BATTERSEA YARD – BRIDGE INFILL PROJECT

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ABSTRACT

Rail First is currently engaged in the Design, Management and Construction of a multi-span bridge infill scheme on behalf of Railtrack Project Delivery (Southern). This project is a Target Cost contract incorporating the concepts of partnering and value engineering to generate shared benefits. Commitment on both sides is demonstrated by a programme of Team Building and Value Engineering Workshops which has generated many benefits. This paper will illustrate how a combination of well established engineering solutions were brought together in an innovative and unusual way to meet both the design parameters and maintenance of normal train services. Whilst the trackwork forms an integral part of the contract, this paper is only concerned with the embankment infill details and only general information regarding the trackwork is provided.

BACKGROUND

The railway bridge structure, built in 1866, is located between Victoria and Battersea Park stations on a busy section of the Victoria to Brighton line in South London. It consists of wrought iron girders in five spans, supported on heavily skewed brick piers, and carries three timber sleepered tracks fixed to longitudinal baulk timbers.

The bridge spans a total of 120 metres over Battersea Yard Depot, which once served as a busy marshalling yard and sidings, before becoming vacant several years ago. As part of Railtrack's continuous Bridge Maintenance Programme, Battersea Yard Bridge was identified as being in need of a long-term repair solution. To this end Railtrack commissioned a feasibility study to look at various options, which ranged from complete renewal, to repairs and strengthening of smaller structural elements. Railtrack was keen to adopt a scheme that would not only reduce maintenance costs in the long term, but also satisfy budgetary and train performance objectives. The conclusions reached by the feasibility study suggested that substantial repair and strengthening was the option that best met Railtrack's requirements. However, Rail First was invited to look at the site and offer advice based on their considerable experience and knowledge of repairs and maintenance of old railway structures.

In conjunction with our design team partners Gifford & Partners and Stents, a different approach to the problem was investigated by Rail First. This centred around a bridge infill proposal that enabled the bridge structure to be replaced progressively by an embankment during normal train services so that the tracks could be supported by a low maintenance formation and track ballast.

The key elements forming the parameters for the design were:

- Settlement to be controlled to ensure structural integrity and serviceability of the 1866 structure and adjacent structures. This included a multi-span railway viaduct structure built in 1903.
- Settlement to be controlled as part of a track maintenance strategy to ensure the track remains within specified tolerances.
- All embankment work to be undertaken without disruption to the train service or line speed.

Whilst an infill option had been investigated by Railtrack previously, a conventional approach involving removal of the bridge girders etc., ruled out the potential benefits of a low maintenance structure. The proposal jointly developed by Rail First and Gifford & Partners not only addressed these issues, but also showed substantial savings compared to other proposals.

SOLUTION

Alternative Solution

The alternative solution consists of a foam concrete/PFA embankment supported by a granular load distribution layer over piles to transfer embankment loads to stiffer materials at depth in order to limit settlements. This solution had the following advantages over the previously proposed strengthening solution:

- Significantly lower cost
- Minimum work during track possession
- Proportionally lower future track maintenance cost
- Provision of an almost maintenance free load path to the foundation

In this project the issue was not the ability of the soil to take the embankment loads, but the limiting of the resulting settlements to acceptable values, or the provision of mitigating measures and designing out of the settlements. In addition the influence of the resulting settlements on a parallel railway viaduct only a few metres away, and on the masonry arches along the infill viaduct had to be assessed. Therefore, the following design criteria were considered for this solution:

- Ensuring the integrity of the masonry foundation of the adjacent parallel viaduct by limiting the differential settlements
- Maintaining the existing RA rating of the parallel viaduct for the additional ballast required to satisfy track alignments as a result of differential settlements by limiting the total settlement
- Limiting the total and differential settlements along the infill structure to ensure the integrity of the masonry arches

Assessment of Existing Structures

The bridge parallel to the infill is referred to as the 1903 structure. This was assessed to Railtrack Line Code of Practice RT/CE/C/15. The RA ratings of all the components were calculated. Based on this assessment the maximum amount of additional ballast that this structure could carry without affecting its RA rating was determined. The masonry piers of the 1903 structure were also assessed and the maximum additional differential settlement that they could safely sustain was determined. The masonry arches at either end of the infill bridge were assessed to determine their RA rating and the maximum differential settlement that they could safely sustain. These limits were then combined for the design of the pile lengths and their arrangement.

