# DESIGN CONSULTANT FRAMEWORK CONTRACT C122 – BORED TUNNELS

# Standard Track Systems Specification

### Document Number: C122-OVE-R4-RSP-CR001-50003

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| CROSSRAIL REVIEW AND ACCEPTANCE STATUS | | |
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| ☑ | Code 1. | Accepted. Work May Proceed |
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| | | | Amendments to specification to remove references to swing nose crossings as Fisher Street crossover is to be installed with fixed nose crossings. The following sections/tables have been revised:Section 3.2; Table 1; section 5.2.1; section 2.2.2; section 5.2.4; section 5.2.6; section 5.2.10; section 5.2.11 | | |
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# Table of Contents

# 1 Introduction

The following Trackwork Specifications define the technical requirements for the design and installation of Trackwork for the central section of Crossrail.

**C122-OVE-R4-RSP-50001 General Trackwork Specification**

This comprises elements which are common throughout the route, and applies to all trackforms within the Central Operating Section.

**C122-OVE-R4-RSP-50002 Enhanced Track Systems Specification**

This comprises the Enhanced Track System sections of the route, for which an Engineer's Design is available.

**C122-OVE-R4-RSP-50003 Standard Trackwork Specification (this document)**

This comprises the Standard Track System sections of the route, for which a *Contractor's* Design is required.

## 1.1 Design History

Crossrail has prepared trackwork design as follows:

- Enhanced Track Systems have been designed to RIBA Stage F (Detailed Design) and are hereafter described as 'Engineer's Design'
- Standard Track Systems (including Surface Rail Sections) have been designed to RIBA Stage E (Reference Design) and are hereafter described as '*Contractor's* Design', as the C610 *Contractor* will progress these designs to RIBA Stage F.

The design work to date is further documented in the following documents:

- Track Design Report (C122-OVE-R4-RGN-CRG01-0004);
- Track Maintenance Plan (C122-OVE-R4-TPL-CRG01-00001);
- Track Constructability Report (C122-OVE-R4-RGN-CRG01-00001).

## 1.2 Contractor's Design

Where the sections of track are designated as '*Contractor's* Design', the C610 *Contractor* may propose alternative designs to the RIBA Stage E Reference Design for the Employer's consideration, or use the Reference Design as the basis of their design.

For whichever option is taken forward by the C610 *Contractor* as their proposed design for Standard Track Systems (including Surface Rail Sections) the *Contractor* is considered to be solely responsible for the satisfactory performance of the track system.

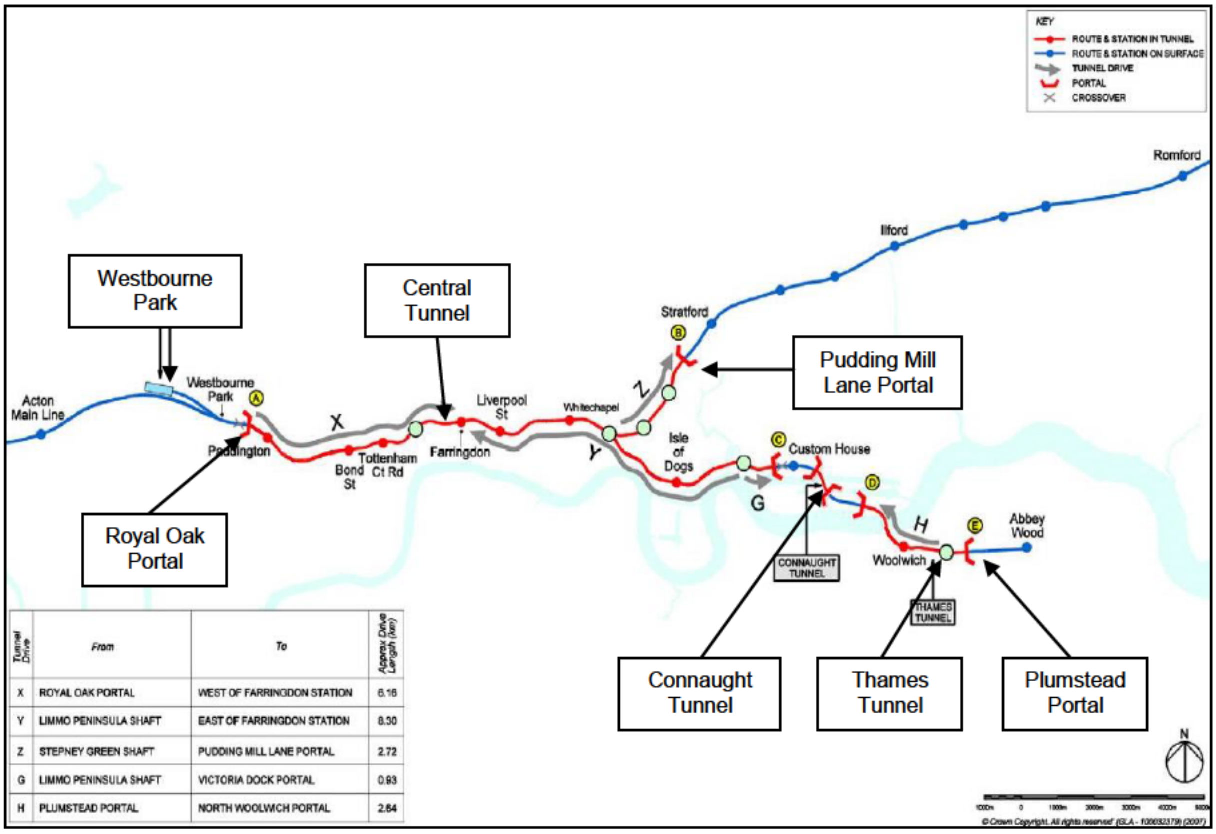
The *Contractor* shall provide all items and work in accordance with this specification. The *Contractor* shall examine this Specification and shall report any discrepancies or omissions and obtain written guidance on these matters from the Employers Representative.

The *Contractor* shall construct and co-ordinate the works in cooperation with other interfacing Contractors. Before construction, all necessary provisions shall be made to avoid interference with interfacing Contractors.

# 2 Geographical Extents

Refer to Part 4.3.5 of WI Volume 2A for details of agreed demarcation points beyond which the alignment and track design is the responsibility of Network Rail.

**Figure 1 Geographical Extents of Crossrail**




| Tunnel Drive | From | To | Approx Drive Length (km) |
|---|---|---|---|
| X | ROYAL OAK PORTAL | WEST OF FARRINGDON STATION | 6.16 |
| Y | LIMMO PENINSULA SHAFT | EAST OF FARRINGDON STATION | 8.30 |
| Z | STEPNEY GREEN SHAFT | PUDDING MILL LANE PORTAL | 2.72 |
| G | LIMMO PENINSULA SHAFT | VICTORIA DOCK PORTAL | 0.93 |
| H | PLUMSTEAD PORTAL | NORTH WOOLWICH PORTAL | 2.64 |

## 2.1 Interface with Network Rail

At the portals the interface with Network Rail is defined in section 4.3.5 of WI Volume 2A.

Network Rail requires the GRIP process to be followed for approval of changes to the Network Rail infrastructure which may include both ballasted and concrete trackform for plain line and junctions.

Form A (GRIP 4) approval will have been gained by CRL for changes to Network Rail infrastructure at Westbourne Park (C122-OVE-R4-ZFM-CR076_SD005-50001) and Pudding Mill Lane (C122-OVE-R4-RGN-CR094-PT002-00004). It will be the responsibility of the *Contractor* to obtain Form B (GRIP 5) approval from Network Rail for Westbourne Park only.

## 2.2 Units, Abbreviations and Definitions

Refer to General Trackwork Specification (C122-OVE-R4-RSP-CR001-50001).

# 3 General Description of Works

## 3.1 Plain Line Track

The trackform consists of ballasted and various non-ballasted (concrete slab) trackforms dependent upon operational criteria, site conditions and design requirements.

Standard trackforms are to be *Contractor's* Design and may comprise more than one type for particular locations such as trackform transitions, bridges or existing tunnels or trackbed.

Consistency of components throughout the route is to be incorporated in the design wherever practicable and acceptable.

Where they are required, enhanced trackforms have been taken to RIBA Stage F as Engineer's designs; see Enhanced Track Systems Specification (C122-OVE-R4-RSP-CR001-50003).

## 3.2 Junctions

Within the central section of Crossrail, junctions are proposed at:

- Royal Oak – crossovers between Crossrail tracks;
- Fisher Street – trailing crossover between the Crossrail tracks;
- Whitechapel – facing crossover between the Crossrail tracks;
- Stepney Green – equal spilt junction of Crossrail north-east and south-east spurs ;
- Custom House – three operational crossovers between Crossrail tracks;
- Plumstead – two turnouts to access Plumstead Crossrail Sidings

Fisher Street, Whitechapel and Stepney Green Junctions are located within tunnelled sections of route, with all the other junctions being located either on the surface or on ramps leading to and from the portals.

All the junction designs use standard NR60 switch and crossing geometries, with the exception of Royal Oak which uses 113A geometry. See Table 1 for details of the proposed S&C.

