Patent Pending

Smartbase® Precast Modular Signal, Gantry & OLE Foundation

Designed to significantly reduce programme and onsite costs whilst vastly improving safety, sustainability and quality, Smartbase® has been developed to revolutionise the installation of signal, gantry and OLE bases across the UK's rail network.

VAN ELLE RAIL

Demonstration Modular Precast Concrete OLE, Signal & Gantry Bases Design Calculations

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1. Smartbase® Introduction

The most expensive and programme intensive part of the planned UK rail network improvements is that for the OLE infrastructure upgrades. Most of this work, from the ground engineering perspective, takes place during night-time possessions and therefore poses unique challenges on completing these works safely, within programme and to budget.

Van Elle has the experience and the latest, most powerful RRVs and attachments for installing 610 & 762mmØ steel, augered and drilled piles quicker and more accurately than any other contractor, however, the traditional cast insitu OLE bases are outdated, slow and quickly lose any advantage already gained.

The existing generic foundation designs vary greatly from 2m(L) x 2m(W) x 1m(D) to the largest at 5m(L) x 2m(W) x 1.5m(D). These require a great deal of ground preparation, planning and expense prior to delivery of the large volumes of readymix concrete. Once poured, a curing period of at least 28 days is essential before the stanchions can be installed requiring further possessions, more contractors and significant expense. Getting wet concrete to remote rail locations at night also presents its own challenges including having to pay for the plant to stay open out-of-hours, the need for specialist plant to transport the concrete to the work site, making sure the steel is available and placed prior to the pour and due to the volumes required, catering for multiple trips to the plant, taking up valuable possession time and slowing the overall process. Uniform curing of concrete is also a significant factor both in direct sunlight and freezing winter conditions. This can weaken the finished product, reduce the quality, longevity and in some cases, make it unfit for purpose.

Reductions in materials, cost and programme could be realised simply by designing each base bespoke to its location, however, this would be unrealistic and we saw a much greater opportunity here to significantly magnify the benefits and savings of such a system.

The resulting solution, Smartbase®, uses post-tensioned technology to connect precast sections to form a one-size-fits-all foundation suitable for locations across the network and as defined in the following design document.

With 10s of 1000s of OLE bases to install in CP5, CP6 and beyond, Smartbase® has the potential to significantly reduce programme and save many millions of pounds for the client.

Design

In order to ensure that any innovation could tackle as many of the issues with the existing process as possible, we created a list of criteria which had to be considered;

- Design & Manufacture
- Material Usage and Sustainability
- Storage
- Transport and Accessibility
- Maintenance and Longevity
- Bespoke Vs. Generic
- Programme Benefits/Drawbacks
- Cost

This was used to create the brief for the design team to maintain maximum efficiency and cost reduction.

Manufacture

Smartbase® is manufactured in gravity-fed reinforced steel shutters in a modern, purpose-built precast factory. Our state-of-the-art batching plant ensures a consistent mix design tested for its suitability for the Smartbase® product guaranteeing strength, a quality, aesthetic finish and repetitive engineered tolerances.

Our large, indoor heated curing area, is ideal for all weather conditions preventing the possibility of uneven hardening due to excess direct sunlight or weak concrete due to the crystallisation of water molecules in winter, again, an advantage of precast over insitu.

Installation

Planning is key to ensuring that this and follow-on products are installed with maximum efficiency. The individual sections are transported to site on track mounted trailers towed by RRVs which lift them into position installing a complete unit in circa 1 hour, once preparation has taken place, negating the requirement for any ‘wet’ products and therefore eliminating any curing period. Stanchions can be installed immediately significantly improving the ‘global process’ and reducing the overall programme. In addition to the benefits offered by a precast solution during the production stage, the same benefits can also be realised in the installation on site eliminating its weather dependency. Quality, speed and accuracy remains the same regardless of the time of year and weather conditions.

Additional

For areas of track at risk from landslips and to reduce the requirement for six monthly visual inspections, 2 dimensional tilt sensors can be fitted to the Smartbase® units to relay any movement back to a central office in real-time or at specific intervals.

2. Scope

These calculations detail the design of a demonstration precast concrete modular base to be employed on the railway network as the foundation for signals and other associated infrastructure which might require a conventional pad foundation.

The base comprises 3 No. sections or units denoted A (base) to C (top unit) upon which the signal or gantry mast sits. The base is designed so that each section may be lifted individually and the whole base connected together using a series of threadbars to form one large gravity structure.

