkable soils.

Defects above foundations

24. Mr Cort has addressed the defects shown in the following table.

Table 1. Defects above Foundations

DEFECT REFERENCE	DEFECT DESCRIPTION
DEF 293	Lack of longitudinal restraint from shallow foundations
DEF 290	Lack of longitudinal restraint from screw pile foundations
DEF 294 & 294a	Lack of longitudinal restraint from brackets
DEF 284	Lack of longitudinal restraint from consecutive free ends
DEF 268	Lack of longitudinal restraint from flawed fixed end design and/or construction
DEF 288	Lack of lateral restraint causing excessive lateral steps in upstand guide faces
DEF 279, 282 & 283	Foundation Type 1/Type 2 interface
DEF 168, 193, 196, 250 to 256, 260, 263, 264, 272, 276, 277, 279, 280, 281, 282 & 287	Bearing displacement and loss of bearings/shims
DEF 009	Reduced gap widths at free end joints
DEF 289	Excessive crack widths in guideway beams

DEF 292	Non-functioning guideway drainage – not as designed
DEF 295	Non-functioning guideway drainage – design does not accommodate soils of low permeability at Histon

Effect of Guideway Ladder and Support Defects

25. The first six Defects described in the table above mean that the guideway ladders are unrestrained longitudinally (i.e. in the direction of bus travel) and laterally (i.e. across the direction of travel). The ladders are consequently free to move in an uncontrolled fashion when buses brake or accelerate or when the guideway ladders expand or contract when temperatures rise or fall. The result of these many movements is that bearings and/or shims gradually move away from their intended locations and from one another. Eventually, either the bearings or the shims slip out from between the raised upper surface of the foundations and the ladders. This leads to steps developing at the joints in the ladders as well as see-sawing of the ladders as buses run along them. Work has been necessary to put the bearings and shims back into position, and this is an ongoing issue.

Longitudinal Restraint

26. The Contractor's design basis is indicated in the Design Document for the Guideway Revision 6 (DDG6). This shows that alternate joints in the guiderails are 'fixed' and that between these the joints are 'free', as described at §14 above. The guideway was supposed to be designed so that horizontal forces arising from braking of buses would be resisted at the fixed joints and so that the guideway would not move about.

27. There are various ways whereby the design failed to provide the required longitudinal restraint.

Defect 293

28. Defect 293 has been notified because the design, which requires that the longitudinal braking force is resisted by a single pad foundation, is deficient in that there is insufficient friction developed at the underside of the pad foundation and consequently the foundation can slide if the full braking force is transmitted down to that point. We have calculated that five foundations are required to resist the longitudinal design load specified as 240 kN (about 24 tonnes).

Defect 290

29. Defect 290 has been notified because the design, which requires that the longitudinal braking force is resisted by a single pile cap supported on two screw piles per track, is deficient in that the horizontal capacity of the screw piles is substantially below that required to accommodate the specified horizontal design load. The result is that the screw piles can deflect excessively and means that the guideway is not fixed in a longitudinal direction as intended by the design.

Defects 294 and 294a

30. Longitudinal restraint depends not only on the fixity of the foundations, but also on

(i) the connection between the guiderails and the spacer beams adjacent to 'fixed' joints; and

(ii) the steel restraint brackets which abut the spacer beams.

31. The bolts which connect the guiderails to the spacer beam pass through ducts in the guiderails and spacer beams. A plastic spacer is placed between the guiderail and the spacer beam to avoid spalling of concrete at the concrete connection faces. The bolts are 32mm in diameter and the ducts through which they pass are 50mm in diameter, which means that the connections have to rely on friction to transfer horizontal forces to the spacer beam and thence to the restraint brackets. Each connection needs to transfer a force of 120 kN from the guiderails to the spacer beam but we have calculated that the friction generated is insufficient for this purpose.

32mm dia connection bolts

32. In addition, because the restraint bracket rests against the spacer beam at the bottom (see photograph at Figure 4 above), there will be a rotating force (torsion) applied to the spacer beam when the buses brake or accelerate. There is insufficient friction to resist this and this causes the spacer beams to rotate as may be seen in these photographs below.

Figure 9. Photographs of rotated spacer beams.

33. The longitudinal restraint brackets have slotted holes (see photographs at Figure 4 above and here) and the fixings therefore rely on friction being generated by tightening of the bolts. We have calculated that the bracket bolts (which are screwed into plastic sockets in the foundation concrete) cannot be tightened sufficiently to generate the required friction.

34. Defect 294 has been notified because, for the above reasons, there is a lack of longitudinal restraint which is contrary to the intended design.

Defect 284

35. Defect 284 records that there are some locations where guiderails have free ends at both ends, meaning that they are <u>entirely</u> unrestrained in a longitudinal direction. The beams can therefore move in a longitudinal direction under braking forces which the bearings/shims are not designed to accommodate, since the design assumes of one end of the guideway beams is fixed/restrained. Defect 284 has been notified for this reason.

Defect 268

36. As indicated at §15 above, longitudinal restraint at the fixed ends was supposed to be provided by brackets bolted to the pad foundations or pile cap and abutting the outside of the spacer beams as shown in Figure 4 and Figure 9 above and in the diagram at Figure 10 below. Fixity in a longitudinal direction is then <u>only</u> achieved if:

(i) The guiderails actually abut each other;

(ii) The connection between the spacer beams and the guiderails is capable of transferring (by friction) the braking force of 240 kN from the guiderail into the spacer beams; and

(iii) The bolting down of the brackets ensures that the brackets do not move under the applied braking force, and the bracket actually abuts the spacer beam.

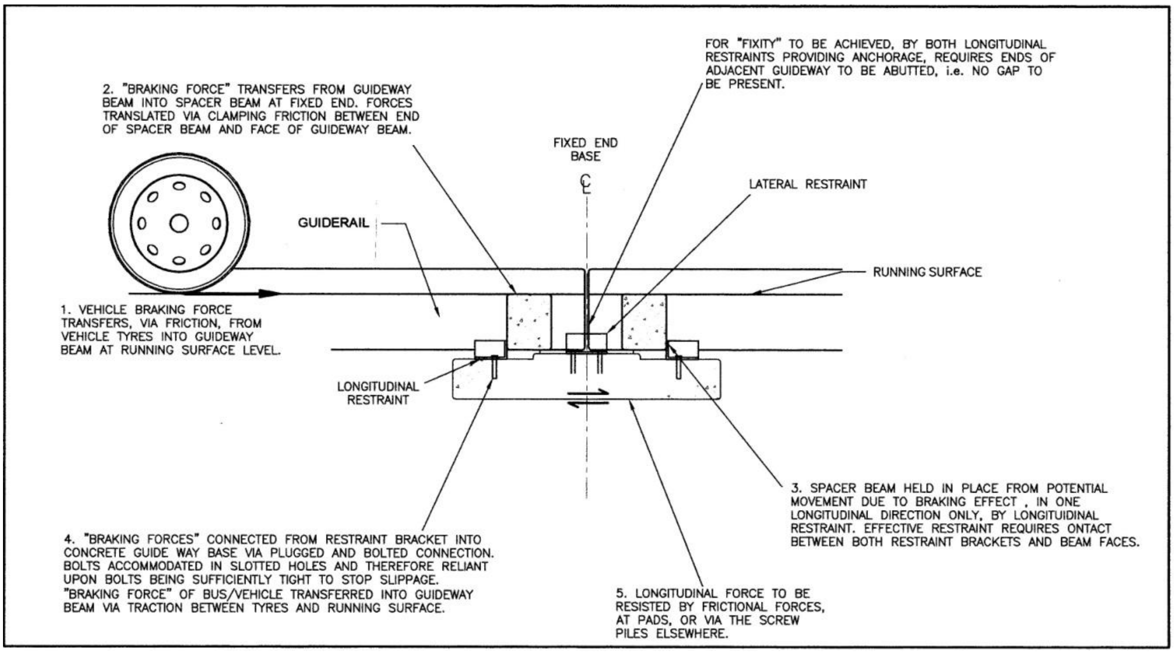


Figure 10. Fixed end detail

37. Issues (ii) and (iii) are dealt with at §31 to §34 above and Defect 268 relates to the fact that there are situations in which guiderails at fixed ends do not abut one another.

38. Where the guiderails <u>do not</u> touch and there are gaps at the joint, therefore, there is lack of longitudinal restraint.

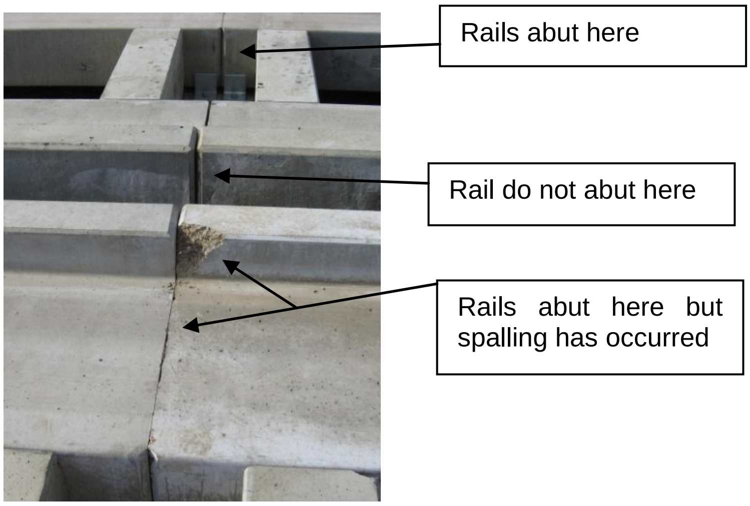


Figure 11. Photograph of guiderails not abutting, and spalling in a location where they do abut.

39. Where the guiderails do touch, however, there is the risk of spalling because of localised pressure points.

40. In addition there is the likelihood of foundation movement (up and down) and this will cause rotation to occur at the joints. If the guiderails are touching, either the guiderails will be forced apart with the restraint brackets sliding in their slotted holes or spalling of concrete will occur as has occurred here (Figure 11 and Figure 12). Examples of spalling and failed spalling repairs are also shown in Appendix C.

Figure 12. Spalling of concrete.

41. The design of the fixed joints is therefore flawed in our opinion, because there are defects that arise whether the guiderails touch or not.

Defect 288

42. Defect 288 has been notified because steps have formed in the guiderail faces caused by lateral movement of the guiderails. Such movement means the lateral restraint brackets, which, like the longitudinal restraint brackets, contain slotted holes (see Figure 13 below).

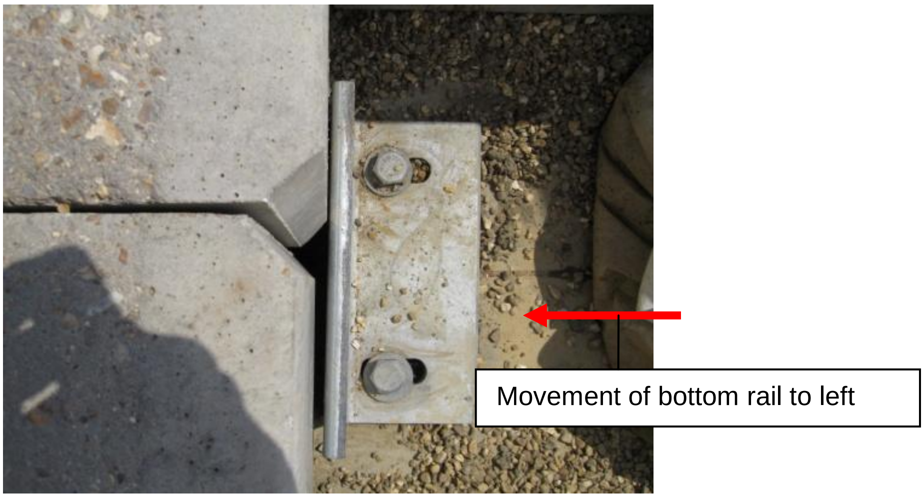


Figure 13. Photograph of a guiderail that has moved to the left, and that now does not abut the lateral restraint bracket.

43. This means that again there is reliance upon friction between the brackets and the foundation and evidently this is insufficient. According to Defect Notification 288A, steps of up to 7mm have been observed. See photographs in Appendix C (starting on page 67).

Defect 279, 282,& 283

44. These defect notifications relate to the foundation at a change in depth of the concrete guiderails (the interface between Type 1 and Type 2 beams[3]). At these locations, a precast concrete support block has been provided beneath the thinner Type 2 beam to make up the difference in depth.

45. Photographs show that this support block has failed resulting in movement of the bearings/shims. The spacer block is unstable, being loosely laid on the precast foundation pad, and cannot transmit the loads adequately, evidenced by failure. In our opinion, the precast spacer block should have been bedded on epoxy mortar. This is illustrated in the photographs at Figure 14 and Figure 15 below, which also show slippage of shims and displaced bearing pad.

[3] Type 2 beams are thinner than Type 1 beams because their span is 5 metres between foundations rather 7.5 metres.

Figure 14. Photograph showing cracked block and displaced shims

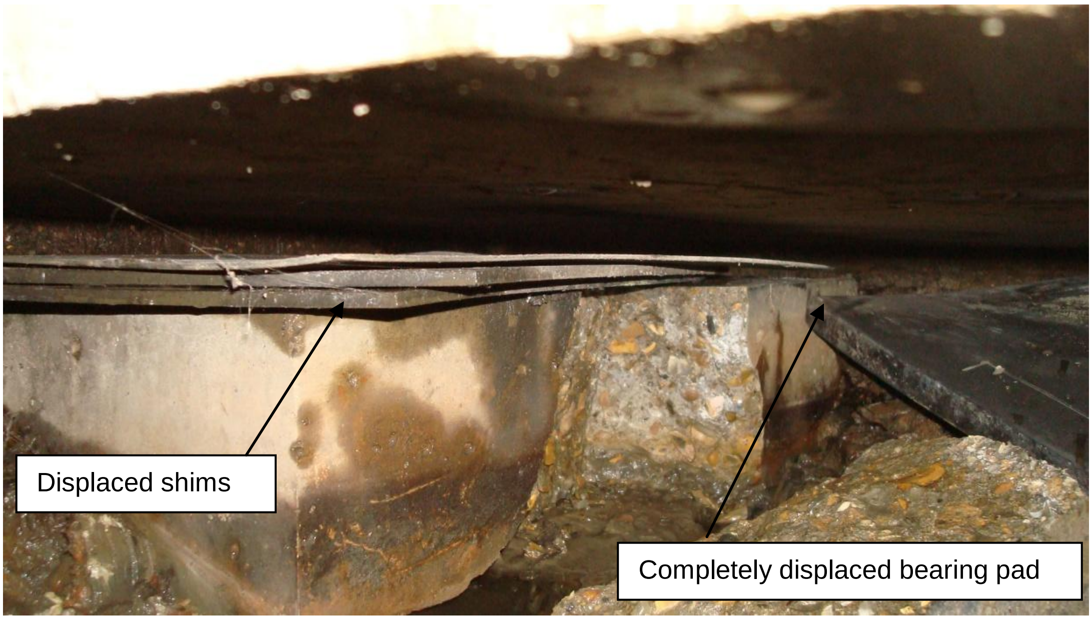


Figure 15. Photograph showing displaced shims and bearing pad.

Defects 168, 193, 196, 250 to 256, 260, 263, 264, 272, 276, 277, 279, 280, 281, 282 & 287

46. These defect notifications relate to the slippage of bearing pads and/or shims from their intended positions resulting in steps in the running surface and see-sawing of the guiderails.

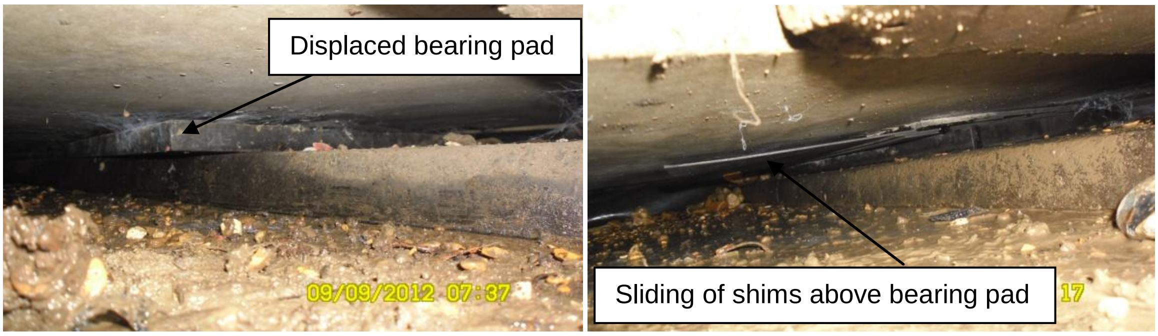


Figure 16. Photograph of a displaced bearing pad (left) and slipped shims (right).

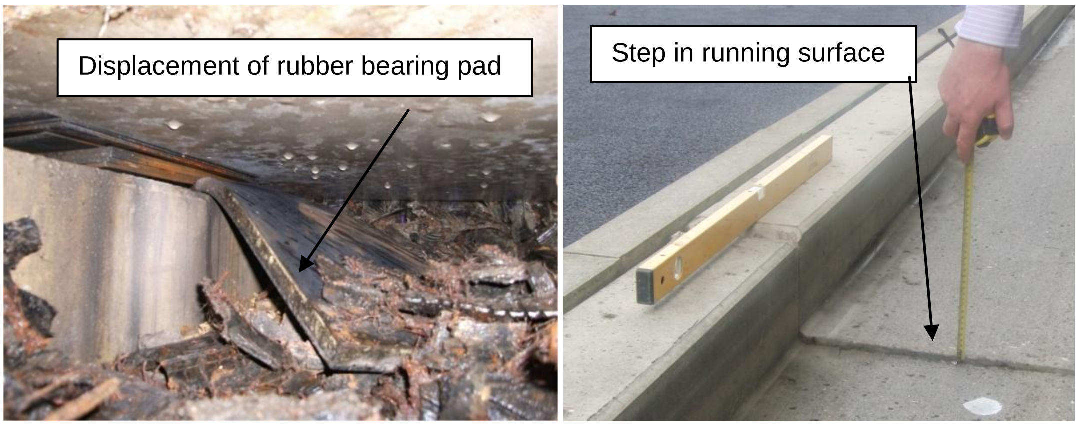


Figure 17. Photographs of displaced rubber bearing pad and a step in the running surface.

47. In our opinion, the reason for the slippage is a combination of lack of longitudinal and lateral restraint of the guideway coupled with the repeated cycles of expansion and contraction of the guiderails. The bearing pads and shims are not fixed in place in any way and rely on friction to retain them in position. We have calculated, however, that there is insufficient vertical load to generate the required friction.

48. This problem is likely to be repeated many times during the design life of the guideway unless a permanent solution is implemented.

Defect 009

49. According to Defect Notification 009, various free-end joints have gap widths less than designed. If the free-end gaps are too small, then the beams cannot expand as intended by the design. BNL's argument is that this does not matter because the fixed ends are not fixed, but such freedom to move or 'self-adjust' contributes to the issue of bearing displacement as indicated above.

50. This defect essentially relates to the construction not being in accordance with BNL's design, in which gap widths for various temperatures are given. In addition, the gap widths specified are inadequate because they fail to take account of the rotation of the beams that occurs at the joints principally due to differential movement of supports.

51. The consequence of this defect is that breaking off of a fragment of concrete (i.e. spalling) is likely to occur as shown. There are further examples of spalling in Appendix C.

Figure 18. Two examples of spalling.

Defect 289

52. This defect notification relates to excessive cracking that has been observed in the guiderails, principally over the central support of two-span beams. The contract requirement is for cracks to be no wider than 0.25mm, but cracks wider than this have, according to the Defect Notification, been recorded. We have additionally carried out calculations that show excessive cracking to be theoretically expected – so the theory has been borne out in practice.

Figure 19. Examples of excessive cracking in guiderails

53. The excessive cracking will influence the durability of the guiderails and potentially shorten their life if correction is not carried out.

Defect 292

54. Defect 292 has been notified in respect of non-functioning infiltration drains over a length of guideway (between chainage 17+530 and 17+710) in the vicinity of Bridge Road Bridge, Histon. Standing water occurs around the guide tracks. Investigations arranged by the PM have shown that the cross drains do not connect with the longitudinal side drains which, in part, act as infiltration trenches. These trenches are either insufficiently deep for the connection of the cross drains or the cross drains do not extend sufficiently to connect with the side drains. The construction does not comply with the accepted design.

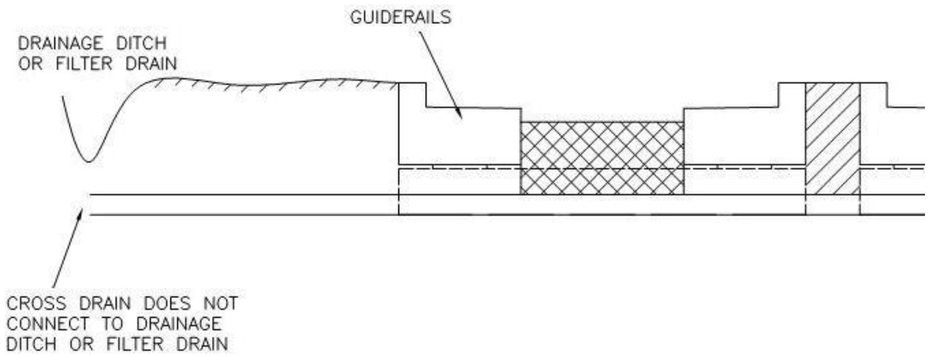


Figure 20. Cross section showing non-connection of drainage

Defect 295

55. Defect 292 presents a warning that the infiltration rates for the infiltration trenches at Histon may be insufficient due to the underlying clay strata. An instruction to search was issued by the PM following which DEF 295 was issued regarding defective design in relation to infiltration rates in the clays at Histon. BNL did not correctly determine ground conditions where infiltration systems may be employed and based the drainage design on unreliable infiltration rate data. Consequently, the flood storage will remain saturated and the drainage system is ineffective as a result.

REASONS WHY THE DEFECTS REQUIRE TO BE ADDRESSED

Guideway Superstructure Defects (GUD)

57. The defects listed at §25 above, with the exception of drainage defects DEF 292 & 295, may be collectively described as 'The Grand Unified Defect' or 'GUD' because the design is fundamentally flawed and the remedial measures essentially deal with individual defects collectively; a solution dealing with one defect actually deals with several at the same time.

58. Remedial measures or periodic reactive repairs are required because there are ongoing problems with the guideway and its operation. The fundamental problem as described above at §25 is that bearings and shims are slipping out resulting in steps in the guideway running surface. These steps result in temporary speed restrictions to the buses (see §92 below and the Council's letter in Appendix D) until the bearings/shims have been relocated, which involves jacking up the guiderails, generally at night time. Lateral displacements are also occurring which cause horizontal steps in the guiderail upstands with associated speed restrictions. In addition to these issues, there are problems of cracking and spalling of concrete. Photographs are attached in Appendix C showing such problems.

59. Options are discussed in the Superstructure Remedial Works section commencing at §108 below.

Drainage Defects

60. The drainage defects in the Histon area will, in our view, require to be corrected as soon as possible because of their potential impact on the foundations, i.e. softening of clays and a risk of future settlement.

Foundations – Defect 016 and 016a

61. The vast majority of the guideway's foundations are built upon clay soils. Clay expands or shrinks depending on the amount of water in the soil. If excess water is present the clay will expand and if water is sucked out of the clay, by a tree say, then the clay will shrink. A further discussion of clay soils is included in Appendix K.

62. As most of the guideway is built on clay, the guideway's foundations will move as the clay shrinks and expands. This movement is called 'settlement' if the foundations 'sink' as a result of the clays shrinking and 'heave' if the foundations rise due to expansion of the clay.

63. Movement of the foundations can result in damage to the guideway. To reduce the movement of the foundations to a point where damage will be highly unlikely to occur it is necessary to dig the foundations to a sufficient depth that the influence of roots from nearby trees is minimised or removed.

64. The depth required is related to the type of tree present, its proximity to the foundation and the amount the particular clay at the foundation can shrink or swell (see §73 below).

65. The Works Information required BNL to comply with the Highways Agency document BD74/00 Foundations and the associated British Standard BS 8006:1996 Foundations. Annex A of BD74/00

updates the British Standard. This requires the designer to use the National House Building Council ('NHBC') 2006 Standard Chapter 4.2 Building near Trees, to determine the depth of foundation. This standard is based on extensive records of movement of house foundations in the vicinity of trees.

66. The NHBC Standard is a risk-based approach to design aimed at a balance between cost of constructing foundations and minimising claims for damage; it does not guarantee that foundations built to its recommended depths will be free of movement, only that the movement which occurs will be at acceptable low levels. The depth derived from applying the standard is aimed at ensuring that, generally, foundations will not be subject to sufficient differential movement to cause damage to the overlying building. The NHBC standard gives a depth for a foundation if there are no trees nearby and a deeper depth if there are trees nearby. Foundations set higher than the NHBC-defined depth will be at greater risk of damage as the magnitude of movements and differential movement between foundations will be greater. The risk of damage will rise the higher the foundation is above the NHBC-defined depth.

67. BNL's design of the superstructure, specifically the guiderails, required that differential movement between foundations must not exceed 25mm to avoid damage that would affect the durability of the superstructure. This means the maximum movement of any foundation next to its adjacent foundation is 25mm up or down. In our view adopting NHBC depth foundations will prevent differential movement of that magnitude.

68. BNL was also required to construct the guideway such that it would lie within 6mm of the design level. This requirement was not set by a need to avoid damage to the guideway. There is thus no cause for concern about the guideway being higher or lower than the design level due to settlement or heave if there is differential movement of less than 25mm between foundations.

69. BNL prepared design spreadsheets tabling the depth at which each foundation should be constructed. It recorded in 'as built' spreadsheet tables the depth of the foundation that it actually constructed. BNL also summarised its design approach in a contractually required document entitled Geotechnical Report.

70. BNL's February 2011 Geotechnical Report states it did not adopt the NHBC Standard; it selected to adopt what it called "50% NHBC", that is, the foundation depth was to be half way between the NHBC depth if no trees were present and the NHBC depth if there was a tree nearby. For example if the NBHC standard required a depth of a foundation to be 2m due to a tree and 1m if the tree was not present, BNL would have used a depth of 1.5m.

71. The foundation design as stated in BNL's February 2011 Geotechnical Report thus substantially raised the risk of settlement/heave affecting the foundations and the magnitude of the differential movement between foundations.

72. Our examination of the BNL's 'as-built' foundation spreadsheets and contemporary photographs shows BNL modified this design approach in practice. They indicate that during foundation excavation BNL also inspected many, but possibly not all, of the excavation bases, see §78 below, to determine whether tree roots were present. If they were present the excavation was extended to a

greater depth than “50% NHBC”. Conversely the ‘as built’ spreadsheets also reveal that some foundations were constructed to a depth less than “50% NHBC”.

73. A summary of BNL’s assessment of soil shrinkage potential and foundation depths on a section-by-section basis is given in Appendix H.

74. BNL’s construction approach of deepening foundations if tree roots are found will have removed the potential for heave in the future but did not remove the potential for settlement due to continued tree growth. With such growth roots are likely to spread beneath the foundations remaining at a depth shallower than the NHBC design depth and cause settlement by abstracting water from the clay beneath the foundation.

75. We believe that at certain locations BNL did not notice tree roots in the foundation excavations or failed to remove such ground. Monitoring of the levels of parts of the guideway since 2009/2010 has revealed up to 101mm of unabated heave has occurred between chainages 17585 – 17645, see Appendix I. The monitoring results between chainages 17585 and 17645 show differential movement between two of the foundations exceeding 25mm and elsewhere are approaching this amount. In our view this heave is a reflection of previous settlement induced by the spread of tree roots prior to the guideway’s construction.

76. A survey of the levels of the guiderails between chainage 17531 and 18906, taken two months after the latest readings for the long term monitoring survey, has revealed that substantial heave has also occurred between chainages 17531 and 17585 and between chainages 17691 and 17811. This has resulted in differential movement exceeding 25mm between six foundations between chainages 17531 and 17585 and between twelve foundations between chainages 17691 and 17811. Differential movement between foundations on the long term monitored section now exceeds 25mm between five foundations. The results of this survey are summarised in Appendix I.

77. We also believe that it is likely that the foundations between the start of the guideway section south from Histon stop, chainage 17510, up to chainage 17531 are likely to have been affected by heave but there have been no level survey of this section to confirm our view. Heave of around 100mm is recorded at chainage 17531 and thus it is highly likely that differential movements between foundations on this additional section exceed 25mm. Our view is also based on aerial photographs taken prior to the guideway construction showing trees that have been removed. These are not recorded in the BNL design spreadsheets. The BNL ‘as-built’ spreadsheet for this further length either states that BNL did not deepen these foundations or does not record any details of the excavation.

78. The result of the defects mentioned above is that differential movements exceeding 25mm will develop between further foundations on these sections of guideway.. Permitting these differential movements to occur will damage the guideway.

79. Settlements from clay shrinkage can be compensated for by placing additional shims between the guiderails and foundation slab but settlement as a result of trees can far exceed BNL’s maximum design height of the shims. Further whilst BNL’s design included for an adjustment by 25mm

examination of bearing and shims show that this amount of adjustment is often not available as more shims have been included than shown in the design. BNL's design allowed for only 10mm of heave and movements to date on the heaved sections far exceed this.

80. We consider that if the foundation defects are left uncorrected, future movements will lead to deflections to the guiderails that will lead to excessive crack widths in them, compromising the durability and life of the guideway.

81. Widespread remedial works are required to rectify the foundation defect and prevent damage.

Determination of extent of defective foundations requiring correction

82. In assessing the extent of the foundations requiring correction we have examined the number of foundations which

    (i) are already showing movements approaching, or exceeding, 25mm of differential movement,

    (ii) fail to meet the NHBC depth requirements, and

    (iii) fail to meet a 25mm of differential settlement criterion.

83. The 36 foundations between chainage 17510 and 17645 and chainage 17691 and 17811 require correction as monitoring and levelling of this section shows differential movements are in excess of 25mm or approaching it.

84. We have found 1222 foundations are shallower than required by the NHBC Standard, 401 solely due to 'existing' trees (growing before the guideway was constructed), 354 solely due to new trees (planted by BNL after construction of the guideway) and 467 due to both 'existing' and new trees. Without correction of the superstructure defects all these foundations require correction or actions taken to remove the influence of the trees as there is an unknown level of adjustment available by adding shims.

85. It is our view, from accumulated experience, that NHBC foundation depths generally allow up to 15mm of differential movement.

86. On the basis of assuming that there is 15mm of differential movement beneath foundations when they are constructed at the NHBC depth we have estimated a potential reduction in foundation depth from NHBC determined depth, if the benefit of 10mm of further movement (totalling 25mm differential settlement) is made.

87. We have found that by applying this approach 1056 foundations will be subject to 25mm or more of differential settlement, 261 due solely to 'existing' trees, 382 due to both 'existing' and new trees and 413 solely due to new trees.

88. By allow the benefit of 25mm of differential movement, some of the foundations which are non-compliant due to either 'existing' or new trees to the full NHBC standard become compliant. Where a foundation is non-compliant to the full NHBC standard due to both new and 'existing' trees it may still be non-compliant, after allowing the benefit of 25mm differential movement, but only for 'existing' or

new trees. The numbers given in §87 above when compared to those in §83 above show that the benefit of 25mm differential movement substantially reduces the number of foundations affected by both ‘existing’ and new trees, down from 467 to 382. However many of those foundations remain non-compliant for the new trees resulting in an increase in number of foundations affected by new trees alone from 354 to 413. A smaller number remain non-compliant for ‘existing’ trees alone thereby raising the number for that category from 401 to 413.

89. We would highlight this latter approach of allowing a benefit of 25mm differential movement does incur a heightened risk, above that which would have been present if BNL had designed and constructed the foundations to the NHBC Standard for foundation depths. This is because of the inherent uncertainties in estimating additional settlements due to a reduction in foundation depth as well as the fact that a NHBC depth is not based on a defined level of differential settlement. We however believe that it is reasonable to allow the reduction in depth we have estimated as applying NHBC depths is likely to be conservative in assessing the number of foundations which will be subject to excessive differential movement in left uncorrected.

TIME RELATED IMPACT OF NON-CORRECTION OF DEFECTS

Guideway Superstructure

90. If defects are not corrected by means of a remedial scheme, the slipping out of bearings and shims together with spalling of concrete etc. is likely to continue. We have sought to address the extent of shim/bearing loss by considering the movement of shims that has occurred from surveys carried out in October 2013 and July 2014.

91. Since the guideway came into operation in 2011, there are some 127 locations where shims and/or bearings have come out entirely resulting in the loss of ride quality.