Need for Monitoring

Normally piles are designed for strength, which is relatively simple to quantify. In this case the piles were designed for settlement which, although theoretically possible, is more difficult to predict accurately and therefore it was important to keep this aspect of performance under close observation. This was achieved by carrying out precise levelling at selected locations along the structure, which could be monitored regularly.

The monitoring is explained in more detail in the next section.

Piling

The choice of piling method was made only partially due to ground conditions. Driven piling was ruled out due to the transfer of unacceptable vibrations into the existing rail viaduct and the potential for inducing additional long-term settlements.

Stratum	Depth below ground level
Made Ground	0 – 2m
Alluvium	2 – 4m
Terrace Gravel	4 – 8m
London Clay	>8m

A bored cast in-situ construction method was used beneath the railway arches due to restricted headroom making the use of a Continuous Flight Auger (CFA) rig impossible. However, a higher productivity CFA rig was able to be used for the piles supporting the sections of embankment not under the viaduct.

The pile layout and spacing were chosen to optimise pile length and load distribution layer reinforcement. The further apart the piles the higher the individual pile loads (and therefore pile length) and a stronger reinforcement grade required for the load distribution layer.

In order to satisfy the design criteria, which were defined earlier, two pile types were adopted. One was longer, a pile which shed load via shaft friction through the London Clay. The other a softer pile, which shed load via the base into the gravels. The base capacity piles (softer) were used predominantly away from the abutments whilst the longer, stiffer, friction piles were used at either end of the viaduct to limit the differential settlements.

The piles used in this project are tabulated below, which were the subject of a number of Value Engineering solutions to achieve the most economic arrangement.

Piles diameter and length	Spacing	Number of piles
400mm dia. x 5m	1.35m centres	720
300mm dia. x 15m	1.50m centres	297
300mm dia. x 19m	Selected areas	22

In order to estimate settlements and deduce the optimum pile type (length) layout, a detailed set of analyses were carried out. These analyses employed an elastic settlement model using a Boussinesq stress distribution (the OASYS programme VDISP). The load shed through the gravel founded piles was modelled as a uniformly loaded raft at the appropriate level in the gravel.

The load was modelled as being applied to the London Clay on an equivalent raft at $^2/_3$ pile penetration into the London Clay.

Reinforced Granular Load Distribution Layer

Originally the load distribution layer consisted of a high quality granular fill reinforced with polyurethane sheathed Para-grid, the grade of which was related to the selected pile spacing. Following a value engineering initiative a reduced specification granular infill (800mm thick crushed concrete) and an alternative reinforcement were proposed. The infill had a higher fines content than was permissible in the DTP specification for earthworks for granular transfer blankets. Following shear box testing this alternative material was found to have sufficient drained shear strength to comply with design assumptions ($\phi' = 35°$). The alternative reinforcement was an unsheathed structural geotextile (Basetex); whilst this material had comparable tensile strength and strain behaviour to the Para-grid, there was concern over the frictional interface (i.e. pull-out) and protection against chemical or mechanical damage of the unsheathed geotextile. Pull-out tests using the appropriate infill and Basetex were carried out under laboratory conditions. The interlock friction between the Basetex and the infill was found to be in excess of the assumed design friction (measured $\alpha = 0.9$ cf. published/assumed $\alpha = 0.8$). In order to allow for the higher risk of mechanical and chemical degradation a stronger grade 6 Basetex was adopted and still proved to be a more economical option.

The tensile loads acting on the load distribution layer were determined using the design method given in BS 8006. This was validated by comparison with a design method developed by Hewlett and Randolf (1988)

<u>Infill</u>
The infill consists of two parts, PFA and foam concrete. PFA is used directly above the granular load distribution layer up to the underside of the bridge girders of the original rail viaduct. The rest of the embankment is filled with foam concrete.

PFA was adopted as an infill material to restrict the embankment loading and because of its high strength gain following deposition. Being a pozzolanic material, cementation within the infill developed within a month of deposition hence limiting the amount of reinforcement required to support the steep embankment side slopes. The PFA was reinforced at the slopes by Geogrid Tensar 55RE.

