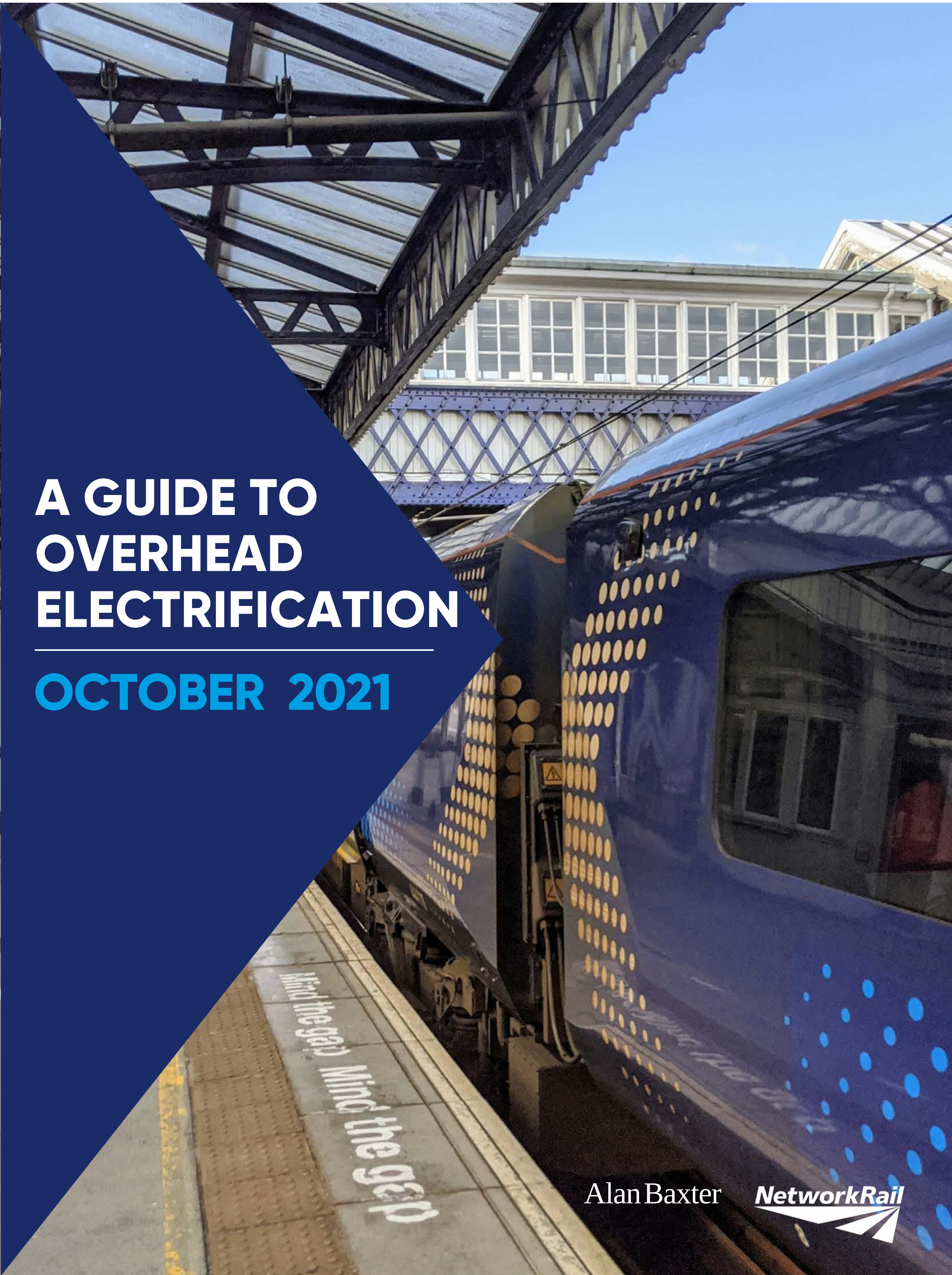
SCOTLAND'S RAILWAY
BETTER IN THE MAKING

A GUIDE TO OVERHEAD ELECTRIFICATION

OCTOBER 2021



Alan Baxter

NetworkRail

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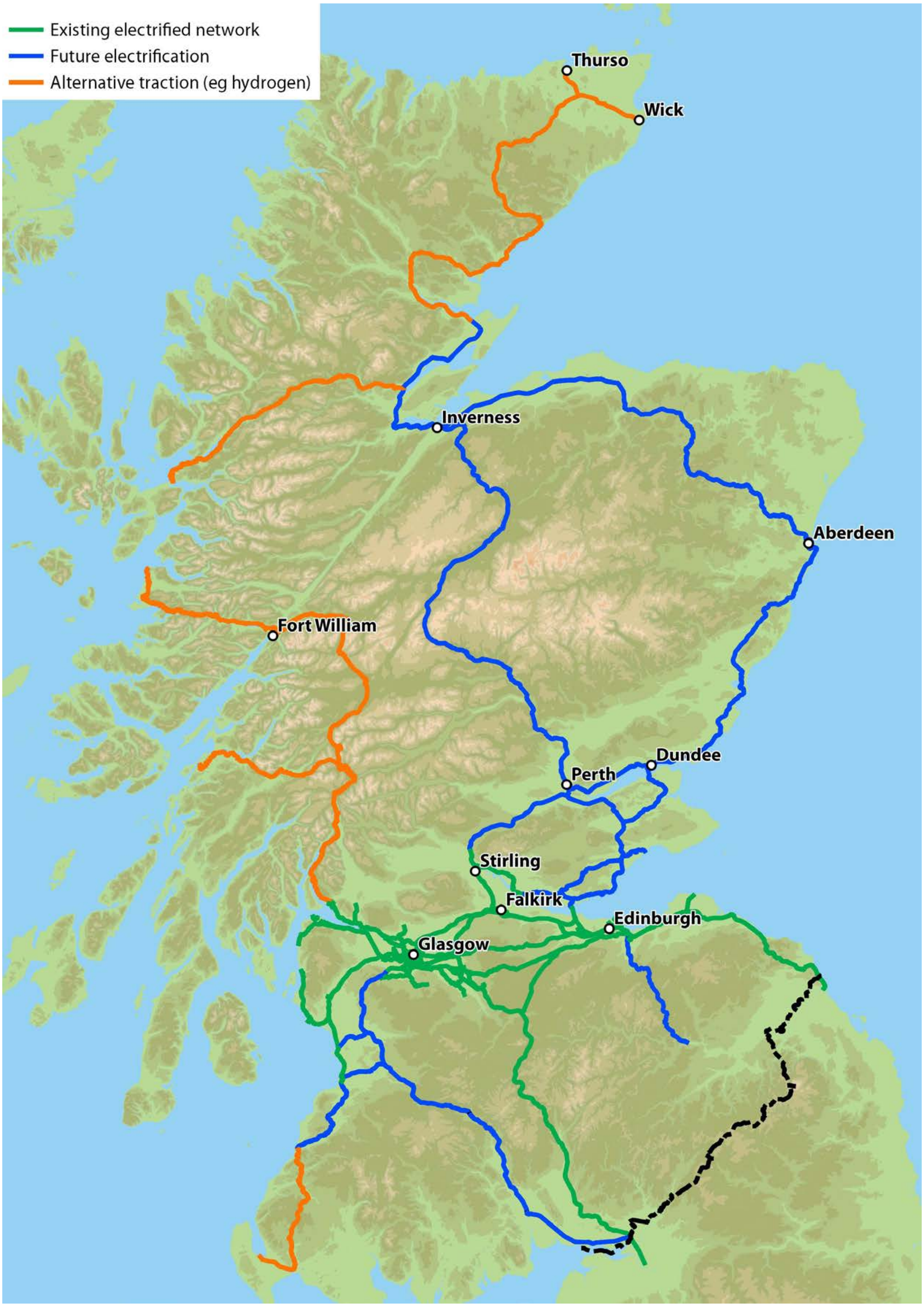


Electrification and decarbonisation of Scotland's railways

1.0 INTRODUCTION

Overhead Line Equipment – or OLE – is the name railway engineers give to the assembly of masts, gantries and wires found along electrified railways.

All this steel and cable has only one purpose – to supply power to make electric trains move.

Environmentally, operationally and from the perspective of passenger service and comfort, OLE is the preferred means of powering trains throughout the world. For example, when HS2 was conceived, there was only one choice for the engineers – OLE. For these reasons, further electrification of Scotland's railway network is central to Transport Scotland's Rail Services Decarbonisation Action Plan to make passenger railways Net Zero by 2035.

But there is also no question that OLE can be visually intrusive, and installing it along existing lines requires alterations to bridges, stations and other structures.

OLE is also undeniably complex and frankly baffling to the lay person.

The purpose of this guide, therefore, is to help all those with an interest in electrification projects – whatever that interest may be – to understand why lines are being electrified, and why some changes to existing structures will be required.