92. The effect of loss of bearings/shims depends on the overall thickness of shims lost at a particular location. Given that the guideway beams are designed (or are supposed to be designed) on the basis of 25mm differential settlement, the loss of bearing/shims of thickness greater than 25mm may adversely stress the guideway beams and if not immediately corrected may lead to progressive bearing loss due to rocking of beams. In addition, there will be an unacceptable loss of ride quality with significant jolts occurring at the joints and this gives rise to a safety concern for passengers, especially any standing passengers. As a result, Campbell Ross-Bain, who manages the CGB for the Council, has advised us of the Council’s policy for when steps in the running surface occur. This is included at Appendix D. The procedure is to firstly assess the severity of the rocking caused by shim/bearing loss and then impose speed limits or diversions on the affected areas of the guideway. For these reasons, the current policy is to remediate dislodged bearings as soon as possible after notification.

93. We note that a survey of 280 bearings was undertaken by the Project Manager in January 2014 and photographs were taken of each of the bearings. We have been provided with this survey and have reviewed it. Robin Clarke of Atkins – see note in Appendix D has informed us that the survey was

carried out on a random basis from chainage 2750 to 2850, 3400 to 3500, 10930 to 11141 and 17600 to 17800, rather than at specific problem areas. The locations were chosen to give a representative picture of the guideway as a whole with its different foundation types rather than, for example, to give a probable worst case scenario.

94. Clearly, the random sample is small compared with the total number of bearings (16,320) but we have no reason to think that similar findings wouldn't be found elsewhere because the construction is similar throughout and problems occur irrespective of ground conditions and where there is negligible differential movement of supports (e.g. Trumpington). A further survey was carried out in July 2014 in the Longstanton area from chainage 10946 to 11141. This shows on average that shims have moved about 2mm (relative to the bearing pads) in 6 months, which is similar to 10mm in 2.5 years since completion of construction. Of the 56 bearing locations surveyed in July 2014, we have assessed that 22 had 2mm or more movement of shims relative to the bearing pads, but we could not determine from the photographs whether the bearing pads themselves had moved.

95. For the January 2014 survey, we were able to draw conclusions from 270 of the 280 photographed bearings and the remainder were not conclusive and hence discounted. Two examples of the photographs are enclosed in Appendix E that illustrate the defects identified and how the shims are sliding relative to the elastomeric pads and to each other. The survey shows that displacements of shims relative to the elastomeric bearings have occurred in the majority of bearings surveyed and we estimate that 181 (i.e. 67%) of these exceed 10mm, with some that we consider exceeded 100mm or more. Of these, 87 out of 106 (i.e. 82%) are at Histon, which appears to be exceptionally adverse compared with the remainder of the guideway. Discounting these bearings in the Histon area leaves a remaining 57% (94 out 164) exceeding 10mm displacement.

96. Clearly, the more that bearing pads/shims have displaced now, the shorter the time is likely to be before repairs are needed in relocating them. Details of our assessment of this are enclosed in Appendix F and we refer to this in consideration of Option 3 scope of work at §148 below.

97. We predict that if the elastomeric bearings or shims have displaced by at least 10mm in 2½ years (June 2011 to January 2014), then they are bound to require replacement during the life of the guideway. We believe that the rate of escape is likely to increase with time due to polishing of the shims. In addition to this, when the (shims or bearing pad) have displaced by say 160mm, there is in our view significant eccentric loading on the bearing pads causing distortion and more rapid shim displacement. We have therefore set an acceptance limit of 160mm displacement for the purpose of our analysis. It is difficult to speculate on why some bearings/shims have displaced more than others, but presumably some sections are more subject to buses braking, other sections more prone to thermal expansion/contraction, and sections restrained to a greater or lesser extent by virtue of variations in restraint bracket tightness, whether the fixed-end joints are constructed as touching or not etc. Such variations could affect the movement of bearings/shims.

Foundations

98. Our inspections suggest that the vast majority of 'existing' trees that may affect the guideway with time are semi-mature, probably planted or self seeded since the mineral railway closed. For these semi-mature, and any juvenile 'existing' trees, significant size increase and tree root spread can be expected with time. However, this future development of the root system and re-growth of roots, removed during foundation excavation, into new ground is not immediate. It will take some years for the roots to extend into the shrinkable clays under the foundations.

99. We expect that new trees planted by BNL on the opposite side of a deep water filled drainage ditch from the guideway are unlikely to extend their root network past the drainage ditch. In our view, such planting should not affect the guideway and it has been ignored for this assessment. Some of the other new trees will affect the guideway as they grow even if the tree maintenance regime proposed by BNL, as part of its design, is implemented.

100. The total number of foundations that could cause excessive differential settlement is detailed in §82, 83 and 87 above.

101. We have undertaken a further assessment to associate a level of risk with each of the foundations which can be affected by 'existing' trees.

102. The NHBC Standard assumes that the depth of foundations is varied to reflect the presence of trees and that all are at the full NHBC depth. This is not the case here and the 'as built' depths are set at variable heights above the NHBC depth for that foundation.

103. We have thus assigned each foundation potentially affected by growth of an 'existing' tree a risk of either "very high risk", "high risk" or "at risk" based on

    (i) its depth short of NHBC compliance,

    (ii) the difference between that shortfall in depth and the shortfall in depth of neighbouring foundations, and

    (iii) soil shrinkage potential.

104. We have classified 105 of the foundations as "very high risk", 62 foundations as "high risk", a total of 167. The remaining foundations are classified as "at risk". Thus where the NHBC standard is the criterion for assessing risk the number in the "at risk" category the number is 701 (868-167), where the criterion is 25mm differential settlement the number in the "at risk" category is 476 (643-167). The "very high risk" foundations include the majority of those most likely to require remediation with the timescales given in Appendix L. We have not applied this classification to foundations affected by newly planted trees as these new trees are within land owned by the Council and can be managed, removed or replaced (as discussed in §171 below).

105. Our assessment of the number of foundations requiring correction with time is detailed in Appendix L. We estimate that up to 54 – 65 foundations will be highly likely to require remediation by year 5, 2019, and between 38 - 45 more foundations will possibly require remediation. In the following 5 years a minimum of a further 24 foundations will be highly likely to require remediation with an

unknown number possibly requiring remediation. By 2029 a minimum of a further 18 foundations will be highly likely to require remediation. By this time all trees that may cause the foundations (the 643 foundations mentioned above in §104) can be expected to be causing movements to the foundations, many of which will require the foundations to be corrected before the end of the guideway's design life in 2051.

SUPERSTRUCTURE REMEDIAL WORKS

106. In the light of the foregoing, we consider that significant future expenditure on the guideway will be necessary for its continued satisfactory operation. Three options are available to the Council in this respect:

(i) Option 1 – Implementation of a remedial scheme now that corrects the defects which embody a flawed design and prevents problems of bearing displacement and spalling of concrete in the future. This scheme fixes the shims and bearings in place and prevents the various defects from arising in the future;

(ii) Option 2 – This option consists of a proposal to carry out reactive repairs as and when they become necessary (i.e. when a bearing pad or shim is completely displaced or displaced sufficiently to cause a vertical step in the running surface), but the repairs include the Option 1 remedial works rather than simply relocating the bearing pads/shims. This means that the remedial works would be implemented on a piecemeal basis over an extended period, probably involving a 30m length of guideway in any one operation, and that, if one bearing requires action because a pad or shim has slipped out, all 12 bearings in a 30 metre length of guideway will be remediated.

(iii) Option 3 – This option accepts the defects as they exist and continue to occur/worsen and consists of implementing an unplannable programme of reactive repairs as and when they become necessary. The guideway will continue to move uncontrollably causing bearing pads and shims to continue to slip out. This would primarily be a 'fix it if and when the bearings/shims come out' approach, though we envisage that there will be a need for other ongoing works of a lesser nature which we describe later. The Council will need to have a response team on hand to carry out such repairs. This differs from Option 2 in that only the bearings/shims that have slipped out are relocated, and they are simply put back into position, rather than being fixed in place.

107. In our opinion, doing absolutely nothing is not an option if the guideway is to remain operational.

108. This report assesses the scope of these three options to assist the Council in its considerations but doing nothing is not an option.

109. We have considered whether the elastomeric bearings will require replacement during the design life of the guideway. The manufacturer, Ekspan, has indicated that its elastomeric bearings have a

design life of well in excess of 60 years and we would expect therefore that routine replacement of the bearings will not be required.

110. Mr Chris Ennis of Time Quantum Expert Forensics (TQEF) has prepared a report on costings of the three Options, taking account of the scope of works outlined in the following sections.

OPTION 1 – PRE-EMPTIVE REMEDIAL WORKS TO CORRECT DEFECTS

Guideway Superstructure

Bearings and shims

111. Because the pad foundations are unable individually to accommodate the design braking force of 240 kN and because we have calculated that 5 foundations are needed, the bearing and shim detail has been revised so that all bearings/shims carry an equal proportion of the braking force. This also deals with some of the other defects. Essentially, therefore, the guiderail system will ‘float’ on the elastomeric bearing pads and will be restrained horizontally (i.e. longitudinally and laterally) by the resistance of the pads to shear forces.

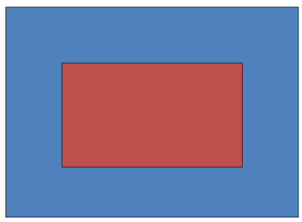
112. The proposed detail is shown in Figures 1, 2 and 3 in Appendix G.

113. Current indications given to us by Ekspan, the manufacturer of the bearing pads, are that the existing bearing pads are adequate to accommodate a longitudinal force of 20 kN (working load), 25 kN lateral load (working load) and up to 213 kN vertical working load. The minimum serviceability permanent load is 17.5 kN and serviceability transient live load is 11.3 kN on the bearings, which means low friction is available on the bearing pads and shims. Because there is insufficient friction available to retain the bearing pads and shims in place and to transmit the shear forces generated by braking loads and thermal effects, we propose to bond the pads/shims in place as shown in the Figures 1 to 3 in Appendix G. The arrangement permits the insertion of additional shims should settlement occur to the foundations and, similarly, they may be removed should heave occur.

114. We have included alternative designs for the shims in Nylatron (plastic) material and in stainless steel. These designs are shown in Figures 2 and 3 respectively in Appendix G.

115. Figure 2 in Appendix G shows the indicative Nylatron shim arrangement with diagonal slots to enable the shims to fit together and convey the horizontal forces without relying on friction. Each shim provides an adjustment of 5 mm.

116. Figure 3 in Appendix G shows an alternative indicative stainless steel arrangement. Shims, both 3 mm and 6 mm, thick are laser or plasma cut to form two pieces. The red piece provides a horizontal key in any direction. Each shim provides an adjustment of 6 mm.



3 mm and 6 mm stainless steel sheet

117. The overall thickness of shim which will be required at any foundation is unknown because BNL has not provided as-built information regarding shim thickness at the foundations. We

suggest that, for pricing purposes, an assumed average total thickness of shim at each foundation is taken as 40 mm (for Nylatron) and 39 mm (for stainless steel).

118. We envisage that the bearings and shims will be replaced by jacking up the guiderails after the drainage infill abutting the guiderails has been excavated.

Stabilising of screwfast pile caps

119. As with the pad foundations, the pile caps are incapable of accommodating the design braking force of 240 kN and we have calculated that the screw piles are so flimsy in a horizontal direction that a single pile can only provide restraint to a horizontal working load of 9 kN longitudinally with the deflection of the top of pile cap limited to 10mm. Maintaining the same principle as the pad foundations in sharing the braking loads over 5 pile caps (or over 5 combinations of pile cap and pad foundation), the bearing pad/shim arrangement will be the same as for pad foundations.

120. We propose that each pile cap be stiffened to resist a load of 80 kN by two raking piles at each end of the existing pile cap, the tops of which are connected to the pile cap by an extension of the cap formed in situ concrete resin anchored to the existing concrete. The arrangement is shown in Figure 6 in Appendix G.

Resin injection of cracks

121. The guiderails are manifesting consistent cracking particularly over the central support and according to Defect Notification 289, this has been recorded as exceeding 0.25mm and is greatest in the upstand sections.

122. We propose that the cracks are injected with low-viscosity resin following final placement of the guiderails.

Longitudinal clamping of guiderails together

123. In order to spread the braking loads over 5 foundations, it is necessary to tie two ladder sections together. This will occur at a ‘pseudo fixed joint’ such that thermal expansion and contraction will take place along the guiderails either side of this joint.

124. We propose that holes are cored in the spacer beams either side of the joint and bolts inserted that tie the ladder sections together.

125. We have detailed a rubber bearing strip in the joint which will be compressed. This strip will keep the guiderails apart at the joint so as to facilitate the theoretical rotation that will occur at the ends of the guiderails.

126. The construction details are shown in Figure 4 in Appendix G.

Shaving of beam ends

127. We envisage that it will be necessary to shave one end of each guiderail to give the necessary gap width at the expansion joints, which will be formed at 15 metres either side of the ‘pseudo fixed joint’.

There should be sufficient cover to the reinforcement at the beam ends to facilitate such trimming work.

128. Allowance would thus be made for the gaps formed at the 'pseudo fixed-ends' as well as the expansion end gaps, many of which are too narrow.

129. We consider that cutting of the concrete could be achieved by specialist high powered laser techniques or by conventional diamond cutting.

Plating of guiderails at joints

130. Because the elastomeric bearing pads can distort under load, a step can result if restraint is not provided at joints in the guiderails when a lateral force is applied to one of the guiderails at one side of a joint. We have calculated that this would be in the order of 5 mm for a lateral force of 50 kN spread on two bearing pads and this would create a temporary horizontal step in the upstand beam which would cause a jolt as the bus traverses the joint.

131. We propose therefore to install a steel plate on the outside of the guiderails at each joint in order to prevent one guiderail moving laterally relative to an adjacent guiderail, thereby ensuring at all times, a smooth transition at the joints when running from one guiderail to the next. The plates contain slotted holes to facilitate the longitudinal movement permitted by the elastomeric bearings including thermal expansion and contraction.

132. The details of the plating assembly are shown on Figure 5 in Appendix G.

Type 1/Type 2 interface, epoxy bedding of precast blocks

133. Failure of precast blocks has occurred, in our opinion, because of uneven bedding of the blocks, which is inevitable even with high-class manufacture of precast units.

134. The blocks should therefore be bedded in medium viscosity epoxy mortar which is sufficiently liquid to ooze out when the blocks are placed.

Atkins' proposals

135. Our proposals are broadly in line with and consistent with proposals independently developed by Atkins. With regard to the bearing pads, we have considered whether these existing pads should be retained and re-used or whether new pads should be installed as proposed by Atkins. Whilst we believe that either of these scenarios is possible, we are advised that there is negligible difference in cost between installing new bearing pads and re-using the existing bearing pads. The latter involves taking the existing pads off site to the pad manufacturer for cleaning and then fixing of shims to the pads. In the light of this, we have decided that it is just as well to provide for installing new bearings, especially as some pads could become damaged during the sliding out of shims and pads.

Logistics for carrying out superstructure pre-emptive remedial works

136. We have given consideration to how the remedial works could be undertaken such that the guideway can remain, to some extent, operational.

137. The scope of the remedial works is extensive and affects the entirety of the guideway. The nature of the work involves lifting the guiderails in order to trim them to required lengths, replacing the bearings etc. and this applies to the entire length of guideway. In addition, screw pile foundations need to be strengthened and pad foundations may require remedial measures in respect of controlling future settlement.

138. We have considered the following possibilities:

(i) Nightime working;

(ii) Weekend working;

(iii) Sectional closures of the guideway over time;

(iv) Total closure of Northern Section followed by Southern Section.

139. We believe that total closure would be unacceptable to the Council and the public even though the overall time to complete the remedial works would probably be less than other methods.

140. Night-time working and/or weekend working would be disruptive to the progress of the work and the time to complete the works would be unduly long and prohibitive. This would consequently incur considerable additional costs. Furthermore, it is questionable whether in fact the guideway could be made operational at the end of each shift particularly where works are required to the foundations. Where the screw pile foundations need to be strengthened, the works could not be completed within a working shift and additional time is required for curing of concrete etc.

141. We are therefore provisionally of the view that one section of guideway is closed at a time between road crossings and local diversions put in place for the buses which are then routed via the road network. We accept that this would increase journey times to some extent but it seems to us that this option presents the most practical solution for carrying out the remedial works and is the best compromise in all the circumstances.

142. It is possible that the Council may be prepared to accept more than one section of guideway to be closed at a time but this is a matter for discussion and further detailed consideration depending on how journey times are affected.

143. We have had detailed discussions with Atkins on the programming of the works from which it is apparent that we (Capita) and Atkins have independently arrived at a similar approach as indicated above. We agree that a reasonable timeframe for carrying out the works is 30 to 36 months, though this may be affected by the foundation works depending whether Option A, B or C is adopted for these (see 184,188 and 198 below).

OPTION 2 – REACTIVE REMEDIAL WORKS WHEN NECESSARY

Guideway Superstructure

144. This option is based on the principle that when a bearing/shims (or bearings/shims) slip out (i.e. completely displaced or displaced sufficiently to cause a vertical step in the running surface), the remedial scheme outlined in Option 1 is implemented for a 30 metre section that contains the defective bearing(s).

145. Thus this is a reactive scheme, the progress of which in putting the guideway right is dependent on the rate at which the bearing pads and/or shims slip out. It does mean however, that many bearings will be rectified before they become displaced and it therefore becomes impossible to predict when and where this will happen.

146. It would seem reasonable to us to assume that rectification could average out at say one 30m length of ladder (containing 12 bearings) per week. It is impossible to predict how this would work out in practice because there is no pattern as to where and when vertical displacements arise in the running surface or how many defective bearings might arise in any one 30 metre section of track. As a guide, we have taken the 50% proportion (considered to be a likely minimum) of bearings to be replaced over the 40 year design life with an average occurrence of defective bearings as being 6 out of 12 bearings. Allowing for holidays and inclement weather with remedial works carried out over 45 weeks per year, this would result typically in 270 (i.e. 6 x 45) defective bearings being remedied in a year, giving a minimum of 30 years (i.e. 8160 ÷ 270) for the guideway to be completely remedied.

147. We suggest that this is a reasonable basis for evaluating the cost of this option, but we would emphasise that the works would be unplannable and may well result in several year’s time, in fewer 30 metre sections being remedied in the early years and more separate 30 metre sections having to be remedied simultaneously which may prove to be impracticable. The 30 years is likely therefore to be exceeded. There are substantial risks associated with this reactive approach in terms of how long it will take and much it will cost.

OPTION 3 – REACTIVE REPAIRS WHEN NECESSARY

Guideway Superstructure

148. For this scenario, the approach is generally to 'fix it if and when the bearings come out'. There are risks associated with this approach because the extent of work in any week or month will be unknown and therefore impossible to plan resources to carry out the works.

149. The implications are that substantial costs will be required in the ongoing repair of the guideway that are a direct result of the defects that we have identified in the works that have been constructed.

150. We anticipate that the scope of this Option 3, in terms of what will be required by way of periodic reactive repairs, will involve the following being required over the 40 year life of the guideway:

(i) Relocation of elastomeric bearings and shims where these have slipped out caused by lack of longitudinal restraint;

(ii) Resetting of guiderails laterally caused by lack of lateral restraint;

(iii) Repair of spalling concrete at joints caused by lack of longitudinal restraint, narrow joints, and/or defective fixed end detail;

(iv) Sealing of cracks in the guideway beams due to these being greater than 0.25mm in width.

Relocation of elastomeric bearings/shims

151. We have carried out analyses from the bearing surveys data to estimate the number of bearings that will probably need to be relocated over the 40 year design life of the guideway. These analyses are enclosed in Appendix F, based upon an assumption that the surveys are representative of the whole guideway.

152. We have carried out two analyses:

(i) Incremental analyses which involved assessing the number of bearings with shim displacements, in bands of 10-15mm, 16-20mm, 21-25mm, 26-30mm, 31-35mm, >35mm. This is because the larger the shim movement now, the shorter the time will be before they will need to be relocated. This analysis has been carried out both including and excluding the Histon influence, where displacements over this limited length are generally larger and greater in number over 10mm. Of the 16,320 bearings, we estimate that the number of bearings that will need to be relocated (on an increasingly frequent basis) over the 40 year design life of the guideway will be:

(ii) 9,736 including the influence at Histon where shim movements are especially severe;

(iii) 9,456 excluding the influence at Histon.

(iv) Statistical analyses which involved assessing the percentage of bearings that will need to be relocated over the 40 year design life of the guideway. On a conservative basis, we have ignored the effect of the more serious results at Histon. The graph is drawn to reflect the probability that displacements will be increasingly frequent. This gives, for a 95% confidence level, a range with an upper and lower percentage figure from which the number of bearings can be determined that will require reactive repair over the design life of 40 years, thus:

(v) 50% of bearings relocated which equates to 8,160;

(vi) 65% of bearings relocated which equates to 10,608.

153. We believe that these results will be conservative because of the likely polishing of the abraded shim surfaces that will lead to an acceleration of this problem. <u>On a conservative basis</u>, therefore, and ignoring the particular problems of instability/movement at Histon, our judgement is that <u>at least</u> 50% of the bearings/shims will require work to relocate the bearings and shims during the life of the guideway.

154. Although the survey sample is small, the survey locations have been chosen to represent fairly the entire guideway and consequently we believe that they will be reasonably representative of all

bearings. We expect there to be an escalating of the problem (a) because there is a large number of bearings with 10 to 15mm displacement compared with the number greater than 35mm, some of which have already totally slipped out and (b) because of potential polishing of shims. It will take longer for those with current small displacements to manifest problems though we anticipate that they will do so during the 40 year design life of the guideway. This is what the incremental analysis shows.

155. The results from the incremental analysis fall between the 8,160 and 10,608 values and give additional confidence on the prediction range.

156. In our opinion, all such estimates are likely to be additionally underestimated because the defects are not corrected under this Option 3, and bearing pads and shims will remain free to displace after being relocated. Indeed, Defect Notification 287 indicates that this has occurred already.

Lateral Displacement

157. Defect Notification 288 records that in June/July 2013 (i.e. after 2 years of guideway operation), there were 219 locations where lateral displacements have occurred to the extent of requiring correction due to exceeding the tolerance of 2mm thereby leading to loss of ride quality. On a directly proportionate basis, this equates to 4400 instances over the 40 year design life of the guideway.

Spalling concrete at joints

158. It is possible that ends of the guiderails will collide as a result of the lack of longitudinal restraint permitting the beams to move in a longitudinal direction to a greater degree than assumed in the design. Such collisions may result in spalling of the beam ends. In addition, spalling is possible because allowance has not been made for the rotation of beam ends as a result of differential movement of supports.

159. The spalling may affect the guideway upstands and/or the running surface of the beams in which case the ride quality will be impaired and remedial repairs would be necessary to rectify the damage.

160. We find it difficult to estimate the number of guiderails that are likely to be affected by spalling over the design life of the guideway. There are about 2,800 joints which comprise alternating ‘fixed-end’ and ‘free-end’ joints. Because of the flawed nature of the ‘fixed’ joint design as reported above at §36 to §41, we believe that the majority of spalling will occur at fixed joints. Taking 50% of the approximate 1400 fixed joints as a conservative minimum, we consider that it is reasonable to assume at least 2800 of the guiderails either side of these joints will spall (i.e. a conservatively estimated 700 joints affected), together with replacement of some 200 spacer beams, which may become damaged as shown in the photograph in Appendix C.

ESSENTIAL REMEDIAL WORKS

161. Irrespective of whether Option 1, 2 or 3 is selected as the appropriate way forward, it is important in our opinion that the following works are carried out as soon as possible as pre-emptive remedial works. The costs for the following should therefore be added to each option.

Sealing of guideway beam cracks

162. Most of the guideway beams are exhibiting cracking, principally at the central supports. There are 5,672 individual type 1 guideway beams (not ladder beams), most of which need to be resin injected in the near future to ensure the life of the beams.

Connection of drainage to side ditches/drains

163. DEF 102 & 102A have been corrected with the cross drains having been connected to the side ditches.

164. DEF 292 refers to a location at Histon where the construction does not comply with the accepted design in that the cross drains do not connect with the longitudinal side drains which, in part, act as infiltration trenches. These trenches are either insufficiently deep for the connection of the cross drains or the cross drains do not extend sufficiently to connect with the side drains. These require correction to comply with the design.

165. DEF 292 also presents a warning that the infiltration rates for the infiltration trenches at Histon may be insufficient due to the underlying clay strata. An instruction to search was issued by the project manager following which DEF 295 has been issued regarding defective design in relation to infiltration rates in the clays at Histon. The proposals to rectify such a defect remain to be developed pending further investigation in the area including investigating the possible connection to a watercourse. Such a proposal would require the consent of the Environment Agency.

‘SHALLOW’ FOUNDATION REMEDIAL WORKS

Correcting the effects of heave

166. There are substantial heave movements recorded between chainage 17531 and 17645 and between chainage 17691 and 17811. Long term monitoring between chainage 17585 and 17465 shows heave is continuing at unabated rates. It also believed that there is a very high risk of continued heave occurring to the foundations between chainage 17510 and 17526. In our view, the only practical option for remediation of these foundations is deepening the 36 foundations involved to reduce or remove the potential for further heave and differential movement beneath them. These remedial works should be performed as soon as possible and, if Option 1 is selected, to rectify the superstructure defects, at the latest immediately prior to the replacement of the bearings and shims under that option. This is because the movements are continuing and there are already two foundations where the differential movement between them exceeds the structural capacity of the guiderails to deflect without causing excessive crack width in the rails.

167. The proposed method of remediation is as follows:

(i) lift the guideway ladders out from the area requiring foundation deepening, starting and fiinshing at a free-end joint, temporarily store upon other sections of guideway ladder;

(ii) lift the precast foundation slabs out of the ground and store adjacent to the remedial works;

(iii) excavate the ground to 2.5m depth removing the Class 6N material (possibly store for reuse) and underlying natural ground (to be removed off site);

(iv) infill the excavation with either Class 6N fill or lean mix/no fines concrete up to 25 – 50mm short of the required level to replace the precast foundation slab at the original design level;

(v) lay a 25 – 50mm mortar bed or 100mm of sand bedding to enable precise placement of the foundation slab;

(vi) replace the foundation slab removed in (ii) above;

(vii) install the new or old bearings and shims (depending on the superstructure option selected), place a minimum of 25mm of new shims to allow for any future adjustment for residual heave; and

(viii) replace the guideway ladders.

Remedial works to prevent unacceptable differential settlement associated with new trees

168. The new trees planted by BNL will seriously affect a substantial number of foundations if allowed to grow even with the tree management regime included in BNL's design. Unlike the 'existing' trees which generally lie outside the Council's ownership, the Council can take action to remove the risks posed by these new trees.

169. We have thus sought arboricultural advice on how the growth of these new trees may be managed more rigorously and an enhanced management regime, as detailed in Appendix J, has a marked impact in reducing the number of new trees seriously affecting the foundations. This is summarised in the table below,

	Foundation depth requirement							
	Full NHBC (see §84)				**Max 25mm differential movement (see §86)**			
	Total number of foundations at risk							
	Due to 'existing' trees	Both 'existing' and new trees	New trees only	Total	Due to 'exist-ing' trees	Both 'existing' and new trees	New trees only	Total
BNL tree management	401	467	354	1222	261	382	413	1056
Enhanced tree man-agement	678	190	111	979	471	172	108	751

170. In the above table we have grouped foundations under the three headings, those affected by 'existing' trees, those affected by new trees and those affected by both 'existing' and new trees. After implementing the enhanced tree management regime, the numbers of foundations affected by new trees decreases. Hence the total number of trees being affected solely by new trees simply decreases. Where a foundation that was being affected by both new and 'existing' trees stops being affected by the new tree, it will still be affected by the 'existing' tree and therefore gets reclassified as being affected solely by an 'existing' tree. Consequently, the number of foundations being affected solely by 'existing' trees increases by the same number as the decrease in trees affected by both new and 'existing' trees. Hence the total number of trees being affected by 'existing' trees remains constant at 868 foundations for full NHBC and 643 foundations after allowing for 25mm differential movement.

171. We have also determined that for those new trees where that enhanced regime does not prevent differential settlement to the foundations there are two means to negate the effects of them:

- Removal of the tree;
- Removal of the tree and replacement by a lower water demand/mature height species which will not cause settlement ot the guideway

172. The first alternative is a very low-cost option. However, if used extensively it will have a detrimental effect on the environment and will risk breaching planning obligations.

173. The second alternative is a low-cost method but mitigates the loss of the tree by planting a replacement tree of lower water demand and/or mature height whilst still meeting the planning obligations for the tree planting, which included details of the mix of trees to be used.

174. Both these method can be employed as remedial works prior to foundation movements occurring or reactively after foundation movements occur.

175. Our preferred solution to prevent the new trees planted by BNL, which are in Council ownership, from causing damage to the guideway is an enhanced tree management regime, see §169 above, combined with replacement of certain trees with lower water demand and/or height trees, see §173 above, prior to foundation movements occurring.

Remedial works to prevent differential settlement associated with 'existing' trees

176. We have considered three alternative methods of remediation, all of which can be employed pre-emtively or reactively:

(i) the use of root barriers to delay roots reaching the ground under foundations for a period of time,

(ii) piling to support the foundation slab above subsiding clay foundations and any Class 6N fill which is between the two; and

(iii) the deepening of foundations by excavating to the NHBC standard depth determined by the assessment above.

177. Reactive works would be reliant on monitoring the level of the guideway over its remaining life. Further details of how this would be applied are given in §193 below.

178. Alternative (i). This method does not require the guideway structure to be disturbed as the root barriers would be constructed in the ground between the guideway and the tree (or trees) whose roots are leading to movements of the guideway. In the vast majority of instances however access will be required over the guideway to allow plant and materials to be taken to the root barrier location and thus there will be interruption to bus operations during the construction of the root barriers.

179. Root barriers

- consist of an impenetrable material which is placed in the ground between the tree and the foundations, through which the tree roots cannot pass.
- are constructed by excavating deep narrow trenches between the tree and the guideway to a depth which will prevent roots passing beneath it and the impenetrable material placed into this trench. Further details on how barriers are constructed are given in Appendix M.
- have uncertain long term effectiveness as tree roots are known to grow around the barrier and then continue on their original growth trajectory.
- are only be effective for up to approximately 20 years.
- may, if installed along continuous lengths of the guideway, interrupt natural drainage paths and cause localised instability of the ground be them. Intermittent use is unlikely to lead to any such detrimental effect.
- have a significant risk of being ineffective when placed as a replacement root barrier at the end of a previous root barrier's effective life.

180. The risk associated with using this method pre-emptively is that the vast majority of the barriers would have to be replaced at least once during the design life of the guideway. Application of this method reactively would reduce this risk as fewer barriers would require replacement as some barriers would not need to be installed for up to 15 years, possibly longer. Root barriers are not recommended by NHBC in its Standard as an alternative to deepening foundations. It considers them to be unreliable. We believe this is due to the limited time period over which they will be effective and that the installation of such barriers needs to be meticulous so as to not allow the tree roots to find a route past the barrier in the short term.

181. Our initial assessment of alternative method (ii) - piling the foundation pads, has indicated this to be a complex operation requiring specialist plant. Tying the piles into the foundation pads would also be complex. The approach would lead to voids under the foundation slabs which would not be desirable. We recommend this option is not considered further for either pre-emptive or reactive remedial works. It, along with alternative (iii), would also require the removal of the guideway ladders to allow construction which would be a major exercise.

182. Alternative (iii) would require specialist plant to lift out the guideway ladders and foundation pads as well as earthmoving plant to remove material from the deepened excavation. If undertaken as a pre-emptive approach, even if just for those foundations assessed as at greatest risk of excessive differential movement there would have an impact on the programming for Option 1 remedial works for the guideway superstructure. In its favour we consider this alternative method of remediation is the most reliable means of remedying the foundations. It would also put the Council back into a similar position that it would have been in had the foundation been designed and constructed fully in accordance with contractual requirements.

183. Piecemeal application of this remedial method as issues develop or ground movements are detected from monitoring of foundations would incur substantial additional costs. This would be due to repeated mobilisations and demobilisation of specialist lifting equipment for the guideway ladders and earthmoving equipment. In our view it would only be appropriate as reactive remedial works where an alternative (i) remedial works is found to be unsuccessful.

Remedial Works Option A - Pre-emptive works

184. This option combines the adoption of the enhanced arboricultural management regime for new trees, see §169 above and Appendix J, replacement of new trees that even with an enhanced arboricultural regime will affect the foundations, see §171 above, remediation of the foundations between chainage 17510 and 17645 and chainage 17691 and 17811 as detailed in §167 above and alternative (iii) for all foundations assessed at risk from 'existing' trees. It thus pre-emptively remedies all "very high risk", "high risk" and "at risk" foundations.

185. New trees would need to be removed and replaced by lower water demand/mature height tree species beside a total of 111 or 108 foundations, the former is based on applying the NHBC standard in full, the latter, lower, number takes into account the benefit of allowing 25mm of differential settlement, see §86 above. A list of these locations is in Appendix L.

186. The number of foundations to be deepened by alternative method (iii) would be 868 or 643 foundations, see §170 above, the former is based on applying the NHBC standard in full, the latter, lower, number takes into account the benefit of allowing 25mm of differential settlement. This option proposes to remedy all foundations at risk of 25mm differential movement due to 'existing' trees, whether categorised as "very high risk", "high risk" or "at risk", as detailed in §104 above.