Parameters:-	Day 1;	$\phi' = 35^o$;	$c' = o$	) supplier's
	Day 28;	$\phi' = 35^o$;	$c' = 5\ kN/m^2$	) figures

The foam concrete was performance based designed to transfer the load from the ballasted track to the PFA. A minimum 28 days strength of $2N/mm^2$ with a maximum density of $1400kg/m^3$ were specified to satisfy the strength requirements whilst restricting the embankment loading. The use of foam concrete provided a reasonably fast method of filling the inaccessible areas between the bridge girders of the original rail viaduct. Temporary steel ties had to be placed between the bridge girders to provide lateral stability against forces generated by the wet foam concrete.

The durability of the PFA was improved by providing additional protection on the elevations. The east elevation of the PFA embankment was covered with topsoil with grass seeding. The west elevation, which is in the shade and susceptible to water run off from the adjacent 1903 structure, was covered with C30 sprayed concrete with $0.90kg/m^3$ polypropylene fibres and a minimum thickness of 40mm.

MONITORING AND TRACK MAINTENANCE STRATEGY
Structure monitoring was an essential part of the track maintenance strategy and provided information about the behaviour of the structures during the construction period, when 60% of the predicted settlement was expected to occur.

The following measurements were taken at regular intervals:-

<u>Structure Levels</u> Targets were positioned on the main girders on the 1866 structure and survey pins were fixed to the masonry piers, which were read from a base station outside the critical settlement zone.

<u>Verticality Checks</u> Verticality of the 1866 and 1903 support piers were measured to detect any possible rotation. For the 1866 structure this was only possible up to the point when infilling covered the datum pins.

<u>Crack Widths</u> Regular inspection and measurement of existing crack widths in the piers and abutments.

Track levels — Levels were taken along the running edge of the tracks to check the following conditions:-

- Vertical alignment
- Cross levels (cant)
- Twist

In addition to the above the following information was made available:-

Structure Defects — Results from regular structure examinations and inspections carried out during the contract.

Track Inspections — Results from visual examinations carried out during routine patrols of the track.

Track Geometry — Results from the running of the High Speed Track Recording machine during the construction.

Predicted settlement and theoretical "trigger level" conditions based on Railtrack Line Specification RT/CE/S/104, were compared with the information gathered during the critical stages of the works, and a review of this information was carried out at regular intervals to assess and arrange any required track packing to comply with the specification.

Appendix C — Gives details of the predicted substructure settlement, and period when track geometry "trigger level" conditions would be exceeded.

Appendix D — Gives a summary of the actual settlement that occurred during the infill period.

TRACKWORK

The project includes the removal of the existing tracks so that the existing longitudinal baulk timbers and wrought iron cross girders can be removed and a new ballast formation approximately 750mm deep laid on top of the new embankment. The track is to be upgraded with concrete sleepers and reinstated to existing line and level.

Due to track access availability, work is not expected to take place until 2001, and this phase of the contract will include the following works:-

- Diversion of HV traction cables
- Diversion of Signal and Telecommunication cables
- Removal of tracks (Down Slow, Up Slow, Down Fast)
- Removal of longitudinal baulk timbers
- Removal of wrought iron cross girders
- Removal of top sections of redundant outer main girders.
- Laying and compaction of bottom ballast
- Reinstatement of tracks with concrete sleepers
- Laying and compaction of top ballast
- Reinstatement of cess walkways