It has been produced by Alan Baxter Ltd on behalf of Network Rail with the assistance of and information supplied by its engineers and other specialists, who have reviewed and signed-off the contents.

With the help of these engineers, the document has been written for the non-specialist, not the expert, and explains with the aid of diagrams how OLE works and why it has to look the way it does.

Most importantly, it explains in ways that we can all understand what is and what is not technically and legally possible – from attaching OLE to listed stations and putting up masts on prominent viaducts, to getting wires under historic bridges and through famous landscapes.

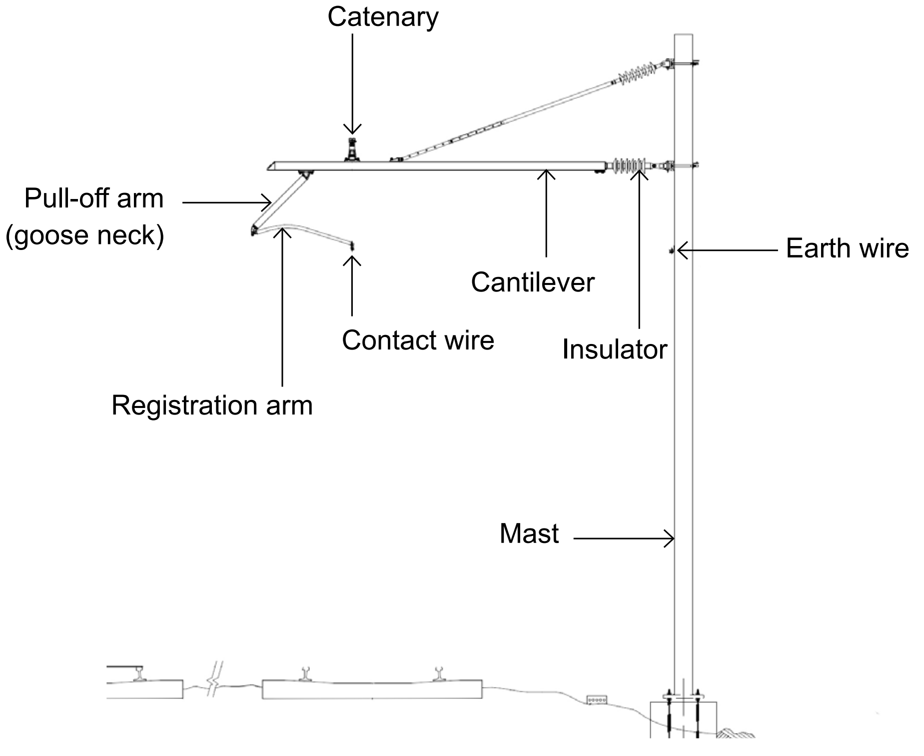
We hope you find the Guide useful. You may even find it interesting!

2.0 DEFINITIONS

The intention of this guide is to explain OLE to a non-technical audience. To that end, we have tried wherever possible to describe electrification in non-professional terms. However, it is impossible to discuss OLE without using some technical language. This glossary explains what these terms mean. The diagram on the following page illustrates many of them:

Alternating Current (AC)	Electrical current that, in the UK, changes direction 50 times per second.
Cantilever	OLE structure comprising horizontal or near horizontal members supporting the *catenary* which project from a single mast on one side of the track, normally over one or two tracks (see diagram on opposite page).
Catenary	The longitudinal wire that supports the *contact wire.*
Conductor	Any insulated wire, cable or bar that carries or may carry electric current.
Contact wire	Carries the electricity which is supplied to the train by its *pantograph.*
Contact & catenary wire tensioning	In order to keep the wires taut, they are in lengths of no more than 1500m (1970m on older systems), and tensioned at each end.
Direct Current (DC)	Electrical current that flows in one direction, like that from a battery.
Dropper	Wires suspended vertically from the *catenary* at regular intervals to support the *contact wire.*
Feeder station	A facility next to National Grid electricity transmission lines that extracts 25,000V and transmits it to the railway. The spacing of these stations depends on the electrification system used.
Insulators	Components that separate electrically live parts of the OLE from other structural elements and the earth. Traditionally ceramic, today they are often synthetic materials.
Kinematic envelope	The space that defines the train and all its allowable movements - rocking, swaying, bouncing, for example.
Loading gauge (vehicle gauge)	The dimensions – height and width – to which trains must conform in order to avoid colliding with line-side structures such as bridges and platforms.