187. The foundations would require to be remediated in a similar way to that proposed in §167 above except the excavation would only be taken to the NHBC depth determined for each foundation and there would not be a need to install 25mm of shims as heave would not be expected. The average depth of excavation to the new foundation depth below foundation pad base level will be 1.1m for deepening to full NHBC depth and 0.88m allowing the benefit of 25mm differential settlement.

Remedial Works Option B – selective pre-emptive works combined with reactive works

Selective pre-emptive works

188. For the selective remedial works this option would combine the adoption of enhanced arboricultural management, see §169 above and Appendix J, replacement of new trees that even with an enhanced arboricultural regime will affect the foundations, see §171 above, remediation of the foundations between chainage 17510 and 17645 and chainages 17691 and 17811 as detailed in §166 above and alternative (iii) for the 105 foundations assessed as having a "very high risk" of differential movement between foundations as detailed in §104 above. The average depth of excavation to the new foundation depth below foundation pad base level for these 105 foundations will be 0.95m allowing the benefit of 25mm differential settlement.

189. This option is aimed at remedying the "very high risk" foundations which are all considered to pose a risk of differential movements well in excess of 25mm in the short to medium term i.e. in the next 10 - 15 years. Thus the need for reactive remedial works to foundations would be substantially reduced over that period. A small number of foundations assessed as "high risk" or "at risk" will require reactive remedial works during the next 10 – 15 years leading to some disruption to the operation of the guideway. Additionally those reactive remedial works will require replacement in the second half of the life of the guideway.

190. We present in the accompanying table in Appendix L to this report a full list of the foundations that would require to be pre-emptively remediated under this option.

Reactive works

191. These works would be undertaken using alternative (i) as described in §178 - 179 above. Where the criterion for foundations is the full NHBC standard the reactive works would apply on up to 763 "high risk" and "at risk" foundations (determined from deducting the 105 "very high risk" foundations from the total number of 868 foundations in all risk categories, as given in final sentence of §170 above). Where the criterion is amended to give the benefit associated with allowing 25mm of differential settlement the reactive works would apply on up to 538 "high risk" and "at risk" foundations (determined from deducting the 105 "very high risk" foundations from the total number of 643 foundations in all risk categories, as given in final sentence of §170 above).

192. To manage these reactive remedial works it will be necessary to monitor the levels of these foundations for the guideway's remaining design life on a minimum six-monthly cycle. This can be achieved by monitoring the level of the guideway upstand and we recommend the levelling is performed in early March and early October as monitoring at these times should record the peaks of any seasonal movements because these months should correspond with potential maximum rewetting and drying times of the shrinkable clays.

193. Once the monitoring records show significant settlement movement between March and October, in our view, in the order of 10mm, then it is likely that the foundations are starting to be significantly affected by tree roots but recovery, partial or whole, of levels will occur over the subsequent 6

months to March. In our view, intervention by remedial works at this point is unnecessary. However, such movement is an indication that issues are likely to start to arise with bus operation in the subsequent year(s) as tree roots extend further. We would expect that the settlement to increase year on year thereafter in the October surveys as the roots extend further under the foundations. We are of the opinion that rocking of the beams can start to occur when around 20mm of differential settlement occurs, which suggest the beams are sometimes stiffer than calculations indicate. On that basis, to avoid that situation arising, and getting into a cycle of adjusting the shims on a very frequent basis (as marked seasonal movement will be occurring), we recommend that when monitoring shows:

(i) 15mm or more of differential movement has occurred between foundations supporting a guiderail between March and October; or

(ii) when a comparison of yearly increases show this is likely to occur in the following year; or

(iii) when settlement will result in an excessive depth of shims being required

that a root barrier is installed between the tree(s) considered to be causing the movement and the guideway foundation.

194. There is a risk that the first significant recorded differential movement between foundations not pre-emptively deepened on clays particularly prone to shrinkage will be in excess of 25mm where a tree initially only affects one foundation. This comprises 14 foundations assessed as “high risk” and 235 “at risk” foundations on the sections between Swavesey stop and the south eastern end of Over Cutting and between Longstanton and 300m north of Oakington stop. If this occurs it is likely to lead to issues of steps between guideway ladders requiring imposition of speed limits and/or damage to the guiderails requiring additional superstructure repairs i.e. repairing cracks in the guiderails.

195. This method of remediation is not 100% reliable. In the event that the level monitoring in the first few years after installation of the root barrier shows remediation is not preventing a progressive increase in differential movements it will be necessary to adopt alternative method (iii) – deepened foundations. We expect that initially the vast majority of such barriers will be effective. For the purpose of estimation we recommend that it is assumed that 2% of such barriers may prove ineffective in preventing differential movements when root barriers are first installed. A much higher percentage of replacement root barriers are likely to prove ineffective as the location of roots, diverted by the first phase of root barriers but eventually reaching the foundations, will not be determinable. In such instances a third phase of remediation will be required replacing the root barriers by deepened foundations. For the purpose of estimation we recommend that it is assumed that 10% of the replacement barriers will prove ineffective.

196. Where alternative (iii) is adopted to rectify failed root barriers this would involve lifting out the guideway beams over a 30m length (free end to free end), the foundation(s) deepened to full NHBC depth, undertaking the works as otherwise described for the pre-emptive approach in §187 above. If the foundation is at a free-end a 60m length would need to be removed. It would require closure of the guideway and the mobilisation and use of heavy lifting and earthmoving plant.

197. If this Option is selected and remediation Option 1 has not been undertaken for the GUD there will be an unknown amount of ‘existing’ differential movement between foundations. When detailed monitoring is commenced for all 538 “high risk” and “at risk” foundations, estimates of that in built differential movement will need to be made. This could result in reactive repairs being needed before a further 15mm of differential movement occurs.

Remedial Works Option C – pre-emptive works to heaved foundation and arboricultural work combined with reactive works

198. This option combines the adoption of the enhanced arboricultural management regime for new trees, see §169 and Appendix J, replacement of new trees that even with an enhanced arboricultural regime will affect the foundations, see §171 above, deepening of the foundations between chainage 17510 and 17645 to avoid imminent excessive differential movement between those foundations and for all foundations including the “very high risk”, “high risk” and “at risk” categories reactive remedial works undertaken using alternative (i) as described in §178 - 179 and §192 - 195 above.

199. It thus varies from Option B by excluding the pre-emptive remediation construction works for foundations assessed at “very high risk” of excessive differential movement between foundations as detailed in §188 above.

200. Our estimate of the possible timetable for such remedial works is given in Appendix L.

201. Where the criterion for foundations is the full NHBC standard the reactive works would be to 868 foundations in all risk categories, as given in final sentence of §170 above and where the criterion is amended to give the benefit associated with allowing 25mm of differential settlement the reactive works would apply on up to 643 “high risk” and “at risk”, as given in final sentence of §170 above.

202. An additional risk associated with this approach compared to Options A and B above is that for the 47 “very high risk” category foundations on high shrinkage potential clays there is a distinct possibility that the differential movement in the first season of significant movement may well exceed 25mm between monitoring dates. This is likely to lead to issues of steps between guideway ladders requiring imposition of speed limits and/or damage to the guiderails requiring additional superstructure repairs i.e. repairing cracks in the guiderails. This will also apply to “high risk” and “at risk” foundations where they lie upon clays particularly prone to shrinkage, see §194 above.

203. Additionally for the above reason, the number of foundations to be remediated reactively and the likelihood of at least two phases of remedial works for each foundation remediated there will be substantially more disruption to the operation of the guideway over its lifespan. This is discussed in more detail in §195 - 196 above. It will also incur a substantially higher level of technical and managerial input by the Council over that period.

Which Option?

204. If Option A were adopted it avoids the need for long term monitoring and frequent reactive remedial works during the design life of the guideway and thus disruption to the operation of the guideway. However, it would have a major impact on the temporary works methodology and programming of the remedial works Option 1 for the GUD. It would have a substantial environmental impact because large volumes of excavated material would need to be disposed of off-site and there would be an import of substantial volumes of new fill material. In our view, it would probably lead to a limited number of foundations being remediated which may not require to be remediated if a reactive approach is taken.

205. Option B is essentially a 'half way house' between Options A and C. It pre-emptively remediates the foundations assessed as being at greatest risk of excessive differential movement, many of which can be expected to show such movement in the next 10 – 15 years if not remediated. It thus can be expected to significantly reduce the amount of reactive remedial works in those early years but only slightly reduce the amount of reactive remedial works in subsequent years. It reduces the impact on the temporary works methodology and programming of the remedial works Option 1 for the GUD and environment impact inherent in Option A. The option, however, will require long term monitoring to occur and significant reactive remedial works will be necessary over the remaining life of the guideway. Prediction of when such reactive remedial works will be required is not feasible and thus forward year-on-year budgeting for such reactive remedial works will not be possible. Additionally, as the expected effective life of the remedial works is around 20 years, a second phase of remediation will be necessary in the final years of the life of the guideway. This second phase will include a significant number of root barriers that will fail to halt differential movement and in such cases foundation deepening is likely to be required as a third phase of remediation.

206. Option C is a wholly reactive approach in respect of trees in existence at the start of construction. It will only address those foundations where monitoring reveals that excessive differential movement is being approached. There will be no impact on the GUD remedial works programme and temporary works and a reduced environmental impact over the other two options. As with Option B, prediction of when such reactive remedial works will be required and forward year-on-year budgeting for such works is not feasible. As the expected effective life of the remedial works is around 20 years, a second phase of remediation will be necessary in the latter half of the life of the guideway. This second phase will include a significant number of root barriers that will fail to halt differential movement and in such cases foundation deepening is likely to be required as a third phase of remediation. As Option C will have the 105 additional "very high risk" foundations being remediated reactively there will be considerably more on-going disruption to the operation of the guideway than with Option B in the next 10 – 15 years.

207. In our view the best engineering solution is Option A as this option remedies the defects in the next few years.

208. Options B and C require frequent closure of the guideway towards the end of the guideway life to reactively remedy defects. Option B alleviates such frequent closures for the next 10 – 15 years but

thereafter the frequency of closures will be similar to Option C. Compared to Option C it also reduces the number of foundations at risk from moving in excess of 25mm in the first season of significant movement.

209. If the full pre-emptive remedial works of Option A are not adopted by the Council we would recommend Option B as it provides lower long term risks that Option C and reduced disruption over the next 10 -15 years.

210. If superstructure repairs are performed reactively the engineering advantage of Option A is reduced. We discuss in §238 -243 below our recommendations with regard to combining superstructure and foundation options.

211. We consider logistics for carrying out foundation deepening pre-emptive remedial works in Appendix N.

CONCLUSIONS FOR SUPERSTRUCTURE

212. We have summarised the defects that exist with the guideway and have detailed the extensive scope of the remedial works or repairs required to the guideway.

213. Our brief was to consider the remedial works to correct the defects to the guideway itself that have collectively been given the overarching title of 'Grand Unified Defect'. There are other miscellaneous notified defects that require correction which are not within our brief.

214. Our brief was also to consider the shallow foundations and the remedial works required given the potential impact of trees in close proximity.

215. The details of the remedial works presented in this report are outline and preliminary but we consider that they are sufficient for costing purposes to assist the Council in deciding how to proceed.

216. The Option 1 <u>pre-emptive</u> remedial works are presented in Figures 1 to 6 in Appendix G. In essence, the bearing pads are fixed in place and the shims are arranged so that they cannot slide out and can all take a proportion of the horizontal load that the guideway is required to accommodate. For this Option, we propose that the guideway is closed in sections to carry out the remedial works and the details for this need to be fully assessed in conjunction with the Council. We consider that a reasonable timeframe to carry out the works is 30 to 36 months and that any remedial works to the foundations should be possible within that period, simultaneous to the guideway superstructure works.

217. The Option 2 <u>reactive</u> remedial scheme consists of implementing the Option 1 proposals on a piecemeal basis. When one or more bearings and/or shims slip(s) out resulting in a step in the guideway running surface, this would trigger remedial works being carried out to a 30 metre section the details for which are as in Figures 1 to 6 in Appendix G. It may be expected that this means of carrying out the remedial scheme will be protracted and could well take 30 or more years to complete the remedial works.

218. The Option 3 scheme of reactive repairs comprises relocating the bearing pads/shims (but not fixing them in place) when steps appear in the running surface of the guideway together with repairing concrete spalling and other issues. We anticipate that the work will be carried out in the manner adopted for the emergency repairs to bearings, i.e. jacking up the guiderails to access the bearing pads and shims in order to relocate them. This Option simply replaces the bearings/shims back to what presumably was their position at construction. The bearing pads and shims remain unfixed. It does nothing to prevent the pads/shims continuing to slip out, nor does the Option correct the defects that in our opinion are inherent in the design/construction.

Summary of Costs for Options 1, 2 & 3

219. Mr Chris Ennis of TQEF has prepared cost estimates for the Options described in this report. Mr Ennis' report should be consulted in respect of cost comparisons of the three Options.

Which Option?

220. In our opinion, it is unsatisfactory from an engineering viewpoint to allow defects to remain. In particular, the guideway as currently designed and constructed can move uncontrollably in a longitudinal direction and is inadequately restrained in a lateral direction, with the result that:

(i) Bearing pads and shims, which are loosely placed and unfixed, gradually slide out;

(ii) Concrete elements spall; and

(iii) Lateral displacement of guiderails occurs.

221. Photographs are enclosed at Appendices C and E which demonstrate that these problems have already occurred. If the design/construction defects are not corrected, then we anticipate that further problems of pad/shim slippage, spalling of concrete, and lateral displacement of guiderails will continue to occur and incur substantial repair work which will not in any event fix the problems. Such periodic work (i.e. Option 3 reactive repairs), which is estimated to be at greater cost than implementing a remedial scheme now (i.e. Option 1 pre-emptive remedial works), will be throwing money at a design that is fundamentally flawed and trying to keep a guideway operational whilst it continues to deteriorate. It will be equivalent to 'papering over the cracks' and will not address the root cause of the problems. We cannot recommend such an approach.

222. Option 2 does, on an intermittent and reactive basis, gradually address the defects. However, as long as they exist, problems may be expected to continue and even accelerate and problems of spalling will also continue to occur until the guideway is fully remedied to the Option 1 details. Option 2 is also at significantly higher cost because of the inefficiency of periodic stop-start working. We cannot recommend such an approach.

223. We also recognise that Options 2 and 3 are likely to give rise to disruption of the guideway and cause unplannable operational difficulties over the remaining design life of the guideway.

224. We believe therefore that the correct and wisest solution to the inherent problems the guideway has, is to implement the Option 1 pre-emptive remedial works. This deals in the earliest possible time

(say 30 to 36 months) with the serious design flaws that are causing physical damage and will continue to do so. We commend this approach to the Council as the appropriate engineering action in the circumstances.

225. Our view is that the contract the Council has with BNL entitles the Council to have the notified defects corrected. Option 1 is the solution that best accomplishes this.

CONCLUSIONS FOR FOUNDATIONS

226. This report details the background to defects, how they have been assessed to develop a scheme for remedial work, the alternatives for remedial works and it provides details on the scope of the remedial works required to the guideway over its design life.

227. Our brief was also to consider the most reasonable and practical means of undertaking work to correct or nullify the effects of the foundation defects.

228. The details of the remedial works presented in this report are outline and preliminary but we consider that they are sufficient for costing purposes in forming the basis of a claim against BNL.

229. We have presented three remedial options for foundations, Options A, B and C.

230. All options deal with the assessed future effects of trees planted as part of the guideway construction work by pre-emptive arboricultural works and an enhanced arboricultural maintenance regime. All options also include pre-emptive foundation deepening works for the foundations between chainages 17510 – 17645 and chainages 17691 – 17811.

231. Remedying all 868 foundations which do not comply with NHBC depths under Option A would place the Council in the position it would have been if it BNL had constructed the works in accordance with the contractual requirements. In our view it is possible to remedy a reduced number of such foundations, 643, with only a slightly heightened risk to the Council if the benefit of allowed up to 25mm of differential foundation settlement is made. This is discussed in §86 above.

232. The application of the latter approach under Option A is possibly a slightly conservative approach in respect of the number of foundations that will, with time, move sufficiently to develop excessive differential movement between them. This is because there is an inherent uncertainty as to how the roots of the trees will develop with time and thus precisely how many, and which, of the foundations assessed as requiring remediation by pre-emptive works, will move such that the differential movement with the adjacent foundations will definitely be sufficient for deflections on the guiderails to become excessive.

233. If a pre-emptive approach is considered appropriate by the Council so as to minimise long term disruption to operation of the guideway Option A, adopting the benefit of 25mm of foundation movement, is recommended.

234. If the Council is adverse to the environmental impact associated with Option A but also wishes to minimise the frequency of closure of the guideway during its life and to an extent limit additional risks

inherent with reactive remedial works, as summarised below, Option B is recommended. The Council should bear in mind however that with this option there is a risk that 14 “high risk” and 235 “at risk” foundations on clays particularly prone to shrinkage may move in excess of 25mm during the first season of significant movement and this would compromise the durability of overlying guiderails.

235. Option C does not include pre-emptive work for any foundations at risk from ‘existing’ trees. It minimises environment impact and relies wholly upon reactive remedial works when movements of the guideway approach levels of differential movement between foundations that could comprise the durability of the guiderails due to excessive crack widths. This option increases the number of foundations at risk moving more than 25mm during the first season of significant movement and thus more guiderails are at risk of having their durability compromised.

236. Both Options B and C require long term monitoring of the levels of the guideway throughout its design life to determine when and where to undertake remedial works and to monitor the effectiveness of the remedial measures over the long term when they are installed.

237. Both options rely on tree root barriers for the reactive works but these barriers will only be effective for up to 20 years. Thereafter new root barriers will need to be installed but there is a high risk that a significant number of these replacement root barriers will prove ineffective. In such instances the foundations will have to be deepened and this is likely to involve closure of the guideway for an extended period i.e. in excess of a weekend even if only one foundation is deepened at a time.

CONCLUSION ON COMBINED OPTIONS FOR SUPERSTRUCTURE AND FOUNDATIONS

238. If the Council wishes to minimise the amount of future disruption to the guideway and the additional long term internal costs for monitoring and managing a reactive remedial works to the foundations we recommend that Option 1 is selected for superstructure together with Option A for the foundations, the latter based in giving the benefit of allowing up to 25mm of differential movement between foundations rather than applying a requirement to correct all foundations shallower than the required NHBC depth.

239. In our view Option 1 with Option A represents the best engineering solution. It would avoid the enhanced technical and managerial input on the guideway for the remainder of its life associated with assessing monitoring results and arranging/supervising reactive remedial works at numerous times during the remaining life of the guideway.

240. If the Council wishes to limit the environmental impact of foundation remedial works it must be prepared to accept the additional long term internal resourcing and commitment associated with monitoring and managing frequent reactive remedial works to the foundations for the next 37 years. We consider combining Option 1 and Option B would be the most appropriate combined option in this case. In our view it does not provide the best engineering solution. We would highlight that there are uncertainties associated with the replacement of root barriers when they fail and this may well

incur frequent prolonged disruption to the guideway in the final years of its design life during to the need to deepen foundations at that stage.

241. If Option 1 is adopted for the superstructure and Option C for the foundations, then the prolonged disruption to guideway operations in the early years associated with Option 1 remedial works is, in our opinion, likely to be followed by further disruption at frequent intervals throughout the life of the busway, possibly after a short respite at the end of Option 1 works. This short respite would arise from the resetting of the guiderails removing any existing movement distortion in the guiderails and re-shimming would offset any limited foundation movement during the Option 1 remedial works. The Council would have to accept a substantial risk of more than 25mm of differential movement occurring to 47 “very high risk” and 14 “high risk” and 235 “at risk” foundations before monitoring indicates remedial works are required and, in such instances, the durability of the overlying guiderails will be compromised.

242. The adoption of superstructure Options 2 or 3, and /or foundation Options B or C will involve reactive remedial works to be undertaken throughout the life of the guideway and the timing and frequency of the repairs on any one section of the guideway cannot be predicted. If either Option 2 or 3 is selected for the superstructure then Option C is recommended for the foundations as all major corrective works will then be reactive. All these options require additional long term internal costs for monitoring and managing a reactive remedial works programme. The uncertainties associated with the replacement of root barriers when they fail also applies to these combination of options.

243. Combining Option 2 or 3 with Option B will have limited benefit because neither of the superstructure Options will provide the benefit of Option B in minimising the disruption to operations over the next 10 - 15 years. Thus the only significant benefit of combining Option 2 or 3 with Option B rather than Option C is the reduced number of foundations at risk of differential settlement exceeding 25mm in the first season of significant movement.

APPENDIX A – CVS OF TONY CORT & ROBIN SANDERS

CURRICULUM VITAE

Name: **Anthony Cort**
BSc(Eng), CEng, MICE, MCIHT

Nationality: British

Profession: Civil Engineer

Position in Firm: Associate Director

Key Expertise: Tony has acted as an expert witness/advisor on countless occasions since 1985, has written numerous reports, and has appeared in court to give evidence on several occasions. He has also been instructed several times as a Single Joint Expert.

He has experience in the design and construction of highways and bridges. He has key expertise in investigation of curtain wall failures/corrosion, building refurbishments, concrete, steelwork (including repair & refurbishment), steel corrosion and protection, structures, watertight basements, piling, and ground engineering.

Tony has a special interest in carrying out drainage assessments (foul and surface water and highway drainage), and in reporting of drainage problems and appraisal of flooding cases.

Experienced in contract administration and contractual claims.

Tony has investigated and reported on drainage issues in relation to various highway and retail distribution centres and in relation to flexible and concrete pavements in the UK.

Education/ Professional: 1965: BSc(Eng) in Civil Engineering at Queen Mary College, University of London

Qualifications: 1970: Chartered Engineer
1970: Member of Institution of Civil Engineers
1981: Member of Chartered Institution of Highways and Transportation

---

Experience Record:

Capita June 2008 onwards

Associate Director

Recently provided expert advice and expert evidence on a major UK highway dispute involving drainage, and also major pavement failures essentially related to drainage issues.

Currently engaged on a wide range of expert appointments including:

- As a party-appointed expert on several road traffic collisions involving highway conditions/drainage;
- As a party-appointed expert on a hotel development with a structural failure of the basement
- As a party-appointed expert on a major UK highway dispute involving drainage;
- As a party-appointed expert on building defects in various buildings;
- As a party-appointed expert on a new housing development subject to flooding;
- As a party-appointed expert on numerous cases involving flooding and drainage problems, including highway drainage design and maintenance.

Jacobs UK Ltd 2004 to 2008

Senior Consultant, Technical Director

Expert Witness including legal cases relating to drainage and flooding including road traffic collisions, contractual claims and advice, project design reviews and risk assessments, including advice to householders regarding tunnelling proposals beneath properties. Other cases included investigation of structural failures, scaffolding collapse, roofing failures, water supply disputes, flooding of buildings, drainage defects, highway drainage, concrete slab failures, piling failures, foundation failures, etc.

Acted both as single joint expert and expert to single party.

Design reviews within office including pile design, pile capacities, highway drainage, marine structures.

Contract administration including final accounts and assisting contractors with claims, including multi million high rise buildings. Expert Witness to contractors seeking redress from designers

Babtie Group Ltd 2002 to 2004

Technical Director

Moved to form part of a new team of expert witnesses to develop this new specialism within the group.

Cases involved highway assessments, highway drainage design defects, highway alignments, flooding disputes, drainage problems (foul and surface water), structural failures, scaffolding collapse, waterproofing to basements, disputes involving concrete, drainage, asbestos, cracking in roof cladding, and building and domestic property disputes. Problems also included corrosion of steel curtain walling/cladding and failure of concrete cladding units. Specific cases have included dealing with foul sewer issues with properties.

Maintained significant involvement in major civil engineering construction projects involving project management, claims assessments, project verification, design reviews, and advice to design teams.

Peer review of piling on multi-million ferry terminal extension together with management assessments associated with additional services. Surveys of properties including condition surveys and drainage surveys including condition of pipework and tanks.

1995 to 2002

Responsible for the structural engineering section in the Group's Cardiff Office including business development and bid submissions.

Extensively involved in contract administration and dispute resolution, and expert witness work. Director responsible for marine works (including refurbishment of a Victorian pier, marina sheet piling at Poole, and ferry terminal expansion at Pembroke Dock), involving extensive refurbishment/grit blasting of existing steelwork. Advice on steelwork corrosion and protection.

Advice/project monitor to Millennium Commission for various projects including Millennium Stadium Cardiff, Millennium Coastal Park Llanelli, and Marine Environment Centre, Swansea. Engineer to £45m Main Civil Works Contract for power station including valuation/certification and dispute resolution.

1990 to 1995

Director responsible for the management of Cardiff Office in addition to the structures team. Responsible for cost control, planning, submissions, marketing and client liaison.

Experience includes dealing with the preparation of various capital projects including building and civil engineering structures; marine projects; drainage schemes. Project Director for building structures (including building refurbishments and extensions), building and civil drainage and external works/pavings, sheet pile structures, foundation structures, piled foundations, reinforced concrete design, water retaining structures including building basements and lift shafts, foul sewer storage tunnel in Cardiff.

Structural inspections of buildings together with strengthening of cooling towers, bridge inspections, and condition surveys/refurbishment of marine structures including seaside piers and berthing facilities.

Design of marine structures and refurbishment of buildings including listed buildings. Identification and repair proposals for water ingress and damp problems in properties.

Dobbie and Partners 1985 to 1990

Associate

Associate responsible for the development of Barry Old Harbour incorporating new lock, breakwater, land reclamation and infrastructure. Foundation strengthening schemes for cooling towers at Ratcliffe-on-Soar and Fiddlers Ferry Power stations.

Miscellaneous foul sewerage schemes including tunnels and pipe jack construction.

The position involved a management role within the office including staff administration, cost control, planning and promotion and liaison with clients. Specific responsibility for structures (civil and building) and for marketing.

Principal Engineer 1977 to 1985

Principal Engineer with responsibility for reports, design work and administration for site investigations, highways, sewerage and flood alleviation projects and building structures for United Kingdom and overseas, including design and construction administration of foundations, design and remedial works to foundations in varying ground conditions. Piled foundation design. Responsible for Kidwelly rail washery project including replacement and realignment of tracks, rail structures and coal washery buildings.

Structures design in Middle East included reinforced concrete framed office blocks, mosques and large villas with swimming pools.

Design and build structures projects including supermarket and miscellaneous building structures.

Expert consultancy on hydrological and hydraulic studies, including analysis and regression of local data, rainfall run off estimations both in United Kingdom and Middle East.

Contract administration and claims assessment.

Computer development and usage within firm including development of design software packages for hydraulics, highways and structures. Participation in local computer seminars.

Overseas experience includes nine months in Africa and the Middle East in connection with structures, highways design and office management.

Senior Engineer 1974 to 1977

Team Leader for design of Furnace and Eglwys Fach Bypass including assistance at public inquiry.

Traffic engineering and preliminary reports for approach roads to Aberystwyth including traffic assignment and economic analysis.

Site investigations including general geotechnical appreciation and reporting for various aspects of engineering and housing projects.

Involvement in preparation of trunk foul sewer schemes and associated structures.

Rendel Palmer and Tritton 1969 to 1974

Engineer

Time spent on site as Section Engineer and Deputy Resident Engineer on the Cardiff-Merthyr A470 Trunk Road with experience on the construction of own bridge designs, railway bridge and working adjacent to and over rail tracks.

Design Engineer 1968 to 1969

Design Engineer with Rendel Palmer and Tritton, period spent in the design of bridge structures (including rail), retaining walls and vertical and horizontal alignments for road works.

Trainee Engineer 1965 to 1968

Trainee Engineer with Rendel Palmer and Tritton in bridge design section, becoming responsible for design of various bridge types on Cardiff - Merthyr A470 Trunk Road (7 No. bridges in total).

Specialist experience in expert witness and advisory services:

Site supervision, contract administration and claims assessments (including delay evaluation) of major civil engineering contracts including piling and groundworks.

Extensive knowledge of CDM Regulations, reviewing of risk assessments, Planning Supervisor role on contracts. Holder of Manager CSCS card.

Examples of contract administration and claims assessment in last 15 years:

- £3m Foul sewer storage tunnel (lined segmental construction 3 metre diameter) in South Wales
- £10m Flood alleviation contracts on River Ebbw in South Wales
- £2.5m Refurbishment of pleasure pier
- £7m Ferry terminal extension at Pembroke Dock
- £48m main civil works for gas turbine power station

Overseas Experience:

Overseas experience includes nine months in Africa and the Middle East in connection with structures, highways design and contracts, and office management.

Worked extensively in Libya and Oman.

CURRICULUM VITAE

Name:	**Robin Sanders**
	BSc (Hons), MSc/DIC, CEng, MIMMM, FIHT, FGS
Nationality:	British
Profession:	Geotechnical, Environmental and Waste Engineer
Position in Firm:	Director

Key Expertise: Extensive experience as director on a wide range of geotechnical, geo-environmental, and waste projects, including the co-ordination of multi-disciplinary teams to achieve completion of commissions within target programmes and within budget.

Expert advisor to insurers and expert witness instructed by solicitors on matters involving earthworks, landfill, coastal and geotechnical engineering claims.

Education/ Professional:

1974: BSc (Hons) in Geology, Sir John Cass College, London

1979: MSc/DIC in Engineering Geology, Imperial College, London

Qualifications:

1975: Fellow of the Geological Society

1980: Member of the Chartered Institution of Highways and Transportation

1984: Member of the Institution of Materials, Minerals and Mining

1984: Chartered Engineer

1990: Fellow of the Chartered Institution of Highways and Transportation

Experience in Forensic Investigations and Expert Witness/Advisor Role:

Forty years experience in engineering geology and soil mechanics including a wide variety of forensic investigation into soil/structure failures and impending failures. Twenty years experience as an expert witness/advisor including as an expert at adjudications and in the Technology and Construction Court.

Ridgemont Housing Estate, Colchester

Expert advisor to housebuilder on a large housing development built on London Clay with localised overlying granular layers. Building commenced on the less wooded areas of the site and houses were occupied when issues with heave developed on some, but on all, properties and on partially complete properties on the former heavily wooded area of the site. Investigations for potential future movement undertaken and reports issued for 15 occupied properties, 3 of which assessed as not subject to future movement. Advice given on failed foundations on partially completed houses.

Great Elms Farm, South Hanningfield, Essex

Expert advisor for professional indemnity insurers for architect who approved foundations for a large detached farmhouse and car collection garage which developed severe heave damage.

Automated High Stacking Storage Warehouse, Basildon

Expert advice to designer and client with regard to whether the ground investigation for the development had correctly indicated the site was not subject to heave if vegetation was removed. The investigation was found to be erroneous and site was subject to significant potential heave if vegetation was removed.

Anerley Road, Penge, London

Expert advisor and witness on a case involving unauthorised removal by a third party of a large lime tree adjacent to a recently extended Victorian property which then suffered heave damage. Expert advice and expert reports prepared reviewing the behaviour of the ground and property due to the tree removal. Attendance at expert meetings. Expert evidence given in the Technology and Construction Court.

Navigation Point, Castleford

Expert advice and report on gasworks waste contamination of a 1337 unit residential development site on alluvial soil adjacent to a major river, including expert meetings and giving expert evidence in the Technology and Construction Court.

Major Excavation, Dubai

Expert advisor and witness in a dispute under DIAC rules with respect to the assessment and foreseeability of rock conditions in a 60m deep earthworks excavation. Expert report prepared and expert meetings attended.

Major Petrochemical Plant Extensions, UAE

Expert advice with respect to a dispute over the foreseeability of soft and unsuitable ground conditions during the development of the base platform for a 350Ha extension.

Airport and Frontier Access Road Tunnel, Gibraltar

Expert witness in a dispute related to the termination of a contract for the construction of the project. Advice and evidence on the foreseeability of encountering ground that could not be excavated with a clamshell grab during the construction of diaphragm walls forming the tunnel side and central support walls. Attendance at expert meetings. Expert evidence given in the Technology and Construction Court.

Raising and Reclamation of Extensive Sabkha Areas, UAE

Expert advisor to Korean contractor on an EPC contract to review whether existing raising and reclamation of extensive sabkha areas complied with the stated specification requirements.

Deodar Road, Putney, London

Expert advice and expert reports into the impending failure of a section of brick and concrete river wall due to extensive ground raising by riparian owners. Reports detailed the historical instability of the wall before ground raising and established ground raising had accelerated substantial lateral and vertical displacement of the river wall. Attendance at expert meetings.

Rammed Earth Walls, London

Expert advice and witness reports on the deficiencies in material selection and construction of load bearing unstabilised rammed earth walls constructed as the external walls to a children's nursery. Attendance at expert meetings and meetings with expert determiner.

Coastal cliff stability, Fairlight Cove, Sussex

Expert geotechnical advisor with coastal engineering colleagues on the limitations and assumptions in the government cost benefit assessment for protecting the rock cliff toe to halt its rapid retreat. Advised on the unreliability of historic retreat rates due to site geology. Presented case to public open meeting with DEFRA consultants giving opposing view. Coastal protection scheme subsequently implemented.