Junctions with the Network Rail existing network are proposed as follows:

- Westbourne Park – Link to Great Western Main Line and Marcon Sidings
- Pudding Mill Lane – Link to Great Eastern Main Line

**Table 1 Switch & Crossing Locations**

| Location | Crossing Type | Turnout Geometry | Points Heating Required | Trackform | Points Machine Type |
|---|---|---|---|---|---|
| **Westbourne Park** | | | | | |
| W1 EB Trailing | Fixed | 113A EVs15 | Points Heating | Ballasted | In bearer* |
| W2 WB Facing | Fixed | 113A EVs15 | Points Heating | Ballasted | In bearer |
| W3 T/B C Trailing | Fixed | 113A CVs(STR) 10S | Points Heating | Ballasted | In bearer |
| W4 T/B A Facing | Fixed | 113A CVs(STR) 10S | Points Heating | Ballasted | In bearer* |
| W5 T/B C Facing | Fixed | 113A CVs(STR) 10S | Points Heating | Ballasted | In bearer* |
| W6 T/B A Trailing | Fixed | 113A CVs(STR) 10S | Points Heating | Ballasted | In bearer* |
| W7 T/B A Facing | Fixed | 113A CVs(STR) 10S | Points Heating | Ballasted | In bearer* |
| W8 T/B C Trailing | Fixed | 113A CVs9.25 | Points Heating | Ballasted | In bearer* |
| W9 T/B B Facing | Fixed | 113A CVs9.25 | Points Heating | Ballasted | In bearer* |
| S1 Turnout | Fixed | 113A Bv8 | No Points Heating | Ballasted | Hand levers |
| S2 Crossover | Fixed | 113A Bv8 | No Points Heating | Ballasted | Hand levers |
| S3 Crossover | Fixed | 113A Bv8 | No Points Heating | Ballasted | Hand levers |
| S4 Turnout | Fixed | 113A Bv8 | No Points Heating | Ballasted | Hand levers |
| **Royal Oak** | | | | | |
| 1 EB Facing | Fixed | 113A DV13S | Points Heating | Standard | In bearer* |
| 2 WB Trailing | Fixed | 113A DV13S | Points Heating | Standard | In bearer* |
| 3 EB Trailing | Fixed | 113A DV13S | Points Heating | Standard | In bearer* |
| 4 WB Facing | Fixed | 113A DV13S | Points Heating | Standard | In bearer* |
| **Fisher Street** | | | | | |
| 5 WB Trailing | Fixed | NR60 C 8.25 | No Points Heating | Standard | In bearer* |
| 6 EB Trailing | Fixed | NR60 C 8.25 | No Points Heating | Standard | In bearer* |
| **Whitechapel** | | | | | |
| 7 WB Facing | **Fixed** | NR60 C 8.25 | No Points Heating | Standard | In bearer* |
| 8 EB Facing | **Fixed** | NR60 C 8.25 | No Points Heating | Standard | In bearer* |
| **Stepney Green** | | | | | |
| 9 EB Facing | Fixed | NR60 F 15.75 | No Points Heating | Standard | In bearer* |
| 10 WB Trailing | Fixed | NR60 F 15.75 | No Points Heating | Standard | In bearer* |
| **Custom House** | | | | | |
| 11 EB Facing | Fixed | NR60 C 11 | Points Heating | Standard | In bearer* |
| 14 EB Trailing | Fixed | NR60 D 13.5 | Points Heating | Standard | In bearer* |
| 12 WB Facing | Fixed | NR60 C 11 | Points Heating | Standard | In bearer* |
| 13 WB Trailing | Fixed | NR60 C 11 | Points Heating | Standard | In bearer* |
| 15 WB Trailing | Fixed | NR60 F 15.75 | Points Heating | Standard | In bearer* |
| 16 EB Trailing | Fixed | NR60 F 15.75 | Points Heating | Standard | In bearer* |
| Pudding Mill Lane WB Facing | Fixed | NR60 G 33.5 | Points Heating | Ballasted | In bearer* |
| **Plumstead Sidings** | | | | | |
| PLU1 | Fixed | 113A CV 9.25 | Points Heating | Ballasted | In bearer* |
| PLU2 | Fixed | 113A CV 9.25 | Points Heating | Ballasted | In bearer* |

*In bearer* (Specific type in accordance with NR/SP/SIG/1980)

Works by Others

Prior to the commencement of track installation works the following works will have been completed by others:

- Construction of all tunnels and portals;
- Installation of the first stage concrete to all tunnels, including drainage pipes and UTXs;
- Construction of civil engineering works on the surface section, including track sub-base, drainage and transition slab.

These factors will influence the design and installation method of the track system in the central section.

# 4 Track System Requirements

For general track system requirements, refer to General Trackwork Specification (C122-OVE-R4-RSP-CR001-50001).

## 4.1 Design Life

The minimum design life of any track system and its track components when exposed to the predicted traffic levels and environmental conditions of the Crossrail central section shall be those stated in Table 2. The *Contractor* shall state the anticipated component design life in all design submissions for the *Contractor's* Design sections, supported by RAMS and component life data.

The design life of trackform elements shall be that period for which they are designed to fulfil their intended function when inspected and maintained in accordance with the relevant Operations and Maintenance Manuals of Crossrail.

**Table 2 Required Design Lives for Track System Components**

| Trackform Component | | Design Life |
|---|---|---|
| Standard Slab Track and Surface Rail Sections (*Contractor's* Design) | rail; rail pads; insulators; rail movement joints | 15 years |
| | baseplates (bonded or vibration isolating) | 30 years |
| | spring clips | 40 years |
| | concrete sleepers; concrete blocks; concrete bearers; shoulders; resilient pads; rubber boots; baseplates | 50 years |
| | mass concrete | 120 years |
| Switches & Crossings (*Contractor's* Design) | plain line components | As standard slab track |
| | rail; switches; crossings; rail movement joints | 15 years |
| | Points Operating Equipment including hollow bearer | 15 years |
| | concrete bearers; | 50 years |

## 4.2 General Design

The *Contractor* shall demonstrate that the trackwork performance shall function to a high standard under the climatic and operating conditions of the railway. The *Contractor* shall provide submissions on reliability, maintainability, life cycle cost, etc. of their proposed design.

In all cases, the *Contractor* shall provide evidence that the proposed track system is proven in conditions comparable to those of Crossrail.

The *Contractor* shall comply with the proposed track alignment design. If any revision is proposed, the *Contractor* shall perform the alignment revisions as a part of the track design submissions for statement of no-objection by the Employer's Representative.

Those sections of the Central Section of Crossrail for which an Enhanced Track System is not proposed through the Engineer's Design, is deemed to be *Contractor's* Design.

The *Contractor* shall design and install a Standard Track Slab:

- throughout the tunnelled sections that minimises the length of Enhanced Track required to meet the requirements of Information Paper D10 (IPD10); and
- in the central surface sections which delivers the trackform airborne noise performance predicted within the Demonstration of Trackform Airborne Noise Performance for Central Section Surface Rail Report (refer to section 6.4).

The Standard Track Slab in tunnels shall be installed as set out in the final version of the Demonstration of Groundborne Noise and Vibration Mitigation Report (refer to section 6.4).

Further, the *Contractor* shall provide a Standard Track Slab that complies with the requirements set out in Section 6.

## 4.3 Design Approvals

The *Contractor* shall submit all the designs for the trackwork and associated works to the Employer's Representative for approval, as per Design Assurance requirements in Volume 2b of the ITT Documentation.

## 4.4 Performance Criteria

The proposed trackwork shall conform to the following general performance criteria. The *Contractor* shall incorporate these criteria in all design submissions.

### 4.4.1 Life Cycle Cost

The trackwork and components shall have minimal life cycle costs. The life cycle cost comparison between alternatives under conditions of the operating railway shall include initial cost, maintenance requirements, service life, replacement costs, comparative ease of replacement with an acceptable maintenance program, to be defined by the *Contractor*, and methods of cost amortisation to which the Employer's Representative has given a statement of no-objection. Performance and reliability shall not be compromised in favour of a lower life cycle cost.

### 4.4.2 Passenger Comfort

The installed trackwork shall permit the rolling stock to maintain comfort levels at all operating speeds. The *Contractor* shall interface with the train contractor to confirm the train Technical Specification.

### 4.4.3 Compliance with Environmental Minimum Requirements

The track system shall comply with all the noise and vibration requirements set out in Section 6 of this document, and in Volume 2B of the ITT Documentation.

### 4.4.4 Maintenance Provisions

The proposed track system shall be designed and installed in a way that facilitates efficient track maintenance. Further details of maintenance provisions are provided in the Track Maintenance Plan (C122-OVE-R4-TPL-CRG01-00001).

The trackform shall be designed to provide optimum performance with minimum maintenance by ensuring full compatibility of components, particularly with respect to tolerances and effects of vibration from dynamic loading.

# 5 Materials & Equipment

## 5.1 Introduction

The materials and equipment used in the permanent way and associated works shall comply with the minimum requirements contained in this section and in the General Trackwork Specification (C122-OVE-R4-RSP-CR001-50001).