PROGRAMME

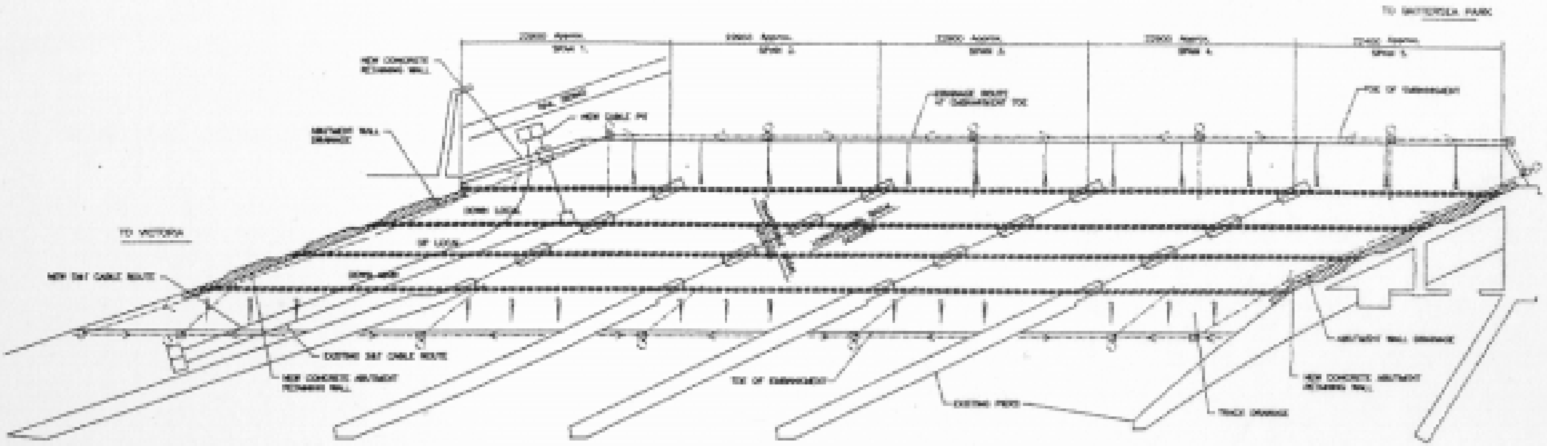
The contract is split into 3 phases:-

Phase One – Piling and Infill
Phase Two – Track Maintenance
Phase Three – Trackwork

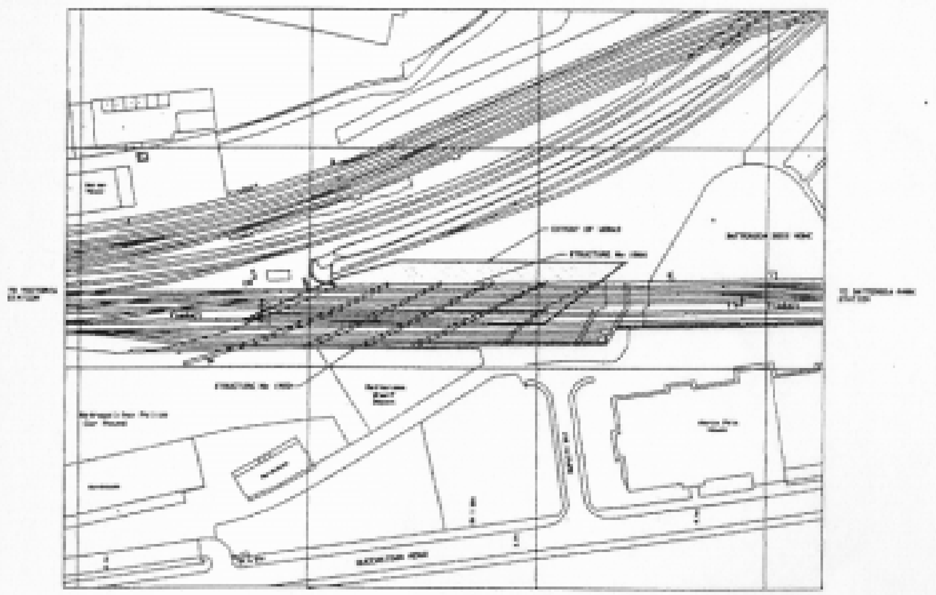
<u>Phase One</u>	Work commenced in June 1998 with site clearance, access works and site accommodation etc. Piling commenced in August 1998 and the infilling in November 1998. Completion of phase one was achieved on programme by July 1999.
<u>Phase Two</u>	Due to the reduced settlement actually experienced during the infill stage, it is not anticipated that any track packing will be required prior to the replacement of the tracks on a ballast formation.
<u>Phase Three</u>	Removal of the redundant parts of the bridge structure and replacement of the tracks on a ballast formation will not take place until 2001 due to availability of a 100 hour track possession. The associated cable diversions and alterations to the cess walkway will be carried out during a 10 week enabling works programme prior to the possession.

REFERENCES

Hewlett, WJ and Randolf, MF (1988), “Analysis of Piled Embankments”, Ground Engineering, Vol. 21, No. 3, pp 12-18.