Development site, Great Yarmouth

Expert advisor on the failure of surface and foul water sewers due to ground movements on a large residential development on deep soft ground. Review of remedial design measures and advice on the approach to re-design of infrastructure. Expert report and attendance at mediations and expert meetings.

Commercial building, Scarborough

Expert advice and report on the failure of a sheet pile retaining wall to retain residential gardens on a major extension of a former museum on a steep valley in Scarborough. Attendance at mediation.

A12 Capel St Mary, Suffolk, UK – Crib Wall Failure

Geotechnical director for the evaluation of the failure mechanism and remedial measures for a major crib wall failure on a large Highways Agency project. The project included an extensive length of concrete crib walling to retain an existing road above a new slip road to the A12. Catastrophic failure of a 20-30m length occurred and investigations indicated extensive internal failure of the crib units. Reports were prepared highlighting causation was related to the weakness of the British Standard Code of Practice in the analysis of such structures. Research into world-wide design codes and papers on crib wall design.

Major DBFO Highway scheme, North East England

Geotechnical and geological advice to expert advising PII insurers on cause of almost immediate pavement failure on opening of the scheme.

Major Landfill Odour Incident, Essex

Expert report for the Environment Agency in contemplation of a criminal prosecution of a major commercial landfill operator under the 1990 Environmental Protection Act for extensive air pollution incidents over a period of many months. The report reviewed the operational management and landfilling practice of the site over its considerable lifetime and in particular in the period leading up to the pollution incidents at one of the United Kingdom's largest former co-disposal landfill.

Cement Works, Vietnam

Geotechnical advisor for insurers into the review of the claimed slope failure of eighteen metre high earthworks on soft ground causing shearing of the piled foundations to the cement works buildings by lateral displacement. Expert advice report prepared into causation of the damage and the liability of various parties involved in the design and construction of the works.

UK airport

Expert advisor into repeated severe distortion and collapse of runway apron pavements caused by movement of material, within the underlying coastal reclamation earthworks built to extend the runway. Expert report for referrer at adjudication, attendance at adjudication hearing for cross examination.

Warehouse, Tilbury, Essex, UK

Expert advisor in relation to severe differential settlement of warehouse floor/surrounding pavements, punching failure of piles of former structures through the warehouse floor and effects on these issues on the piled foundations of the superstructure. Review of design competency, expert advice report on projected future settlement and defects that have, or will occur, with continued settlement including health and safety risks associated with failed gas protection measures. Advice on potential remedial measures.

Grimsby Fish Docks, Lincolnshire, UK

Investigation and assessment of the effects of unexpected high settlements on the piles for a new fish market building constructed upon a reclaimed section of the existing dock basin.

Freeport, Grand Bahamas – Phase 1

Examination of the design of the pavement and hurricane tie down anchors for ship to shore cranes followed pavement failure and determination of karstic (voided limestone) nature of ground. Supervised the ground investigation to inspect foundations and test the founding strata to the tie down anchors for competency to resist hurricane induced forces. Advice given on remedial measures.

Cobbolds Point, Felixstowe, Suffolk

Expert witness for catastrophic failure of privately owned timber piled seawall which collapsed into new coastal engineering works after storm. Work included review of design of remedial works and the production of expert advice and expert reports. Attendance at mediation.

Stanley Reservoir, Stafford, UK

Investigation of a Victorian dam with a vertical toe masonry wall to evaluate the slope stability of the dam under static and quasi-dynamic (earthquake) loading. A desk study revealed the dam had overtopped in the 1930's and led to near collapse. No record drawing of its construction or remedial measures was found. An investigation of the dam and its toe masonry wall were undertaken and slope stability and other analyses were undertaken to examine existing stability with a new spillway structure. Instrumentation was installed to examine the response of groundwater pressures in and under the dam to changes in reservoir level.

DTSS Contract 6, Singapore

Geotechnical support to external expert witness appointed by Singapore contractor examining causation of a major roof collapse of tunnelling machine launch chamber at 45m depth. Reviewing expert reports produced by experts appointed by client body for arbitration and assisting in formulation of rebuttal report.

Major Highway, Luton

Expert advice to Contractors All Risk insurers on the stability of a 11m high widened reinforced soil embankment.

Major DBFO Highway scheme, East of England

One of two expert advisors to Contractors All Risk insurers on the cause of premature pavement failures of an eight lane highway.

Ipswich Sewer Tunnel, Suffolk

Examination of repeated failure of the construction of an access shaft and the failed remedial measures. Presentation of evidence at adjudication into failures.

Coastal defence, North Norfolk

Expert advisor/witness on a case involving the slope failure of an earth revetment coastal defence structure as a result of wave action. Expert report prepared and attendance at expert meetings.

The Dip, Felixstowe, Suffolk

Geotechnical advisor into the catastrophic failure of 150m length of timber piled mass concrete seawall after a major storm. Investigation into the stability of 1.5km of remaining seawall and clay cliffs was undertaken. Reports revealed a history of sea wall failures due to both toe erosion and over-steep coastal cliffs.

Calvert Landfill Site, Buckinghamshire

Expert report and presentation of evidence at a Planning Inspectorate inquiry into the non determination by the Environment Agency of an application to retain an unlicensed composting facility on a completed landfill cell.

Distribution Centre, Dartford

Expert advisor into the design of specialist ground support for the road pavement following settlement of part of the road pavement. Expert report prepared and attendance at expert meetings.

Specialist experience in infrastructure earthworks, slopes and foundations:

Forty years experience in site investigation, specification and design of earthworks, slopes and foundations for major infrastructure projects in the United Kingdom, North Africa, West Africa, Gulf region and South East Asia including contractual management or advice on investigation and construction contracts.

United Kingdom Highways

Engineering geologist and geotechnical project manager/director for earthworks, slopes and structural foundations advice including site and ground investigations, specification and design on over 20 major highway projects with a combined length in excess of 300km and construction value over £1bn. The investigations included a wide range of techniques, with trial pits and trenches up to 40m long and 7m deep in landslipped ground. The earthworks included design and specification of embankments over former landslips, old landfills, deep recent soft alluvium, made ground and around structures including Armco arch culverts. Cutting design and assessments included the evaluation of acceptability for reuse as natural or stabilised materials, mitigation of gas release in old landfills and stabilisation of existing landslips. Foundation design included a wide range of piled, raft and spread foundations. Extensive design and reporting on the results of ground instrumentation into ground movements and piling induced vibrations for a wide variety of earthworks and structures undertaken and the preparation of detailed feedback reports on construction. Design included the use of innovative techniques included expanded polystyrene fill on five projects to reduce structural loads and accelerate construction together with preparation of research papers on its design, specification and construction. Investigation and design into widening of MI Junction 6A-10 and alternative designs for Second Severn Crossing, Avon Approach Roads. Forensic investigation and reporting of a crib wall failure on the A12 Capel St Mary Bypass, Suffolk.

United Kingdom Railways

Geotechnical project director for the investigation and remedial design of existing earthwork slopes and structures for London Underground Limited, Railtrack, Network Rail and private companies. Detailed desk studies, investigation and remedial work outline design were prepared for fifteen sites on Northern, Central, District and Piccadilly lines including the emergency work remedial design for an embankment. Detailed design and design review for various embankment and cutting remedial works including the use of traditional and lime piles for Railtrack. Category 3 check of piled embankment on A120 Dovercourt Bypass and for the UK's first expanded polystyrene railway embankment replacing an existing structure over an infilled river channel. Design input on use of polystyrene fill for emergency rebuilding of a failed railway embankment in Ireland. Review of earthwork issues during the construction of a new rail link to Felixstowe Docks.

Other United Kingdom Earthworks

Design of earthworks and slopes for Thames Flood Bank Raising Contracts 14 and 26, investigation and earthworks design and/or assessment of the reclamation earthworks and slopes for port extensions at Grimsby, Felixstowe and Tilbury and general reclamation at Cattedown, Plymouth. Designs involved extensive use of ground improvement, staged construction and hydraulic filling. Design of earthworks and slopes on peat for the construction of oil interception facilities at BP Llandarcy.

Overseas Highways:

Libya

Geological/geotechnical mapping, ground investigations and earthworks design for new rural roads in coastal sabkha, inland mountain and wadi areas.

Oman

Earthworks design for new cross-country roads within major wadis including the design of rock cuttings, reinforced earth walls and the reuse of coarse wadi infill deposits as structural fill.

Nigeria

Ground investigations and earthworks design for new urban roads in Lagos, Nigeria including evaluation of potential imported construction materials.

Specialist Experience in Building Foundations:

Twenty five years experience into the investigation and design of new building foundations and forensic investigation into failure or damage to piled foundations.

Property Services Agency

Geotechnical advisor to the UK Property Services Agency investigating and designing foundations for major new government building structures on civil and military, principally RAF and USAF bases, in South and East of England including the assessment of the foundation design of new extensions to existing building structures.

Port of Felixstowe, Suffolk, UK – Maintenance Workshop and Store

Investigation and design of piled foundations to new workshops for container fork lift plant within reclaimed area of port. Trial piling contract design and onsite pile test monitoring to investigate and test the suitability of bitumen slip coating piles to minimising negative skin friction in coarse gravels and cobbles overlying soft clays. Inspection of abstracted slip coated piles and design of novel alternative pile design to minimise negative skin friction due to unsuitability of coated piles.

Warehouse, Tilbury, Essex, UK

Investigation of severe differential settlement, punching failure of piles of former structures through the floor of the warehouse and surrounding pavements and effects on piled foundations to warehouse superstructure. Review of design competency in relation to ground conditions advice report on projected future settlement and defects that have, or will occur, with continued settlement including health and safety risks associated with failed gas protection measures. Advice on potential remedial measures.

Mason Landfill, Suffolk Material Recycling Facility

Investigation and design of piled foundations for the materials recycling facility building founded upon deep industrial and commercial waste material.

Nghi Son Cement Works, Vietnam

Geotechnical advisor for insurers into the review of the claimed failure of eighteen metre high earthworks on soft ground causing shearing of the piled foundations to the cement works buildings by lateral displacement. Expert advice report prepared into causation of the damage and the liability of various parties to the design and construction of the works.

Various Residential and Commercial Property Foundations

Investigation into the foundation failures of both piled and strip foundation on a wide variety of residential and commercial properties throughout England for underwriters and insurers to assess causation of the failures and potential remedial measures.

Research into climate change effects on UK foundation in shrinkable clays

Review of methods of foundation construction that can be adopted to allow for predicted climate change for the UK over the next 50 years. Outline design of recommended solutions for shrinkable clay foundations.

Capita May 2007 onwards

Director

Expert advisor/witness for CAR, PII and domestic insurance claims and contractual and technical disputes on construction and building projects in the UK, Europe and Middle East. Review of NEC3 and GCWorks contracts for London Development Agency and Her Majesty's Customs and Excise. Preparation of revised construction contract Benina Airport, Benghazi, Libya. Design reviewer for remediation of existing landfill cells and design of new landfill cells at St Helier, Jersey.

Babtie Group and latterly Jacobs Babtie 1990 - April 2007

Divisional Director,

Director managing up to 200 staff with direct involvement in undertaking a variety of projects worldwide including site investigations, materials assessment, geotechnical design, forensic engineering studies, hydrogeology, mining, geotechnical risk assessment, environmental studies and waste engineering. Particular technical expertise includes ground investigations, earthworks and foundation engineering, slope stability, landfill design. Directed redevelopment of major USAF airbase to form a new village. Contract management on construction contracts in UK and Slovakia. Expert witness/advisor for litigation, insurance, planning appeal cases for structural movements and failures for construction projects including earth build structures, coastal defences and waste projects. Earthworks expertise includes investigation and design of new/remedial earthworks and slopes for highways, railways, tunnels, ports, cliffs and reclamation sites for housing and commercial development on soft ground. Projects include MRT and DTSS tunnels and shafts, Singapore, 2000Ha reclamation Jakarta, Indonesia, earth slopes for London Underground and Network Rail.

Dobbie and Partners 1974 - 1990

Junior Engineer to Associate Partner,

Projects in the UK, West Africa and Middle East including soft ground tunnels, dams, major highway earthworks, slopes and foundations, tidal and non tidal defences, reinforced embankments and ultra lightweight embankments, remedial works for slope and cliff failures, residential, industrial and heavy commercial foundation. Prepared research reports for TRL on A12 Great Yarmouth Western Bypass. Expert witness at arbitration with respect to drainage trench excavations in Norfolk.

Appointments:

East Anglian Branch, Institution of Highways and Transportation
Secretary 1986-1989

Institution of Civil Engineers Site Investigation Steering Group Working Panel Three – Procurement
Member 1991-1993

Committee C12 Earthworks Drainage & Subgrade Permanent International Association of Road Congresses UK Member 1994-1996

Technical papers:

Co-author and author of seven technical papers including state of the art papers in polystyrene fill design and construction. Some specific papers are detailed below:-

Design of reinforced embankments for Great Yarmouth Bypass (with D Williams) Proc 11th Int. Conference on Soil Mechanics and Foundation Engineering, San Francisco, USA pp 1811-1814 1985

Geotechnical investigation, design and construction on soft compressible soils. Sino-British Highways and Urban Conference, Beijing, China pp 171-182 1986

Polystyrene as an ultra lightweight engineered fill. Engineered Fills, Newcastle, UK Thomas Telford pp 281-301 1993

United Kingdom Design and Construction Experience with EPS, Tokyo, Japan. EPS Tokyo '96 EDO Japan pp 236-246 1996

APPENDIX B – Photographs showing foundation arrangements

Photograph B1 – Foundation pads

Photograph B2 – Pile Cap Foundation

APPENDIX C – Photographs showing spalling, failed repairs & alignment issues

PHOTOS OF SPALLING, ALIGNMENT AND FAILED CONCRETE REPAIRS

CGB Northern section, Milton to Histon

CH19261 C/B – Previous concrete repair has failed (nearside)

CH18876 C/B – Previous concrete repair has failed (nearside)

CH18786 C/B – Spalling of concrete on running surface (offside)

CH18756 C/B – Previous concrete repair has failed (nearside)

CH18261 S/I B – beam dropped (nearside)

CH17856 C/B – Laterally displaced (offside)

CH17811 C/B – Dropped beam (offside)

CH17796 C/B – Twisting spacer beam

CH177796 SI/B – Twisting spacer beam

CH17751 C/B –beam dropped (nearside)

CH17736 C/B – Laterally displaced (nearside)

CH17706 C/B – Laterally displaced (nearside)

CH17691 S/I B – Laterally displaced (offside)

CH17646 C/B – spalling of concrete on running beam (nearside)

CH17631 C/B – beam dropped (offside)

CH17631 SI/B – beam dropped (nearside)

CH17586 SI/B – beam dropped (nearside)

CH17586 C/B – beam dropped

CH17586 C/B – Laterally displaced

Orchard Park, Iceni way to Cambridge Rd (East to West)

Beam 1 - beam dropped

Beam 1 - Twisting spacer beam

Beam 9 – Broken spacer beam

Beam 10 – Dropped beam

Beam 10 – Twisting spacer beam

Southern section, Trumpington P&R to railway stations

6th beam from Shelford Rd Bridge towards P&R – dropped beam

CH43102 – spalling of concrete on upstand

CH43087 – dropped beam

CH43072 - spalling of concrete on upstand

CH43072 - dropped beam

CH42997 – Previous concrete repair has failed

CH42274 S/B – spalling of concrete on upstand (nearside)

CH42259 S/B – spalling of concrete on upstand (offside)

CH42259 P&R/B – spalling of concrete on upstand (nearside)

CH42229 S/B – spalling of concrete on upstand (offside)

CH42199 S/B – Twisting spacer beam

CH42124 S/B – spalling of concrete on upstand (nearside)

CH41944 S/B – spalling of concrete on upstand (nearside)

CH41048 P&R/B – spalling of concrete on running beam (nearside)

Addenbrookes Link Road

CH60262 H/B - spalling of concrete on running beam (nearside)

CH60262 H/B – dropped beam (nearside)

CH60387 H/B – spalling of concrete on running beam (offside)

CH60417 H/B - spalling of concrete on running beam (nearside)

APPENDIX D – Correspondence from the Council and Atkins

My ref:
Your ref:
Date: 7 August 2014
Contact: Campbell Ross-Bain
Direct dial: 01223 845561
E Mail: Campbell.ross-bain@cambridgeshire.gov.uk

Cambridgeshire County Council

Economy, Transport and Environment
Executive Director, Graham Hughes

Box No. ET1026
Trumpington Park & Ride
Hauxton Road
Cambridge
CB2 9FT

Mr A.J. Cort
Property & Infrastructure
Capita
St.Davids House
Pascal Close
St.Mellons
Cardiff CF3 0LW

Dear Mr Cort

Severe Infrastructure Damage Procedure – Cambridge Guided Busway

Further to your enquiry I can confirm the procedure when shim/bearing loss is apparent with associated step(s) in the running surface is as follows.

Once damage has been reported to the Busway team by either of the Bus Operator's or picked up via our CCTV, an inspection is carried out immediately by the team.

A decision is made regarding severity of the rocking. If not severe then a 10 mph speed limit is imposed on the guideway affected. If severe, but the bus is still able to proceed through the area at 5 mph then this limit will be imposed. If the severity of the rocking causes a hazard to the bus or is likely to damage the vehicle then a diversion is put in place around the affected area.

In all cases the Skanska quick response team will be called to investigate the damage and remediate as soon as possible, either during engineering hours, or during a full closure of the Guideway if the work cannot be undertaken within this time-frame.

Yours sincerely

Campbell Ross-Bain
Bus Operations & Facilities Manager

Explanation of the basis of the CGB bearing survey Jan-Feb 2014

The following has been provided at the request of Capita, providing Experts engineering advice for Cambridgeshire County Council in respect of their dispute with BAM Nuttall over the uncorrected Defects on the Cambridgeshire Guided Busway.

The survey was undertaken by Skanska staff under the direction of the Supervisor Mr. Robin Clarke.

The survey had two objectives, firstly to attempt to provide the data to support an understanding of the extent of the manifestation of the bearing displacement Defect (Ref DEF 287a). Observations prior to this survey related only to those locations where significant differences in the level of the running surface across guideway joints had necessitated an investigation of the underlying cause and replacement of the observed displaced bearings and/or shims. The second objective was to confirm that the bolts fixing the lateral beam restraints to the foundations were torqued to the value specified by the designer, a potential factor in the lateral beam displacement Defect (Ref DEF 288).

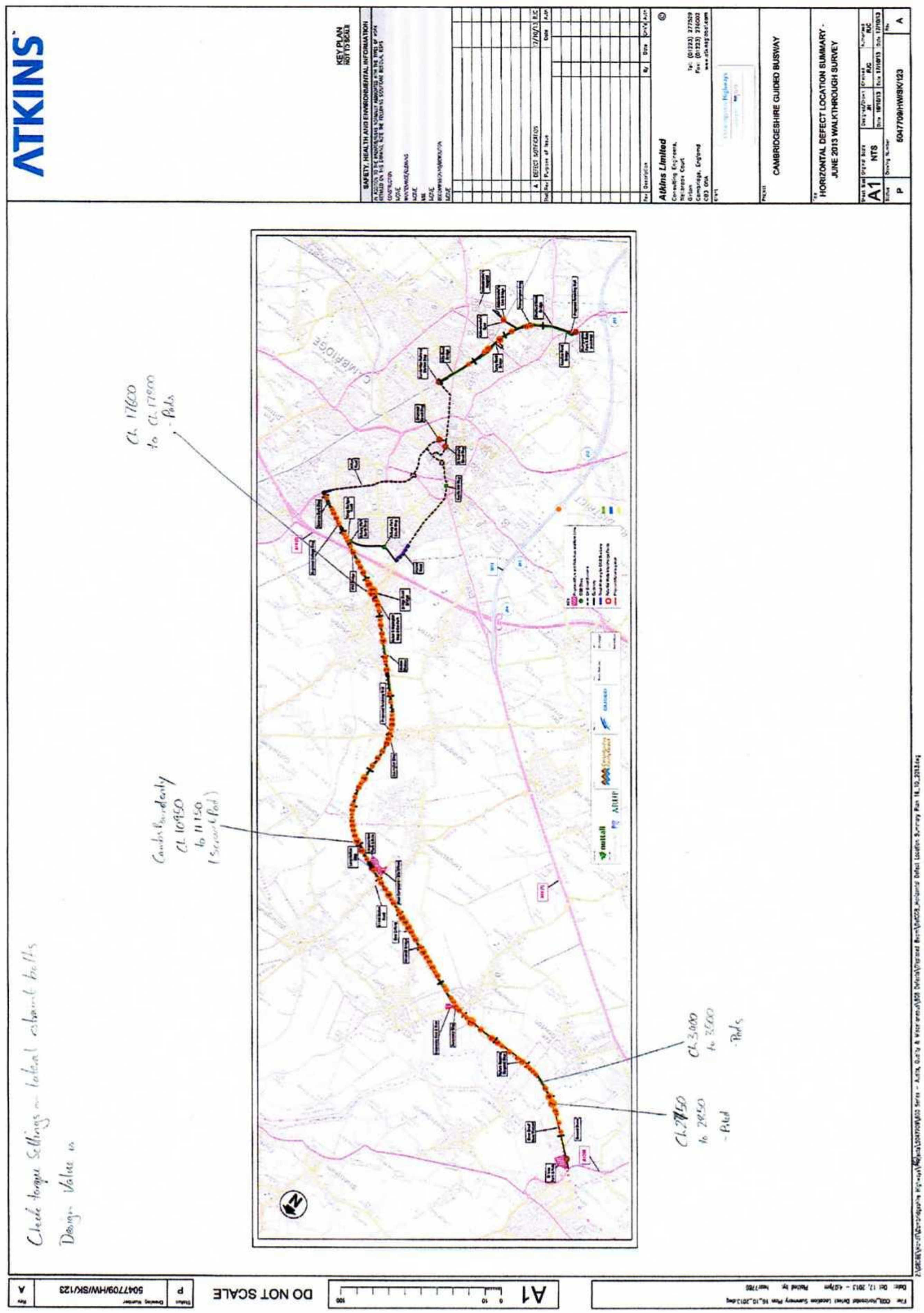
The first objective was addressed by exposing the supporting bearings and shims beneath the guideway beams by excavating the fill between the guideway beams, and recording the position of the bearings with a photographic record to permit later analysis of the degree of displacement of the bearings and shims over the period following construction.

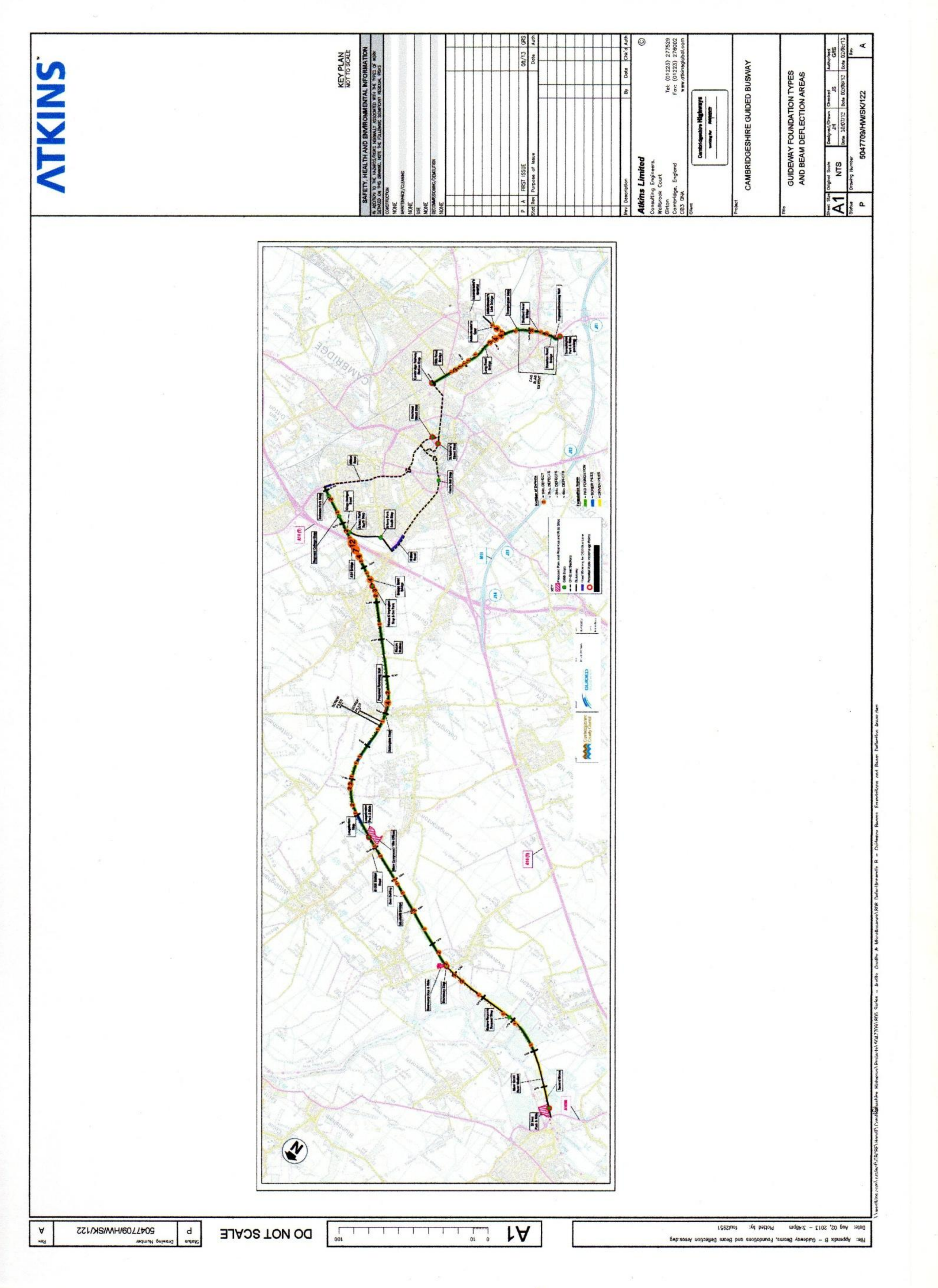
The second objective was addressed by exposing the lateral restraint bracket holding down bolts as part of the same excavation. A calibrated torque wrench was used to apply a torque to the bolts in incrementally increasing values up to the limit specified by the designer.

Four areas were surveyed in total, with observations relating to both objectives taken at all locations.

The attached hand annotated plan (a modified copy of Sketch ref. 5047709/HW/SK/123 previously issued as part of the DEF288 notification) shows the four areas covered by the bearing survey. The Supervisor selected the areas to provide sample surveys of the varying foundation types occurring on the guideway; driven pile, screw pile and pad foundations and selected the respective section chainage lengths such that the percentage of the sample of each foundation type reflected the proportion of the foundation type as occurring on the whole the northern section of the guideway.

The Supervisor also sought to include areas with high and low concentrations of lateral relative beam displacements (the locations of these displacements being indicated by orange points on the sketch) and of the vertical relative beam displacements (as shown on Sketch ref 5047709/HW/SK/122, previously issued as part of the DEF287A notification).


ATKINS
KEY PLAN
NOT TO SCALE
Atkins Limited
CAMBRIDGESHIRE GUIDED BUSWAY
HORIZONTAL DEFECT LOCATION SUMMARY - JUNE 2013 WALKTHROUGH SURVEY
A1
NTS
5047709/HW/SK/123
DO NOT SCALE


ATKINS
KEY PLAN
NOT TO SCALE
SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION
FIRST ISSUE
Atkins Limited
Consulting Engineers,
Wellbrook Court
Girton
Cambridge, England
CB3 0NA
Tel: (01223) 277529
Fax: (01223) 276002
CAMBRIDGESHIRE GUIDED BUSWAY
GUIDEWAY FOUNDATION TYPES AND BEAM DEFLECTION AREAS
NTS
A1
5047709/HW/SK/122
DO NOT SCALE

APPENDIX E – Bearing survey photographs

Histon 17781 St Ives bound_1


St Ives 3478 St Ives bound_2
ROTATE 180°
2014/02/09/19:10:59

APPENDIX F – Analyses for bearing relocation (Option 3)

Statistical Analysis

1. We have made a statistical assessment of these results on the basis that 270 bearings represent a statistically small sample. We have applied statistical formulae for evaluating standard error and margin of error at, say, 95% confidence.

2. The **standard error** (SE) is the standard deviation of the sampling distribution of a statistic and is calculated by the formula: Standard Error = $((p / n) * (1 – p / n)/n)^{0.5}$

3. The **margin of error** (MofE) is a statistic expressing the amount of random sampling error in the results of a survey. The larger the margin of error, the less confidence one should have that the reported results are close to the 'true' figures; that is, the figures for the whole number of bearings (the so-called population). There are two ways of calculating the Margin of Error:

4. ~ Margin of Error at 95% confidence based on SE and cumulative probability

5. ~ Margin of Error at 95% confidence based on the formula MofE $0.98 / n^{0.5}$

6. The standard error of the reported proportion p / n of tested samples having defects measures its accuracy, and is also the estimated standard deviation of that proportion. A common statistical interpretation of this would be that the true proportion of defects is highly likely to be located within two estimated standard deviations of the reported proportion p / n.

7. The reported proportion p / n plus or minus the margin of error at 95% confidence level will give the corresponding confidence intervals for the sample testing.

8. On this basis, the following figures and graphs have been developed for the statistical range calculated for a confidence level of 95%:

Statistical Analysis of Jan 2014 Survey Sample of Bearings/Shims

No of bearings in meaningful sample	270		
No of displaced bearings > 10mm	181		
Proportion of displ/total =	0.67		
Standard Error (SE) =	2.86%		
Margin of Error @ 95% confidence, from SE =	5.61%		
Confidence interval@ 95% confidence =	67.04%	+/-	5.61%
=	**72.64%**	**or**	**61.43%**

alpha =	1-0.95	0.05		
critical probability	p* =		1-alpha/2	0.975
cumulative probability =			p*	0.975
critical value (CV) =				1.96
Standard Error		3.20%		
Margin of error	+/- 6.20%		6.27%	

Alternatively

Margin of Error @ 95% confidence ($0.98/n^{0.5}$) =	5.96%		
Confidence interval@ 95% confidence =	67.04%	+/-	5.96%
=	**73.00%**	**or**	**61.07%**

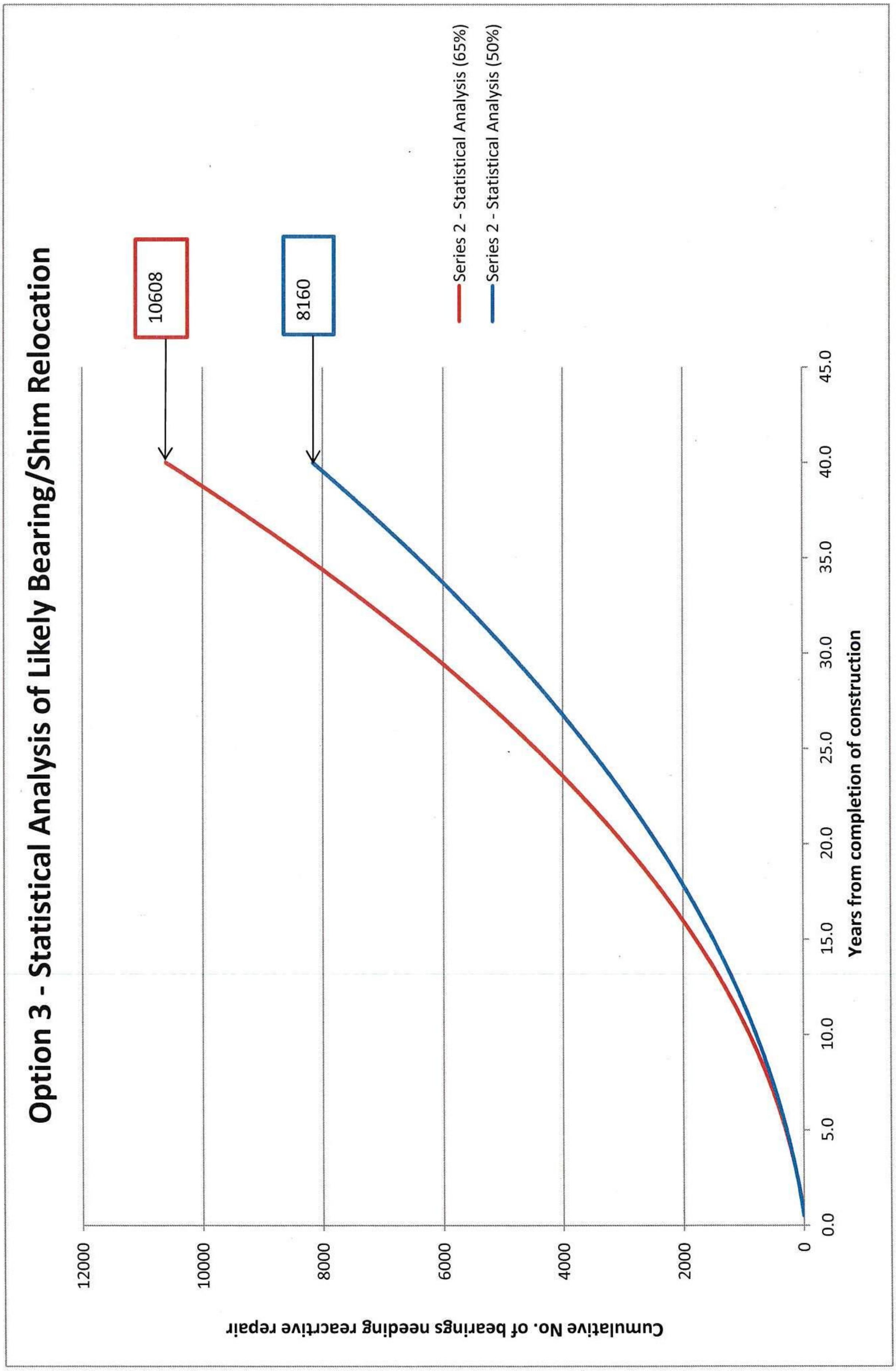
Statistical Analysis of Sample Excluding Histon

No of bearings in meaningful sample	164		
No of displaced bearings > 10mm	94		
Proportion of displ/total =	0.57		
Standard Error (SE) =	3.86%		
Margin of Error @ 95% confidence, from SE =	7.57%		
Confidence interval@ 95% confidence =	57.32%	+/-	7.57%
=	**64.89%**	**or**	**49.75%**

Alternatively

Margin of Error @ 95% confidence ($0.98/n^{0.5}$) =	7.65%		
Confidence interval@ 95% confidence =	57.32%	+/-	7.65%
=	**64.97%**	**or**	**49.66%**

At 50%	**Bearing Replacement after 40 years**	**8160**
At 65%	**Bearing Replacement after 40 years**	**10608**


Option 3 - Statistical Analysis of Likely Bearing/Shim Relocation
10608
8160
Series 2 - Statistical Analysis (65%)
Series 2 - Statistical Analysis (50%)
Cumulative No. of bearings needing reactive repair
12000
10000
8000
6000
4000
2000
0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
Years from completion of construction

Incremental Analysis

9. We have also carried out an analysis of the survey data taking account of the extent of displacement of the shims. This extent has been considered in incremental bands of 10-15mm, 16-20mm, 21-25mm, 26-30mm, 30-35mm, and greater than 35mm.