This materials specification is not exhaustive. Where materials are proposed for use and are not covered by this specification, advice shall be sought from the Employers Representative. In these circumstances it should be assumed that materials currently approved for use on rail systems similar to Crossrail are likely to be suitable.

All materials should have a design life that is in accordance with the requirements of Table 2.

## 5.2 Switches & Crossings

### 5.2.1 General

The geometry of all turnouts shall be compliant with the project's track alignment.

The un-machined rail sections for turnouts shall be at a minimum hardness grade of 335.

The turnouts and crossings shall be designed, supplied, tested and installed in accordance with BS EN 13232 "Railway Applications – Track – Switches & Crossings".

The design of switches, crossings and check rails shall be compatible with the wheel profile and designed to support the wheel tread during the movement of the vehicle through turnouts.

The areas inside supporting the wheel movement through the turnouts shall follow the same inclination of the running rail crown. The wheel/rail analysis shall be submitted for approval.

Switches shall be of a lubrication-free type.

The point machines and switch point connecting rods, electrical connectors and hardware for switches shall be designed, procured and installed by the *Contractor.* The points machines are to designed in accordance with NR/SP/SIG/19809 "Specification of Points Operating Equipment"

For S&C's S1 to S4 (Marcon Sidings at Westbourne Park see Table 1) the contractor shall design, procure, and install, and test track-side hand levers to operate the switches.

The *Contractor* shall perform the mechanical installation of the switch point machines including connecting rods and electrical connectors. The commissioning of the points machines shall be by the *Contractor*

Installation of the electrical connections from point machine connector up to track side signalling cabinet shall be by Others

Turnouts and crossings shall be designed to be supported on pre-cast reinforced concrete turnout bearers, blocks or direct fix baseplates.

The requirements for insulated rail joints are to be agreed with the Systems Contractor.

The elastic fastenings used in turnouts and crossings shall exhibit similar properties to the mainline track and have interchangeable components.

Localised stiffening of the Standard Track System is permitted at turnouts and crossings within the tunnels. Turnouts and crossings within the tunnels shall have a track modulus as close to that of the Standard Track System as possible, while meeting all other requirements.

#### 5.2.2 **Operating Force**

The maximum allowable operating force for all switches shall be 2.2kN after 10 throws in each direction.

#### 5.2.3 **Switch Rails**

Switch rails shall be manufactured from a single asymmetrical rail section with tangential (low entry angle) geometry at the switch toe and a forged transition to the rail section of plain track. No joints or welds will be permitted in any moveable parts or the forged transition areas of the turnout.

If using normal grade rail, Head Hardening of switchblades shall be executed after machining. Alternatively, they can be machined using hardened rail at a minimum grade of 335.

Switch and crossing designs shall incorporate inclined switch rails, and shall be designed for both new and fully worn wheel profiles. Drawings showing the wheel/rail interface conditions shall be submitted to the Employer's Representative for a statement of no-objection.

The switch rail drive system, locking devices, and position detection devices shall be designed and procured by the *Contractor.*

#### 5.2.4 **Points Machines**

The point machines and switch point connecting rods and hardware for switches shall be designed, procured and installed by the *Contractor.* The points machines are to be designed in accordance with NR/SP/SIG/19809 "Specification points Operating Equipment"

As a minimum the following design development shall be required to the solution.

- Certification of the points by the Notified Body against the Safety in Railway Tunnels Technical Specification for Interoperability.
- Development of the solution to drive lock and detect S&C on Slab Track.

The points shall achieve a maximum swing time of 3s.

RAM

The hours of operation of the Points System for the purpose of measuring RAM characteristics are assumed to be 20 hours a day, during normal traffic operation. The number of operations of an individual point will vary between typically 1 per day/week for points not used in normal operations to between 200 and 300 per day, depending on the location within the layout.

The following Points locations are considered to be critical points from a service recovery viewpoint:

- Stepney Green

Two sets of RAM targets for Points System are specified below:

| **Failure Type** | **Targets scope** | **Reliability** | **Maintainability** |
|---|---|---|---|
| **All failures** | Each point | MTBSAF > 6.5 years | MART < 1 hour |

| **Failure Type** | **Targets scope** | **Reliability** | **Maintainability** |
|---|---|---|---|
| **All failures** | Each critical point | MTBSAF > 10 years | MART < 1 hour |

### 5.2.5 Points Heating

Point ends shall be provided with appropriate points heating as shown in Table 1, and the proposed system shall be compatible with Systemwide equipment and power supplies.

Where required, strip heaters shall comply with the following requirements:

All materials and equipment, including heaters and cable, shall be suitable for long life and satisfactory operation in the arduous environment in which they will be required to operate. Hazards will include severe and continuous vibration due to rail traffic, immersion in water, and possible exposure to diesel oils, lubrication oils, oxalic acid and de-icing fluids.

Strip heaters shall be suitable for operation on a 110V AC ± 10% 2 wire unearthed power supply. The power rating of the heaters shall be 200W/m ± 3% for all point ends.

Heaters shall be in standard lengths where possible to meet the requirements of the relevant switch geometry and type.

The heaters shall be able to operate in 'free air', totally or partially without affecting their working life.

The connection of the heater lead to the heating element shall:

- Provide satisfactory electrical connections and provide such connections as to ensure mechanical protection
- Provide adequate insulation of the electrical connection;
- Provide satisfactory mechanical security of the lead in such a manner that if a force of 5N is applied to the lead, no strain is applied to the electrical connection; and
- Have a connection housing filled with an insulating compound to eliminate entry of moisture of the risk of condensation.

With the exception of a factory-formed set at the cable connection, the heater shall be supplied straight, without twists or curvature along its entire length.

The factory-formed set at the cable connection end of the heater shall be neatly formed and lie in the same plane as the straight part of the heater.

Strip heaters shall be secured to the rail by means of rail clips. The heater sheath material shall be compatible with the rail clip material in contact with the heater, to prevent dissimilar metal (bi-metallic) corrosion.

### 5.2.6 Crossing Types

Crossing types for S&C shall be specified and installed as shown in Table 1.

Fixed crossings shall be cast centre-block crossings with weld-able legs.

### 5.2.7 Switch Baseplates

All switch assemblies shall incorporate a system of integrated roller slide plates. All rollers in the system shall be independently adjustable in height to ensure graduated lift of the switch blade to minimise switch drive forces and ensure the correct vertical clearance between baseplate sliding surface and switch rail.

The roller assembly shall be adjustable laterally (towards the centre of gauge) to ensure that a single design of slide plate will cover the full range of switch assemblies and the adjustment of supplementary drives.

To ensure consistent drive forces and longevity of roller assembly life, rollers of a sealed bearing type shall be used.

#### 5.2.8 **Bearers**

All S&C units shall be mounted on pre-stressed or reinforced concrete bearers or blocks where possible. Bearer design shall incorporate the requirements of impact-loading particular to turnouts in heavily trafficked track.

A ‘box’ sleeper or recess in the base concrete shall be provided to encase the switch rodding and equipment.

Long bearers, connecting the turnout to adjacent Main Line tracks, shall not be permitted.

The proposed system shall be maintainable in the constrained sites within the tunnel, and compatible with adjacent main line. Particular consideration shall be made towards the use of components which can be readily installed, inspected, maintained and ultimately renewed.

#### 5.2.9 **Direct Fix**

Where it is not possible for turnouts to be mounted on bearers, turnouts shall be mounted on resilient baseplates fastened directly to the concrete surface.

A ‘box’ sleeper or recess in the base concrete shall be provided for the switch machine / rodding as necessary.

#### 5.2.10 **Labelling**

The *Contractor* shall design, supply, and install the turnout labelling for all Main Line turnouts for a statement of no-objection by the Employer’s Representative. The labelling shall take the form of numbering / lettering complying with the following requirements:

- minimum individual letter size 100mm high x 50mm wide;
- minimum thickness of 5mm;
- manufactured from corrosion resistant metal of a contrasting colour to the surface upon which it will be attached.

The numbering shall be installed at switch toes and positioned nearest to the position "normally" closed according to the signalling system.

The labelling shall describe the turnout number, the words ‘normal’ or ‘reverse’, and an arrow indicating the ‘normal’ lay of the switch.

#### 5.2.11 **Co-ordination with Systems Contractor**

The following items shall be incorporated for the design and the construction of the S&C units in consultation with the Systems contractor:

- holes in the rails;
- insulated rail joints (as necessary)
- threaded inserts in the sleeper or track slab;
- provision and insulation of soleplates and stretcher bars (if required);
- provision for the installation of point operating equipment;
- provision for points heating lineside equipment;
- provision for S&C monitoring lineside equipment.

#### 5.2.12 S&C Pre-assembly and Inspection

All S&C units shall be pre-assembled, inspected prior to marking, dismantling into transportable sections and storing, prior to delivery and installation.

Turnouts shall be pre-assembled on a flat, well-drained slab that shall not have surface variations in any direction greater than 5mm in 5000mm.

Prefabricated insulated rail joints (IRJs), if required, shall be incorporated whenever feasible. If the IRJs cannot be included in the pre-assembled layout, the *Contractor* shall ensure that later installation shall not increase the number of welds over that of a standard turnout.