The precast base eliminates the need for concrete pours on site and therefore reduces the overall construction time required under possession resulting in time and cost savings.

3. Documentation

Package from Van Elle Limited containing:

1. 140625 Load table F15-Rev.2- Variable-Permanent Loads for Signal Bases
2. Network Rail Site Instruction 4.20.1/004 for R3 Concrete Foundations including the following Atkins / Parsons Brinckerhoff drawings for Great Western Electrification GRIP Stages 4 to 8:
   a. 13407-APB-DRG-EGE-000025 Route Section – Multiple Conventional (2m x 2m) Shallow Foundation Details Rev C01
   b. 13407-APB-DRG-EGE-000026 Route Section – Multiple Conventional (3m x 2m) Shallow Foundation Details Rev C01
   c. 13407-APB-DRG-EGE-000027 Route Section – Multiple Conventional (4m x 2m) Shallow Foundation Details Rev C01
   d. 13407-APB-DRG-EGE-000028 Route Section – Multiple Conventional (5m x 2m) Shallow Foundation Details Rev C01
   e. 13407-APB-DRG-EGE-000032 Concrete Side Bearing Foundation Details 800 x 800 Rev C01
   f. 13407-APB-DRG-EGE-000041 1200 x 1500 Concrete Conventional Connection Detail Rev C01
   g. 13407-APB-DRG-EGE-000053 Concrete Foundation Holding Down Bolt and Anchorage Details Rev C01
   h. 13407-APB-DRG-EGE-000054 Concrete Foundation Holding Down Bolt and Anchorage Details Rev C01
   i. 13407-APB-DRG-EGE-000055 Concrete Foundation Holding Down Bolt Details Rev C01
   j. 13407-APB-DRG-EGE-000061 Holding Down Bolts Sheet 1 of 2 Rev C01
   k. 13407-APB-DRG-EGE-000062 Holding Down Bolts Sheet 2 of 2 Rev C01
   l. 13407-APB-DRG-EGE-000065 Route Section – Multiple Conventional (2m x 2m) Shallow Foundation Details Rev C01
   m. 13407-APB-DRG-EGE-000066 Route Section – Multiple Conventional (3m x 2m) Shallow Foundation Details Rev C01
   n. 13407-APB-DRG-EGE-000067 Route Section – Multiple Conventional (4m x 2m) Shallow Foundation Details Rev C01
   o. 13407-APB-DRG-EGE-000068 Route Section – Multiple Conventional (5m x 2m) Shallow Foundation Details Rev C01

4. Specification & References

i) BRE Special Digest 1 Concrete in Aggressive Ground - 3rd edition (2005)

ii) BS 8002 (1994) – Code of Practice for Earth Retaining Structures, BSI, London

iii) BS EN 10080 (2005) – Steel for the Reinforcement of Concrete — Weldable Reinforcing Steel – General, BSI, London

iv) BS 8500 (2006) – Concrete – Complimentary British Standard to BS EN 206-1, BSI, London

v) BS 4449 (2005) - Specification of Carbon Steel Bars for the Reinforcement of Concrete, BSI, London

vi) BS EN 206-1 (2000) – Concrete — Part 1: Specification, Performance, Production and Conformity – General, BSI, London

vii) BS EN 1990 (2002) + A1 (2005) – Eurocode: Basis of structural design, BSI, London.

viii) NA to BS EN 1990 (2002) + A1 (2005) – UK National Annex to Eurocode: Basis of structural design, BSI, London.

ix) BS EN 1992-1-1 (2004) – Eurocode 2: Design of Concrete Structures – Part 1-1: General rules and rules for Buildings, BSI, London.

x) NA to BS EN 1992-1-1 (2004) - UK National Annex to Eurocode 2: Design of Concrete Structures – Part 1-1: General rules and rules for Buildings, BSI, London.

xi) BS EN 1997-1 (2004) – Eurocode 7: Geotechnical Design – Part 1 General Rules – BSI, London.

xii) NA to BS EN 1997 -1 (2004) – UK National Annex to Euorcode 7: Geotechnical Design – Part 1 General Rules – BSI, London.

xiii) Tomlinson MJ (2001) – Foundation Design and Construction - 7th Edition, Prentice Hall.

5. Ground Conditions

The design of the spread foundation base will be based on assumed ground conditions. These ground conditions must be confirmed by site specific ground investigation prior to the installation of the base.