PLAN ON EXISTING FOUNDATIONS



ORDNANCE SURVEY MAP

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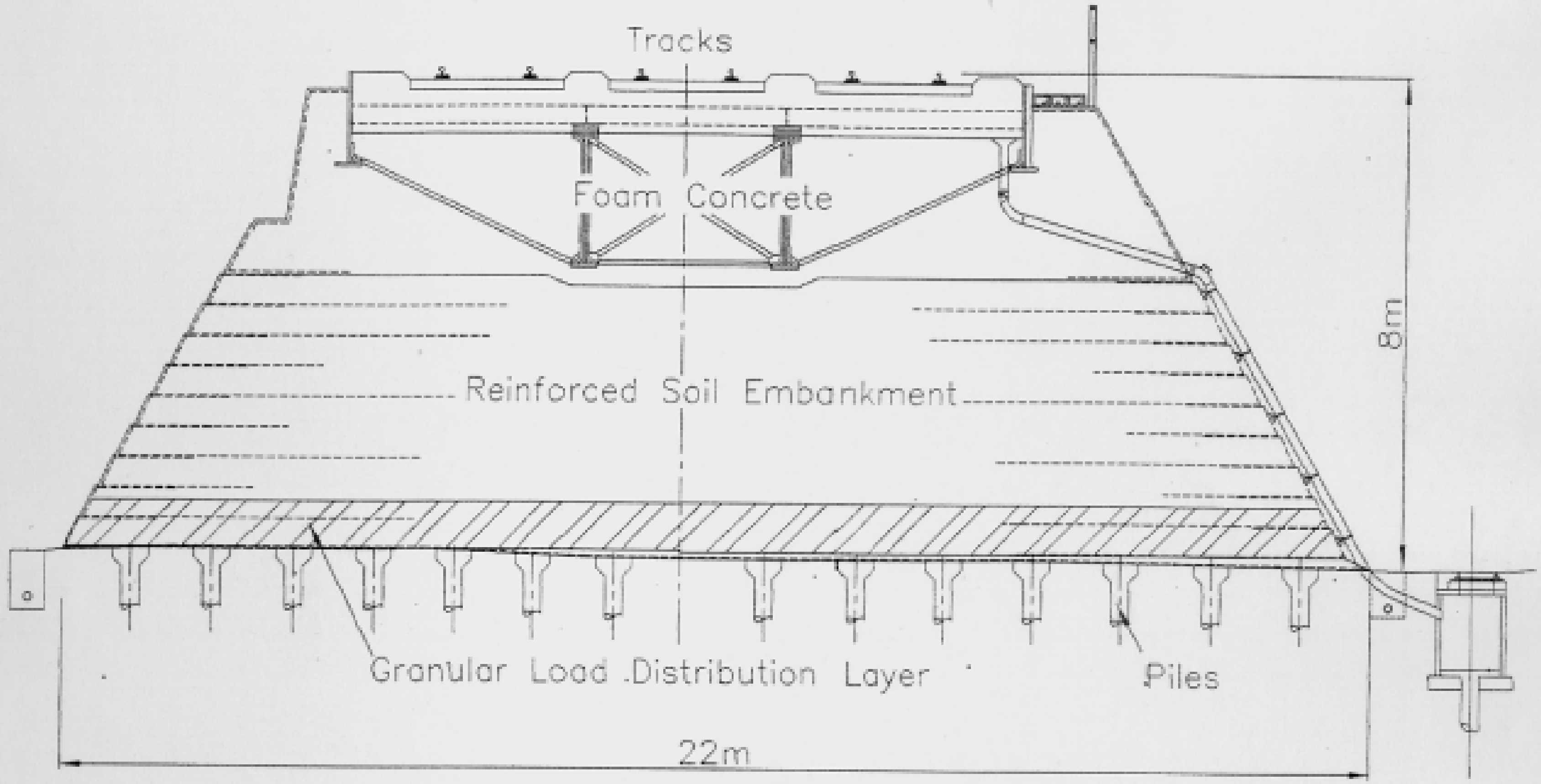
APPENDIX A



BATTERSEA YARD – BRIDGE INFILL PROJECT

TYPICAL SECTION

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APPENDIX B

APPENDIX C

BATTERSEA YARD BRIDGE

Percentage of Total Settlement at Which Railtrack Geometric Track Tolerances First Exceeded

Short 5.5m piles at 1.35m c/c extended 6m (skew) into end spans 1 and 5 - ie. approximately 1 No full row