10. On this basis, the following figures and graphs emerge for the incremental analysis, recognising that the larger the shim displacement, the earlier will be the need for its replacement.

INCREMENTAL ANALYSIS OF BEARING SURVEY(JANUARY 2014) - INCLUDING HISTON INFLUENCE

ASSESSMENT OF PHOTOGRAPHS OF BEARINGS

Total bearings	270	2758 on	52
		3403 on	56
Displaced bearings	181	11126 on	60
		17601 on	112
			280

2750-2850 St Ives		3400-3500 St Ives		10930-11141 Longstanton		17600-17800 Histon	
> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm
28	20	31	25	35	25	87	19

Histon	82.1%	87 out of	106
Remainder	57.3%	94 out of	164
Overall	67.0%		

Threshold for repair of bearings - say 160 mm

After 40 years, displacement > > 10mm gives 40/2.5*10 = 160 mm

Total length for replacement 40798 m

Assume Histon section is from Histon Jtn to A14 Bridge (bubble of defects on 5047709/HW/SK/122A)

17480 to 18830 1350 m

Total No. of bearings approx 12 per 30 16320 No.

At least 50% bearing repairs 8160 no. minimum

ASSESSMENT OF BEARINGS SURVEYED WITH > 10MM MOVEMENT

2750-2850 St Ives		3400-3500 St Ives		10930-11141 Longstanton		17600-17800 Histon	
> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm
28	20	31	25	35	25	87	19

Breakdown of Movements

30mm

	<10mm	10-15mm	16-20mm	21-25mm	26-30mm	31-35mm	>35mm	Total	Non
2750-2850	20	21	4		3			52 St Ives	4
3400-3500	25	25	3				3	56 St Ives	0
10930-11141	25	27	4		2		2	60 Longstanton	0
17600-17800	19	47	12	8	3	0	17	106 Histon	6

Typical Effect on Whole Guideway

Movement after 2.5 years	Tine for bearings/ to come out from Jan 2014		Guideway except Histon No.	Guideway except Histon Distance surveyed	Guideway except Histon Total length	Histon No.	Histon Distance surveyed	Histon Total length, say	Number Bearings to be Repaired	Cumulative Bearings to be Repaired
										126 at 2.5 years
35	**13.71**	years	5	411	39448	17	200	1350	595	**721**
30	**16.00**	years	5	411	39448	3	200	1350	500	**1221**
23	**20.87**	years	0	411	39448	8	200	1350	54	**1275**
18	**26.67**	years	11	411	39448	12	200	1350	1137	**2412**
13	**36.92**	years	73	411	39448	47	200	1350	7324	**9736**

INCREMENTAL ANALYSIS OF BEARING SURVEY(JANUARY 2014) - EXCLUDING HISTON INFLUENCE

ASSESSMENT OF PHOTOGRAPHS OF BEARINGS

Total bearings	270	2758 on	52
		3403 on	56
Displaced bearings	181	11126 on	60
		17601 on	112
			280

2750-2850 St Ives		3400-3500 St Ives		10930-11141 Longstanton		17600-17800 Histon	
> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm
28	20	31	25	35	25	87	19

Histon	82.1%	87 out of	106
Remainder	57.3%	94 out of	164
Overall	67.0%		

Threshold for repair of bearings - say 160 mm

After 40 years, displacement > > 10mm gives 40/2.5*10 = 160 mm

Total length for replacement 40798 m

Assume Histon section is from Histon Jtn to A14 Bridge (bubble of defects on 5047709/HW/SK/122A)

17480 to 18830. 1350 m

Total No. of bearings approx 12 per 30 16320 No.

At least 50% bearing repairs 8160 no. minimum

ASSESSMENT OF BEARINGS SURVEYED WITH > 10MM MOVEMENT

2750-2850 St Ives		3400-3500 St Ives		10930-11141 Longstanton		17600-17800 Histon	
> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm	> 10 mm	< 10 mm
28	20	31	25	35	25	87	19

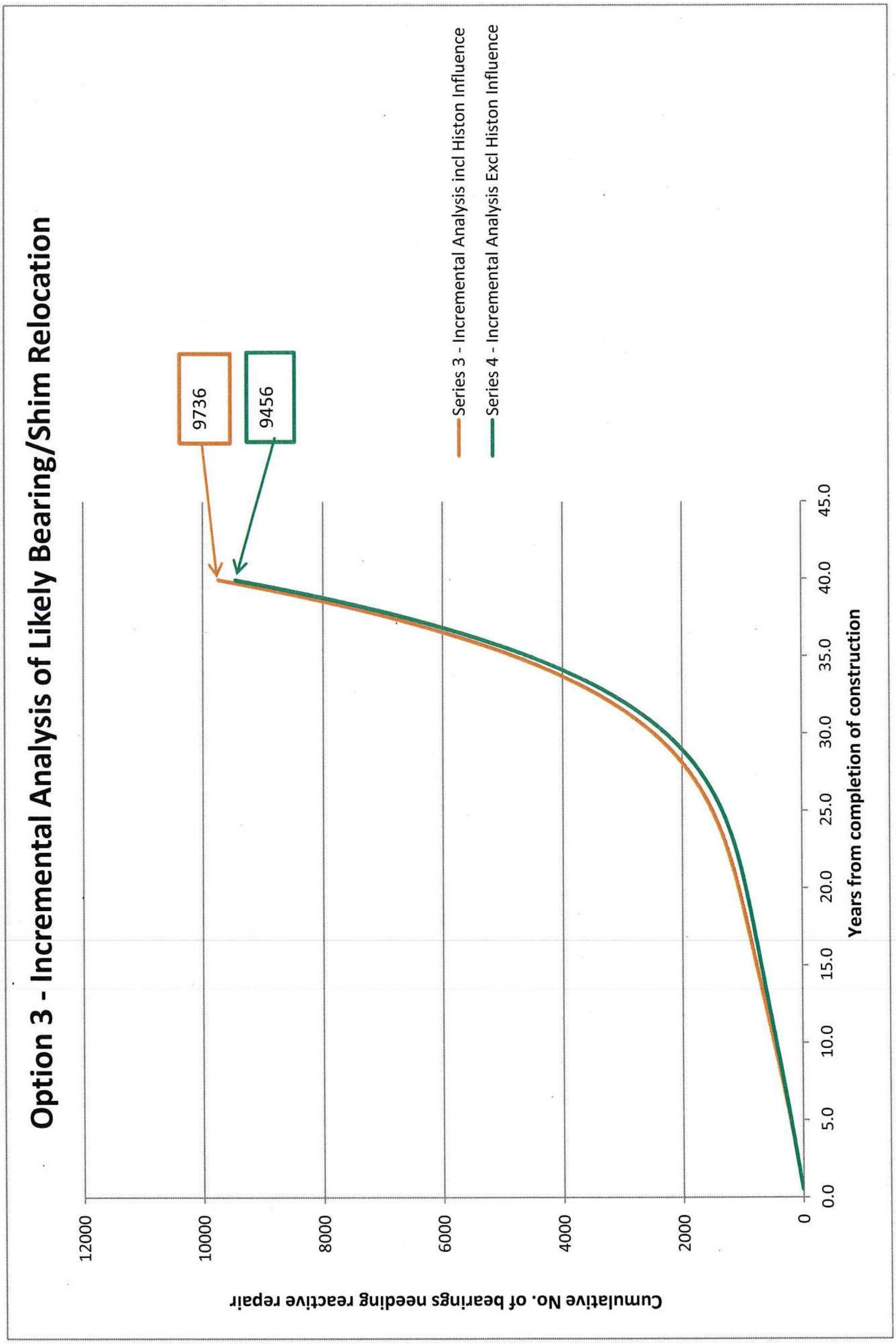
Breakdown of Movements

30mm

	<10mm	10-15mm	16-20mm	21-25mm	26-30mm	31-35mm	>35mm	Total	Non
2750-2850	20	21	4		3			52 St Ives	4
3400-3500	25	25	3				3	56 St Ives	0
10930-11141	25	27	4		2		2	60 Longstanto	0
17600-17800	19	47	12	8	3	0	17	106 Histon	6

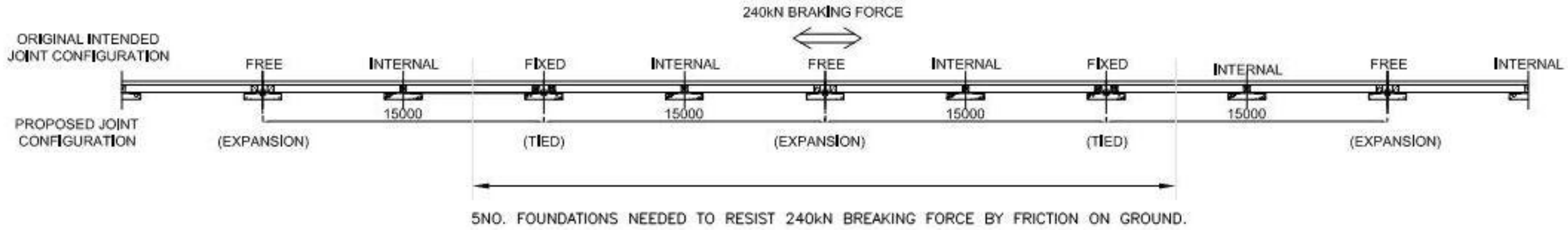
Typical Effect on Whole Guideway

Movement after 2.5 years	Tine for bearings/ to come out from Jan 2014	Guideway except Histon No.	Guideway except Histon Distance surveyed	Guideway except Histon Total length	Histon No.	Histon Distance surveyed	Histon Total length, say	Number Bearings to be Repaired	Cumulative Bearings to be Repaired
									126 at 2.5 years
35	**13.71** years	5	411	40798	17	200	0	496	**622**
30	**16.00** years	5	411	40798	3	200	0	496	**1118**
23	**20.87** years	0	411	40798	8	200	0	0	**1118**
18	**26.67** years	11	411	40798	12	200	0	1092	**2210**
13	**36.92** years	73	411	40798	47	200	0	7246	**9456**


Option 3 - Incremental Analysis of Likely Bearing/Shim Relocation
9736
9456
Series 3 - Incremental Analysis incl Histon Influence
Series 4 - Incremental Analysis Excl Histon Influence
Cumulative No. of bearings needing reactive repair
0
2000
4000
6000
8000
10000
12000
Years from completion of construction
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0

APPENDIX G – Option 1 remedial scheme, figures 1 to 6

ADEQUATE LONGITUDINAL RESTRAINT OF THE GUIDERAIL IS REQUIRED TO STOP THE STRUCTURE "SLIDING" UNDER EXTREME BRAKING OF VEHICLES



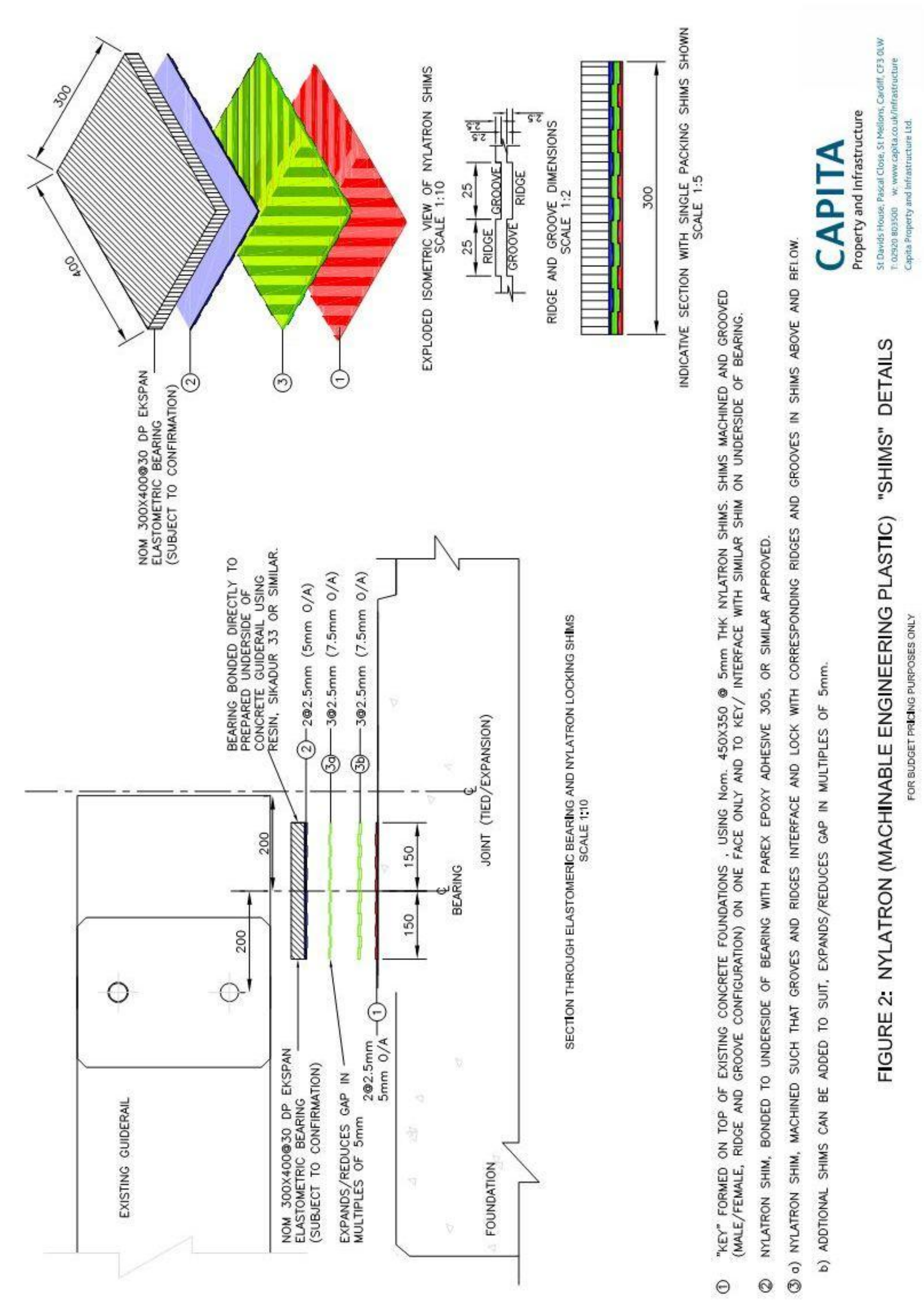
ELEVATION OF TYPE 1, INDICATIVE ARRANGEMENT (WITH PAD FOUNDATIONS, PILE CAPS SIMILAR)

LACK OF LONGITUDINAL RESTRAINT PROVIDED AT "FIXED" SUPPORT JOINTS BY THE FOUNDATIONS/ SUBSTRUCTURE. A SINGLE "FIXED" SUPPORT IS INADEQUATE TO RESTRAIN THE MAXIMUM REQUIRED LONGITUDINAL (BRAKING) FORCES. THESE FORCES NEED TO BE DISTRIBUTED AND SPREAD OVER NOMINALLY FIVE ADJACENT FOUNDATIONS SUPPORTS. REPLACEMENT BEARINGS AND SHIMS TO BE PROVIDED AT ALL SUPPORTS TO FACILITATE THE TRANSFER OF THE LONGITUDINAL, AS WELL AS THE TRAVERSE, FORCES FROM THE GUIDERAILS DOWN INTO THE FOUNDATIONS. ALSO REFER TO FIGURES 2 AND 3.

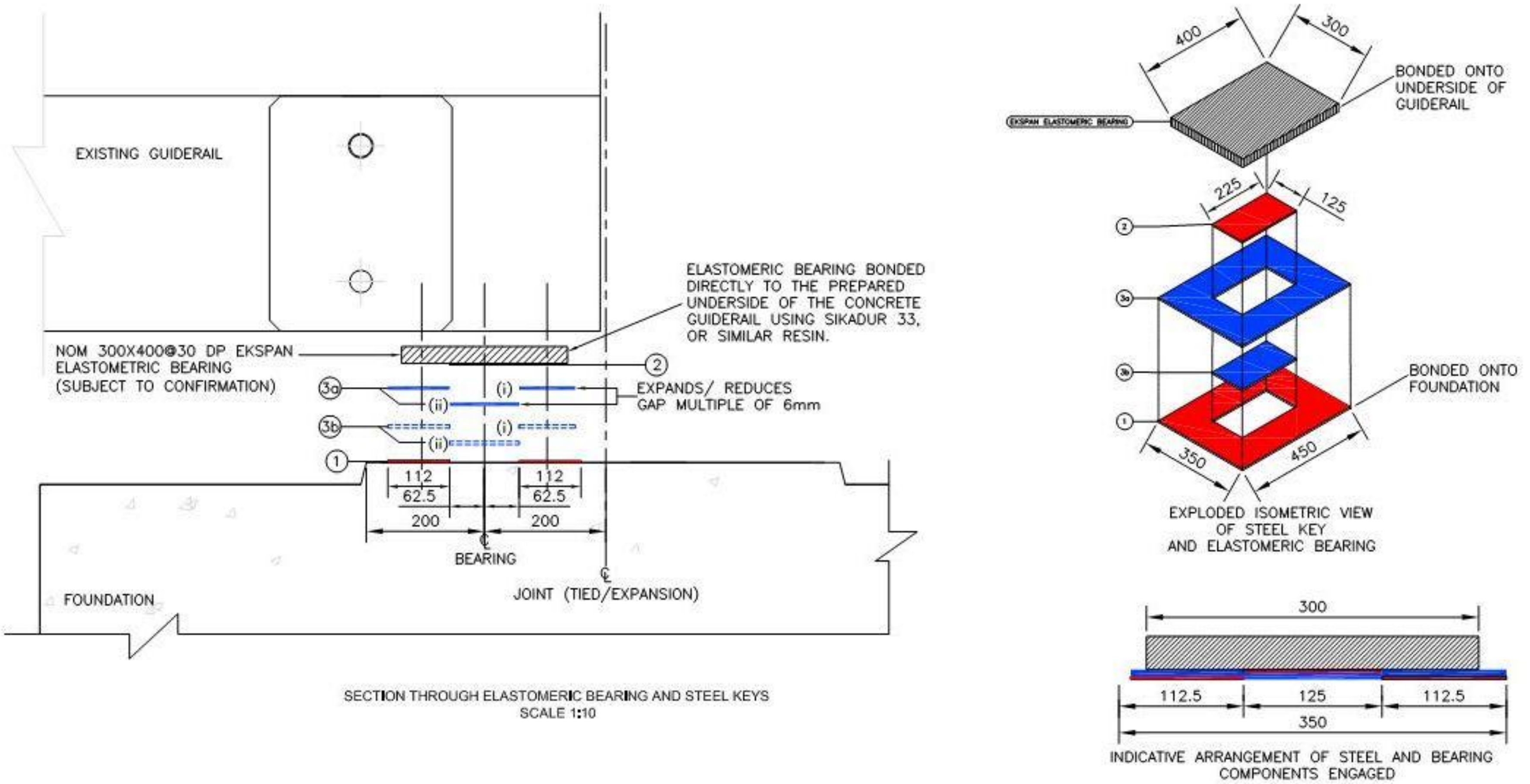
FIGURE 1: INDICATIVE ARRANGEMENT OF GUIDERAIL SUPPORTS

FOR BUDGET PRICING PURPOSES ONLY

CAPITA
Property and Infrastructure
St Davids House, Pascal Close, St Mellons, Cardiff, CF3 0LW
T: 02920 803500 w: www.capita.co.uk/infrastructure
Capita Property and Infrastructure Ltd.



300
400
NOM 300X400@30 DP EKSPAN ELASTOMETRIC BEARING (SUBJECT TO CONFIRMATION)
EXPLODED ISOMETRIC VIEW OF NYLATRON SHIMS SCALE 1:10
RIDGE
GROOVE
25
RIDGE AND GROOVE DIMENSIONS SCALE 1:2
INDICATIVE SECTION WITH SINGLE PACKING SHIMS SHOWN SCALE 1:5
EXISTING GUIDERAIL
FOUNDATION
NOM 300X400@30 DP EKSPAN ELASTOMETRIC BEARING (SUBJECT TO CONFIRMATION)
EXPANDS/REDUCES GAP IN MULTIPLES OF 5mm
2@2.5mm 5mm O/A
BEARING BONDED DIRECTLY TO PREPARED UNDERSIDE OF CONCRETE GUIDERAIL USING RESIN, SIKADUR 33 OR SIMILAR.
2@2.5mm (5mm O/A)
3@2.5mm (7.5mm O/A)
3@2.5mm (7.5mm O/A)
200
150
BEARING
JOINT (TIED/EXPANSION)
SECTION THROUGH ELASTOMERIC BEARING AND NYLATRON LOCKING SHIMS SCALE 1:10
1 "KEY" FORMED ON TOP OF EXISTING CONCRETE FOUNDATIONS, USING Nom. 450X350 @ 5mm THK NYLATRON SHIMS. SHIMS MACHINED AND GROOVED (MALE/FEMALE, RIDGE AND GROOVE CONFIGURATION) ON ONE FACE ONLY AND TO KEY/ INTERFACE WITH SIMILAR SHIM ON UNDERSIDE OF BEARING.
2 NYLATRON SHIM, BONDED TO UNDERSIDE OF BEARING WITH PAREX EPOXY ADHESIVE 305, OR SIMILAR APPROVED.
3 a) NYLATRON SHIM, MACHINED SUCH THAT GROVES AND RIDGES INTERFACE AND LOCK WITH CORRESPONDING RIDGES AND GROOVES IN SHIMS ABOVE AND BELOW.
b) ADDTIONAL SHIMS CAN BE ADDED TO SUIT, EXPANDS/REDUCES GAP IN MULTIPLES OF 5mm.
CAPITA
Property and Infrastructure
FIGURE 2: NYLATRON (MACHINABLE ENGINEERING PLASTIC) "SHIMS" DETAILS
FOR BUDGET PRICING PURPOSES ONLY



① "KEY" FORMED ON TOP OF EXISTING CONCRETE FOUNDATIONS. USING Nom. 450X350 @ 3mm THK SHIMS. WITH 225 X125 CENTRAL RECTANGLE REMOVED. BOND TO PREPARED CONCRETE SURFACE WITH APPROPRIATE PROPRIETY EPOXY RESIN. SIKADUR 33, OR SIMILAR.

② NOMINAL 125 X 225 @ 3mm THICK SHIM PLATE, BONDED TO ELASTOMERIC BEARING USING A SUITABLE PROPRIETARY EPOXY RESIN, SIKADUR 33, OR SIMILAR.

③ a) "GAP" FILLED/ REDUCED THROUGH ADDITION /OMISSION OF 6mm THICK , i) "FRAMED" / MORTICE SHIM AND ii) TENON SHIM

b) ADDITIONAL SHIMS CAN BE ADDED TO SUIT, EXPANDS/REDUCES GAP IN MULTIPLES OF 6mm.

STAINLESS STEEL SHIMS TO BE FABRICATED FROM GRADE 316L STAINLESS STEEL TO BS EN 10088-2

FIGURE 3: EKSPAN ELASTOMERIC AND STAINLESS STEEL "SHIMS" DETAILS
INTERMEDIATE SUPPORTS SIMILAR

FOR BUDGET PRICING PURPOSES ONLY

CAPITA
Property and Infrastructure
St Davids House, Pascal Close, St Mellons, Cardiff, CF3 0LW
T: 02920 803500 w: www.capita.co.uk/infrastructure
Capita Property and Infrastructure Ltd.

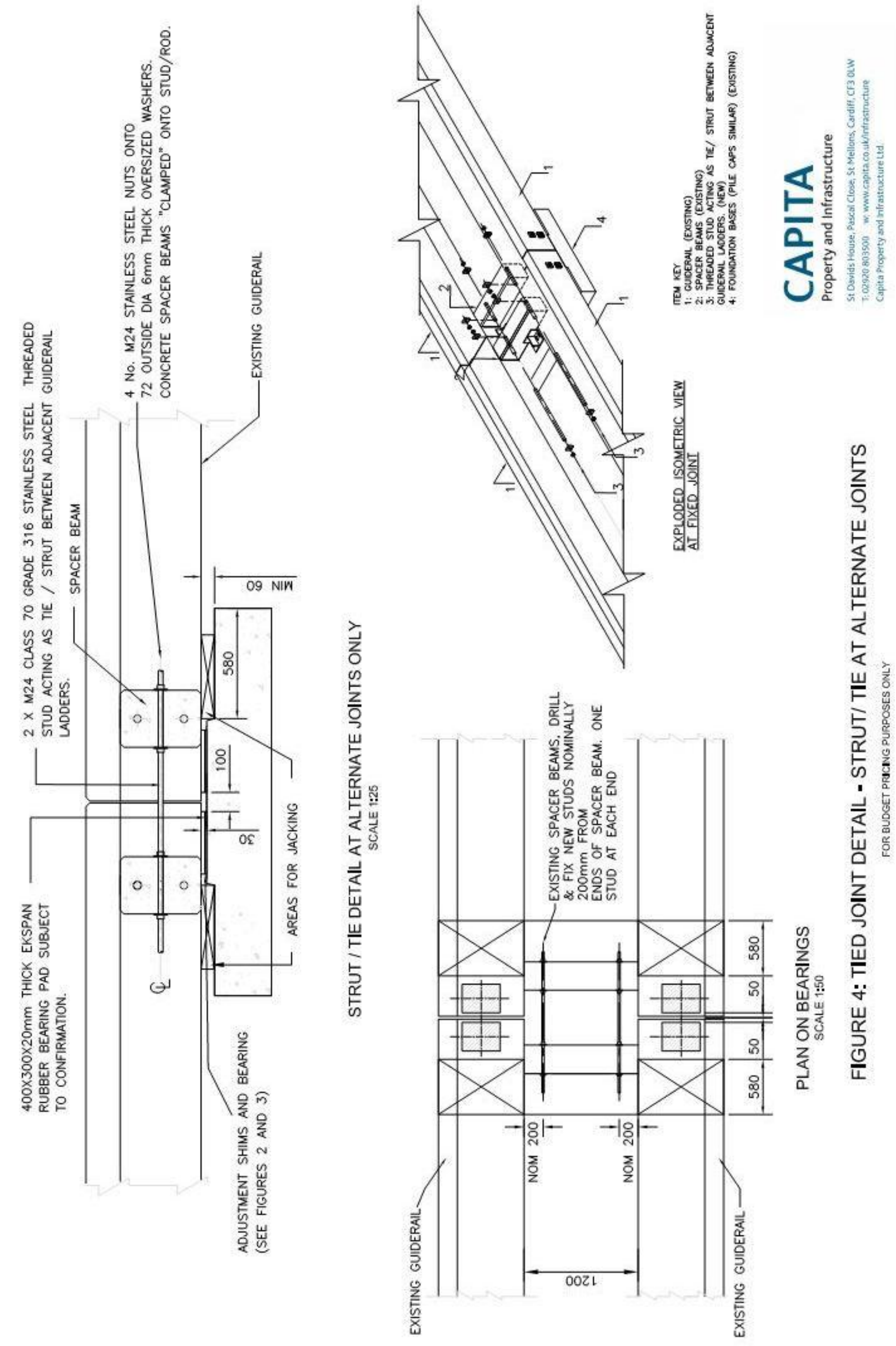


FIGURE 4: TIED JOINT DETAIL - STRUT/ TIE AT ALTERNATE JOINTS
FOR BUDGET PRICING PURPOSES ONLY

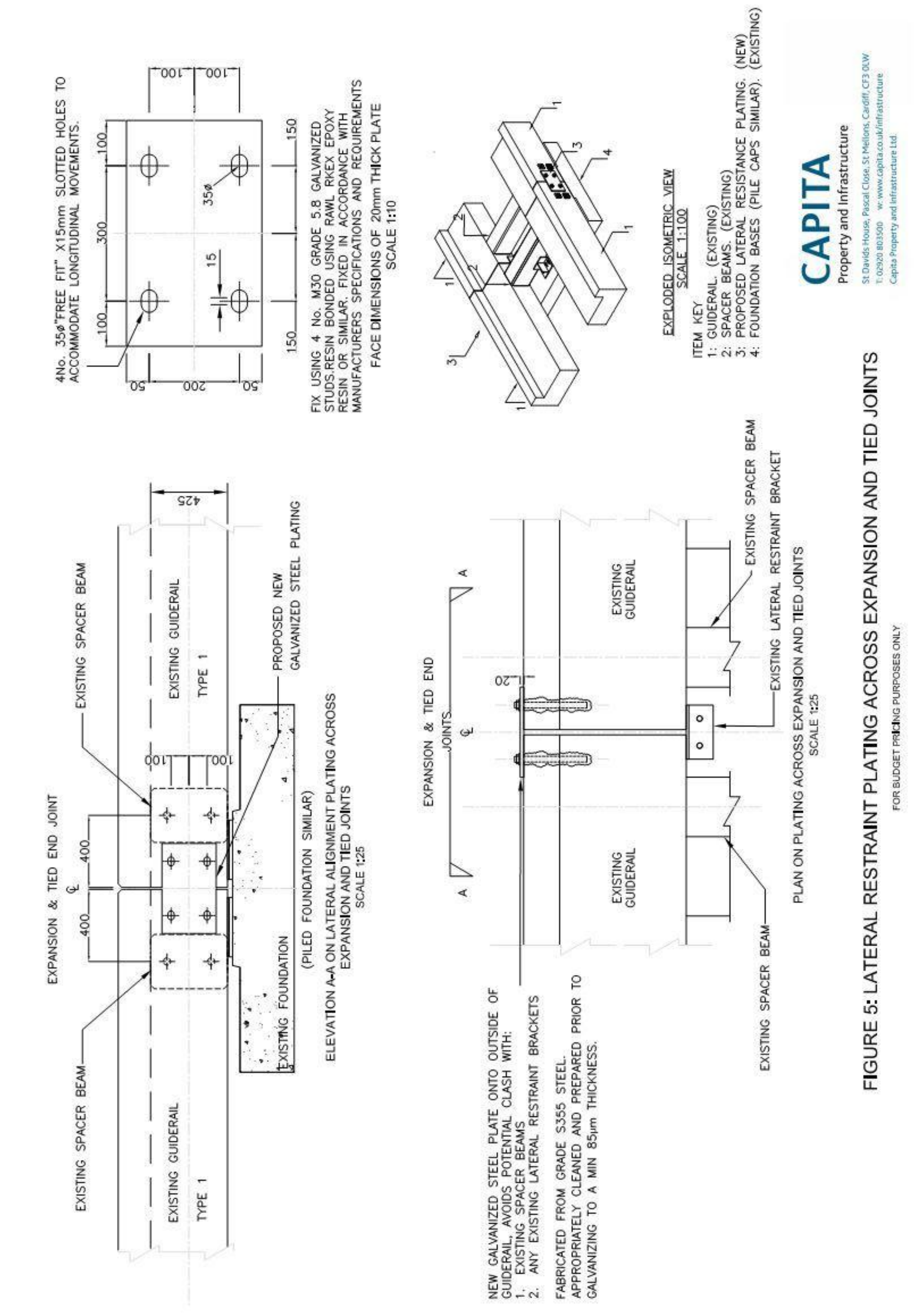
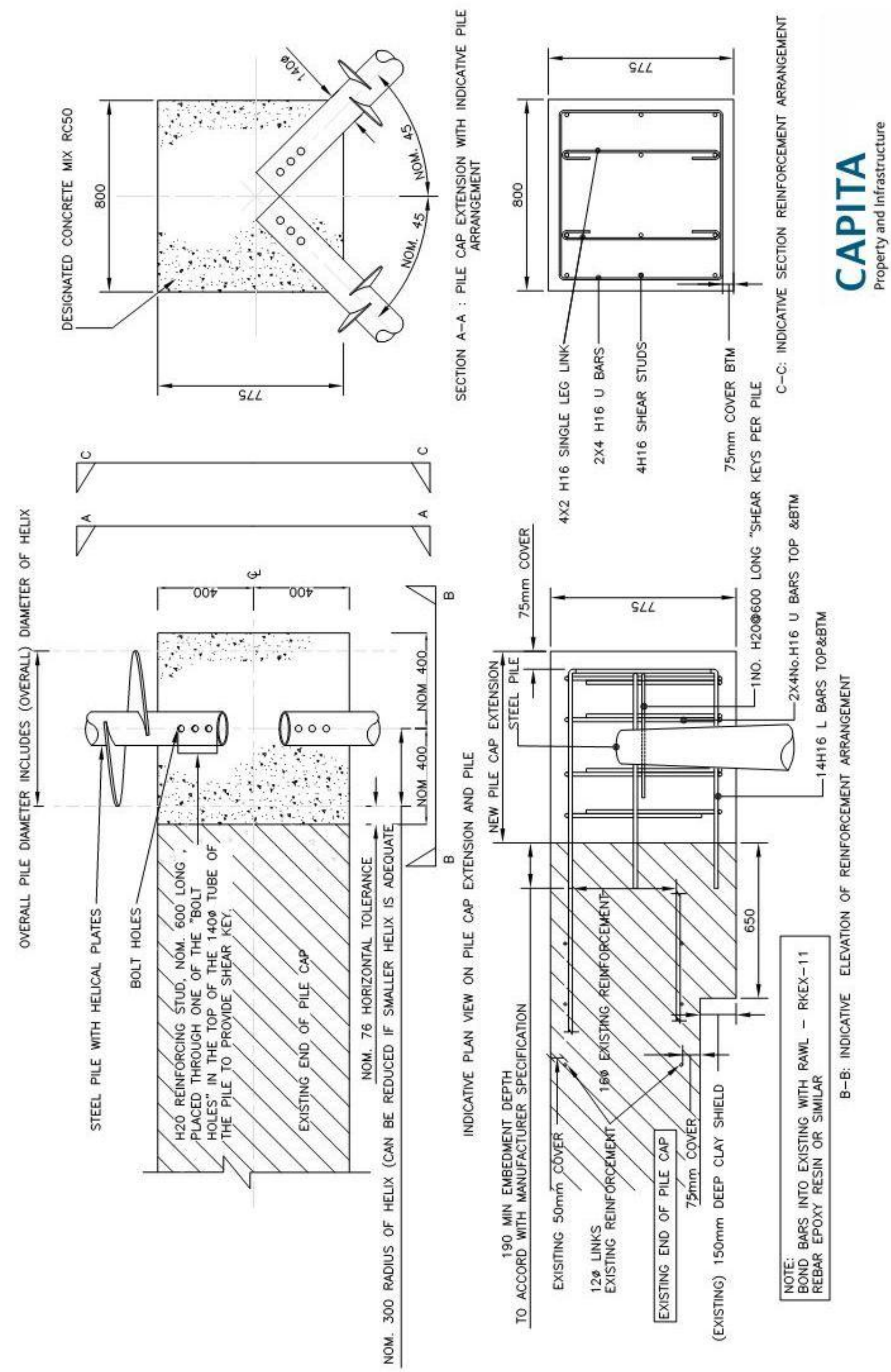