The design will be checked for both cohesive and granular soil. The following geotechnical parameters will be used:

Stratum	Unit weight, γ (kN/m^3)	ϕ' (°)	ϕ'_{cv} (°)	Undrained shear strength (kPa)	α
Cohesive	20	-	-	40	0.5
Granular	20	30	29	-	-

Groundwater

Groundwater will be assumed to be at depth below the base and has not been considered within the design.

6. Geotechnical Design

6.1 Preamble

In order to provide a quick and cost effective means of constructing conventional shallow gravity foundations for railway infrastructure, a precast concrete modular system has been designed consisting of 3 No. smaller units which can be bolted together to form one large base. This removes the need for time consuming concrete pours on site where time may be limited.

These calculations detail the design for a trial base being constructed to test the construction methodology.

The trial base has been designed based on the Portal 2*4 loadings provided in the F15 Load table.

No load split has been provided for the axial load and therefore a 2:1 permanent:variable spilt has been assumed for these calculations.

The base is designed in accordance with the relevant Eurocodes.

6.2 Calculation of Applied Loads (Actions)

The design actions acting on the foundation are therefore is given by the following expression:

$$F_{c;d} = G_k \gamma_G + Q_{0k} \gamma_Q$$

Where,

$F_{c;d}$=Design action (M=moment, V=vertical, H=shear)

G_k=Permanent actions

Q_{0k}=Leading Variable action – in this case the imposed load

Q_{1k}=Secondary Variable action – in this case the wind load

A breakdown of variable actions has not been provided and therefore variable action combinations have not been considered.

γ_Q and γ_G are partial factors given in tables NA.A1.2 (B) and NA.A1.2 (B) of NA to BS EN1990 (2002) and summarised in the following table:

Partial factors on actions - Table NA.A1.2(B)				
Action		**Symbol**	**Set**	
			(Set B) A1	**(Set C) A2**
Permanent	Unfavourable	γ_G	1.35	1.00
	Favourable		1.00	1.00
Variable	Unfavourable	γ_Q	1.50	1.30
	Favourable		0.00	0.00

The foundation loads have been provided in the F15 document. For the trial base the Portal 2*4 loadings have been adopted. The characteristic and design actions are as follows:

Base Type	**Load case**	**Permanent**			**Variable**		
		Moment, M (kNm)	**Axial, V (kN)**	**Shear, H (kN)**	**Moment, M (kNm)**	**Axial, V (kN)**	**Shear, H (kN)**
Portal 2*4	Characteristic	17.1	29.7	2.1	53.7	14.8	7.8
	Combination 1 (Set B)	23.1	40.1	2.84	80.6	22.2	11.7
	Combination 1 (Set B) fav*	23.1	29.7	2.84	80.6	0	11.7
	Combination 2 (Set C)	53.7	29.7	7.8	22.2	19.2	2.7

*- An additional analysis for the Combination 1 loadings has been undertaken assuming the vertical loadings are favourable.

The above loadings do not take into account the self weight of the base which has been added separately in the spreadsheet calculations.

6.2.1 Bearing Capacity Calculations

The Eurocodes adopt the approach of applying partial factors to the input and output parameters. Applied loads, known as actions are factored up and design resistances are factored down.

The structure has been assumed to be a Geotechnical Category 2 structure which applies to conventional structures and foundations with no exceptional risk or loading conditions as detailed in BS EN 1997-1 (2004): Clause 2.1, sub-clause 18.

The design assumes that the foundation is being used where the track is at grade or within a cutting. Embankments are excluded from these calculations and therefore the overall stability does not need to be checked in accordance with BS EN 1997-1 (2004): Clause 6.5.1.

It should be noted that where this base design is adopted for use adjacent to a cutting slope, it may be necessary to undertake additional temporary works to allow installation of the base, however such works will need to be designed on a case by case basis and are outside the scope of these calculations.

The foundation design has been carried out in accordance with BS EN 1997-1 (2004): Annex D using Design Approach 1. For design of spread foundations the following combinations are used:

Combination 1: A1 + M1 + R1

Combination 2: A2 + M2 + R1

Where,

A1 & A2 are the partial factors applied to actions

M1 & M2 are partial factors applied to materials

R1 are the partial factors applied to bearing and sliding which based on in NA to BS EN 1997-1 (2004): Table A.NA.5 are both equal to 1.0.