The welded joints within turnouts shall be temporarily jointed such that the gauge and alignment can be accurately checked.

The inspection of the pre-assembled S&C units, shall include, but not be limited to, the following:

- check that the switch rail mates with the stock rail throughout the length of the switch planing with the switch lying naturally;
- the underside of the switches and stock rails bear evenly on all slide baseplates and rollers;
- the switch rail is in contact with all the switch distance blocks. The switch rail is stress-free when closed;
- all dimensional checks of gauge, alignment, offset, lead, nose to nose and flangeways are within tolerance;
- all baseplates and fittings are correctly fitted;
- the moving parts (i.e. switches and moveable crossing) can be moved by a force within that specified.
- To complete a full test of the points operating machine including primary/ secondary drives and detection systems

The *Contractor* shall provide all gauges and measuring equipment necessary to completely check the prefabricated turnouts.

All the checks on the pre-assembled S&C units shall be presented to the Employer's Representative, for his statement of no objection. The same pro forma shall be used for the checking of the installed units.

On completion and acceptance, the pre-assembled S&C units shall be clearly marked with numbers, joint numbers, centre lines and bearer locations.

The marking of the turnouts shall be carried out by gluing a non-ferrous metal, or similar material plate on to the rail web of all components. The plate shall carry black characters on a "Dayglo" background. The marking shall be subject to the Employer's Representative's Representative statement of no-objection.

## 5.3 Sleepers

All sleepers shall be concrete and shall comply with the requirements of BS EN:13230 parts1 to 5.

## 5.4 Railway Ballast

All railway ballast shall conform with the requirements of Network Rail Standard NR/L2/TRK/8100 Railway Ballast and Stone-blower Aggregate.

### 5.4.1 General

All the constituent materials of in-situ concrete shall comply with Section 5 of BS EN 206-1 and Section 4 of BS 8500-2.

All concrete mixes shall be designed mixes and shall comply with the requirements of BS EN 206-1, BS 8500-1 and BS-8500-2.

Mix design sheets shall be prepared by the *Contractor* and submitted for acceptance to the Employer's Representative prior to commencing any work, in sufficient time as to allow full discussion and agreement between the responsible parties.

### 5.4.2 Cement

Cement shall comply with one of the following:

- Cement to BS EN 197-1;
- Sulphate resisting cement to BS 4027;
- A mixture of BS EN 197-1 and BS EN 15167-1 and 2 provided that the amount of GGBS is not less than 50% or more than 90% by weight of the total cement.

Under no circumstances shall High Alumina Cement (cement fondue) be incorporated into the works.

### 5.4.3 Aggregates

Aggregates shall comply with one of the following:

- BS EN 12620;
- BS EN 13055-1.

### 5.4.4 Steel Reinforcement

Steel reinforcement shall be of the following types:

- Hot rolled deformed bars to BS 4449;
- Cold worked deformed bars to BS 4449;
- Plain round steel bars to BS 4449;
- Welded hard drawn steel wire fabric and other cold worked high bond bar fabric to BS4482 or BS 4449 with mesh sizes to BS 4483;
- Galvanised mild steel deformed bars to BS 4449;
- Steel wrapping fabric to BS 4482;
- Steel tying wire to BS 4482;
- Weld able reinforcing steel to BS EN 10080.

All reinforcement shall be obtained from a Certificate Authority for Reinforcing Steels (CARES) Quality Assurance approved supplier. The CARES certificate to be provided to the Employer's Representative four weeks before delivery of the steel.

### 5.4.5 Fibre Reinforcement

Steel fibre reinforcement shall be deformed steel fibre Group 1, 2 or 3 in accordance with BS EN 14889-1, except that Group 1 fibre may be either circular or rectangular in section.

Micro synthetic fibres may be used for fire resistance only. They shall be made from polypropylene and shall comply with the requirements of BS EN 14889-2.

## 5.5 Demonstration Track

Refer to General Trackwork Specification (C122-OVE-R4-RSP-CR001-50001).

# 6 Noise and Vibration

## 6.1 Trackform Performance

The Contactor shall design, procure and install groundborne noise and vibration mitigation to ensure compliance with the requirements of IPD10 and IPD26, and the Crossrail Undertakings and Assurances (all as amended by this Specification) and set out in section 6.7, and the insertion gains in section 6.5.

The trackform shall be designed to minimise the airborne noise radiation from the rails. The overall A-weighted sound power level radiated by the two rails shall be predicted using industry standard software for the prediction of the sound emission from railway tracks, such as the Track Wheel Interaction Noise Software (TWINS) or equivalent. The predicted overall A-weighted sound power radiated by the two rails shall be no greater than that which would be predicted for a track comprising of CEN60 rails supported on rail pads with a dynamic stiffness of 300MN/m per metre run of rail.

IPD10 places a responsibility on the Infrastructure Maintainer (IM) and Rolling Stock Operating Company (ROSCO) to maintain the combined wheel/rail roughness profile within specified limits. The *Contractor* shall provide a track system which shall not constrain the IM and ROSCO from maintaining the specified wheel/rail roughness profile through grinding.

Where others are responsible for the design and installation of any noise barriers and other mitigation measures, the *Contractor* shall provide information on the proposed vertical and horizontal alignment of the track to these parties to enable them to calculate the required noise mitigation if requested.

## 6.2 Liaison with Stakeholders

Consultation with the local authorities and other key stakeholders will be necessary on the steps to be taken to meet the requirements in relation to the permanent railway. The *Contractor* shall support the Employer's Representative with any consultation/stakeholder engagement exercises. To this end the *Contractor* shall prepare and implement a consultation plan to be submitted to and approved by the Employer's Representative. The consultation plan shall include, but not be limited to:

- provision and presentation of information/material for discussions with stakeholders, including local authorities;
- engagement in discussions with representatives of the local authorities and, if necessary, other third parties, about:
  - prediction methods for vibration, groundborne noise, and structure borne noise for tunnelled sections;
  - prediction methods for vibration for the surface railway;
  - effect of chosen slabtrack on airborne noise for central surface sections;
  - the predicted noise and vibration;
  - the design and performance of all noise and vibration mitigation;
- consultation for, organisation of and attendance at meetings with stakeholders;
- Community liaison.

## 6.3 Methodology

The *Contractor* shall submit the noise and vibration prediction methods and design assumptions to the Employer's Representative for no-objection  This shall be part of a technical report to be entitled "Central Section Noise and Vibration Assessment Methodology" that shall contain at least the following information:

- definition of the prediction methods to be used for all noise and vibration sources and their validation;
- confirmation of acoustic design assumptions (e.g. number of train movements, speed profiles etc.);
- confirmation of rolling stock axle and bogie design characteristics (e.g. overall and unsprung mass per axle) as the basis for the design of groundborne noise, structureborne noise, structure-radiated noise and vibration mitigation (the *Contractor* shall obtain this information from the Rolling Stock Contractor and/or other sources as necessary (see section 6.5.3));
- confirmation of noise source emission levels for the rolling stock to be used consistent with the requirements of Calculation of Railway Noise 1995 (Department of Transport);
- confirmation of location of noise and/or vibration sensitive property categorised as per IPD10 Table 1 within 33m in the horizontal plane of the running tunnels. The locations of noise sensitive receptors are provided to the *Contractor* for information in the Land Use Data report (document number C122-OVE-T1-RGN-CRG01-00001);
- confirmation of method to be used to demonstrate that airborne noise radiation from the rails will be minimised;
- representative prediction locations to be used for designing mitigation (should the *Contractor* propose that analysis will not be performed for all receptors).

Once the Employer's Representative has stated his no-objection to this report, the *Contractor* shall, at the Employer's Representative's request, prepare a version of the report suitable for submission to the relevant local authorities to seek their no-objection to the methods and prediction locations proposed.

The *Contractor* shall use the agreed prediction methodologies and design assumptions to design noise and vibration mitigation as required to ensure compliance with the design criteria in the documents identified in this Specification, and the clauses within this Specification.

## 6.4 Demonstration of Compliance

Demonstration of compliance with noise and vibration requirements affecting the Standard Track System shall be by design.

The *Contractor* shall prepare a report entitled "the Groundborne Noise and Vibration Mitigation Assessment Report" that shall present the mitigation proposals and resulting noise and vibration predictions for the operational scheme.

The *Contractor* shall submit the report to the Employer's Representative for acceptance within six months of the award of the trackwork contract.

Following review of the report by the Employer's Representative and the incorporation by the *Contractor* of any comments resulting from the Employer's Representative's review, the *Contractor* shall prepare a version of the report suitable for submission to the relevant local authorities to seek their no-objection (the "Groundborne Noise and Vibration Mitigation Demonstration Report").

Suitable versions of the Demonstration Report shall be prepared and submitted by the *Contractor* as necessary to other stakeholders at the request of the Employer's Representative.

The *Contractor* shall carry out modelling and prepare a Technical Note entitled "Assessment of Trackform Airborne Noise Performance for Central Section". The Technical Note shall set out the results of the modelling carried out as described in the Methodology Report and demonstrate that the requirement set out in section 6.1 paragraph 3 has been met.