FIGURE 5: LATERAL RESTRAINT PLATING ACROSS EXPANSION AND TIED JOINTS



CAPITA
Property and Infrastructure

FIGURE 6: INDICATIVE PILE CAP AND RAKE PILING ARRANGEMENT

FOR BUDGET PRICING PURPOSES ONLY

APPENDIX H – Schedule 1 from BNL's Feb 2011 Geotechnical Report Summarising BNL's Foundation Construction

SHRINK / SWELL DUE TO TREES FOUNDATIONS(Northern Section) SCHEDULE 1

LOCATION	CHAINAGE		LOCATION	LENGTH (m)	SHRINKAGE POTENTIAL	MINIMUM GUIDEWAY FOUNDATION DEPTH	length deepened for trees(m)	length deepened for trees(%)	Length Designed to 50% NHBC (excludes low plasticity clays) (m)
	From	To				(m)			
start of guideway	1,700	2,080	start of viaduct	380	medium	piled	0		
start of viaduct	2,080	2,310	end of viaduct	230		piled	0		
	2,310	2,400		90	high	piled	0		
	2,400	3,055	Moore Brook	655	high	piled	0		
	3,055	3,785		730	high	1.00	0		
	3,785	4,200		415	high	piled	0		
	4,200	4,450		250	high	piled	0		
	4,450	6,193	Swavesy Stop	1,743	high	piled	0		
Swavesy Stop	6,300	7,800	start Over cut	1,500	high	1.00	830	55%	830
start Over cut	7,800	8,700	approx end Over cut	900	high	1.00	90	10%	90
approx end Over Cut	8,700	9,200		500	high	1.00	343	69%	343
	9,200	9,950	B1050	750	medium	0.90	395	53%	395
B1050	10,000	10,300		300	medium	0.90	22	7%	22
	10,300	10,728		428	high	1.00	0		
	10,728	10,998		270	high	piled	0		
	10,998	12,430		1,432	high	1.00	0		
	12,430	12,745		315	high	piled	0		
	12,745	13,061		316	high	1.00	0		
	13,061	13,136		75	high	piled	0		
	13,136	13,200		64	high	1.00	0		
	13,200	13,295		95	medium	0.90	0		
	13,295	14,000	Oakington	705			0		
	14,000	14500		500	medium	0.90	500	100%	500
	14,500	15,540		1,040	low	0.75	180	17%	
	15,540	16,415		875	non shrinkable	0.75	443	51%	
	16,415	17,100		685	low	0.75	124	18%	
	17,100	17,500		400	medium	0.90	254	64%	254
	17,500	20,000		2,500	medium	0.90	1350	54%	1350
	20,000	20,400		400	low	0.75	400	100%	
NORTH TOTAL				**18,543**			**4931**		**3,784**

APPENDIX I – Monitoring and survey results showing heave and differential movement

Long term monitoring

Monitoring Date		Oct-09	May-10	Jul-10	Oct-10	Oct-11	Jul-12	Jan-13	Jun-13	Dec-13	Jun-14	
Foundation Location (Chainage)		Heave Movement in mm (relative to Design level)										
17585.961		22	18	25	24	40	49	59	69	78	90	
17593.461		12	15	22	16	31	38	44	54	59	70	
17600.961		18	12	19	15	36	41	47	54	61	70	
17608.461		1	18	25	22	40	47	55	65	72	83	
17615.961			23	31	27	46	57	68	80	91	101	
17623.461		26	25	34	27	46	60	70	81	89	99	
17630.961		25	24	34	27	49	62	70	79	88	95	
17638.461		15	12	21	12	36	44	49	57	62	69	
17645.961		6	-7	4	-5	12	11	13	14	17	18	
17653.461		-8	-24	-10	-25	1	-2	-2	0	1	3	
17660.961		4	-11	-2	-15	6	3	3	4	6	7	
17668.461		-5	-23	-10	-27	5	2	3	4	5	7	
17675.961		2	-16	-6	-19	14	11	12	12	15	15	

Negative values in this table means that there was settlement compared to the design levels at the date of monitoring for that value.

August 2014 Survey with June 2014

New August 2014 survey with assessed baseline levels					Long term Monitoring survey	
Foundation Location (Chainage)	**Surveyed levels 16/08/2014**	**Assessed original rail level 2009**	**Assessed heave since 2009 in mm**	**Differential movement between adjacent foundations in mm**	**Monitored heave from 2009/2010 to June 2014 in mm**	**Differential movement between adjacent foundations in mm**
17530.961	14.323	14.222	101		-	
17535.961	14.320	14.217	103	-2	-	
17540.961	14.251	14.212	39	**64**	-	
17548.461	14.257	14.204	53	-14	-	
17555.961	14.251	14.196	55	-2	-	
17563.461	14.211	14.188	23	**32**	-	
17570.961	14.201	14.180	21	2	-	
17578.461	14.241	14.172	69	**-48**	-	

17585.961	14.270	14.164	106	**-37**	90	
17593.461	14.234	14.156	78	**28**	70	20
17600.961	14.230	14.148	82	-4	70	0
17608.461	14.231	14.141	90	-8	83	-13
17615.961	14.244	14.133	111	-21	101	-18
17623.461	14.229	14.125	104	7	99	11
17630.961	14.219	14.117	102	2	95	4
17638.461	14.180	14.109	71	**31**	69	**26**
17645.961	14.120	14.101	19	**52**	18	**51**
17653.461	14.095	14.093	2	17	3	15
17660.961	14.091	14.085	6	-4	7	-4
17668.461	14.089	14.077	12	-6	7	0
17675.961	14.080	14.069	11	1	15	-8
17683.461	14.081	14.061	20	-9	-	
17690.961	14.132	14.054	78	**-58**	-	
17698.461	14.118	14.046	72	6	-	
17705.961	14.067	14.038	29	**43**	-	
17713.461	14.111	14.030	81	**-52**	-	
17720.961	14.144	14.022	122	-41	-	
17728.461	14.126	14.014	108	13	-	
17735.961	14.137	14.006	131	-19	-	
17743.461	14.123	13.998	125	5	-	
17750.961	14.080	13.990	90	**35**	-	
17758.461	14.068	13.982	84	6	-	
17765.961	14.072	13.974	96	-12	-	
17773.461	14.044	13.967	77	20	-	
17780.961	14.035	13.959	76	1	-	
17788.461	13.977	13.951	26	**53**	-	
17795.961	13.979	13.943	36	-10	-	
17803.461	13.981	13.935	46	-10	-	
17810.961	13.936	13.927	9	**37**	-	

Differential movements in excess if 25mm are in bold

APPENDIX J – Enhanced arboricultural management

Figure	Chainage	Native Hedgerow	Dense Scrub	Scattered scrub	Existing vegetation	Screen Planting	Woodland planting	LEM	Natural Regeneration	Feature Planting	Cost implications
1	**3055 – 3785**			Remove trees within 2m of the bus way and coppice on 5/6 year cycle							Cost increase
1a	**6300 – 6748**	Trim all trees in hedgerow on annual basis									No increase
2	**6756-7168**		Coppice all trees to prevent development of large trees. Reduce coppice rotation to 6-7 years. Remove trees so that there is a 2m clearance from guideway								Cost increase
3	**7175 - 7228**		Remove all surviving trees as they are located to close to the guideway.		Monitor						One off cost
4	**7423 – 7543**		Remove all surviving trees as they are located to close to the guideway.	Monitor					Maintain trees as a hedgerow.		One off cost
5	**7423 – 7543**		Coppice all trees to prevent development of large trees. Reduce coppice rotation to 5/6 years. Remove trees so that there is a 2m clearance from guideway								Cost increase

Figure	Chainage	Native Hedgerow	Dense Scrub	Scattered scrub	Existing vegetation	Screen Planting	Woodland planting	LEM	Natural Regeneration	Feature Planting	Cost implications
6	**7843-8098**		Remove trees so that there is a 2m clearance from guideway.		Trim back on an annual basis and maintain as hedgerow			Monitor			Cost increase
7	***8555 – 8811***			Remove all tree growth within 2m of tack-way. Coppice all trees on a 5/6 year cycle. Alternatively mow area every 3 years	Monitor						Cost increase
8	**8818-9140**			Remove all tree growth within 2m of tack-way. Coppice all trees on a 5/6 year cycle.	Maintain as hedgerow						Cost increase
9	**9238-9778**		Remove all tree growth within 2m of tack-way. Coppice all trees on a 5/6 year cycle. Alternatively manage as a hedgerow on 2 year trim cycle.								Cost increase
10	**9903-10442**	Trim annually including trees that would develop into large specimen trees.	Remove all trees growing within 2m of tack-way. Coppice all trees on a 5/6 year cycle.			Coppice management of all trees by not allowing large trees to develop. Or maintain as a hedgerow					Cost increase

Figure	Chainage	Native Hedgerow	Dense Scrub	Scattered scrub	Existing vegetation	Screen Planting	Woodland planting	LEM	Natural Regeneration	Feature Planting	Cost implications
11	**10495 - 10600**	Trim annually including trees that would develop into large specimen trees.		Coppicing and thinning on 5/6 year cycle							Cost increase
12	**10608-11194**	Trim annually including trees that would develop into large specimen trees.	Remove trees within 2m of guideway and maintain on a 5/6 year coppice cycle	Coppicing on 5/6 year cycle							Cost increase
13	**11201-11441**	Trim annually including trees that would develop into large specimen trees.	Remove trees within 2m of guideway and maintain on a 5 year coppice cycle								Cost increase
14	**11494-12146**			Low risk trees located behind wet ditch	Low risk trees located behind wet ditch.						No cost increase
15	**12154 – 12431**			Remove remaining trees	Low risk trees located behind wet ditch.						One off cost
16	**12745-13054**	Trim annually including trees that would develop into large specimen trees.		Remove remaining trees	Remove trees on embankment. Other trees are located on the other side of a ditch. Monitor situation						Cost increase

Figure	Chainage	Native Hedgerow	Dense Scrub	Scattered scrub	Existing vegetation	Screen Planting	Woodland planting	LEM	Natural Regeneration	Feature Planting	Cost implications
17	**13136-13771**		Treat as hedgerow and trim on every year including trees that would develop into large specimens	Remove remaining trees						Sand/ gravel present here so low risk. Monitor	Cost increase
18	**13778-13916**	Trim annually including trees that would develop into large specimen trees.									No cost increase
19	**14000-14500**		Remove all trees within 2m of track-way. Coppice on 5/6 year cycle.	Remove all trees within 2m of track-way. Coppice on 5/6 year cycle.				Trim along maintenance track			Cost increase
20	**14500-16415**						Remove all trees within 2m of trackway reduce stem numbers by 30%. Coppice on 5/6 year cycle.				Cost increase
21	**16415-17500**	Trim annually including trees that would develop into large specimen trees.									No increase

Figure	Chainage	Native Hedgerow	Dense Scrub	Scattered scrub	Existing vegetation	Screen Planting	Woodland planting	LEM	Natural Regeneration	Feature Planting	Cost implications
22	**17510-18883**	Trim annually including trees that would develop into large specimen trees.		Remove						Maintain hedges, remove standard trees.	Cost increase
23	**18891-19535**	Trim annually including trees that would develop into large specimen trees.	Coppice all trees on 5/6 year cycle. – Remove poplar trees around pylon								Cost increase

APPENDIX K – NOTES ON THE EFFECTS OF TREE ROOTS ON SHRINKABLE CLAYS

1. Climatic conditions generally only affect the ground to around 1m depth in the southern part of England, exceptionally to 1.5m in a very dry year. Foundations are not designed for these exceptional circumstances as any settlement of the ground in such dry years will be temporary and the ground surface will recover to its normal levels during subsequent years. Thus, in the absence of trees, foundations on clay in southern England are set at a minimum of 1m, 0.9m and 0.75m depth for high, medium and low shrinkage potential clays respectively.

2. The lateral and vertical extents to which tree roots affect the ground primarily depends on the tree's water demand, its height and the distance of the foundation from the tree trunk. These characteristics for mature specimens of each tree type are given in the NHBC Standard referred to in §66 above.

3. The lateral spread of the roots is broadly related to the height of the tree, so as a tree grows it affects a wider area around it. In broad terms, and in the design standard, the depth of roots also decreases the greater the distance between the tree trunk and the foundation. Tree roots, however, seek out the best ground to abstract water from, so the root spread both vertically and laterally, can vary from the idealised plan area and depths as defined in the design standard.

4. We are advised by our arboriculturalist colleague, Jonathan Mills, that trees adapt their root systems to environmental changes and removal of part of a root system will tend to stimulate new root growth. A healthy tree, whether juvenile, semi-mature or mature will tend to extend its roots preferentially into ground that contains both air and water, which often includes newly disturbed ground.

5. Roots will follow the line of service and drainage trenches as they are not only generally backfilled with sands but collect water from the surrounding ground due to the permeable nature of the sand backfill. Roots in such situations can thus extend well beyond the idealised plan area and depths for the tree as defined in the design standard.

6. For the same reason new tree roots can also be expected to enter the Class 6N fill placed by BNL under the foundation pads. Whilst the development of the roots into that material will not, in itself, cause settlement because such fill is not shrinkable, it will aid the roots reaching the shrinkable clays under the Class 6N fill. Thus the placement of the Class 6N fill in deepened foundations is not expected to have an influence on reducing the penetration of the roots to the depth suggested by the NHBC Standard and other publications.

7. The Class 6N fill in the foundation excavation is much more permeable than the surrounding clays and rainfall falling on the guideway will rapidly drain down into the base of the Class 6N fill via the shredded tyre infill between the guiderails. Whilst there are drains to take water out from upper part of the Class 6N fill, the infiltrating water will assist in replenishing the clay below the Class 6N fill more rapidly than in ground at the same depth away from the foundation excavation. It is thus likely that roots will preferentially develop at depth in the ground beneath the foundation excavations than in adjacent ground at the same depth. This will not, however, prevent the development of moisture deficits during drier periods of the year.

8. Records from sites monitored for research into tree-root-induced foundation movements show the greatest differential movement and seasonal movement occurs at that the outer edges of a developing root zone of a tree. In this area of the root system of a tree during summer the inflow from rainfall and

any groundwater is less than that abstracted via the roots and the clay shrinks leading to settlement. During winter the reverse occurs and the ground heaves. It returns to a similar level to that before the previous summer months. We thus expect that where ‘existing’ trees did not have roots extending to the guideway foundation at the time of excavation, or where new trees have been planted, once roots develop under the ‘shallow’ foundations, the level of the foundations and thereby the guideway will show marked seasonal fluctuations. Records from monitored research sites show seasonal variations can exceed 25mm in high shrinkage potential clays. Differential movement between ‘shallow’ foundations can in this situation be of a similar magnitude as initially it is likely that one foundation will be affected and the adjacent foundations will be unaffected.

9. There are scant records in relation to medium and low shrinkage potential clays but in our view it is reasonable to assume that trees within the latter classification are highly unlikely to cause seasonal movements that approach 25mm.

10. If the foundation defect continues to be left uncorrected and root systems of trees are allowed to develop further, the roots away from the developing outer edge of the root zone can abstract sufficient water to exceed inflow from rainfall and groundwater over a yearly cycle of weather. The ground thus develops what is called a persistent moisture deficit. Records from monitored research sites show that limited seasonal recovery (heave) will occur in such ground but each year more settlement than heave will occur leading to a gradual accumulation of settlement to the shallow foundations. As settlement builds up the seasonal fluctuations are likely to reduce in magnitude.

APPENDIX L – Foundation non-compliance and remediation locations

Below is a list of all 1222 non-compliant foundations due to settlement as described in §169 detailed by chainage location. The list excludes those foundations where the proximity of water bodies to 'existing' trees will prevent roots extending to lie under the guideway foundations. We have been guided in this by our senior arboriculturalist colleague, Mr Jonathan Mills, who considers that the spread of roots will be substantially reduced due to these features. The list includes foundations non-compliance due to 'existing' trees and newly planted trees.

6283.41	7048.41	7835.91	8623.41	9440.91	10443.33	12123.33	13496	15116.37	16278.89	17930.96	19116.26
6290.91	7055.91	7843.41	8660.91	9448.41	10450.83	12130.83	13568.5	15123.87	16293.89	17953.46	19123.76
6298.41	7063.41	7850.91	8668.41	9455.91	10458.33	12138.33	13576	15131.37	16301.39	17960.96	19131.26
6305.91	7070.91	7858.41	8675.91	9463.41	10465.83	12145.83	13583.5	15138.87	16316.39	17968.46	19138.76
6313.41	7078.41	7865.91	8683.41	9470.91	10473.33	12153.33	13591	15146.37	16323.89	17975.96	19146.26
6320.91	7085.91	7873.41	8690.91	9478.41	10480.83	12160.83	13598.5	15153.87	16331.39	17983.46	19153.76
6328.41	7093.41	7880.91	8698.41	9485.91	10488.33	12168.33	13703.5	15161.37	16338.89	18035.96	19161.26
6335.91	7100.91	7888.41	8705.91	9493.41	10450.83	12175.83	13711	15168.87	16346.39	18050.96	19168.76
6343.41	7108.41	7895.91	8713.41	9500.91	10458.33	12183.33	13718.5	15176.37	16353.89	18058.46	19176.26
6350.91	7115.91	7903.41	8720.91	9508.41	10465.83	12190.83	13726	15183.87	16361.39	18140.96	19183.76
6358.41	7123.41	7910.91	8728.41	9515.91	10473.33	12198.33	13733.5	15191.37	16368.89	18148.46	19191.26
6365.91	7130.91	7918.41	8735.91	9523.41	10480.83	12205.83	13741	15198.87	16376.39	18163.46	19198.76
6373.41	7138.41	7925.91	8743.41	9530.91	10488.33	12213.33	13748.5	15206.37	16383.89	18185.96	19206.26
6380.91	7145.91	7933.41	8750.91	9538.41	10495.83	12220.83	13756	15213.87	16391.39	18193.46	19213.76
6388.41	7153.41	7940.91	8758.41	9545.91	10502.53	12228.33	13763.5	15221.37	16398.89	18200.96	19221.26
6395.91	7160.91	7948.41	8765.91	9553.41	10510.03	12235.83	13771	15228.87	16406.39	18208.46	19228.76
6403.41	7168.41	7955.91	8773.41	9560.91	10517.53	12243.33	13778.5	15236.37	16413.89	18215.96	19236.26
6410.91	7175.91	7963.41	8780.91	9568.41	10525.03	12250.83	13786	15243.87	16436.39	18223.46	19243.76
6418.41	7183.41	7970.91	8788.41	9575.91	10532.53	12258.33	13801	15363.87	16443.89	18230.96	19251.26
6425.91	7190.91	7978.41	8795.91	9583.41	10540.03	12265.83	13808.5	15371.37	16451.39	18238.46	19258.76
6433.41	7198.41	7985.91	8803.41	9590.91	10548.53	12273.33	13868.5	15378.87	16458.89	18245.96	19266.26
6440.91	7205.91	7993.41	8810.91	9598.41	10555.83	12280.83	13876	15386.37	16466.39	18253.46	19273.76
6448.41	7213.41	8000.91	8818.41	9605.91	10562.53	12288.33	13883.5	15393.87	16473.89	18260.96	19281.26
6455.91	7220.91	8008.41	8825.91	9613.41	10570.83	12295.83	13891	15401.37	16481.39	18268.46	19288.76
6463.41	7228.41	8015.91	8833.41	9620.91	10578.53	12303.33	13898.5	15416.37	16488.89	18275.96	19296.26
6470.91	7235.91	8023.41	8840.91	9628.41	10585.83	12310.83	13916	15431.37	16496.39	18283.46	19301.26

6478.41	7243.41	8030.91	8848.41	9635.91	10592.53	12318.33	14011.37	15461.37	16503.89	18290.96	19415.15
6485.91	7250.91	8038.41	8855.91	9643.41	11005.83	12325.83	14018.87	15581.39	16511.39	18298.46	19420.15
6493.41	7258.41	8045.91	8863.41	9650.91	11013.33	12333.33	14026.37	15586.39	16518.89	18305.96	19450.15
6500.91	7265.91	8053.41	8870.91	9658.41	11020.83	12340.83	14041.37	15591.39	16578.89	18313.46	19457.65
6508.41	7273.41	8060.91	8878.41	9665.91	11028.33	12348.33	14048.87	15596.39	16593.89	18320.96	19465.15
6515.91	7280.91	8068.41	8885.91	9673.41	11035.83	12355.83	14056.37	15601.39	16601.39	18328.46	19472.65
6523.41	7288.41	8075.91	8893.41	9680.91	11043.33	12363.33	14063.87	15608.89	16608.89	18343.46	19497.65
6530.91	7295.91	8083.41	8900.91	9688.41	11050.83	12370.83	14071.37	15616.39	16616.39	18350.96	19505.15
6538.41	7303.41	8090.91	8908.41	9695.91	11058.33	12378.33	14078.87	15623.89	16623.89	18358.46	19512.65
6545.91	7310.91	8098.41	8915.91	9703.41	11065.83	12385.83	14086.37	15631.39	16631.39	18365.96	19617.65
6553.41	7318.41	8105.91	8923.41	9710.91	11073.33	12393.33	14093.87	15638.89	16638.89	18373.46	19625.15
6560.91	7325.91	8113.41	8930.91	9718.41	11080.83	12400.83	14101.37	15646.39	16736.39	18380.96	19632.65
6568.41	7333.41	8120.91	8938.41	9725.91	11088.33	12408.33	14116.37	15653.89	16743.89	18388.46	19647.65
6575.91	7340.91	8128.41	8945.91	9733.41	11095.83	12415.83	14123.87	15661.39	16818.89	18395.96	19655.15
6578.41	7348.41	8135.91	8953.41	9740.91	11103.33	12768.5	14131.37	15676.39	16826.39	18463.46	19662.65
6583.41	7355.91	8143.41	8960.91	9748.41	11110.83	12776	14138.87	15706.39	16833.89	18470.96	19670.15
6590.91	7363.41	8150.91	8968.41	9755.91	11118.33	12783.5	14146.37	15713.89	16841.39	18478.46	19677.65
6598.41	7370.91	8158.41	8975.91	9763.41	11125.83	12791	14153.87	15721.39	16848.89	18545.96	19685.15
6605.91	7378.41	8165.91	8983.41	9770.91	11133.33	12798.5	14161.37	15728.89	16856.39	18553.46	19692.65
6613.41	7385.91	8173.41	8990.91	9778.41	11140.83	12806	14168.87	15743.89	16863.89	18575.96	19700.15
6620.91	7393.41	8180.91	9005.91	9785.91	11148.33	12813.5	14176.37	15751.39	16871.39	18583.46	19707.65
6628.41	7400.91	8188.41	9013.41	9793.41	11163.33	12821	14183.87	15758.89	16901.39	18590.96	19715.15
6635.91	7408.41	8195.91	9020.91	9800.91	11170.83	12828.5	14191.37	15766.39	16916.39	18598.46	19730.15
6643.41	7415.91	8203.41	9028.41	9808.41	11178.33	12836	14198.87	15773.89	16923.89	18605.96	19760.15
6650.91	7423.41	8210.91	9035.91	9815.91	11185.83	12843.5	14206.37	15781.39	16931.39	18613.46	19767.65
6658.41	7430.91	8218.41	9043.41	9823.41	11193.33	12851	14228.87	15788.89	16938.89	18620.96	19775.15
6665.91	7438.41	8225.91	9050.91	9830.91	11200.83	12858.5	14243.87	15796.39	16946.39	18628.46	19782.65
6673.41	7445.91	8233.41	9058.41	9838.41	11208.33	12873.5	14251.37	15803.89	16953.89	18635.96	19797.65
6680.91	7453.41	8240.91	9065.91	9845.91	11215.83	12881	14258.87	15811.39	17051.39	18643.46	19812.65
6688.41	7460.91	8248.41	9073.41	9898.41	11223.33	12888.5	14266.37	15818.89	17058.89	18650.96	19820.15

6695.91	7468.41	8255.91	9080.91	9860.91	11230.83	12896	14273.87	15826.39	17066.39	18658.46	19827.65
6703.41	7475.91	8263.41	9088.41	9868.41	11238.33	12903.5	14281.37	15833.89	17073.89	18665.96	19835.15
6710.91	7483.41	8270.91	9095.91	9875.91	11245.83	12911	14288.87	15841.39	17081.39	18673.46	19842.65
6718.41	7490.91	8278.41	9103.41	9883.41	11253.33	12918.5	14296.37	15863.89	17088.89	18680.96	19850.15
6725.91	7498.41	8285.91	9110.91	9890.91	11260.83	12926	14303.87	15901.39	17096.39	18688.46	19857.65
6733.41	7505.91	8293.41	9118.41	9898.41	11268.33	12933.5	14311.37	15908.89	17101.39	18695.96	19880.15
6740.91	7513.41	8300.91	9125.91	9903.41	11650.83	12941	14318.87	15916.39	17106.39	18703.46	19887.65
6748.41	7520.91	8308.41	9133.41	10005.83	11703.33	12948.5	14326.37	15923.89	17136.39	18710.96	19895.15
6755.91	7528.41	8315.91	9140.91	9995.832	11710.83	12956	14341.37	15931.39	17196.39	18718.46	19902.65
6763.41	7535.91	8323.41	9148.41	10005.83	11718.33	12963.5	14348.87	15938.89	17203.89	18725.96	19910.15
6770.91	7543.41	8330.91	9155.91	10015.83	11725.83	12971	14356.37	15946.39	17263.89	18733.46	19917.65
6778.41	7550.91	8338.41	9163.41	10023.33	11755.83	12978.5	14363.87	15953.89	17271.39	18740.96	19940.15
6785.91	7558.41	8345.91	9170.91	10030.83	11763.33	12986	14371.37	15961.39	17278.89	18748.46	19947.65
6793.41	7565.91	8353.41	9178.41	10038.33	11770.83	12993.5	14378.87	15968.89	17286.39	18755.96	19955.15
6800.91	7573.41	8360.91	9185.91	10045.83	11778.33	13001	14386.37	15976.39	17293.89	18763.46	19962.65
6808.41	7580.91	8368.41	9193.41	10053.33	11793.33	13008.5	14393.87	15983.89	17311.39	18770.96	19977.65
6815.91	7588.41	8375.91	9200.91	10060.83	11800.83	13016	14401.37	15991.39	17326.39	18778.46	19985.15
6823.41	7595.91	8383.41	9208.41	10068.33	11845.83	13023.5	14408.87	15998.89	17331.39	18785.96	20000.15
6830.91	7603.41	8390.91	9215.91	10075.83	11853.33	13031	14416.37	16016.15	17336.39	18793.46	20007.65
6838.41	7610.91	8398.41	9223.41	10083.33	11860.83	13038.5	14423.87	16013.89	17341.39	18808.46	20015.15
6845.91	7618.41	8405.91	9230.91	10090.83	11868.33	13046	14431.37	16028.89	17346.39	18815.96	20022.65
6853.41	7625.91	8413.41	9238.41	10098.33	11883.33	13053.5	14438.87	16036.39	17351.39	18823.46	20112.65
6860.91	7633.41	8420.91	9245.91	10105.83	11890.83	13143.5	14513.87	16043.89	17356.39	18830.96	20120.15
6868.41	7640.91	8428.41	9253.41	10113.33	11898.33	13151	14521.37	16051.39	17361.39	18838.46	20157.65
6875.91	7648.41	8435.91	9260.91	10120.83	11920.83	13158.5	14528.87	16056.39	17368.89	18845.96	20165.15
6883.41	7655.91	8443.41	9268.41	10128.33	11928.33	13166	14636.37	16061.39	17383.89	18853.46	20210.15
6890.91	7663.41	8450.91	9275.91	10135.83	11935.83	13173.5	14771.37	16068.89	17391.39	18860.96	20240.15
6898.41	7670.91	8458.41	9283.41	10143.33	11958.33	13271	14778.87	16076.39	17406.39	18868.46	20247.65
6905.91	7678.41	8465.91	9290.91	10150.83	11980.83	13278.5	14786.37	16083.89	17413.89	18875.96	20275.15
6913.41	7685.91	8473.41	9298.41	10158.33	11988.33	13286	14793.87	16091.39	17421.39	18883.46	20287.65

6920.91	7693.41	8480.91	9305.91	10165.83	11995.83	13308.5	14801.37	16098.89	17428.89	18890.96	20355.15
6928.41	7700.91	8488.41	9313.41	10173.33	12003.33	13316	14808.87	16121.39	17436.39	18898.46	20360.15
6935.91	7708.41	8495.91	9320.91	10180.83	12010.83	13323.5	14816.37	16128.89	17443.89	18905.96	20365.15
6943.41	7730.91	8503.41	9328.41	10188.33	12018.33	13331	14823.87	16136.39	17451.39	19011.26	
6950.91	7738.41	8510.91	9335.91	10195.83	12025.83	13338.5	14831.37	16143.89	17818.46	19018.76	
6958.41	7745.91	8518.41	9343.41	10203.33	12033.33	13346	14838.87	16151.39	17825.96	19026.26	
6965.91	7753.41	8525.91	9350.91	10210.83	12040.83	13353.5	14846.37	16158.89	17833.46	19033.76	
6973.41	7760.91	8533.41	9358.41	10218.33	12048.33	13361	14853.87	16166.39	17840.96	19041.26	
6980.91	7768.41	8540.91	9365.91	10233.33	12055.83	13368.5	15048.87	16173.89	17848.46	19048.76	
6988.41	7775.91	8548.41	9373.41	10240.83	12063.33	13376	15056.37	16181.39	17855.96	19056.26	
6995.91	7783.41	8563.41	9380.91	10248.33	12070.83	13383.5	15063.87	16188.89	17863.46	19063.76	
7003.41	7790.91	8570.91	9388.41	10255.83	12078.33	13391	15071.37	16196.39	17870.96	19071.26	
7010.91	7798.41	8578.41	9395.91	10263.33	12085.83	13398.5	15078.87	16203.89	17878.46	19078.76	
7018.41	7805.91	8593.41	9410.91	10270.83	12093.33	13406	15086.37	16211.39	17885.96	19086.26	
7025.91	7813.41	8600.91	9418.41	10278.33	12100.83	13473.5	15093.87	16218.89	17893.46	19093.76	
7033.41	7820.91	8608.41	9425.91	10285.83	12108.33	13481	15101.37	16226.39	17900.96	19101.26	
7040.91	7828.41	8615.91	9433.41	10293.33	12115.83	13488.5	15108.87	16233.89	17908.46	19108.76	

Below is a list of all 1056 non-compliant foundations due to settlement with the less stringent variation on NHBC compliance as described in §169 detailed by chainage location. The list excludes those foundations where the proximity of water bodies to 'existing' trees will prevent roots extending to lie under the guideway foundations. We have been guided in this by our senior arboriculturalist colleague, Mr Jonathan Mills, who considers that the spread of roots will be substantially reduced due to these features. The list includes foundations non-compliance due to 'existing' trees and newly planted trees.