	Line Reference	Percentage of Total Settlement at Which Railtrack Geometric Track Tolerances Exceeded						Remarks
		North End			South End			
		I	II	III	I	II	III	
1866 structure	Down Slow	24.7 N. Abutment	Not Exceeded	Not Exceeded	27.9 S. Abutmen	Not Exceeded	Not Exceeded	Vertical alignment critical during construction at 24.7% of total settlement
	UpSlow	28.6 N. Abutment	Not Exceeded	Not Exceeded	26.0 S. Abutmen	Not Exceeded	Not Exceeded	Vertical alignment critical during construction at 26.0% of total settlement
	Down Fast	29.8 N. Abutment	Not Exceeded	Not Exceeded	20.8 S. Abutmen	Not Exceeded	Not Exceeded	Vertical alignment critical during construction at 20.8% of total settlement
1903 structure	Up Fast	28.6 N. Abutment	91.9 Pier 1 to 5	Not Exceeded	24.7 Pier 5	91.9 Pier 1 to 5	Not Exceeded	Vertical alignment critical during construction at 24.7% of total settlement
	Reversible	31.2 Mid-span 1	Not Exceeded	Not Exceeded	38.3 Pier 5	Not Exceeded	Not Exceeded	Vertical alignment critical during construction at 31.2% of total settlement
	Berthing Lines (East & West)	Not Exceeded	Not Exceeded	Not Exceeded	Not Exceeded	Not Exceeded	Not Exceeded	Railtrack geometric track tolerances not exceeded during the life of the structure

Notes:-

1. Piers and Spans numbered from North Abutment
2. The above predicted trigger times are based on the assumption that the existing track alignment before construction is perfect.

Railtrack Geometric Track Tolerances	
I	Vertical alignment : +/- 13mm / 10m offset
Note:	The above vertical alignment track tolerance is taken from Railtrack Line Specification RT/CE/S/102 'Track Construction Standards' and is applicable for the track speed of 45mph
II	Cross level (cant): +/- 20mm
III	Twist: 1 in 200
Note:	The above cant and twist track tolerances are taken from Railtrack Line Specification RT/CE/S/104 'Track Maintenance Requirements'

Time After Construction	Anticipated Settlement as a % of Total Settlement
Immediately after construction	60%
10 years after	66%
60 years after	76%
120 years after	83.2%
200+ years after	100%

BATTERSEA YARD BRIDGE

Predicted Substructure Settlement
Short 5.5m piles at 1.35m c/c extended 6m (skew) into end spans 1 and 5
(ie. approximately 1 No full row)

1866 Structure

Reference Datum Location		**Settlement value at various stages during the embankment life (mm)**								
	Percentage	100	15	20	40	55	60	66	76	83
North Abutment	East	79.0	11.9	15.8	31.6	43.5	47.4	52.1	60.0	65.6
	West	32.0	4.8	6.4	12.8	17.6	19.2	21.1	24.3	26.6
Pier 1	East	140.0	21.0	28.0	56.0	77.0	84.0	92.4	106.4	116.2
	West	112.0	16.8	22.4	44.8	61.6	67.2	73.9	85.1	93.0
Pier 2	East	145.0	21.8	29.0	58.0	79.8	87.0	95.7	110.2	120.4
	West	141.0	21.2	28.2	56.4	77.6	84.6	93.1	107.2	117.0
Pier 3	East	143.0	21.5	28.6	57.2	78.7	85.8	94.4	108.7	118.7
	West	143.0	21.5	28.6	57.2	78.7	85.8	94.4	108.7	118.7
Pier 4	East	113.0	17.0	22.6	45.2	62.2	67.8	74.6	85.9	93.8
	West	133.0	20.0	26.6	53.2	73.2	79.8	87.8	101.1	110.4
South Abutment	East	58.0	8.7	11.6	23.2	31.9	34.8	38.3	44.1	48.1
	West	63.0	9.5	12.6	25.2	34.7	37.8	41.6	47.9	52.3