If requested to do so by the Employer's Representative, the *Contractor* shall prepare a version of the Technical Note suitable for submission to the relevant local authorities. The note will be titled "Demonstration of Trackform Airborne Noise Performance for Central Section Report".

Demonstration Reports and Technical Notes for stakeholders will be subject to the same regime of checking by the Employer's Representative as the report for the local authorities and the *Contractor* shall engage fully in this process as set out for the report for the local authorities. The *Contractor* shall address the Employer's Representative's comments in revisions of the reports and/or notes and re-issue them as required by the Employer's Representative.

## 6.5 Acoustic Specification for Insertion Gain of Standard Track System

### 6.5.1 **Purpose of Specification**

The following specification defines the acoustic performance criteria for the track for the Crossrail Railway within the Central Section.

Vibration isolation is required to ensure adequate control of groundborne noise and vibration for properties close to the tunnels, and for vibration from the surface railway.

The Specification provides Insertion Gain requirements for the Standard Track System to be used throughout the central section tunnels where Enhanced Track Systems are not required.

Two specifications are provided including:

- a very high performance track system to be used in the bored tunnels where Enhanced Track Systems are not required; and
- a less onerous specification for Connaught Tunnel. For Connaught Tunnel the groundborne noise mitigation requirements are secondary to the requirement to provide safe means of evacuation.

There is no insertion gain specification for surface rail sections as there is no groundborne noise requirement. Surface rail vibration criteria as required by section 6.7.2 apply.

This Specification also provides guidance on the prediction methods to be used to demonstrate compliance of the proposed design with the acoustic performance requirements.

### 6.5.2 **Definition, References**

***Definitions***

$K_{dyn}$ Vertical dynamic stiffness: Ratio between the vertical sinusoidal applied force at 4Hz (±1Hz) on the rail and the maximum vertical displacement of the rail as defined in EN 13481-5:2003.

$K_{stat}$ Static vertical stiffness: Ratio between the vertical applied force on the rail and the maximum vertical displacement of the rail.

$K_{acou}$ Acoustic vertical stiffness: Transfer function of the vertical transferred force and the vertical displacement of the rail. Acoustic stiffness differs from dynamic stiffness in that it is measured under the preload of the overall vehicle while subject to oscillating displacement amplitudes appropriate to wheel/rail roughness profiles. The acoustic stiffness is measured within the frequency range associated with the generation of groundborne noise and vibration (6.3Hz to 250Hz).

***References***

R1 C160-MMD-R1-RCT-CR001-00002 Technical Directorate – Reference Train Report.

### 6.5.3 General Requirements

***General***

The role of the acoustic trackwork is to isolate the transmission of the vibrations caused by the running of the trains on rails, to the neighbouring buildings.

The *Contractor* shall request the following information from the Rolling Stock Contractor, via the Employer's representative:

- axle load;
- unsprung mass of axle.

In the event that the information is not available when the *Contractor* commences his acoustic design, the *Contractor* shall:

- review information available within the Works Information and may rely on this for his input information for initial modelling; and
- when the information becomes available from the Rolling Stock contractor, carry out a sensitivity analysis to confirm any change to their predictions and design conclusions resulting from any differences between the two sets of input data. Present this analysis in a Technical Note;
- provide the Technical Note on the sensitivity analysis to the Employer's Representative for review. Following review of the Note by the Employer's Representative and the incorporation by the *Contractor* of any comments resulting from the Employer's Representative's review, the *Contractor* may continue with design based on the assumptions presented.

The *Contractor's* attention is drawn to the design assumptions with respect to rolling stock provided within the Track Design Report (C122-OVE-R4-RGN-CRG01-0004).

***Vibration Isolation***

*Terms Used to Quantify Vibration Isolation*

The vibration isolation provided by the Standard Slab Track (STS) shall be quantified as Insertion Gain, in 1/3$^{rd}$ of octave bands, relative to the "Reference Track" system as defined in Table 4, "Paved Concrete Track" (PACT). The requirements are set to control vibration and groundborne noise in the tunnelled sections.

All other parameters remaining equal (e.g. rolling stock, speed, ground conditions, vibration prediction location etc), the Insertion Gain, in each 1/3$^{rd}$ of octave band, is the difference between the vertical vibration velocity levels predicted for the proposed trackwork design and those of the `Reference' track. Insertion Gain is the inverse of Insertion Loss.

$$IG(f) = L_{STS,\,f} - L_{Reference\ track,\,f}$$

Where:

L = Vertical vibration velocity level [dB ref 0 dB = $1 \times 10^{-6}$ mm/s]

f = 1/3rd octave band centre frequency [Hz]

*Model for Prediction of Insertion Gain*

The prediction method adopted by the *Contractor* shall include:

- model the excitation of the track as the relative displacement of the unsprung mass of the train and track;
- the track as an infinite layered beam model; and
- include a realistic representation of the mobility of the ground beneath the track.

*Evaluation of Insertion Gain*

The Insertion Gain for the track work being assessed shall be calculated either directly or by predicting the absolute vibration velocity for the Reference Track at a location on the ground surface, located no closer than 10 m from the nearest rail, and subtracting it from the prediction of the absolute vibration velocity of the proposed trackwork at the same location. In the latter case, the vibration velocity levels shall be evaluated as logarithmic average levels over the duration of a train pass by. The pass by period is that taken for the whole train to pass by the prediction point. All parameters, other than the trackwork, shall be held constant for the two predictions (i.e. parameters regarding the rolling stock, formation and surrounding ground conditions).

Predicted Insertion Gains shall be presented as graphs over, as a minimum, the frequency range of 6.3 to 250 Hz superimposed over the relevant acoustic performance criteria.

The Insertion Gain for each track work design shall be evaluated for the stock as advised by the Employer's Representative.

The predictions shall assume underlying ground with the following properties:

Elastic modulus =372 $MNm^{-2}$;

Density $\rho$ = 2000 $kgm^{-3}$;

Loss factor $\eta$ = 0.1.

*Reference Track*

Insertion Gains for the required Standard Slab Track shall be calculated relative to PACT as defined in Table 3, and are plotted in Figure 2.

It is recognised that the *Contractor* may employ a different prediction methodology from that used by the Employer's Representative. It is important that any differences in prediction methodologies are evaluated and taken account of when demonstrating compliance against the levels of mitigation set out in **Table 6**.

To evaluate any difference between the prediction methodologies, the Insertion Gain of the PACT Reference Tracks shall be quantified in $1/3^{rd}$ of octave bands relative to a `very stiff Reference Track' as defined in Table 5. This Insertion Gain shall be superimposed on the Insertion Gain predicted by the Employer's Representative (shown on Table 3). The difference (The Difference Function) between the Insertion Gains calculated by the *Contractor* and the Employer's Representative is a gauge of the difference between the two prediction methods. The Difference Functions for the slab track should be added to all of the Insertion Gains predicted by the *Contractor* for his trackwork designs before they are compared against the relevant acceptance criteria defined in **Table 6**.

The calculations shall be submitted to the Employer's Representative for approval. The *Contractor* shall address the Employers Representative's comments and resubmit the calculations to the Employer's Representative's until he provides his no-objection to the calculations.

Validation and confidence limits shall be provided for all prediction methods used.

| Track type | 1/3rd Octave Band Centre Frequency, Hz | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **6.3** | **8** | **10** | **12.5** | **16** | **20** | **25** | **31.5** | **40** | **50** | **63** | **80** | **100** | **125** | **160** | **200** | **250** |
| **IG PACT re Very Stiff Ref.** | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.5 | 0.7 | 1.2 | 1.9 | 3.3 | 6 | 9.4 | 5.5 | -4.5 | -13 | -23.7 |