6283.41	6950.91	7633.41	8375.91	9110.91	9823.41	11133.33	12926	14378.87	15998.89	17885.96	19056.26
6290.91	6958.41	7640.91	8383.41	9118.41	9830.91	11140.83	12933.5	14386.37	16006.39	17893.46	19063.76
6298.41	6965.91	7648.41	8390.91	9125.91	9838.41	11148.33	12941	14393.87	16013.89	17900.96	19071.26
6305.91	6973.41	7655.91	8398.41	9133.41	9845.91	11163.33	12948.5	14401.37	16051.39	17908.46	19078.76
6313.41	6980.91	7663.41	8405.91	9140.91	9853.41	11170.83	12956	14408.87	16056.39	17930.96	19086.26
6320.91	6988.41	7670.91	8413.41	9148.41	9860.91	11178.33	12963.5	14416.37	16061.39	17953.46	19093.76
6328.41	6995.91	7678.41	8420.91	9155.91	9868.41	11185.83	12971	14423.87	16068.89	17983.46	19101.26
6335.91	7003.41	7685.91	8428.41	9163.41	9875.91	11193.33	12978.5	14431.37	16076.39	18050.96	19108.76
6343.41	7010.91	7693.41	8435.91	9170.91	9883.41	11200.83	12986	14636.37	16091.39	18058.46	19116.26
6350.91	7018.41	7700.91	8443.41	9178.41	9890.91	11208.33	12993.5	14771.37	16121.39	18140.96	19123.76
6358.41	7025.91	7708.41	8450.91	9185.91	9898.41	11215.83	13001	14778.87	16128.89	18148.46	19131.26
6365.91	7033.41	7753.41	8458.41	9193.41	9903.41	11223.33	13008.5	14786.37	16136.39	18193.46	19138.76
6373.41	7040.91	7760.91	8465.91	9200.91	10005.83	11230.83	13016	14793.87	16143.89	18200.96	19146.26
6380.91	7048.41	7768.41	8473.41	9208.41	9995.832	11238.33	13023.5	14801.37	16151.39	18208.46	19153.76
6388.41	7055.91	7775.91	8480.91	9215.91	10005.83	11245.83	13031	14808.87	16158.89	18215.96	19161.26
6395.91	7063.41	7783.41	8488.41	9223.41	10015.83	11253.33	13038.5	14816.37	16166.39	18223.46	19168.76
6403.41	7070.91	7790.91	8495.91	9230.91	10023.33	11260.83	13046	14823.87	16173.89	18230.96	19176.26
6410.91	7078.41	7798.41	8503.41	9238.41	10030.83	11268.33	13053.5	14831.37	16181.39	18238.46	19183.76
6418.41	7085.91	7805.91	8510.91	9253.41	10038.33	11793.33	13143.5	14838.87	16278.89	18245.96	19191.26
6425.91	7093.41	7813.41	8518.41	9253.41	10045.83	11800.83	13308.5	14846.37	16293.89	18253.46	19198.76
6433.41	7100.91	7820.91	8525.91	9260.91	10053.33	11898.33	13316	14853.87	16301.39	18260.96	19206.26
6440.91	7108.41	7828.41	8533.41	9268.41	10060.83	11920.83	13323.5	15048.87	16316.39	18268.46	19213.76
6448.41	7115.91	7835.91	8540.91	9275.91	10068.33	11928.33	13331	15056.37	16323.89	18275.96	19221.26

6455.91	7123.41	7843.41	8548.41	9283.41	10075.83	11935.83	13338.5	15063.87	16331.39	18283.46	19228.76
6463.41	7130.91	7850.91	8563.41	9290.91	10083.33	11958.33	13346	15071.37	16338.89	18290.96	19236.26
6470.91	7138.41	7858.41	8570.91	9298.41	10090.83	12025.83	13353.5	15078.87	16391.39	18298.46	19243.76
6478.41	7145.91	7865.91	8578.41	9305.91	10098.33	12033.33	13361	15086.37	16406.39	18305.96	19251.26
6485.91	7153.41	7873.41	8593.41	9313.41	10105.83	12048.33	13368.5	15093.87	16413.89	18313.46	19258.76
6493.41	7160.91	7880.91	8600.91	9320.91	10113.33	12108.33	13376	15101.37	16436.39	18320.96	19266.26
6500.91	7168.41	7888.41	8608.41	9328.41	10120.83	12115.83	13383.5	15108.87	16443.89	18328.46	19273.76
6508.41	7183.41	7895.91	8615.91	9335.91	10128.33	12123.33	13391	15116.37	16451.39	18343.46	19281.26
6515.91	7190.91	7903.41	8623.41	9343.41	10135.83	12130.83	13473.5	15123.87	16458.89	18350.96	19288.76
6523.41	7198.41	7910.91	8660.91	9350.91	10143.33	12138.33	13481	15131.37	16466.39	18358.46	19296.26
6530.91	7205.91	7918.41	8668.41	9358.41	10150.83	12145.83	13568.5	15138.87	16473.89	18365.96	19301.26
6538.41	7213.41	7925.91	8675.91	9365.91	10158.33	12153.33	13576	15146.37	16481.39	18373.46	19420.15
6545.91	7220.91	7933.41	8683.41	9373.41	10165.83	12160.83	13583.5	15161.37	16488.89	18380.96	19450.15
6553.41	7228.41	7940.91	8690.91	9380.91	10173.33	12168.33	13591	15168.87	16496.39	18463.46	19457.65
6560.91	7235.91	7948.41	8698.41	9388.41	10180.83	12175.83	13598.5	15176.37	16503.89	18470.96	19465.15
6568.41	7243.41	7955.91	8705.91	9425.91	10188.33	12183.33	13703.5	15183.87	16518.89	18478.46	19625.15
6575.91	7250.91	7963.41	8713.41	9440.91	10195.83	12190.83	13726	15191.37	16578.89	18545.96	19632.65
6578.41	7258.41	7970.91	8720.91	9448.41	10203.33	12198.33	13733.5	15198.87	16593.89	18553.46	19655.15
6583.41	7265.91	7978.41	8728.41	9455.91	10210.83	12205.83	13786	15206.37	16601.39	18575.96	19670.15
6590.91	7273.41	7985.91	8735.91	9463.41	10218.33	12213.33	13808.5	15213.87	16608.89	18583.46	19700.15
6598.41	7280.91	7993.41	8743.41	9470.91	10233.33	12220.83	13868.5	15221.37	16616.39	18590.96	19707.65
6605.91	7288.41	8000.91	8750.91	9478.41	10240.83	12228.33	13876	15228.87	16623.89	18598.46	19730.15
6613.41	7295.91	8008.41	8758.41	9485.91	10248.33	12235.83	13883.5	15236.37	16631.39	18605.96	19760.15
6620.91	7303.41	8015.91	8765.91	9493.41	10255.83	12243.33	13891	15243.87	16638.89	18613.46	19767.65
6628.41	7310.91	8023.41	8780.91	9500.91	10263.33	12250.83	13898.5	15363.87	16736.39	18620.96	19775.15
6635.91	7318.41	8060.91	8788.41	9508.41	10270.83	12258.33	14011.37	15371.37	16743.89	18628.46	19812.65
6643.41	7325.91	8068.41	8795.91	9515.91	10278.33	12265.83	14018.87	15378.87	16818.89	18635.96	19820.15
6650.91	7333.41	8075.91	8803.41	9523.41	10285.83	12273.33	14026.37	15386.37	16826.39	18643.46	19827.65
6658.41	7340.91	8083.41	8810.91	9530.91	10293.33	12280.83	14041.37	15393.87	16833.89	18650.96	19835.15

6665.91	7348.41	8090.91	8818.41	9538.41	10443.33	12288.33	14048.87	15401.37	16841.39	18658.46	19842.65
6673.41	7355.91	8098.41	8825.91	9545.91	10450.83	12295.83	14056.37	15581.39	16848.89	18665.96	19887.65
6680.91	7363.41	8105.91	8833.41	9553.41	10458.33	12303.33	14063.87	15586.39	16856.39	18673.46	19940.15
6688.41	7370.91	8113.41	8840.91	9560.91	10465.83	12310.83	14071.37	15591.39	16863.89	18680.96	19947.65
6695.91	7378.41	8120.91	8848.41	9568.41	10473.33	12318.33	14078.87	15596.39	16871.39	18688.46	19955.15
6703.41	7385.91	8128.41	8855.91	9575.91	10480.83	12325.83	14086.37	15601.39	16953.89	18695.96	19962.65
6710.91	7393.41	8135.91	8863.41	9583.41	10488.33	12333.33	14093.87	15616.39	17073.89	18703.46	19977.65
6718.41	7400.91	8143.41	8870.91	9590.91	10450.83	12340.83	14101.37	15623.89	17081.39	18710.96	20007.65
6725.91	7408.41	8150.91	8878.41	9598.41	10458.33	12348.33	14116.37	15631.39	17136.39	18718.46	20015.15
6733.41	7415.91	8158.41	8885.91	9605.91	10465.83	12355.83	14123.87	15638.89	17263.89	18725.96	20022.65
6740.91	7423.41	8165.91	8893.41	9613.41	10473.33	12363.33	14131.37	15653.89	17271.39	18733.46	20210.15
6748.41	7430.91	8173.41	8900.91	9620.91	10480.83	12370.83	14138.87	15676.39	17278.89	18740.96	20240.15
6755.91	7438.41	8180.91	8908.41	9628.41	10488.33	12378.33	14146.37	15721.39	17286.39	18748.46	20247.65
6763.41	7445.91	8188.41	8915.91	9635.91	10495.83	12385.83	14153.87	15743.89	17293.89	18755.96	20275.15
6770.91	7453.41	8195.91	8923.41	9643.41	10502.53	12393.33	14161.37	15751.39	17311.39	18763.46	
6778.41	7460.91	8203.41	8930.91	9650.91	10510.03	12400.83	14168.87	15766.39	17331.39	18770.96	
6785.91	7468.41	8210.91	8938.41	9658.41	10517.53	12408.33	14176.37	15781.39	17336.39	18778.46	
6793.41	7475.91	8218.41	8945.91	9665.91	10525.03	12415.83	14183.87	15788.89	17341.39	18785.96	
6800.91	7483.41	8225.91	8953.41	9673.41	10532.53	12768.5	14191.37	15796.39	17346.39	18793.46	
6808.41	7490.91	8233.41	8960.91	9680.91	10540.03	12776	14198.87	15803.89	17351.39	18808.46	
6815.91	7498.41	8240.91	8968.41	9688.41	10548.53	12783.5	14206.37	15811.39	17356.39	18815.96	
6823.41	7505.91	8248.41	8975.91	9695.91	11005.83	12791	14228.87	15818.89	17361.39	18823.46	
6830.91	7513.41	8255.91	8983.41	9703.41	11013.33	12798.5	14243.87	15826.39	17368.89	18838.46	
6838.41	7520.91	8263.41	8990.91	9710.91	11020.83	12806	14251.37	15833.89	17406.39	18845.96	
6845.91	7528.41	8270.91	9005.91	9718.41	11028.33	12813.5	14258.87	15863.89	17413.89	18853.46	
6853.41	7535.91	8278.41	9013.41	9725.91	11035.83	12821	14266.37	15901.39	17421.39	18860.96	
6860.91	7543.41	8285.91	9020.91	9733.41	11043.33	12828.5	14273.87	15908.89	17428.89	18868.46	
6868.41	7550.91	8293.41	9028.41	9740.91	11050.83	12836	14281.37	15916.39	17436.39	18875.96	
6875.91	7558.41	8300.91	9035.91	9748.41	11058.33	12843.5	14288.87	15923.89	17443.89	18883.46	

6883.41	7565.91	8308.41	9043.41	9755.91	11065.83	12851	14296.37	15931.39	17451.39	18890.96	
6890.91	7573.41	8315.91	9050.91	9763.41	11073.33	12858.5	14303.87	15938.89	17818.46	18898.46	
6898.41	7580.91	8323.41	9058.41	9770.91	11080.83	12873.5	14311.37	15946.39	17825.96	18905.96	
6905.91	7588.41	8330.91	9065.91	9778.41	11088.33	12881	14318.87	15953.89	17833.46	19011.26	
6913.41	7595.91	8338.41	9073.41	9785.91	11095.83	12888.5	14326.37	15961.39	17840.96	19018.76	
6920.91	7603.41	8345.91	9080.91	9793.41	11103.33	12896	14341.37	15968.89	17848.46	19026.26	
6928.41	7610.91	8353.41	9088.41	9800.91	11110.83	12903.5	14348.87	15976.39	17855.96	19033.76	
6935.91	7618.41	8360.91	9095.91	9808.41	11118.33	12911	14356.37	15983.89	17870.96	19041.26	
6943.41	7625.91	8368.41	9103.41	9815.91	11125.83	12918.5	14363.87	15991.39	17878.46	19048.76	

Below is a list of 868 non-compliant foundations that require remediation under Option A due to 'existing' trees only, with revised NHBC depth, see §186, (detailed by chainage location). The list excludes those foundations where the proximity of water bodies to 'existing' trees will prevent roots extending to lie under the guideway foundations. We have been guided in this by our senior arboriculturalist colleague, Mr Jonathan Mills, who considers that the spread of roots will be substantially reduced due to these features. These are the foundations that will be remediated as part of Option A.

6283.41	6845.91	7648.41	8248.41	8938.41	9695.91	12063.33	14386.37	16196.39	17451.39	18875.96	19700.15
6290.91	6853.41	7655.91	8255.91	8945.91	9703.41	12070.83	14393.87	16203.89	17818.46	18883.46	19707.65
6298.41	6860.91	7663.41	8263.41	8953.41	9710.91	12078.33	14401.37	16211.39	17825.96	18890.96	19715.15
6305.91	6868.41	7670.91	8270.91	8960.91	9718.41	12085.83	14408.87	16218.89	17848.46	18898.46	19730.15
6313.41	6875.91	7678.41	8278.41	8968.41	9725.91	12093.33	14416.37	16226.39	17855.96	18905.96	19760.15
6320.91	6883.41	7685.91	8285.91	8975.91	9740.91	12100.83	14423.87	16233.89	17870.96	19011.26	19767.65
6328.41	6890.91	7693.41	8293.41	8983.41	9748.41	12160.83	14431.37	16391.39	17893.46	19018.76	19775.15
6335.91	6898.41	7700.91	8300.91	9005.91	9755.91	12168.33	14636.37	16406.39	17900.96	19026.26	19782.65
6343.41	6905.91	7708.41	8308.41	9013.41	9763.41	12175.83	15581.39	16413.89	17908.46	19033.76	19797.65
6350.91	6913.41	7730.91	8315.91	9020.91	9770.91	12280.83	15586.39	16436.39	17930.96	19041.26	19812.65
6358.41	6920.91	7738.41	8323.41	9028.41	9778.41	12288.33	15591.39	16443.89	18058.46	19048.76	19820.15
6365.91	6928.41	7753.41	8330.91	9035.91	9785.91	12295.83	15596.39	16451.39	18140.96	19056.26	19827.65
6373.41	6935.91	7760.91	8338.41	9043.41	9793.41	12303.33	15601.39	16458.89	18148.46	19063.76	19835.15
6380.91	6943.41	7768.41	8345.91	9050.91	9800.91	12310.83	15608.89	16466.39	18163.46	19071.26	19842.65
6388.41	6950.91	7775.91	8353.41	9058.41	9808.41	12318.33	15616.39	16473.89	18185.96	19078.76	19850.15
6395.91	6958.41	7783.41	8360.91	9065.91	9815.91	12325.83	15623.89	16481.39	18193.46	19086.26	19857.65
6403.41	6965.91	7790.91	8368.41	9073.41	9830.91	12355.83	15631.39	16488.89	18200.96	19093.76	19880.15
6410.91	6973.41	7798.41	8375.91	9080.91	9838.41	12363.33	15638.89	16496.39	18208.46	19101.26	19887.65
6418.41	6980.91	7805.91	8383.41	9088.41	9845.91	12370.83	15646.39	16503.89	18215.96	19108.76	19895.15
6425.91	6988.41	7813.41	8390.91	9095.91	9898.41	12400.83	15653.89	16511.39	18223.46	19116.26	19902.65
6433.41	6995.91	7820.91	8398.41	9103.41	10005.83	12408.33	15661.39	16518.89	18230.96	19123.76	19910.15
6440.91	7003.41	7835.91	8405.91	9110.91	10015.83	12415.83	15676.39	16578.89	18238.46	19131.26	19917.65
6448.41	7010.91	7843.41	8413.41	9118.41	10023.33	12806	15706.39	16593.89	18253.46	19138.76	19940.15
6455.91	7018.41	7850.91	8420.91	9125.91	10060.83	12813.5	15713.89	16601.39	18260.96	19146.26	19947.65
6463.41	7025.91	7858.41	8428.41	9133.41	10083.33	12821	15721.39	16608.89	18283.46	19153.76	19955.15
6470.91	7033.41	7865.91	8435.91	9140.91	10090.83	12828.5	15728.89	16616.39	18290.96	19161.26	19962.65

6478.41	7040.91	7873.41	8443.41	9148.41	10098.33	12836	15743.89	16623.89	18298.46	19168.76	20247.65
6485.91	7048.41	7880.91	8450.91	9155.91	10120.83	12843.5	15751.39	16631.39	18305.96	19176.26	20275.15
6493.41	7055.91	7888.41	8458.41	9163.41	10128.33	12903.5	15758.89	16638.89	18320.96	19183.76	20287.65
6500.91	7063.41	7895.91	8465.91	9170.91	10135.83	12911	15766.39	16736.39	18328.46	19191.26	20355.15
6508.41	7108.41	7903.41	8473.41	9178.41	10143.33	12918.5	15773.89	16743.89	18343.46	19198.76	20360.15
6515.91	7115.91	7910.91	8480.91	9185.91	10150.83	12933.5	15781.39	16818.89	18350.96	19206.26	20365.15
6523.41	7123.41	7918.41	8488.41	9193.41	10158.33	13001	15788.89	16826.39	18358.46	19213.76	
6530.91	7130.91	7925.91	8495.91	9200.91	10165.83	13008.5	15796.39	16833.89	18365.96	19221.26	
6538.41	7138.41	7933.41	8503.41	9208.41	10173.33	13016	15803.89	16841.39	18373.46	19228.76	
6545.91	7175.91	7940.91	8510.91	9215.91	10180.83	13023.5	15811.39	16848.89	18380.96	19236.26	
6553.41	7250.91	7948.41	8518.41	9223.41	10188.33	13031	15818.89	16856.39	18388.46	19243.76	
6560.91	7310.91	7955.91	8525.91	9230.91	10195.83	13038.5	15826.39	16863.89	18395.96	19251.26	
6568.41	7318.41	7963.41	8533.41	9238.41	10203.33	13046	15833.89	16871.39	18545.96	19258.76	
6575.91	7325.91	7970.91	8540.91	9245.91	10218.33	13053.5	15841.39	16946.39	18553.46	19266.26	
6578.41	7333.41	7978.41	8548.41	9253.41	10233.33	13868.5	15863.89	16953.89	18575.96	19273.76	
6583.41	7340.91	7985.91	8563.41	9260.91	10240.83	13876	15901.39	17051.39	18583.46	19281.26	
6590.91	7348.41	7993.41	8570.91	9268.41	10255.83	13883.5	15908.89	17058.89	18590.96	19288.76	
6598.41	7355.91	8000.91	8578.41	9275.91	10263.33	13891	15916.39	17066.39	18598.46	19296.26	
6605.91	7363.41	8008.41	8593.41	9283.41	10270.83	13898.5	15923.89	17073.89	18605.96	19301.26	
6613.41	7370.91	8015.91	8600.91	9290.91	10278.33	13916	15931.39	17081.39	18613.46	19415.15	
6620.91	7378.41	8023.41	8608.41	9448.41	10285.83	14011.37	15938.89	17088.89	18620.96	19420.15	
6628.41	7385.91	8030.91	8615.91	9455.91	10293.33	14018.87	15946.39	17096.39	18628.46	19450.15	
6635.91	7393.41	8038.41	8623.41	9463.41	11650.83	14026.37	15953.89	17101.39	18650.96	19457.65	
6643.41	7400.91	8045.91	8660.91	9470.91	11703.33	14041.37	15961.39	17106.39	18658.46	19465.15	
6650.91	7408.41	8053.41	8668.41	9478.41	11710.83	14048.87	15968.89	17136.39	18673.46	19472.65	
6658.41	7415.91	8060.91	8675.91	9485.91	11718.33	14056.37	15976.39	17196.39	18680.96	19497.65	
6665.91	7423.41	8068.41	8683.41	9493.41	11725.83	14063.87	15983.89	17203.89	18688.46	19505.15	
6673.41	7430.91	8075.91	8690.91	9500.91	11755.83	14071.37	15991.39	17263.89	18695.96	19512.65	
6680.91	7438.41	8083.41	8698.41	9508.41	11763.33	14078.87	15998.89	17271.39	18703.46	19617.65	
6688.41	7445.91	8090.91	8705.91	9515.91	11770.83	14101.37	16016.15	17278.89	18710.96	19625.15	

6695.91	7453.41	8098.41	8713.41	9523.41	11778.33	14116.37	16013.89	17286.39	18718.46	19632.65	
6703.41	7460.91	8105.91	8720.91	9530.91	11845.83	14123.87	16028.89	17293.89	18725.96	19647.65	
6710.91	7468.41	8113.41	8728.41	9538.41	11853.33	14243.87	16036.39	17311.39	18733.46	19655.15	
6718.41	7475.91	8120.91	8735.91	9545.91	11860.83	14251.37	16043.89	17326.39	18740.96	19662.65	
6725.91	7483.41	8128.41	8743.41	9553.41	11868.33	14258.87	16051.39	17331.39	18748.46	19670.15	
6733.41	7490.91	8135.91	8750.91	9560.91	11883.33	14266.37	16056.39	17336.39	18755.96	19677.65	
6740.91	7505.91	8143.41	8758.41	9568.41	11890.83	14273.87	16061.39	17341.39	18763.46	19685.15	
6748.41	7550.91	8150.91	8765.91	9575.91	11898.33	14281.37	16068.89	17346.39	18770.96	19692.65	
6755.91	7558.41	8158.41	8773.41	9583.41	11920.83	14288.87	16076.39	17351.39	18778.46	19977.65	
6763.41	7565.91	8165.91	8780.91	9590.91	11980.83	14296.37	16091.39	17356.39	18785.96	19985.15	
6770.91	7573.41	8173.41	8788.41	9598.41	11988.33	14303.87	16121.39	17361.39	18793.46	20000.15	
6778.41	7580.91	8180.91	8795.91	9605.91	11995.83	14311.37	16128.89	17368.89	18808.46	20007.65	
6785.91	7588.41	8188.41	8803.41	9613.41	12003.33	14318.87	16136.39	17383.89	18815.96	20015.15	
6793.41	7595.91	8195.91	8810.91	9620.91	12010.83	14326.37	16143.89	17391.39	18823.46	20022.65	
6800.91	7603.41	8203.41	8863.41	9628.41	12018.33	14341.37	16151.39	17406.39	18830.96	20112.65	
6808.41	7610.91	8210.91	8870.91	9635.91	12025.83	14348.87	16158.89	17413.89	18838.46	20120.15	
6815.91	7618.41	8218.41	8878.41	9643.41	12033.33	14356.37	16166.39	17421.39	18845.96	20157.65	
6823.41	7625.91	8225.91	8885.91	9650.91	12040.83	14363.87	16173.89	17428.89	18853.46	20165.15	
6830.91	7633.41	8233.41	8893.41	9680.91	12048.33	14371.37	16181.39	17436.39	18860.96	20210.15	
6838.41	7640.91	8240.91	8900.91	9688.41	12055.83	14378.87	16188.89	17443.89	18868.46	20240.15	

Below is a list of 643 non-compliant foundations that require remediation under Option A due to ‘existing’ trees only, allowing the benefit of 25mm of differential movement , see §186, (detailed by chainage location). The list excludes those foundations where the proximity of water bodies to ‘existing’ trees will prevent roots extending to lie under the guideway foundations. We have been guided in this by our senior arboriculturalist colleague, Mr Jonathan Mills, who considers that the spread of roots will be substantially reduced due to these features. These are the foundations that will be remediated as part of Option A.

6283.41	6695.91	7700.91	8218.41	8683.41	9260.91	10180.83	15581.39	16406.39	17818.46	18823.46	19273.76
6290.91	6703.41	7708.41	8225.91	8690.91	9448.41	10188.33	15586.39	16413.89	17825.96	18838.46	19281.26
6298.41	6710.91	7753.41	8233.41	8698.41	9455.91	10195.83	15591.39	16436.39	17848.46	18845.96	19288.76
6305.91	6718.41	7760.91	8240.91	8705.91	9463.41	10203.33	15596.39	16443.89	17855.96	18853.46	19296.26
6313.41	6725.91	7768.41	8248.41	8713.41	9470.91	10218.33	15601.39	16451.39	17870.96	18860.96	19301.26
6320.91	6733.41	7775.91	8255.91	8720.91	9478.41	10233.33	15616.39	16458.89	17893.46	18868.46	19420.15
6328.41	6740.91	7783.41	8263.41	8780.91	9485.91	10240.83	15623.89	16466.39	17900.96	18875.96	19450.15
6335.91	6748.41	7790.91	8270.91	8788.41	9493.41	10263.33	15631.39	16473.89	17908.46	18883.46	19457.65
6343.41	6755.91	7798.41	8278.41	8795.91	9500.91	10270.83	15638.89	16481.39	17930.96	18890.96	19465.15
6350.91	6763.41	7805.91	8285.91	8803.41	9508.41	10278.33	15653.89	16488.89	18058.46	18898.46	19625.15
6358.41	6770.91	7813.41	8293.41	8810.91	9515.91	10285.83	15676.39	16496.39	18140.96	18905.96	19632.65
6365.91	6778.41	7820.91	8300.91	8863.41	9523.41	12280.83	15721.39	16503.89	18148.46	19011.26	19655.15
6373.41	6785.91	7835.91	8308.41	8870.91	9530.91	12288.33	15743.89	16518.89	18193.46	19018.76	19670.15
6380.91	6793.41	7843.41	8315.91	8878.41	9538.41	12295.83	15751.39	16578.89	18208.46	19026.26	19700.15
6388.41	6800.91	7850.91	8323.41	8885.91	9545.91	12933.5	15766.39	16593.89	18215.96	19033.76	19707.65
6395.91	6808.41	7858.41	8330.91	8893.41	9553.41	13868.5	15781.39	16601.39	18223.46	19041.26	19730.15
6403.41	6815.91	7865.91	8338.41	8900.91	9560.91	13876	15788.89	16608.89	18238.46	19048.76	19760.15
6410.91	6823.41	7873.41	8345.91	8945.91	9568.41	13883.5	15796.39	16616.39	18253.46	19056.26	19767.65
6418.41	6830.91	7880.91	8353.41	8953.41	9575.91	13891	15803.89	16623.89	18260.96	19063.76	19775.15
6425.91	6838.41	7888.41	8360.91	8960.91	9583.41	13898.5	15811.39	16631.39	18283.46	19071.26	19812.65
6433.41	6845.91	7895.91	8368.41	8968.41	9590.91	14011.37	15818.89	16638.89	18290.96	19078.76	19820.15
6440.91	6853.41	7903.41	8375.91	8975.91	9598.41	14018.87	15826.39	16736.39	18305.96	19086.26	19827.65
6448.41	6860.91	7910.91	8383.41	8983.41	9605.91	14026.37	15833.89	16743.89	18320.96	19093.76	19835.15
6455.91	6868.41	7918.41	8390.91	9005.91	9613.41	14041.37	15863.89	16818.89	18328.46	19101.26	20240.15
6463.41	6875.91	7925.91	8398.41	9013.41	9620.91	14048.87	15901.39	16826.39	18343.46	19108.76	20247.65

6470.91	6883.41	7933.41	8405.91	9020.91	9628.41	14056.37	15908.89	16833.89	18350.96	19116.26	20275.15
6478.41	6935.91	7940.91	8413.41	9028.41	9635.91	14063.87	15916.39	16841.39	18358.46	19123.76	
6485.91	6950.91	7948.41	8420.91	9035.91	9643.41	14071.37	15923.89	16848.89	18365.96	19131.26	
6493.41	7018.41	7955.91	8428.41	9043.41	9650.91	14078.87	15931.39	16856.39	18373.46	19138.76	
6500.91	7025.91	7963.41	8435.91	9050.91	9680.91	14101.37	15938.89	16863.89	18380.96	19146.26	
6508.41	7408.41	7970.91	8443.41	9058.41	9688.41	14116.37	15946.39	16871.39	18545.96	19153.76	
6515.91	7430.91	7978.41	8450.91	9065.91	9695.91	14123.87	15953.89	16953.89	18553.46	19161.26	
6523.41	7438.41	7985.91	8458.41	9073.41	9703.41	14243.87	15961.39	17073.89	18575.96	19168.76	
6530.91	7445.91	7993.41	8465.91	9080.91	9710.91	14251.37	15968.89	17081.39	18583.46	19176.26	
6538.41	7483.41	8000.91	8473.41	9088.41	9718.41	14258.87	15976.39	17136.39	18590.96	19183.76	
6545.91	7505.91	8060.91	8480.91	9095.91	9725.91	14266.37	15983.89	17263.89	18598.46	19191.26	
6553.41	7550.91	8068.41	8488.41	9103.41	9740.91	14273.87	15991.39	17271.39	18605.96	19198.76	
6560.91	7558.41	8075.91	8495.91	9110.91	9748.41	14281.37	15998.89	17278.89	18613.46	19206.26	
6568.41	7565.91	8083.41	8503.41	9118.41	9755.91	14288.87	16006.39	17286.39	18620.96	19213.76	
6575.91	7573.41	8090.91	8510.91	9125.91	9763.41	14296.37	16013.89	17293.89	18628.46	19221.26	
6578.41	7580.91	8098.41	8518.41	9133.41	9770.91	14303.87	16051.39	17311.39	18688.46	19228.76	
6583.41	7588.41	8105.91	8525.91	9140.91	9778.41	14311.37	16056.39	17331.39	18695.96	19236.26	
6590.91	7595.91	8113.41	8533.41	9148.41	9785.91	14318.87	16061.39	17336.39	18703.46	19243.76	
6598.41	7603.41	8120.91	8540.91	9155.91	9793.41	14326.37	16068.89	17341.39	18710.96	19842.65	
6605.91	7610.91	8128.41	8548.41	9163.41	9800.91	14341.37	16076.39	17346.39	18718.46	19887.65	
6613.41	7618.41	8135.91	8563.41	9170.91	9808.41	14348.87	16091.39	17351.39	18733.46	19940.15	
6620.91	7625.91	8143.41	8570.91	9178.41	9815.91	14356.37	16121.39	17356.39	18740.96	19947.65	
6628.41	7633.41	8150.91	8578.41	9185.91	9838.41	14363.87	16128.89	17361.39	18748.46	19955.15	
6635.91	7640.91	8158.41	8593.41	9193.41	9845.91	14378.87	16136.39	17368.89	18755.96	19962.65	
6643.41	7648.41	8165.91	8600.91	9200.91	9898.41	14386.37	16143.89	17406.39	18763.46	19977.65	
6650.91	7655.91	8173.41	8608.41	9208.41	10005.83	14393.87	16151.39	17413.89	18770.96	20007.65	
6658.41	7663.41	8180.91	8615.91	9215.91	10015.83	14401.37	16158.89	17421.39	18778.46	20015.15	
6665.91	7670.91	8188.41	8623.41	9223.41	10023.33	14408.87	16166.39	17428.89	18785.96	20022.65	
6673.41	7678.41	8195.91	8660.91	9230.91	10083.33	14416.37	16173.89	17436.39	18793.46	20210.15	
6680.91	7685.91	8203.41	8668.41	9238.41	10090.83	14423.87	16181.39	17443.89	18808.46	19258.76	

6688.41	7693.41	8210.91	8675.91	9253.41	10098.33	14431.37	16391.39	17451.39	18815.96	19266.26	

Below is a list of all non-compliant foundations which are affected by newly planted trees and which require remediation under Option A and Option B, see §169, (detailed by chainage location). These are the foundations where the new trees will be removed and replaced by lower water demand/mature height replacements. This list excludes foundations where the impact of an enhanced vegetation management regime will render the foundations compliant and those foundations where the impact of other factors, in particular water-filled ditches between trees and the guideway. The first table list the full NHBC foundations and the second table refers to the altered NHBC foundation levels.