1903 Structure

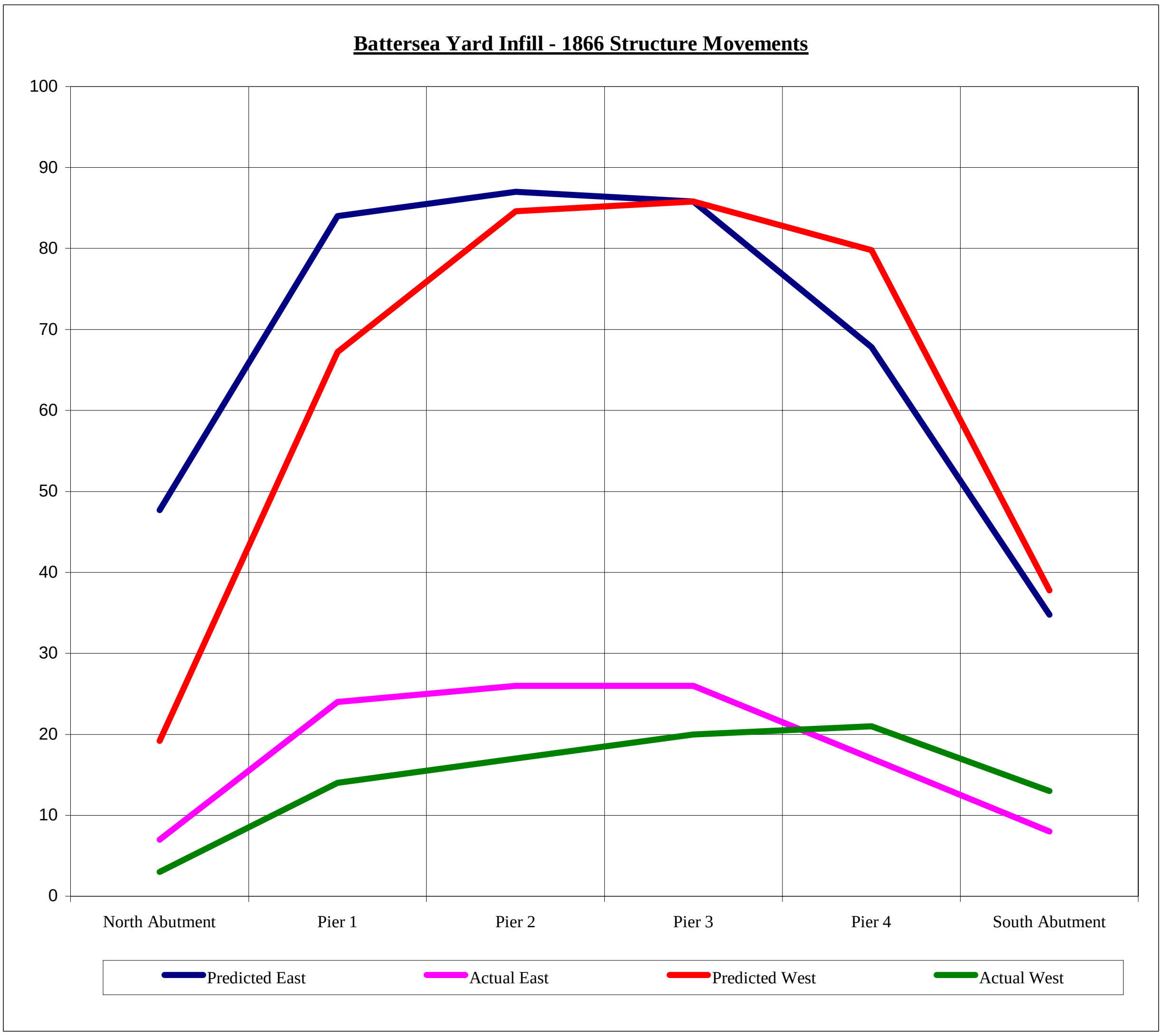
Reference Datum Location		**Settlement value at various stages during the embankment life (mm)**								
	Percentage	100	15	20	40	55	60	66	76	83
North Abutment	East	23.0	3.5	4.6	9.2	12.7	13.8	15.2	17.5	19.1
	Middle	2.0	0.3	0.4	0.8	1.1	1.2	1.3	1.5	1.7
	West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pier 1	East	80.0	12.0	16.0	32.0	44.0	48.0	52.8	60.8	66.4
	Middle	17.0	2.6	3.4	6.8	9.4	10.2	11.2	12.9	14.1
	West	2.0	0.3	0.4	0.8	1.1	1.2	1.3	1.5	1.7
Pier 2	East	100.0	15.0	20.0	40.0	55.0	60.0	66.0	76.0	83.0
	Middle	48.0	7.2	9.6	19.2	26.4	28.8	31.7	36.5	39.8
	West	13.0	2.0	2.6	5.2	7.2	7.8	8.6	9.9	10.8
Pier 3	East	130.0	19.5	26.0	52.0	71.5	78.0	85.8	98.8	107.9
	Middle	57.0	8.6	11.4	22.8	31.4	34.2	37.6	43.3	47.3
	West	25.0	3.8	5.0	10.0	13.8	15.0	16.5	19.0	20.8
Pier 4	East	108.0	16.2	21.6	43.2	59.4	64.8	71.3	82.1	89.6
	Middle	44.0	6.6	8.8	17.6	24.2	26.4	29.0	33.4	36.5
	West	25.0	3.8	5.0	10.0	13.8	15.0	16.5	19.0	20.8
Pier 5	East	70.0	10.5	14.0	28.0	38.5	42.0	46.2	53.2	58.1
	Middle	60.0	9.0	12.0	24.0	33.0	36.0	39.6	45.6	49.8
	West	25.0	3.8	5.0	10.0	13.8	15.0	16.5	19.0	20.8
Pier 6	East	11.0	1.7	2.2	4.4	6.1	6.6	7.3	8.4	9.1
	Middle	8.0	1.2	1.6	3.2	4.4	4.8	5.3	6.1	6.6
	West	5.0	0.8	1.0	2.0	2.8	3.0	3.3	3.8	4.2
Pier 7	East	1.0	0.2	0.2	0.4	0.6	0.6	0.7	0.8	0.8
	Middle	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	West	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Time After Construction	Anticipated Settlement as a % of Total Settlement
Immediately after construction	60%
10 years after construction	66%
60 years after construction	76%
120 years after construction	83%
200+ years after construction	100%