**Table 3:** Predicted Insertion Gains for Rolling Stock on PACT Relative to Very Stiff Reference Track

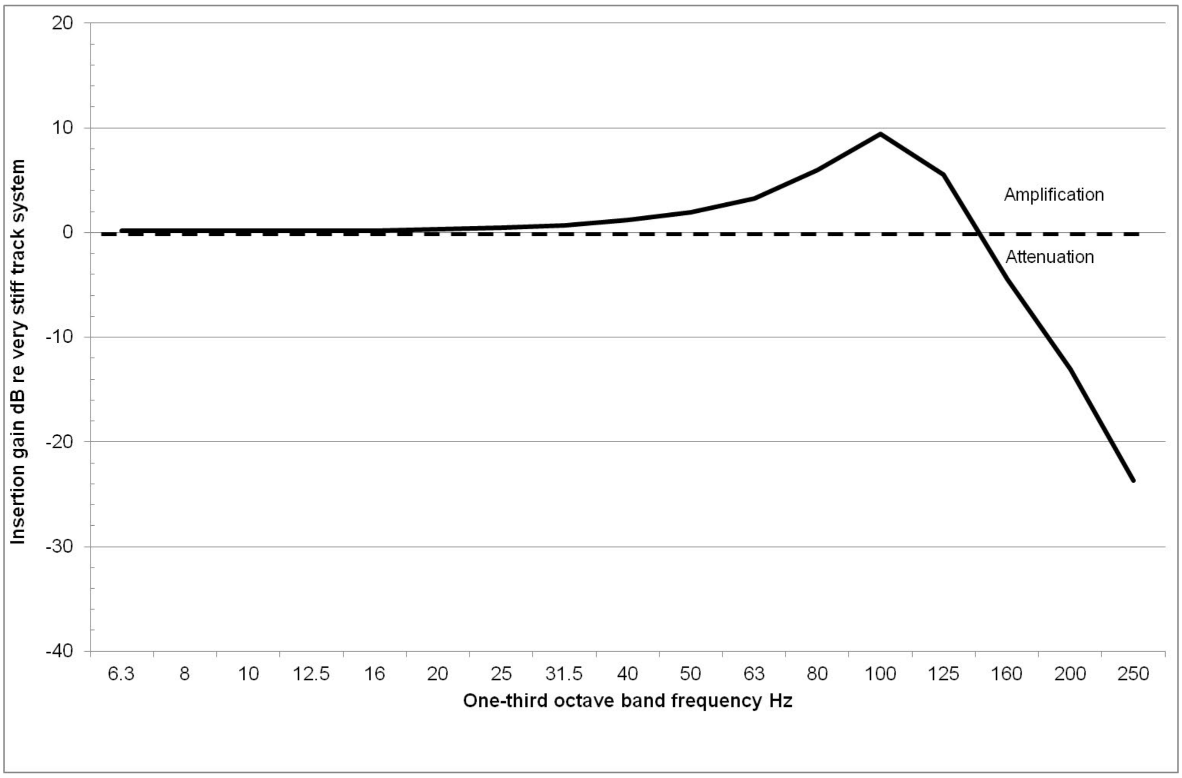



**Figure 2:** PACT Reference Slab Track Insertion Gain Specification Relative to 'Very Stiff Reference Track'

The component parameters to be assumed in predicting the vibration velocity levels for the Reference Track system are defined in Table 4 and Table 5. These values are defined for one track (i.e. two rails).

The "very stiff" Reference Track has no modes of vertical vibration response in the frequency range of interest (6.3 to 250 Hz).

The maximum unsprung mass used to define the insertion gains in Table 3 and **Table 6** was 1690Kg/axle.

| **Component** | **Bending Stiffness** [MN.m$^{-2}$] | **Dynamic Stiffness per metre length of track** [MN.m$^{-2}$] | **Loss factor** | **Mass per metre length of track** [Kg.m$^{-1}$] |
|---|---|---|---|---|
| Rail: CEN60 | 12.4 | - | 0.001 | 120 |
| Rail pad | - | 720 | 0.2 | - |
| Concrete Base Slab | 6320 | - | 0.01 | 2880 |

**Table 4:** Component parameters for `PACT' Reference Track

| **Component** | **Bending Stiffness** [MN.m$^{-2}$] | **Dynamic Stiffness per metre length of track** [MN.m$^{-2}$] | **Loss factor** | **Mass per metre length of track** [Kg.m$^{-1}$] |
|---|---|---|---|---|
| Rail: CEN60 | 12.4 | - | 0.001 | 120 |
| Rail pad | - | 400000 | 0.01 | - |
| Concrete Base Slab | 6320 | - | 0.01 | 2880 |

**Table 5:** Component parameters for “very stiff” Reference Track, used for validation of models

***Slab Track Mitigation Requirements***

The Insertion Gain performance requirements for the Standard Slab Track for vibration and groundborne noise for the tunnelled sections with the Crossrail Rolling Stock are defined in **Table 6** relative to the PACT slab Reference Track. The chainages between which the IGs shall be provided are given in Table 7, based on alignment U.

The performance criteria are also presented in Figure 3 together with examples of compliant and non-compliant insertion gain predictions in Figure 4.

| | Insertion Gain, dB re PACT | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1/3rd Octave Band Centre Frequency, Hz | | | | | | | | | | | | | | | | |
| | **6.3** | **8** | **10** | **12.5** | **16** | **20** | **25** | **31.5** | **40** | **50** | **63** | **80** | **100** | **125** | **160** | **200** | **250** |
| **STS Track 1** | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 12.5 | 2.6 | -4.7 | -10.4 | -19.3 | -28.6 | -29.6 | -18.8 | -16.7 | -7.2 |
| **STS Track 2** | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 13.7 | 12.5 | 10.0 | 3.0 | -6.1 | -14.6 | -22.1 | -21.8 | -18.8 | -16.7 | -7.2 |
| STS Track 1 = STS Specification for bored tunnels<br>STS Track 2 = STS Specification for Connaught Tunnel | | | | | | | | | | | | | | | | | |

**Table 6**: Insertion gain acceptance specification for the Standard Track Systems relative to PACT Reference Track

| Royal Oak Portal to Plumstead Portal | | | | |
|---|---|---|---|---|
| Acoustic performance specification | Eastbound | | Westbound | |
| | Chainage Start | Chainage End | Start chainage | End chainage |
| STS Track 1 | 511 | 16592 | 511 | 16637 |
| STS Track 2 | 17757 | 18327 | 17832 | 18400 |
| STS Track 1 | 19580 | 22558 | 19656 | 22644 |
| Stepney Green Junction to Pudding Mill Lane Portal | | | | |
| Acoustic performance specification | Eastbound | | Westbound | |
| | Chainage Start | Chainage End | Start chainage | End chainage |
| STS Track 1 | 11338 | 14154 | 11429 | 14329 |

**Table 7: Track Extents for STS Insertion Gains**

There is no Insertion Gain specification for surface rail. The surface railway section Insertion Gain shall be chosen by the *Contractor* to meet the requirements of section 6.7.2.

The above chainages represent those calculated for the Reference Design (RIBA Stage E). At RIBA Stage F, the Contractor shall validate and verify all calculations and analysis, and shall assume full ownership of such calculations and analysis, plus the resultant design.

All Standard Track Systems shall comply with the Insertion Gain Specification set out in the STS Track 1 line of Table 6, except for track lengths for STS Track 2 defined in Table 7, where the appropriate STS Insertion Gain from Table 6 shall be provided as a maximum.

***Design Constraints***

Increased vibration mitigation (or improved Insertion Gain) will be achieved by selectively increasing the dynamic resilience of the trackwork. It is essential that any increase in resilience does not compromise conformance with RAMS criteria such as the maximum permitted rail deflection