7070.91	7205.91	8818.41	9665.91	10450.83	10488.33	12138.33	12243.33	12423.33	12978.5	18470.96	
7078.41	7235.91	8825.91	9673.41	10458.33	10495.83	12145.83	12250.83	12851	12986	18478.46	
7085.91	7243.41	8833.41	9860.91	10465.83	10502.53	12153.33	12258.33	12858.5	12993.5		
7093.41	7258.41	8840.91	9868.41	10473.33	11328.33	12183.33	12265.83	12888.5	15431.37		
7100.91	7265.91	8848.41	9875.91	10480.83	11335.83	12190.83	12273.33	12903.5	15461.37		
7145.91	7273.41	8855.91	9883.41	10488.33	11793.33	12198.33	12333.33	12926	16098.89		
7153.41	7280.91	8908.41	9890.91	10450.83	11800.83	12205.83	12340.83	12941	16331.39		
7160.91	7288.41	8915.91	9898.41	10458.33	12108.33	12213.33	12348.33	12948.5	16338.89		
7190.91	7295.91	8923.41	9903.41	10465.83	12115.83	12220.83	12378.33	12956	16346.39		
7198.41	7303.41	8930.91	10005.83	10473.33	12123.33	12228.33	12385.83	12963.5	16398.89		
7205.91	7828.41	9658.41	10443.33	10480.83	12130.83	12235.83	12393.33	12971	18463.46		

7078.41	8750.91	8923.41	10005.83	10465.83	12123.33	12250.83	12355.83	12828.5	12963.5		
6890.91	8758.41	8930.91	10293.33	10473.33	12130.83	12258.33	12363.33	12851	12971		
7078.41	8765.91	8938.41	10443.33	10480.83	12138.33	12265.83	12370.83	12858.5	12978.5		
7370.91	8818.41	9253.41	10450.83	10488.33	12145.83	12273.33	12378.33	12888.5	12986		
7828.41	8825.91	9268.41	10458.33	10495.83	12153.33	12303.33	12385.83	12903.5	12993.5		
8008.41	8833.41	9275.91	10465.83	10502.53	12160.83	12310.83	12393.33	12911	13001		
8015.91	8840.91	9658.41	10473.33	11328.33	12168.33	12318.33	12400.83	12918.5	18448.46		
8023.41	8848.41	9665.91	10480.83	11793.33	12175.83	12325.83	12408.33	12926	18463.46		
8728.41	8855.91	9673.41	10488.33	11800.83	12228.33	12333.33	12415.83	12941	18733.46		
8735.91	8908.41	9890.91	10450.83	12108.33	12235.83	12340.83	12806	12948.5			

8743.41	8915.91	9903.41	10458.33	12115.83	12243.33	12348.33	12813.5	12956			

Below is a list of foundations (detailed by chainage location) that we have assessed as being at “very high risk” and “high risk” due to ‘existing’ trees and that require remediation, see §188, as part of Option B.

6283.41	Very High Risk	8570.91	High Risk	10180.83	Very High Risk	14371.37	Very High Risk	18208.46	Very High Risk	19715.15	High Risk
6350.91	Very High Risk	8578.41	Very High Risk	10188.33	Very High Risk	14378.87	Very High Risk	18230.96	High Risk	19730.15	High Risk
6358.41	Very High Risk	8593.41	High Risk	10203.33	Very High Risk	14401.37	High Risk	18253.46	Very High Risk	19812.65	High Risk
6365.91	High Risk	8615.91	High Risk	10233.33	Very High Risk	14408.87	High Risk	18260.96	High Risk	19820.15	High Risk
6455.91	Very High Risk	8623.41	High Risk	10240.83	High Risk	14416.37	High Risk	18283.46	Very High Risk	19827.65	High Risk
6688.41	Very High Risk	8660.91	Very High Risk	10263.33	Very High Risk	15581.39	High Risk	18298.46	High Risk	19842.65	High Risk
6755.91	Very High Risk	8728.41	High Risk	10293.33	High Risk	15591.39	Very High Risk	18320.96	Very High Risk	19850.15	High Risk
6793.41	Very High Risk	8863.41	High Risk	10930.83	Very High Risk	15901.39	High Risk	18328.46	Very High Risk	19887.65	Very High Risk
6890.91	Very High Risk	8945.91	High Risk	10953.33	Very High Risk	16028.89	High Risk	18343.46	Very High Risk	19895.15	Very High Risk
7018.41	High Risk	9005.91	Very High Risk	10975.83	Very High Risk	16091.39	High Risk	18350.96	Very High Risk	19940.15	Very High Risk
7033.41	Very High Risk	9013.41	Very High Risk	10998.33	Very High Risk	16391.39	Very High Risk	18380.96	High Risk	19977.65	High Risk
7550.91	Very High Risk	9095.91	High Risk	12280.83	High Risk	16406.39	Very High Risk	18545.96	Very High Risk	20210.15	High Risk
7678.41	Very High Risk	9125.91	Very High Risk	12288.33	Very High Risk	16436.39	Very High Risk	18575.96	Very High Risk		
7685.91	Very High Risk	9133.41	Very High Risk	12295.83	Very High Risk	16736.39	High Risk	18598.46	High Risk		
7700.91	Very High Risk	9140.91	Very High Risk	12806	Very High Risk	17136.39	High Risk	18613.46	High Risk		

7708.41	Very High Risk	9148.41	Very High Risk	12903.5	Very High Risk	17263.89	Very High Risk	18733.46	High Risk		
7730.91	High Risk Risk	9155.91	Very High Risk	13001	Very High Risk	17311.39	Very High Risk	18755.96	High Risk		
7753.41	Very High Risk	9448.41	Very High Risk	13868.5	Very High Risk	17406.39	High Risk	18763.46	High Risk		
7760.91	Very High Risk	9463.41	Very High Risk	14003.87	Very High Risk	17825.96	High Risk	18793.46	High Risk		
7768.41	Very High Risk	9643.41	High Risk	14041.37	Very High Risk	17848.46	Very High Risk	18808.46	Very High Risk		
7775.91	Very High Risk	9680.91	Very High Risk	14056.37	High Risk	17855.96	Medium Risk	18815.96	High Risk		
7783.41	Very High Risk	9740.91	High Risk	14063.87	Very High Risk	17870.96	Very High Risk	18830.96	High Risk		
7790.91	Very High Risk	9748.41	Very High Risk	14071.37	Very High Risk	17893.46	High Risk	18875.96	Very High Risk		
7820.91	Very High Risk	9830.91	Very High Risk	14101.37	Very High Risk	17908.46	High Risk	18905.96	Very High Risk		
7835.91	Very High Risk	9838.41	High Risk	14116.37	Very High Risk	17930.96	Very High Risk	19011.26	Very High Risk		
7843.41	Very High Risk	9898.41	Very High Risk	14243.87	Very High Risk	18058.46	Very High Risk	19108.76	High Risk		
7858.41	Very High Risk	10005.83	Very High Risk	14251.37	Very High Risk	18140.96	High Risk	19116.26	High Risk		
7865.91	Very High Risk	10015.83	Very High Risk	14266.37	High Risk	18163.46	High Risk	19415.15	Very High Risk		
7873.41	Very High Risk	10023.33	Very High Risk	14341.37	Very High Risk	18185.96	Very High Risk	19450.15	Very High Risk		
7903.41	Very High Risk	10090.83	Very High Risk	14348.87	High Risk	18193.46	Very High Risk	19625.15	High Risk		
8563.41	High Risk	10098.33	Very High Risk	14356.37	Very High Risk	18200.96	Very High Risk	19700.15	High Risk		

11. We classifed 105 foundations as “very high risk” and 62 foundations as “high risk” across the entire guideway.

    (i) North of Nature Reserve (Chainage 3050 – 3755): nil foundations out of 94 total foundations;

    (ii) Swavesey to B1050 (Chainages 6283 – 10480): 53 “very high risk” foundations and 17 “high risk” foundations out of 550 total foundations;

    (iii) Longstanton to Oakington(Chainages 10450 – 13916):10 “very high risk” foundations and 1 “high risk” foundation out of 364 total foundations;

    (iv) Chainages (14003 – 14393): 11 “very high risk” foundations and 4 “high risk” foundations out of 52 total foundations;

    (v) Chainages (14401 – 15493): 1 “very high risk” foundation and 3 “high risk” foundations out of 147 total foundations;

    (vi) Girton to Histon (Chainages 15581 – 17451): 5 “very high risk” foundations and 7 “high risk” foundations out of 257 total foundations;

    (vii) Histon to Arbury (Chainages 17510 – 18905): 20 “very high risk” foundations and 17 “high risk” foundations out of 187 total foundations;

    (viii) Arbury to CRC (Chainages 19011 – 19306): 1 “very high risk” foundation and 2 “high risk” foundations out of 41 total foundations;

    (ix) CRC to Milton (Chainages 19415 – 20365): 4 “very high risk” foundations and 11 “high risk” foundations out of 131 total foundations.

Approach to foundation assessment

12. To determine if a foundation is compliant with NHBC we need to know two things;

    (i) the NHBC compliance depth of the foundation, and,

    (ii) the as-built depth of the foundation.

13. Assessment was restricted by having an incomplete set of BNL’s design and ‘as-built’ ‘shallow’ foundation spreadsheets. The missing information is as follows;

    (i) Design spreadsheets

    Chainage 7911 – 8555

    Chainage 14000 – 14500

    Chainage 14500 – 15581

    (ii) ‘As-built’ spreadsheets

Chainage 3055 - 3785

Chainage 6288 - 6448

14. For the spread foundations between chainage 3058 and 3778 we were able to make an assessment because, whilst we do not have the as-built spreadsheets, Schedule 1 of BNL's February 2011 Geotechnical Report, see Appendix H, records that all the foundations for this section were at the minimum depth for high shrinkage potential clays, i.e. 1m.

15. For foundations between chainages 7911–8555 and 14401–15581 we have been able to make assessments with regard to the new planting as we have the 'as-built' details of the foundations. For the remaining section listed in §13 above, chainage 6288–6448, we have been unable to make an assessment of the remedial works required because Schedule 1 (see Appendix H) indicates that some of the foundations were deepened for trees and we do not have the details of the trees in sufficient detail to determine the required depth for the foundations. We have been unable to make any assessment of remedial works for 22 'shallow' foundations. This represents just over 1% of the 'shallow' foundations.

16. BNL recorded the ground conditions met at the base of many, but not all, the foundation excavations. If non-shrinkable soils were present in the base of the foundations excavations in areas zoned as shrinkable clay BNL did not confirm that the non-shrinkable soils extended to a depth equivalent to the width of the excavation below the foundation i.e. to 2m below the excavation level. The NHBC Standard requires that confirmation if the design of the foundation is to be based on non-shrinkable soil being present. In the absence of such confirmation we adopted the NHBC Standard requirement that the foundation should be at the depth required for the expected shrinkable soil class.

17. Where no details of the founding material were recorded for a foundation excavation, we have adopted for that foundation the class of shrinkable soil (high, medium or low) related to its chainage, as defined in Schedule 1 of BNL's February 2011 Geotechnical Report.

18. Where clay was recorded in an 'as-built' spreadsheet at the base of the foundation excavation in an area which was zoned by BNL as non-shrinkable ground, we assumed it is a low-shrinkage potential clay in the absence of any other information. We made this assumption on the basis of this being the most likely class of shrinkable clay present and our view that the available investigation information suggests there is a low probability of the clay extending to the full depth that could be influenced by tree roots.

Determination of NHBC foundation depth

19. To calculate the NHBC depth of foundation we need to know;

    (i) soil type- high shrinkage clay, medium shrinkage clay, low shrinkage clay or sand,

(ii) species of any nearby trees – containing information on water demand and mature height of the tree, and

(iii) distance nearby tree to the foundation

20. We relied upon the tree species as detailed for each foundation on the BNL design spreadsheets, where these spreadsheets were available, as the 'existing' tree at the time of design which had the greatest potential influence on the determining the design depth of each foundation.

21. We undertook a random check on the BNL assessment, both on site and via the tree survey details provided by BNL in May 2014. We found the selection was generally appropriate except that BNL had failed to consider the influence of a tree recorded at one foundation influencing adjacent foundations. We included the influence of those trees on the adjacent foundations in our assessment.

22. Our assessment of the potential extent of remedial works also considers the new tree planting but we have not relied upon the BNL 'as-built' detailed planting plan drawings dated 30 June 2010. Inspection of the trees present on site frequently does not accord with the 'as-built' drawings. In many locations trees are either absent or the location of trees relative to the guideway is different. We believe the drawings show the design layout of planting. We thus determined the specific tree type of the new planting that is adjacent to each foundation.

23. We input this data into a table contained in the NHBC guidelines and from this we calculate the NHBC compliant foundation depth.

24. NHBC also instructs us to take a climate into consideration. As the guideway is north of Cambridge we subtracted 0.05m for the depth of compliance as required by NHBC.

Determination of as-built foundation depth

25. We calculated how deep a foundation was dug by considering the as-built top of the beam level of the guideway.

26. We subtracted the depth of the superstructure of the guideway which included the depth of shims, the depth of bedding, the amount of blinding and mass fill from this level to give us the level to which the foundation was dug.

27. We then subtracted this dig level from the original ground level to give us a depth of any foundation.

28. We then compared this as built depth to the NHBC depth to determine whether a foundation was NHBC compliant.

29. The accuracy of my conclusions is therefore dependent on having both accurate original ground levels and accurate top of beam levels.

30. We received ground level data from multiple sources including data from long and cross sectional drawings of the guideway. We interpolated this data to give ground levels at specific chainages of the guideway.

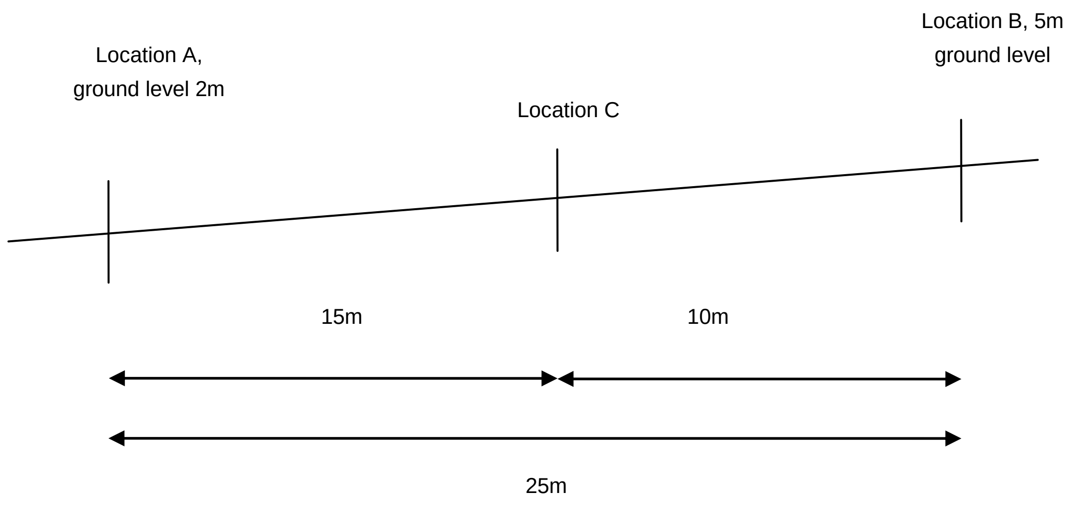
Interpolation

31. Ground level data from the long section drawings and the cross section drawings is generally given at intervals of 20m and 25m respectively. However the foundations were generally built at a distance of 7.5m from each other. Therefore, the locations of the foundations, for the most part, do not match the locations where we have ground level data.

32. We have interpolated the ground level data to obtain a reasonably accurate ground level at any foundation. Interpolation is easiest to explain through an example, suppose there are two locations, A and B say, at a distance of 25m apart, with ground levels 2m and 5m respectively. If we want the ground level of a foundation at location C, which is 15m from location A, we would take the difference in ground levels between A and B, divide this by 25m, the distance between A and B, and then multiply this by the distance between A and C, 15m and add the ground level at A to this. In this example this gives a ground level of 3.2m.

33. $Ground\ level = \frac{(Difference\ in\ level\ between\ A\ and\ B)}{(Distance\ between\ A\ and\ B)} \times (Distance\ between\ A\ and\ C) +\ level\ of\ A = \frac{(5-3)}{25} \times 15 + 2 = 3.2m$

34. The ground level at location C is 3.2m.



35. We used this method to calculate the ground levels at every foundation using ground level data from long section and cross section drawings.

Long Sections

36. We have seen long section drawings of the guideway which show the original ground levels and proposed levels of the guideway at intervals of 20 metres. We have interpolated this data to match the chainages where there are foundations. Below is a table contains a list of all the drawings we have received and the changes that they cover.

Index of long section drawings

Title	Date	Chainages
General Arrangement drawing sheet 11 of 28 as built	20/07/2007	7990-8700
General Arrangement drawing sheet 12 of 28 as built	20/07/2007	8690-9400
General Arrangement drawing sheet 13 of 28 as built	15/12/2006	9390-10100
General Arrangement drawing sheet 14 of 28 as built	15/12/2006	10090-10800
General Arrangement drawing sheet 15 of 28 as built	15/12/2006	10790-11500
General Arrangement drawing sheet 16 of 28 as built	15/12/2006	11490-12200
General Arrangement drawing sheet 17 of 28 as built	15/12/2006	12190-12900
General Arrangement drawing sheet 18 of 28 as built	15/12/2006	21890-13600
General Arrangement drawing sheet 19 of 28 as built	15/12/2006	13590-14300
General Arrangement drawing sheet 20 of 28 as built	15/12/2006	14290-15000
General Arrangement drawing sheet 21 of 28 as built	15/12/2006	14990-15700
General Arrangement drawing sheet 22 of 28 as built	15/12/2006	15690-16400
General Arrangement drawing sheet 25 of 28 as built	15/12/2006	17790-18500
General Arrangement drawing sheet 26 of 28 as built	15/12/2006	18490-19200
General Arrangement drawing sheet 27 of 28 as built	15/12/2006	19190-19900
General Arrangement drawing sheet 28 of 28 as built	15/12/2006	19890-20420

Cross Sections

37. We have seen cross section drawings of the guideway which show the original ground levels and proposed levels of the guideway at intervals of 25 metres.

38. The cross section drawings show multiple levels across any chainage for both original ground level and top of the guideway beam level. We have recorded the minimum and maximum

original ground levels as well as the ground level nearest to the proposed top of the guideway beam. We have interpolated this data to match the foundation locations.

39. We have also taken note of proposed top of beam level in these drawings and interpolated this data to match the foundation chainages.

40. Below is a table contains a list of all the drawings we have received and the chainages which they cover.

41. Index of cross section drawings

Title	Sheets	Date	Chainages
Second drove to Holywell ferry road cross sections	19 of 37 to 32 of 37	14/09/2007	3025-3825
Swavesey to B1050 cross sections	2 of 74 to 50 of 74	14/09/2007	6300-8725
Swavesey to B1050 cross sections	50 of 74 to 74 of 74	14/09/2007	8700-9875
B1050 to Oakington typical cross sections	1 of 61 to 61 of 61	23/04/2007	9970-13950
Oakington to Girton typical cross sections	1 of 24 to 24 of 24	23/04/2007	14050-15498
Girton to Histon typical cross sections	1 of 28 to 28 of 28	23/04/2007	15581-17451
Histon to Arbury typical cross sections	1 of 22 to 22 of 22	23/04/2007	17510-18920
Arbury to Kings Hedges typical cross sections	1 of 5 to 5 of 5	23/04/2007	19011-19326
Kings Hedges to Milton typical cross sections	1 of 15 to 15 of 15	23/04/2007	19410-20370

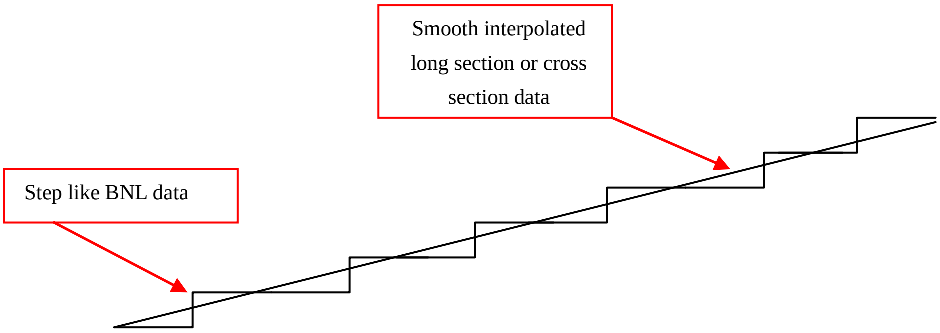
BNL Complete

42. We list the spreadsheets of which we have copies below

Doc ID	Chainage	A list written on one of the sheets	A list written on one of the sheets	
ES100121685	15581-17451	BAM00112935	ES100115100	ES100121606
ES100121686	17510-18901	BAM00113932	ES100115101	ES100121623
ES10012687	19011-19306	BAM00114175	ES100115102	ES100917953
BAM00012031	19011-19306	BAM00114309	ES100115108	ES100926311
BAM00012115	19011-193003	BAM00114732	ES100115435	ES100930845
BAM00012115	19415-20347	BAM00129465	ES100119796	ES101092968
BAM00012115	10601-10308	BAM00129743	ES100119993	ES100119993

BAM00112935	17436-15586	BAM00129813	ES100120103	ES100926311
ES100919867	15581-17451	BAM00189619	ES100120130	
ES100919872	17510-18905	BAM00114732	ES100121422	

43. These spreadsheets originated with BNL and contain original ground levels and top of beam levels for each foundation, therefore interpolation was not necessary for this data. However the original ground levels in this data set appears to be incorrect in places. For example, when the long sections and cross sections show that the ground level is sloping over, say, 50m, the BNL data might show that section to be flat and then immediately jump to higher level at the end of the section, making the ground level appear steplike, see diagram below.



44. We also have a set of data which appears to have originated from BNL, we refer to this data as BNL complete. This data contains top of beam levels for each foundation as well as blinding and mass fill. These as-built top of beam levels appear to be accurate across the full length of the guideway.

45. However, on occasion, the foundation locations used in the above two data sets do not agree. Furthermore, the data appearing in the BNL data set has many typographical errors and at places the same ground level was used across many foundations when all other data sources do not show a flat surface.

Ground levels

46. Below is a table showing where we obtained the ground levels that we used in our analysis of the guideway.

Origin of data used			
Chainage	**OGL**	**Chainage**	**TOB**
3050-8060	Long Section	0-7985	Cross Section
8060-16391	Long Section	7985-8060	Cross Section
16398-17096	Cross Section	8068-11156	Cross Section
17101-17646	Long Section	11163-15446	Cross Section
17653-17691	BNL	15453-15493	Long Section
17698	Cross Section	15500-18576	Cross Section
17706	BNL	18583-18906	BNL Complete
17713-18486	Long Section	19011-19183	Long Section
18493-18771	Long Section	19198-20365	Cross Section
18777-20365	Long Section		

Original ground level

Chainages from 3050 – 3755: Long section interpolated data

47. Long section data was consistent with top of beam cross section data for this section.

Chainages from 6305 – 16391: Long section interpolated data

48. Long section data was consistent with top of beam cross section data for this section.

Chainages from 16398 – 17096: At beam cross section interpolated data

49. We used at beam cross section data at this point as we do not have long section data for this section.

Chainages from 17101 – 17691: Long section interpolated data

50. Long section data was consistent with top of beam cross section data for this section.

Chainages from 17653-17706: BNL data and cross section data

51. There is an overpass in this area and the BNL data, although not accurate, appears to be the only data which was not taken from the top of the overpass. At chainage 17698 we have used cross section data as it appear to be the most reasonable for this one foundation.

Chainages from 17713 – 20365: Long section interpolated data

52. Long section data was consistent with top of beam cross section data for this section.

Top of beam level

Chainages from 3050 – 3755: Cross section data

53. We used cross section data for this section. All of the data sources are agree on the proposed level of the guideway.

Chainages from 6305 – 15446: Cross section data

54. We used cross section data for this section. All of the data sources are agree on the proposed level of the guideway.

Chainages from 15453-15493: Long Section

55. We used long section data for this section. All of the data sources are agree on the proposed level of the guideway.

Chainages from 15500-18576: Cross section data

56. We used cross section data for this section. All of the data sources are agree on the proposed level of the guideway.

Chainages from 18583-18906: BNL complete data

57. In this section there is a significant difference between BNL complete data and all other data sources. During a discussion with representatives from Atkins, we were informed that during construction changes to the layout of the guideway were made at this section and that the BNL data is most likely correct at this section.

Chainages from 19011-19183: Long Section

58. We used long section data for this section. All of the data sources are agree on the proposed level of the guideway.

Chainages from 19198-20365: Cross section data

59. We used cross section data for this section. All of the data sources are agree on the proposed level of the guideway.

Anticipated development of excessive foundation differential movement

60. In assessing the timescale of when foundations may move sufficiently to cause excessive differential settlement between them we have examined when the trees will grow to affect the nearby foundations. Using this we have estimated a timescale for the risk of damage to the guideway.

61. The rate of growth of roots will also be dependent on a range of other environmental factors, which cannot be predicted with any certainty but we have relied on published data from the Forestry Commission to assess the rate of growth of the various tree species present and thereby the rate of spread of the tree roots.

62. BNL recorded whether or not it found tree roots in any foundation excavation during construction. These records tell us whether trees roots had already reached the area where a foundation was to be built.

63. If BNL did not find any roots in a foundation excavation then we have assumed that the nearby trees were not fully grown. For these foundations we checked how far away the tree was from the guideway and determined a time when a tree is likely to start to affect a foundation. Over time as the trees grow larger, foundations which previously may only have moved slightly will start to move more and will require remediation. Therefore foundations which start to show limited differential settlement and thus not require immediate remediation may become highly likely to require remediation in future years. Thus as the trees grow more and more foundations will require remediation.

Year 1 – 5 (2014 – 2019)

64. During this period we do not anticipate that there will be significant issues developing until towards the middle to end of the period when roots from 'existing' high water demand and high growth rate trees, significantly penetrate below foundations well short of NHBC depths. This will probably first occur in June to September of any particular year. In these initial years of recovery much, possible all, of the subsidence can be expected to occur during winter leading to heave of the foundations back to, or close to, the previous winter level. The rate of development of the subsidence under foundations affected is impossible to determine but we estimate that up to between 54 and 65 foundations will be highly likely to require remediation by year 5, between 38 and 45 more foundations will possibly require remediation and between 253 and 319 may start moving but are unlikely to immediately require remediation. An indeterminable number of these latter foundations will require remediation in future years as the tree which are affecting them grow larger.

Year 5 – 10 (2019 – 2024)

65. The foundations affected in the latter part of years 1 – 5 will continue to be affected if remediation is not undertaken. A further 24 foundations will be highly likely to require remediation by year 10, a further 6 foundations, not included in those moving up to year 5, will possibly require remediation. An indeterminable number of the foundations that started to move by year 5 will require remediation in this period as the trees grow larger.

66. A further 102 foundations may start moving but will not immediately requiring remediation but may require remediation in future years.

Year 10 – 15 (2024 – 2029)

67. At the end of this period it is expected that all of the ‘existing’ trees which NHBC standard shows could affect the guideway will be affecting it. By year 15 there will a further 17 foundations which will be highly likely to require remediation, 15 will possibly require remediation. An indeterminable number of the foundations that started to move from around year 5 to year 10 will require remediation in this period as the trees grow larger.

68. A further 265 may start moving but are unlikely to immediately requiring remediation but may require remediation in future years.

After Year 15 (2029 onwards)

69. It is not feasible to estimate how many more foundations will develop excessive differential settlement beyond year 15 but it may approach the total number of foundation given in §87. Others examining the same data may well assess different numbers of foundations affected with time.

APPENDIX M – Further details on root barriers

1. We expect that root barriers will extend up to 3m in depth with an average depth of approximately 2m. The actual barrier, generally in the form of either a very tight mesh woven fabric which traps find roots or a non-woven, felt like fabric containing slow release herbicide to kill the roots that approach it, is inserted after sections are bonded together to form a continuous sheet. The depth required for each foundation will be dependent on the tree species and the precise location of the tree in relation to the foundations. The lateral extent of the barrier for each foundation is likely to be 7.5 – 8m. The barriers will be placed in a narrow 0.3-0.5m wide trench.
2. For the purposes of estimating costs replacement root barrier will need to be on average 0.5m deeper and the lateral extent will need to be 9.5 -10m in an attempt to cut of those roots that have found their way around the original root barrier.
3. Excavation of trenches of the barriers and placement of the barriers for the vast majority of foundations potentially requiring reactive remedial work between chainage 6600 – 8700, 10800 – 11700, 12300 – 12900 and 14300 – 14600 is likely to be required on the slopes of the cutting and embankment that the guideway is built upon. In these locations it is thus likely that additional temporary works will be required to excavate the trench and install the barrier.
4. Where there is a concern that water may get trapped on the guideway side of the barrier, sand and gravel fill can be passed between the barrier and the wall of the trench to form a vertical drain. Once the barrier is placed and any drain installed, any remaining space in the formed trench is filled to ground level. Thus once the barrier is installed and surface vegetation recovers it is not a readily visible feature.
5. There are drains that extend from the foundations to soakaways/outfalls remote from the guideway on one side of the foundations. Where these are on the side where the root barrier is to be installed it will be necessary for the design of the barrier to either allow them to pass through the barrier without compromising the barrier’s function, be rerouted around the barrier or be replaced by a drain exiting on the opposite side of the foundation for the barrier. In our view, rerouting or replacement is the preferred option as it removes the significant risk of compromising the barrier by the drain passing through the barrier. The extent of the drainage works associated with such rerouting or replacement will vary from location to location and locally may require new carrier drains to an outfall.
6. Further, the positioning of each barrier needs to be defined by an arboriculturist. This is to ensure amongst other matters that the tree that has produced the roots is not destabilised by the barrier restricting root growth required to provide long term stability to the tree.

APPENDIX N - LOGISTICS FOR CARRYING OUT FOUNDATION DEEPENING PRE-EMPTIVE REMEDIAL WORKS

1. We have given consideration to how the remedial works could be undertaken such that the guideway can remain, to some extent, operational.

2. The nature of the work involves lifting of 30m or 60m lengths of guideway ladders from the foundations, removing the bearing and shims and then the foundation pads. Excavation then occurs to the new foundation depth, the excavation is backfilled and the foundation pad replaced. Depending on the superstructure option selected either the new bearings and shims are then placed or the old bearings and shims reinstalled. The guideway ladders are then brought back and placed on the shims. It is not amenable to night time working as the scope of the work is too great for such a short duration of works, additionally noise as a result of the works would pose an issue close to residential properties.

3. We have considered the following possibilities:

   (i) For remedial works Option A, total closure of the Northern Section between Station Road, Swavesey and Milton Road, Chesterton,

   (ii) Weekend working; and

   (iii) Closure of one section of guideway at a time.

4. For remedial works Option A the scope of foundation deepening works is extensive and affects around 14 km of the northern section of the guideway but, unlike the superstructure works, does not involve every foundation along those 14kms. As with Option 1, we believe that total closure would be unacceptable to the Council and the public even though the overall time to complete the remedial works would probably be less than other methods.

5. Weekend working would be disruptive to the progress of the work and the time to complete the works would be unduly long and prohibitive. This would consequently incur considerable additional costs. Furthermore, it is questionable whether the guideway could always be made operational at the end of each shift as weather and unexpected ground conditions could impact on the work programme.

6. Sectional closures of the guideway appears to be the most appropriate option for the pre-emptive foundation deepening works required under all three options.