APPENDIX D

SUMMARY OF TOTAL SETTLEMENT DURING THE CONSTRUCTION PERIOD

1866 STRUCTURE	LOCATION	PREDICTED (mm)	ACTUAL (mm)
North Abutment	East	47.40	7.00
	West	19.20	3.00
Pier 1	East	84.00	24.00
	West	67.20	14.00
Pier 2	East	87.00	26.00
	West	84.60	17.00
Pier 3	East	85.80	26.00
	West	85.80	20.00
Pier 4	East	67.80	17.00
	West	79.80	21.00
South Abutment	East	34.80	8.00
	West	37.80	13.00



APPENDIX F

FACTS AND FIGURES

Contract Details:

Client:	Railtrack Project Delivery (Southern)
Value:	£2.7m
Contract:	Design & Build ICE Standard Form, with Railtrack Special Conditions and Particular Conditions

Principal Contractor:	Rail First Ltd
Designers	Gifford & Partners
Subcontractors	
Piling	Stent Foundations Ltd.
Infill	Balfour Beatty Construction Ltd.

Technical Details:

Soil Stratum:

Made ground	0 - 2m – below ground level
Alluvium	2 - 4m – below ground level
Terrace gravels	4 - 8m – below ground level
London clay	8m+ – below ground level

Piling:

400mm dia x5m long piles	- 720 No.
300mm dia x 15m long piles	- 297 No.
300mm dia x 19m long piles	- 22 No.

Granular Load Distribution Layer:
800mm thick crushed concrete
Approximate volume – 2150m^3

Geosynthetic Reinforcement:

Geotextile separator	Lotrak 10/7
Basal geotextile reinforcement:	
Perpendicular to piers	Basetex 1000/100
Parallel to piers	Basetex 200/50
PFA geogrid reinforcement	Tensar 55RE

PFA:
Class 7B material to SHW
Approximate volume – 7850m^3

Foamed Concrete:
Minimum 28 day strength – 2.0 N/mm^3
Maximum dry density – 1400kg/m^3
Approximate volume – 4300m^3

Finishes:
East face of PFA embankment – topsoil with grass seeding.
West face of PFA embankment – sprayed concrete with polypropylene fibres.

Predicted Settlement:

At end of construction	96mm
After 10 years	106mm
After 120 years	133mm
After 200 + years	160mm (Settlement prediction relates to centre of embankment)

APPENDIX E

PILES INSTALLED BENEATH THE BRIDGE STRUCTURE

VIEW OF EAST SIDE EMBANKMENT UNDER CONSTRUCTION

APPENDIX E

COMPACTION OF PFA BENEATH BRIDGE STRUCTURE

VIEW OF COMPLETED EMBANKMENT