Mast	Trackside column, normally steel, that supports the OLE.
Mid-point anchor	At the midpoint of the standard length of OLE wires, the wires are fixed in position to keep the *contact wire* stable.
Neutral section	A length of electrically isolated or non-conducting material incorporated into the *contact wire* to completely separate electrical sections of OLE. It may take the form of a short insertion in the *contact wire* or that of an extended *overlap*.
OLE	Overhead line electrification equipment, which supplies electric power to the trains.
Overlap	Each length of the *contact wire* overlaps with the next so that the *pantograph* slides smoothly from one to the other.
Pantograph	The device on top of the train that collects electric current from the *contact wire* to power the train.
Portal frame	Sometimes called a gantry: a steel OLE support structure comprising uprights on either side of the track supporting a horizontal member spanning between them, typically used where there are several tracks.



An example of an OLE mast, cantilever and associated equipment (in this case, 'UK Master Series')

Structure gauge	The defined space into which a structure must not intrude, to avoid trains colliding with it. This is larger than the *kinematic envelope* and *loading gauge*.
Third rail system	Railway electrification system using a third rail located alongside the track to supply DC power to the trains. No longer permitted for new installations on national railways.
Voltage-controlled clearance (VCC)	A system for minimising electrical clearance beneath bridges, by using surge arrestors, insulated paint and bridge arms, and twin, covered *contact wires*.

3.0 WHY ELECTRIFY?

3.1 DECARBONISING THE RAIL NETWORK

Transport accounts for 37% of all greenhouse gas emissions in Scotland. Decarbonising transport is therefore vital to meeting the Scottish Government's commitment to achieving Net Zero greenhouse gas emissions by 2045.

At the moment, all trains on un-electrified routes are powered by diesel engines, similar in concept if not size to those under the bonnets of many lorries. Diesel engines emit carbon dioxide, whereas the operation of trains powered by electricity derived from hydroelectric, nuclear and wind generation can be carbon neutral.

For this reason, further electrification of Scotland's rail network is fundamental to decarbonising the rail share of the country's carbon emissions, and helping to encourage a 'modal shift' from road to rail. This ambition is enshrined in Transport Scotland's Decarbonisation Action Plan to make passenger services in Scotland carbon neutral by 2035, which will be implemented through a long-term rolling programme of decarbonisation run by Scotland's Railway, a part of Network Rail.

3.2 THE OTHER BENEFITS OF ELECTRIC TRAINS

The benefits of electrification spread much wider than carbon reduction: electric trains are also lighter, cleaner, cheaper, quieter and faster to accelerate. So they help improve the railway service by allowing more trains to be run more efficiently and more quickly, transporting passengers in greater comfort.

Electric trains are cheaper than diesel trains because:

- they cost less to build and are 20% cheaper to lease
- maintenance costs are typically 33% lower
- fuel costs are typically 45% lower because electric trains are lighter and more efficient and electricity from the National Grid is cheaper than diesel fuel
- they are lighter and therefore cause on average 13% less wear to the tracks
- track maintenance costs are therefore lower

Electric trains provide a better service because:

- they have a higher power-to-weight ratio, which means that they are generally faster than diesel trains
- they accelerate more quickly, which reduces journey times
- they are quieter and vibrate less due to the absence of diesel engines

4.0 A BRIEF HISTORY OF RAIL ELECTRIFICATION IN THE UK

Steam engines

From the birth of the railways in the early 19th century until the 1950s, steam locomotives were the dominant form of motive power on Britain's railways. They were finally phased out by 1968.

Diesel power

Diesel power – pioneered in America – started to become widespread in the 1950s. On some routes this is still how long-distance services are powered – either in the form of locomotives at both ends of the train, like High Speed Trains, or where a number of smaller diesel engines are distributed underneath carriages, as found on many other trains (see drawing over the page). Freight, too, remains predominantly diesel-hauled.

Underground trains

Electrically powered trains have a much longer history in the UK, beginning with the London Underground in 1890 and the Glasgow Subway six years later. These were - and still are - powered by a direct current system.

The first overground electrification systems

The first systems using OLE appeared before the First World War in south London and Lancashire (using 6,600V DC, and later dismantled), and others followed in East London and on Merseyside in the 1920s and 30s. The first major electric network was created by the Southern Railway from the 1920s.

This did not use OLE but the 750V DC third rail system that still powers trains throughout South East England.