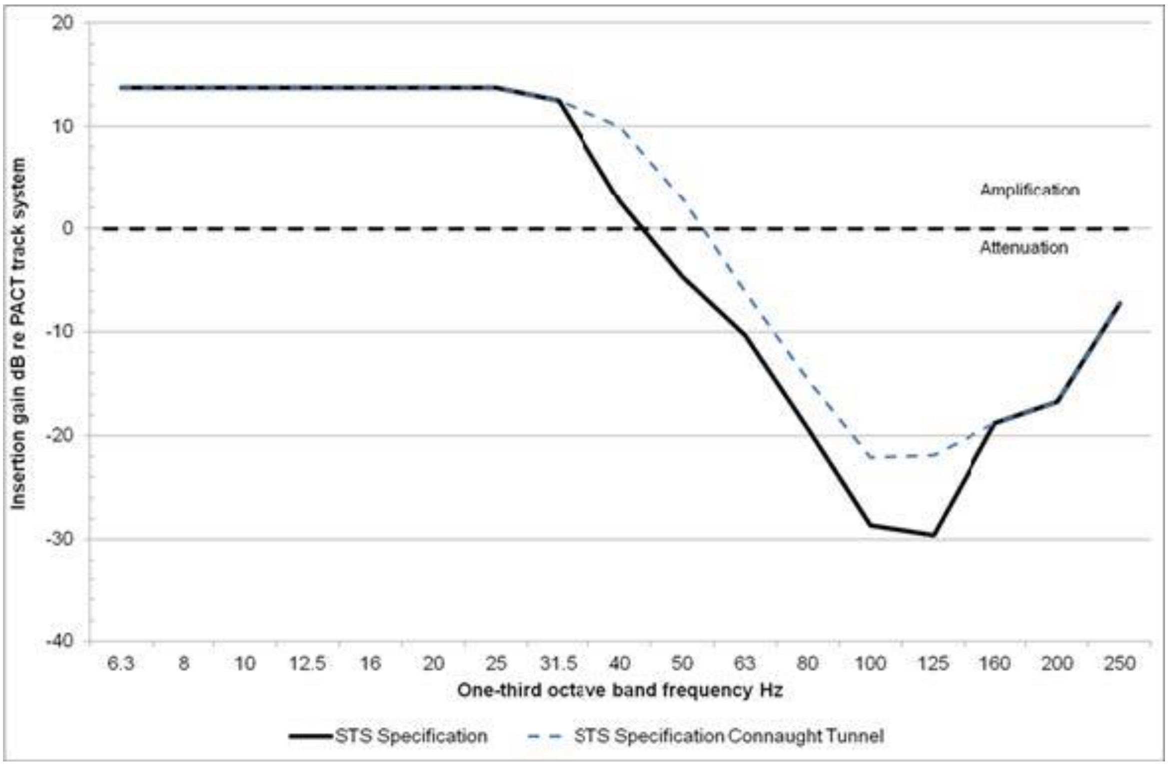



**Figure 3:** Informative Showing Specification Insertion Gains from Table 6

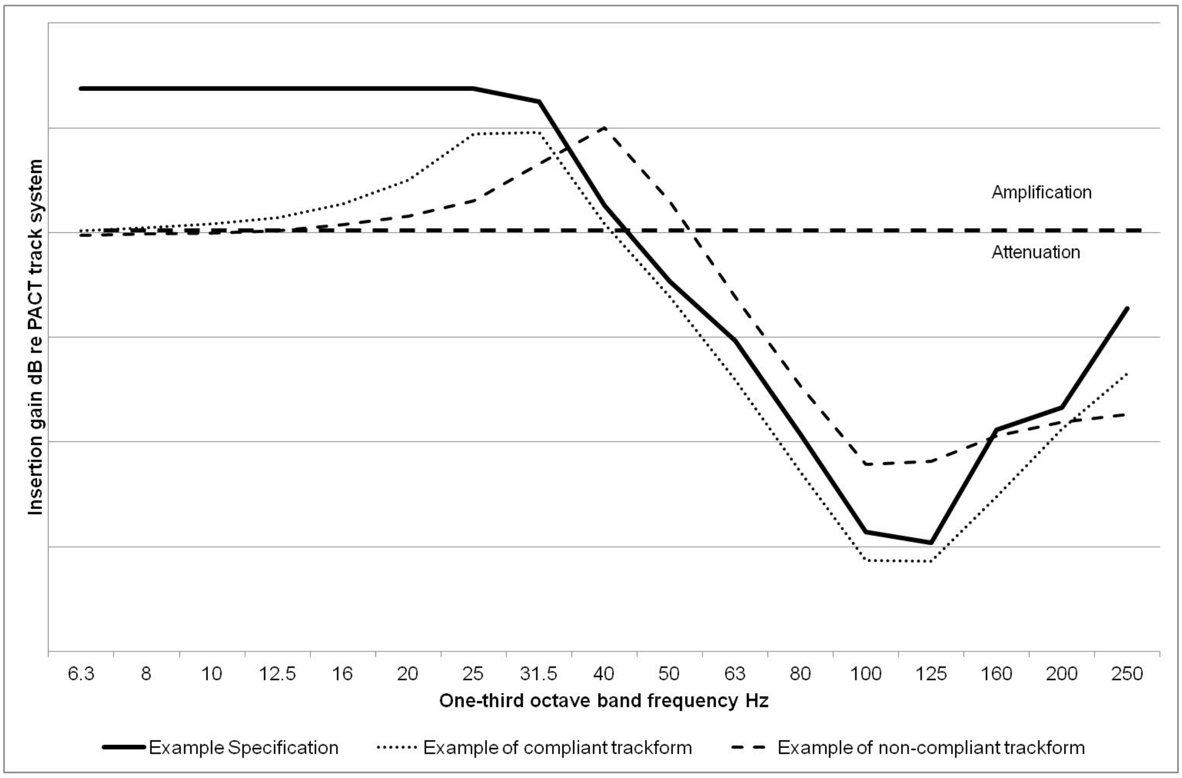



**Figure 4**: Informative Showing STS Specification Insertion Gain from **Table 6** and Examples of Compliant and Non-Compliant Insertion Gains

## 6.6 Laboratory Testing of Track

A sample of the STS shall be acoustically tested according the following specification at a laboratory to which the Employer's Representative has given a statement of no-objection. The proposed tests and the results shall be submitted to the Employer's Representative for statement of no-objection.

### 6.6.1 Test Aims

The principal aim of the tests is to measure the static and acoustic parameters of a prototype length of the standard slab track system.

The tests are to be at conditions considered to be as representative as possible of in situ operational conditions. Currently, there is no unambiguous standard for the testing and reporting of the acoustic stiffness at the frequencies and load conditions associated with groundborne noise generated by heavy rail. The tests will therefore provide a consistent, and relevant, set of information to allow verification of the assumptions made as part of detailed design development.

The objectives of the tests on the prototype track are:

- to determine its overall static vertical stiffness;
- to determine its acoustic vertical stiffness at a range of frequencies; and
- to determine their loss factor at the same range of frequencies.

Following the determination of the above parameters, the parameters will be used to predict the vibration isolation performance of the track system as defined in Appendix A.

### 6.6.2 Description of Test Assemblies

Test assemblies shall consist of at least a 600 mm long section prototype track. The prototype test section shall include:

- CEN60 rail;
- The rail fastening system over the full 600 mm length (or systems if discrete rail support is to be supported); and
- A section of supporting structure (e.g. sleepers and section of track slab, booted sleepers and section of track slab, section of track slab with plinth, section of track slab, etc.)

Loading shall be a spherical recess machined half way along the rail head with the loads applied via a steel ball at the end of the test rig loading ram or similar. The section of track slab shall be fixed onto the test machine.

### 6.6.3 Test Procedures

The test shall use calibrated equipment. In the case of the acoustic test, where the force and displacement signals are to be recorded, calibration signals of appropriate magnitude shall be recorded before each set of tests. The temperature and humidity of the Test Lab shall be maintained as a constant for all the tests and documented in the report.

### 6.6.4 Vertical Load/Deflection Test

A 100 kN capacity test rig shall be used for this test. A force transducer integral to the loading ram shall be employed to measure applied load and dial gauges used to measure the deflection of the rail head on either side of the loading point. If force transducers are installed under the slab, these force transducers may be used to measure the applied load.

Three load/unload cycles shall be applied to the system under test in each case. The maximum load shall be 70 kN, applied at a rate of approximately 2.5 kN/s in 5 kN increments. Deflection measurements shall be made at each load increment and decrement and recorded on the third cycle of loading.

The applied load shall be measured to the nearest 0.1kN and the deflection to the nearest 0.01mm.

The mean deflection shall be calculated from the two deflection measurements.

#### 6.6.5 **Acoustic Tests**

The same 100 kN test rig shall be used for the acoustic test.

If practicable, the use of the direct method (measure of the transmitted force by the use of force transducers fitted underneath the slab) is preferable. In this case the following points shall be verified before the measurements:

- The vibration of the slab shall be measured during the test and the difference of velocity between the rail-head and the slab shall be greater than 15 dB.
- Two displacement transducers (non-contacting linear transducers or accelerometers) shall be used to measure the displacement of the rail. The difference in velocity between the two rails shall be less than 15% (not required when lateral loads are applied).
- The force transducers shall be, as far as practicable, installed below the axis of each rail and symmetrically in relation to the axis of the slab.
- During the application of the static load, the loads measured by the force transducers shall be read. The difference between the measures shall be less than 10%.

The applied force control system shall be connected to an oscillator, such that the applied load is varied sinusoidally at a set frequency. Separate tests shall be undertaken at 8, 16, 31.5, 63, 125, and if possible, 250 Hz.

For each acoustic test, a pre-load shall first be applied to the rail (see below). The frequency of the oscillator shall then be set and the oscillator switched on. The dynamic load shall be held for a minimum period of 10s.

The amplitude of oscillation shall be limited to a maximum of 5mm/s rms vibration velocity on the rail-head. This shall be converted to an rms displacement limit at each frequency for the purposes of the tests. Lower values are acceptable by agreement with CRL and provided that sufficient output oscillating force is generated to enable actual acoustic stiffness to be measured at the frequency and preload conditions required above the equipment and ambient background levels.

When direct method is used, the measurements are according to ISO 10846-2 and the measured force shall be corrected for the inertia force from the slab (blocking mass).

Tests shall be performed on each system under a vertical pre-load. The *Contractor* shall propose a vertical pre-load for the test for acceptance by the Employers Representative. The preload shall be representative of the axle loading imposed on the track by the Crossrail passenger service. Because of the short-term nature of service loads on rail supports, the pre-loads shall not be applied for a long period before testing.

The acoustic stiffness for each system/pre-load/frequency shall be determined by the rms force (from both force transducers) divided by the rms deflection.

The loss factor $\eta = \tan(\varnothing)$, where $\varnothing$ is the phase difference measured between the force and displacement signals.

Care shall be exercised in selecting suitably sensitive displacement transducers. At the frequencies above 100 Hz, the rms displacement is likely to be smaller than 10 µm.

These tests shall be repeated with a lateral load applied to the system and distributed over the two rails. (the load shall be applied on both railheads in the same direction). The *Contractor* shall propose lateral loads for the tests for acceptance by the Employers Representative. The loads shall be representative of the maximum lateral loading imposed on the track by the Crossrail passenger service at locations with cant excess and/or cant deficiency.

These tests shall be repeated with a longitudinal load applied to the system and distributed over the two rails. (the load shall be applied on both rails in the same direction). The *Contractor* shall propose longitudinal loads for the tests for acceptance by the Employers Representative. The loads shall be representative of the maximum longitudinal loading imposed on the track by the Crossrail passenger service at locations where the service is accelerating and or decelerating.

These tests shall be repeated with the proposed lateral and proposed longitudinal load applied to the system.

Important Note: the test specimen resonance will occur within the frequency range of the test. Therefore, it is possible that the test will be difficult to perform above the 50Hz 1/3 octave band for Standard Track System.