The bearing capacity for drained conditions is determined using the following formula:

$$\frac{R_d}{A'} = c'N_c b_c s_c i_c + q'N_q b_q s_q i_q + 0.5\gamma' B' N_\gamma b_\gamma s_\gamma i_\gamma$$

Where,

R_d = the design bearing resistance
A'= effective area of the base of the pile
c'=effective cohesion
N_c, N_q & N_γ= bearing capacity factors
$b_{c,q,\gamma}$=base inclination factors
$s_{c,q,\gamma}$=base shape factors
$i_{c,q,\gamma}$=load inclination factors
g'= effective unit weight of soil
q'=effective overburden pressure

NB – the bearing capacity, base inclination, shape and load inclination factors may be calculated by formulas which are given in BS EN 1997-1 (2004): Annex D and are therefore not reproduced here from brevity.

For cohesive soil the above expression reduces to the following:

$$\frac{R_d}{A'} = (\pi + 2)c_u b_c s_c i_c + q$$

Where,

R_d= the design bearing resistance
c_u=the undrained shear strength
Other parameters are as detailed above.

For the design to be valid the following criteria must be satisfied:

$$V_d < R_d$$

6.2.2 Sliding Resistance

The sliding resistance has also been checked using the following equation for granular soil:

$$R_{hd} = V_d tan\emptyset'_{cv}$$

Where,

R_{hd}=design sliding resistance
V_d=design vertical action
ϕ'_{cv}=angle of friction at constant volume

For cohesive soil

$$R_{hd} = A' c_u \alpha$$

Where,

c_u=undrained shear strength
α=adhesion factor between the base and soil

For the design to be valid the following criteria must be met.

$$H_d < R_{hd}$$

The bearing capacity calculations have been spreadsheeted and are included in Appendix A.

From the analysis a 2m x 2m x 1.5m deep base is proposed comprising 3 No. sections. The upper section will have a concrete plinth to allow attachment of the signal mast etc. A general arrangement is shown on Byland drawing 1096-001 included in Appendix C

6.3 Construction Details

The proposed construction sequence is detailed on Byland drawing 1096-002 in Appendix C.

In addition to the base construction, the following must be taken into account.

1. Excavation – the excavation is greater than 1.2m deep and therefore to allow man entry the side must be battered back or supported by suitable means.

2. Subgrade – the strength of the subgrade must be confirmed by site specific ground investigation in advance of the works and inspection from a suitably qualified engineer once formation level is reached. The design has assumed a subgrade with a minimum undrained shear strength of 40kPa for cohesive soil or a medium dense or better granular soil.

3. Formation – the base must found on 200mm minimum of compacted Type 1 fill. The Type 1 must be compacted in 100mm thick layer using 6 passes of a vibrating tamper compactor (mass 600kg- Bomag BT60 or similar).

4. Backfill around the base to be Class 1A fill with a maximum aggregate size not greater than 125mm compacted in layers. Arisings may be used if they satisfy grading requirements.

7. Structural Design

The base is to be constructed using precast 3 No. modular base sections comprising the following:

- Unit A – base unit measuring 2m x 2m x 0.5m
- Unit B – centre unit measuring 2m x 2m x 0.5m
- Unit C- top unit measuring 2m x 2m x 0.5m with a 1.05m x 1.05m x 0.35m plinth on the top surface

Holding down bolts will be cast integral to the plinth to allow connection of the structure to the completed base. Lifting eyes will also be provided on each unit.

The structural design of the base has been undertaken by DosserMCA. Calculations and reinforcement drawings are included in Appendix B.

The base units are to be connected together using 4 No. threadbars slotted into couplers cast with the base and attached to steel head plates in the lower unit. The upper two units are then lowered over these bars and held down with a plate and nut assembly bearing onto the top unit.

7.1 Base Concrete

The bases are to be constructed using grade C40/50 concrete, maximum aggregate size 20mm.

7.2 Concrete Aggressivity Assessment

The concrete mix will provide a DC-4 chemical class which should provide adequate sulphate resistance for most sites. However, site specific investigation should be undertaken and the results assessed to confirm the provide resistance is adequate.

7.3 Threadbar design

The base units will be connected together using 4 No. threadbars inserted into couplers which are welded to steel plates cast into the base. Voids formed using plastic sleeves will be cast into the bases to allow the threadbar to pass through each unit.

From the Dosser MCA calculations the maximum factored force developed in each threadbar is 51.5kN. A Dywidag 25mm diameter GEWI steel threadbar is proposed.

The 25mm ϕ rebar will have a safe tensile capacity of:

$$\frac{A_s f_y}{\gamma_m} = \frac{\pi \times 12.5^2 \times 500}{1.15} = 213423N = 213kN > 51.5 \therefore OK$$

By inspection the above bar will have adequate redundancy for corrosion resistance over the design life of the structure.