Main lines

Long-distance mainline 25,000V AC OLE systems are more recent. They are a product of the Modernisation Plan that swept steam away from the 1960s. First, the West Coast Main Line from London to Glasgow, in the 1960s and '70s, followed by the East Anglian Main Line in the 1980s, and then the East Coast Main Line, completed in 1990.

Scotland

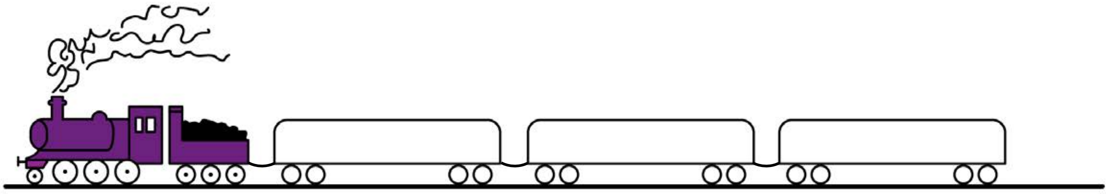
In Scotland, OLE systems were introduced for Glasgow suburban services in the 1960s, and followed on the West Coast Main Line and East Coast Main Line over the next two decades.

Recent expansion

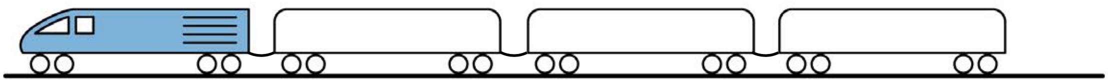
In the last ten years a new generation of schemes has been initiated, including the Edinburgh Glasgow Improvement Programme between the two cities and other locations in the Central Belt, together with the Great Western and Midland Mainline programmes south of the border. This expansion is set to continue with projects such as the rolling programme of decarbonisation in Scotland and the TransPennine Route Upgrade project across the North of England. At the same time, new high speed lines, first to the Channel Tunnel and now HS2 to the north, are equipped with OLE from the outset.

Bimodal trains

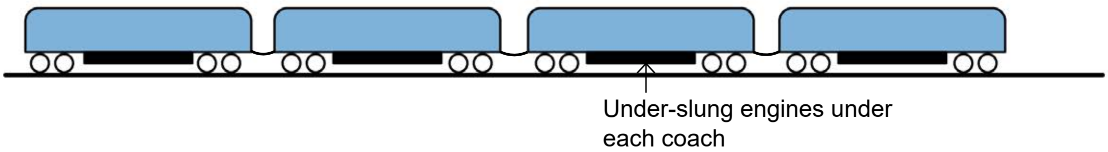
Some of these recent schemes include the use of new ‘bimodal trains’, which combine electrical power drawn from OLE with underslung diesel engines to continue journeys on to parts of the network that are not electrified. Aberdeen to London services now use such trains, for example. In the future, batteries may replace the diesel engines in bimodal trains to reduce carbon emissions.



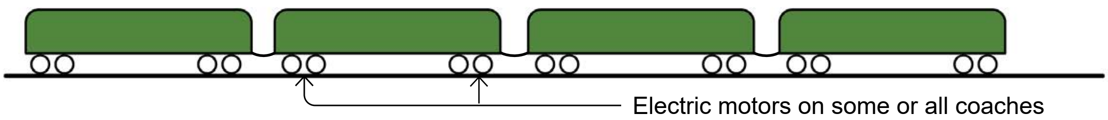
Steam locomotive



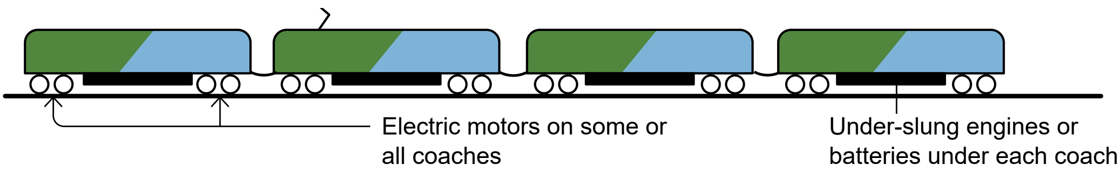
Diesel locomotive



Diesel with under-slung engines (DMU - Diesel Multiple Unit)



Electric train (EMU - Electric Multiple Unit)



Bimodal train (combining diesel, or in future battery, and electric power)

5.0 OTHER MEANS OF DECARBONISING POWER

In most circumstances, overhead line electrification is the most efficient means of decarbonising the railway network, but it is not the only potential solution. For example, in Scotland it is envisaged that some trains will **combine OLE supply and onboard batteries**: using this type of bimodal train, batteries would be charged when running under the OLE to enable the train to continue its journey on sections of the route that have not been electrified.