## 6.7 Undertakings and Assurances

### 6.7.1 IPD10 Operational Requirements for Standard Track System

The *Contractor* shall comply with the following requirements, which derive from Crossrail Information Paper D10 (IPD10), with respect to the design for operational noise and vibration.

<table>
<tr><th></th><th>Requirement</th><th>IPD10 Para Number</th><th>Applies to Construction and/or Operational Phase?</th></tr>
<tr><td>6.7.1.1</td><td>The Contractor shall design the standard track system so that the level of groundborne noise arising from it near the centre of any noise- sensitive room is predicted in all reasonably foreseeable circumstances not to exceed the levels in Table 8. The Contractor shall install this standard track system for the Crossrail tunnel sections.</td><td>2.9</td><td>Operational</td></tr>
<tr><td></td><td><table>
<tr><th>Building</th><th>Level/Measure</th></tr>
<tr><td>Residential buildings</td><td>40dB $L_{Amax,S}$</td></tr>
<tr><td>Offices</td><td>40dB $L_{Amax,S}$</td></tr>
<tr><td>Hotels</td><td>40dB $L_{Amax,S}$</td></tr>
<tr><td>Schools Colleges</td><td>40dB $L_{Amax,S}$</td></tr>
<tr><td>Hospitals, laboratories</td><td>40dB $L_{Amax,S}$</td></tr>
<tr><td>Libraries</td><td>40dB $L_{Amax,S}$</td></tr>
</table>
Table 8</td><td></td><td>Operational and construction</td></tr>
</table>

| | | | |
|---|---|---|---|
| 6.7.1.2 | The *Contractor* shall design and install the standard track such that it includes the following measures:<br>• continuously welded rail;<br>• the rails in tunnels will be supported on resilient track support systems, and track installation will be carried out using modern technology to achieve very much more accurately laid and smoother track than exists in traditional tube tunnels. | 2.8 | Operational |
| 6.7.1.3 | Prior to opening, *Contractor* shall ensure that the rails of the underground sections of Crossrail are conditioned by grinding, or other suitable means, and that his Maintenance Plan ensures that they are appropriately maintained thereafter. The *Contractor* will be required, as part of the final track design development, to provide details to the Employer's Representative suitable for presentation to local authorities addressing the frequency of routine maintenance regimes, and the criteria under which maintenance activities such as rail grinding will be triggered, to demonstrate that Best Practicable Means will be adopted in respect to those matters so far as relevant for the purpose of maintaining the system to achieve the performance levels set out in Table 8 above. | 2.11 | Construction and Operational |
| 6.7.1.4 | The *Contractor* shall design the permanent track system, in accordance with the guidance in British Standard 6472:1992 "Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)", so that operational vibration arising from it at buildings identified in Table 8 expressed as vibration dose value (VDV), is predicted in all reasonably foreseeable circumstances not to exceed the levels presented in Table 9<br>. | 3.1 | Operational |

**Table 9**

| **In the Absence of Appreciable Existing Levels of Vibration** | | **Appreciable Existing Levels of Vibration[1, 2]** |
|---|---|---|
| VDV $ms^{-1.75}$ Daytime (07:00 – 23:00) | VDV $ms^{-1.75}$ Night-time (23:00 – 07:00) | % Increase in VDV |
| 0.31 | 0.18 | 40 |

Notes:
1. Highest impact category used, daytime or night-time.
2. There is an appreciable existing level of vibration where daytime and night-time v bration dose values (VDVs)exceed 0.22 $ms^{-1.75}$ and 0.13 $ms^{-1.75}$ respectively.

| | | | |
|---|---|---|---|
| 6.7.1.5 | The *Contractor* shall do the following in relation to the permanent track system[4] for the tunnel sections:<br>a) At design stage, to apply the relevant Crossrail design criteria relating to Table 8 and Table 9<br>and to predict, through the use of appropriate modelling[5] , the engineering requirements of the track system to meet those criteria.<br>Notes:<br>4. The track system shall comprise the integration of those component parts that together provide the guidance and support to the rail vehicles, including the rails, fastenings, resilient elements and any sleeper, ties, block or slab that transfers the track loads into any tunnel or structure base slab and which together determine the track stiffness and rail restraint.<br>5. For typical residential buildings appropriate modelling is likely to be the generation of contours such as those used for the Environmental Assessment. Buildings with deep foundations will be subjected to more detailed calculation; In both these cases the | 4.1 | Operational |

| | | | |
|---|---|---|---|
| | modelling will follow the guidance of 8.2.2.3 and 9.2.2 of BS ISO 14837:2005. | | |
| | b) In acting under paragraph (a) above, to design the trackform[6] for the tunnel sections with the objective of meeting as many of those design criteria as can reasonably be achieved.<br>Notes:<br>6. The trackform for this purpose does not include an enhanced trackform. such as floating slab | 4.1(b) | Operational |
| | d) To procure and install a permanent track system to meet the contract specifications established in this document.<br>Note:<br>7. The measurement of consequential noise and vibration levels at buildings or other receptors is not a contract requirement. | 4.1(d) | Operational |
| 6.7.1.6 | The *Contractor* shall provide details of the steps taken and to be taken in accordance with 6.7.1.5 above to the Employer's Representative in a form suitable for presentation to the relevant local authority, and shall take into account the authority's comments, including modelling results and details of the type of rail/and or track support system proposed and its predicted performance, and to continue technical discussions concerning groundborne noise issues with local authorities. | 4.2 | Operational |
| 6.7.1.7 | For the detailed design of the permanent track system in Crossrail tunnels, the *Contractor* shall adopt a groundborne noise and vibration prediction model that is fully compliant with the guidance provided in ISO 14837-1:2005 "Mechanical Vibration – Groundborne noise and vibration arising from rail systems – Part 1: General Guidance", and will provide details of the model development, calibration, validation and verification procedures undertaken to comply with that guidance and the resulting model accuracy to the Employer's Representative in a form suitable for presentation to the local authorities whose comments shall be taken in to account. | 5.1 | Operational |

### 6.7.2 **IPD26 Requirements**

<table>
<tr><th></th><th>Requirement</th><th>IPD26 Para Number</th><th>Applies to Construction and/or Operational Phase?</th></tr>
<tr><td>6.7.2.1</td><td>The Contractor shall design and construct the standard track system on the new surface sections of the railway using continuously welded rail to the greatest extent practicable with the objective of reducing noise and vibration due to the operation of the surface railway.</td><td>5.3</td><td>Operational</td></tr>
<tr><td>6.7.2.2</td><td>In carrying out his design for new surface railway the Contractor shall use all reasonable endeavours to minimise railway noise from the track. Such measures shall include, but are not limited to, the quality of the track installation and the use of rail dampers.</td><td>5.4</td><td>Operational</td></tr>
<tr><td>6.7.2.3</td><td>The Contractor shall design the surface railway in accordance with the guidance set out in British Standard 6472:1992 “Guide to evaluation of human exposure to vibration in buildings (1 Hz to 80 Hz)”, to achieve, in all reasonably foreseeable circumstances, predicted operational vibration, expressed as vibration dose value (VDV), at sensitive receptors identified in the ES, no greater than the levels presented in Table 10.<br><br>Table 10: Operational Surface Railway Vibration Criteria<br><br>
<table>
<tr><th colspan="2">In the Absence of Appreciable Existing Levels of Vibration</th><th>Appreciable Existing Levels of Vibration[1, 2]</th></tr>
<tr><td>VDV ms$^{-1.75}$ Daytime<br>(07:00 – 23:00)</td><td>VDV ms$^{-1.75}$ Night-time<br>(23:00 – 07:00)</td><td>% Increase in VDV</td></tr>
<tr><td>0.31</td><td>0.18</td><td>40</td></tr>
</table>
Notes:<br>1. Highest impact category used, daytime or night-time.<br>2. There is an appreciable existing level of vibration where daytime and night-time vibration dose values (VDVs) exceed</td><td>6.1</td><td>Operational</td></tr>
</table>

| | Requirement | IPD26 Para Number | Applies to Construction and/or Operational Phase? |
|---|---|---|---|
| | 0.22 $ms^{-1.75}$ and 0.13 $ms^{-1.75}$ respectively. | | |
| 6.7.2.4 | Where, when carrying out that design work, vibration at residential or other sensitive receptors arising from any section new, additional or altered surface railway, is predicted to exceed the levels set out in Table 10, endeavours shall be made to include mitigation measures in the design, which are predicted to result in compliance with the levels in Table 10 in all reasonably foreseeable circumstances. | 6.2 | Operational |

### 6.8 Professional Advice

The *Contractor* shall employ a Noise and Vibration Specialist to carry out calculations and provide advice to the *Contractor* to ensure compliance with the noise and vibration requirements detailed in this document.

This Noise and Vibration Specialist shall have the following competencies, experience and qualifications as a minimum:

- be an expert in dealing with noise and vibration issues associated with permanent way design with a high level of experience that is commensurate with a recognised expert in this aspect of acoustics;
- experience of liaison with stakeholders including statutory bodies such as local authorities;
- be a Corporate Member(s) of the Institute of Acoustics (or equivalent competent body). The Specialist shall be a member of a firm of consultants able to adequately resource the project and provide the necessary range of personnel and expertise.