7.4 Connection details

The threadbars are to be secured into a coupler cast within the base. This coupler will be welded to a 150mm x 150mm x 10mm thk steel plate – refer to DossorMCA drawing for weld details. Couplers should be 115mm long x 40mm diameter to suit a 25mm diameter bar.

The top unit shall be held down with a 41mmAF x 50mm long hex nut with a 41mmAF x 40mm long locking nut (again to suit a 25mm diameter GEWI bar) placed above it. The nuts will bear onto another 150mm x 150mm x 10mm thk steel plate.

Nuts to be tightened to a minimum torque of 700Nm.

A minimum time period of 1 week should pass after installing the base and tightening the hex nut before the locking nut is installed to allow any slack to be taken out of the system.

The connection details are shown on Byland drawing 1096-001 included in Appendix C.

7.5 Gasket Material

A layer of polyethylene sheet joint filler shall be used as a bedding substitute and shall be placed on the top of unit A (base) and unit B (middle). Nuffins Nucell 500 x 15mm thick (or similar approved) shall be used.

7.6 Corrosion Protection

All components of the connection system are to be hot dipped galavanised. Minimum mean thickness to be 85μm in accordance with BS EN ISO 1461 (1999).

8. Designers Risk Assessment

In accordance with CDM 2007 regulations Byland Engineering Limited are responsible for the element design of the precast base only and are not the overall scheme designers. Risks relating to construction methods are assumed to be covered within the specialist and main contractors method statements. The residual risks considered relevant to the base design are detailed in the following table

Risk	Mitigation
Ground conditions weaker than expected	The ground conditions assumed in this design must be validated by site specific ground investigation prior to construction of the base. In addition the base must be inspected by a suitably qualified engineer to confirm that the design assumptions have been met.
Excavation to install the base	The base will require an excavation in excess of 1.2m deep and therefore the sides must be battered back or suitable temporary works installed to support the ground around.
Use of base on embankments	The base is designed to be used in areas where the track is at grade or within a cutting. Where use on embankments is proposed, a separate stability analysis must be undertaken.
Use of base adjacent to cuttings	Where the base is to be utilised near a cutting slope, appropriate temporary works must be designed to support the excavation and avoid any slope stability issues.

9. Summary

The calculations detail the design of a demonstration modular precast reinforced concrete base to support signals and other railway infrastructure. The base comprises the following:

- 3 No. modular base sections comprising the following:
  - Unit A – base unit measuring 2m x 2m x 0.5m
  - Unit B – centre unit measuring 2m x 2m x 0.5m
  - Unit C- top unit measuring 2m x 2m x 0.5m with a 1.05m x 1.05m x 0.35m plinth on the top surface
- A layer of Nuffins Nucell 500 polyethylene void filler is to be placed between units A and B and units B and C.
- The base unit will be connected together using a threadbar assembly comprising the following components:
  - 115mm long x 40mm diameter static coupler welded to a 150mm x 150mm x 10mm thk steel plate.
  - 25mm diameter GEWI bar threaded through each base unit.
  - 150mm x 150mm x 10mm thk steel plate with a 41mmAF x 50mm long hex nut and a 41mmAF x 40mm long locking nut. Both nuts to be tightened to a torque of 700Nm.
- All connection components are to be hot dipped galvanised with a minimum mean thickness of 85μm in accordance with BS EN ISO 1461 (1999)
- Base to be founded on 200mm minimum of Type 1 compacted granular fill. The Type 1 must be compacted in 2 No. 100mm thick layers using 6 passes of a vibrating tamper compactor (mass 600kg - Bomag BT60 or similar).
- Backfill around the base to be SHW Class 1A fill with a maximum aggregate size not greater than 75mm compacted in layers of 100mm. Arisings may be used if they satisfy grading requirements.
- Reinforcement details are shown on DossorMCA drawing 12963Y-101 included in Appendix B.
- Construction sequence and general arrangement details are shown on Byland drawings 1096-001 and 1096-002 included in Appendix C.

Design Assumptions

The following assumptions must be satisfied for the design to be valid:

- The design is based on the subgrade beneath the base having a minimum undrained shear strength >40kPa (soft to firm – thumb makes an impression easily) where cohesive or being medium dense or better where granular.

- The design assumes the ground is level or within a cutting. Sites with embankments are currently excluded and will need stability analysis to confirm suitability.

- Sites close to cutting slopes may require additional temporary works to allow excavation for the base which are outside the scope of these calculations.

- Groundwater is assumed to be at depth which means at least a foundations width below the underside of the base.

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