In the South East of England there might be occasions where it is sensible to **extend the existing third rail system**, where the ability to use existing third rail trains and avoid bridge and tunnel reconstructions offsets the slightly lower efficiency of third rail DC power. This is not an option in Scotland, where no third rail systems exist.

Where routes are lightly used, the high cost of installing OLE might not be justified, especially if those lines are lengthy, such as they are in the West Highlands. For parts of the network like these, Network Rail and the rail industry are exploring a number of possible solutions, including **battery and hydrogen power**.

At present these new technologies each have limitations, such as the distance battery or hydrogen powered trains can travel before they must refuel, and the energy required to create liquid hydrogen fuel, but across the world engineers and companies are working to overcome these challenges, so they are likely to be adopted in some specific circumstances in the years to come.

A hydrogen powered train in Germany. The fuel is stored on the roof (photograph: © Network Rail)

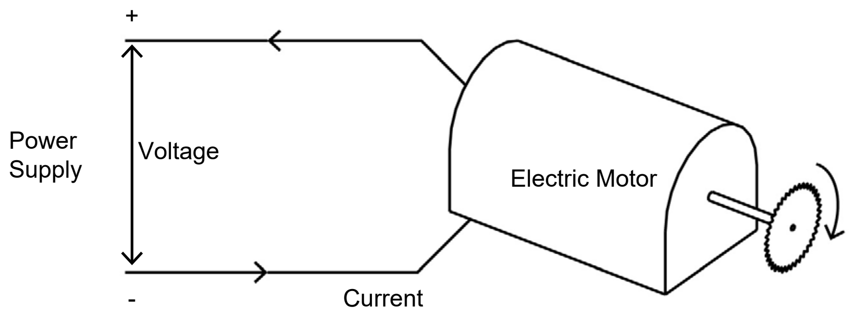
6.0 THE PRINCIPLES OF ELECTRICALLY POWERED TRAINS

In its simplest terms, the electric train power system consists of a power supply wired to an electric motor in the train, which drives the wheels of the train.

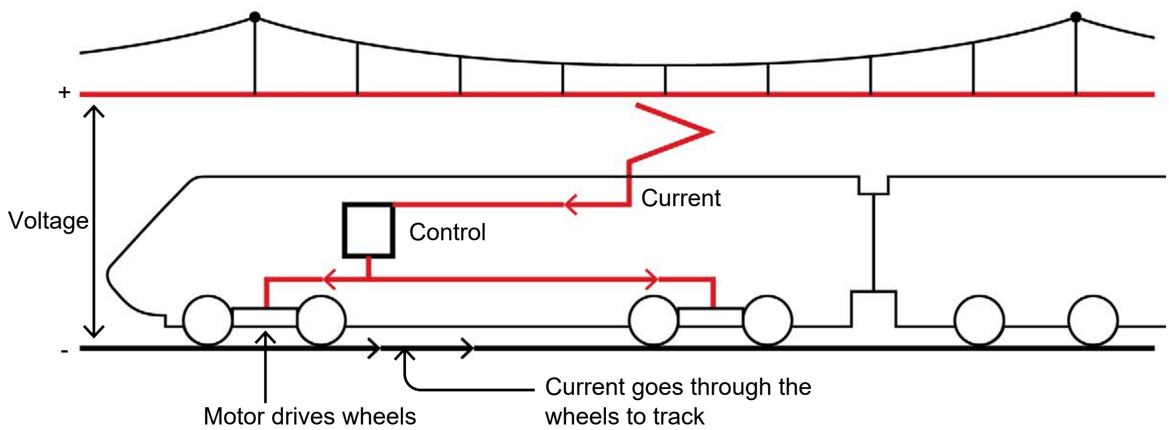
To complete the circuit and thereby allow the current to flow, the track is used to make the return connection.

Within this electrical circuit, the purpose of OLE is to supply electricity to moving trains.

This power supply must be something that trains can access at all times. Therefore the key objective of OLE designers is to ensure uninterrupted, uniform, reliable and safe supply of power to trains.



Principle



The principle applied via OLE

7.0 POWER SUPPLY TO POWER USE: THE FOUR STAGES OF POWERING TRAINS BY OLE

7.1 THE FOUR STAGES

The supply of electricity to power trains is divided into 4 stages:

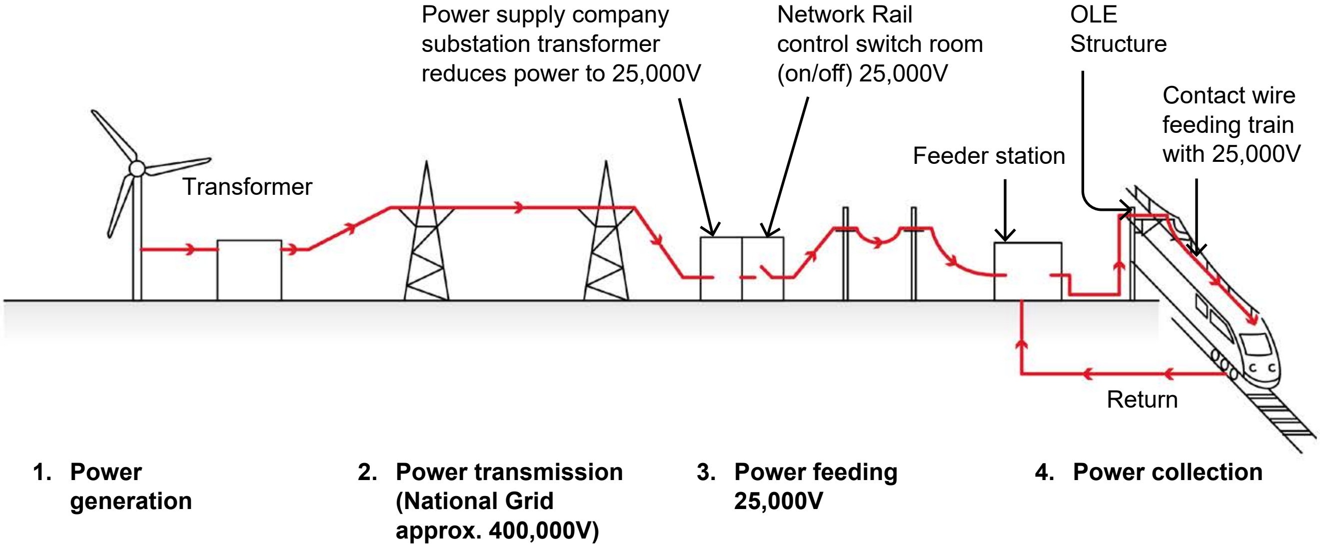
1. power generation
2. power transmission
3. power feeding
4. power collection

Power is generated at an electricity generating source – normally a **power station** - and then transmitted via transformers into overhead **transmission lines** at high voltage (approximately 400,000V) - the National Grid.

The supply is alternating current (AC). AC is more economical and practical to transmit over long distances than direct current because it suffers from smaller losses. High voltages mean smaller wires: to transmit the same power at low voltage needs high currents and therefore large conductors (wires).

Power is taken from the National Grid at **feeder substations** located next to the transmission lines, which reduce the voltage to 25,000V and transmit the power to the OLE. Although it is more economical to transmit electricity at higher voltages, as the voltage grows the required clearances increase and so does the cost of the equipment. Therefore, it has been found that 25,000V is the optimum voltage for trains.

Masts and gantries (portal frames) support the overhead wire carrying the power - the **contact wire**. The power is transmitted from the contact wire to the train by a sprung '**pantograph**', which is attached to the roof of the train. In the train, the current is used to drive the motors with the aid of on-board controllers.



Four stages of power generation and supply

7.2 COMPLETING THE CIRCUIT

There has to be a closed electrical circuit in order for the current to flow and the train to move. The circuit can be completed through the train wheels to the rails and then by connecting the rails back to the feeder substation. However, significant complications arise from power loss over long distances and safety-critical interference with signalling and telecommunication.

7.3 AC AND DC CURRENT

The power supply can be either **direct current** (DC) or **alternating current** (AC). AC changes direction 50 times per second while DC always flows in the same direction. In Scotland, only AC is used.

The National Grid transmits at AC because it is more economical and practical to transmit high voltages long distances. OLE in the UK uses AC too, but the older third rail system used extensively in the South East of England supplies DC. Because OLE is elevated it can transmit higher voltages more safely and efficiently. The standard used in the UK and most of Europe is 25,000V AC.

7.4 REGENERATIVE BRAKING

One major advantage of AC OLE over other systems is its capacity for 'regenerative braking'. A train starting to descend a falling gradient, or applying brakes after a fast run, has considerable kinetic energy, while needing little or no external power to keep moving. This energy can be converted into electrical power and returned to the supply system through the overhead line, and the saving in energy consumption can be considerable.

The high voltages and long sections between feeder stations in AC systems make regenerative braking attractive, and most new traction equipment is designed to make use of it. The technique can be applied, in a limited way, to DC systems, but the short sections between substations and the lower voltages make it much less effective.

8.0 THE COMPONENTS OF OLE EQUIPMENT

8.1 OLE COMPONENTS AND THEIR PURPOSE

Overhead line equipment comprises a large number of standardised components. The latest standard of these components forms what is known as the UK Master Series, or UKMS.

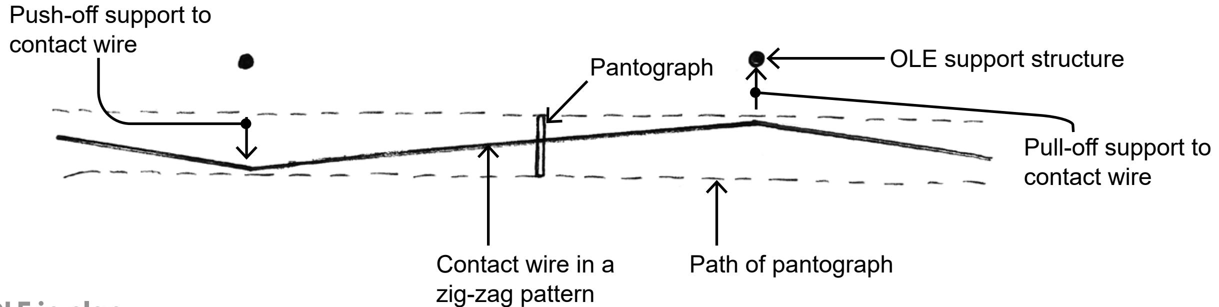
Most of the components are there to achieve the principal aims of OLE designers: keeping the **contact wire** as stationary as possible so that power can flow uninterrupted to the train; and minimising wear of the system.

To achieve this, the contact wire is tensioned between steel support structures in such a way that it can withstand deflection by high winds and extreme temperatures. This ensures that the current passes to the train in all weather, even at high speed.

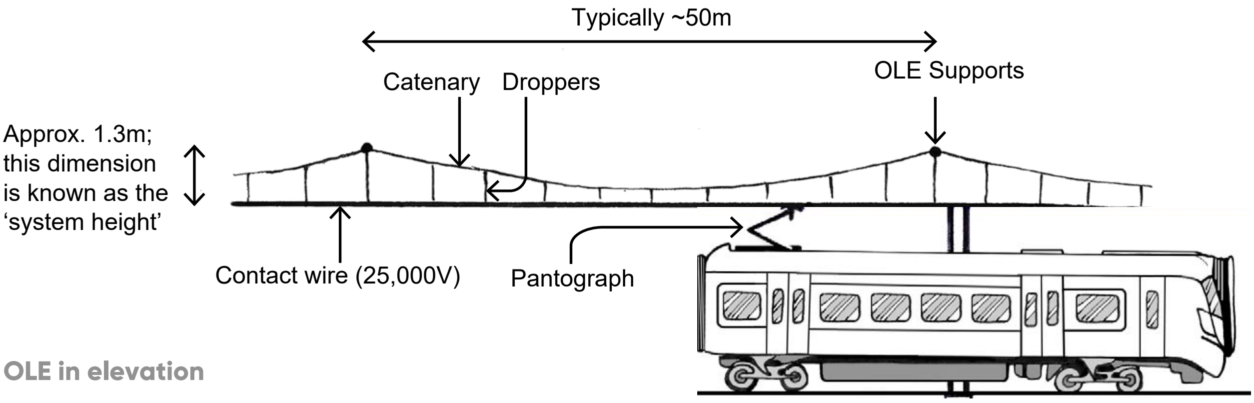
The contact wire is suspended from vertical cables called **droppers** that are hung from a longitudinal cable called the **catenary**. The catenary and contact wire span between steel support structures – either **masts** or **frames** – which are normally spaced approximately 50-60m apart (although there is some flexibility in spacing).

The wires themselves are normally about 1500m long and **tensioned** at either end. To ensure no loss of power to the pantograph, adjoining sections of wire **overlap** for 150m-195m.

In designing the steel supporting structures, the most important engineering consideration is the effect of high winds, both along and across the tracks. The supports are made sufficiently stiff so that they do not deflect enough to impair current collection.

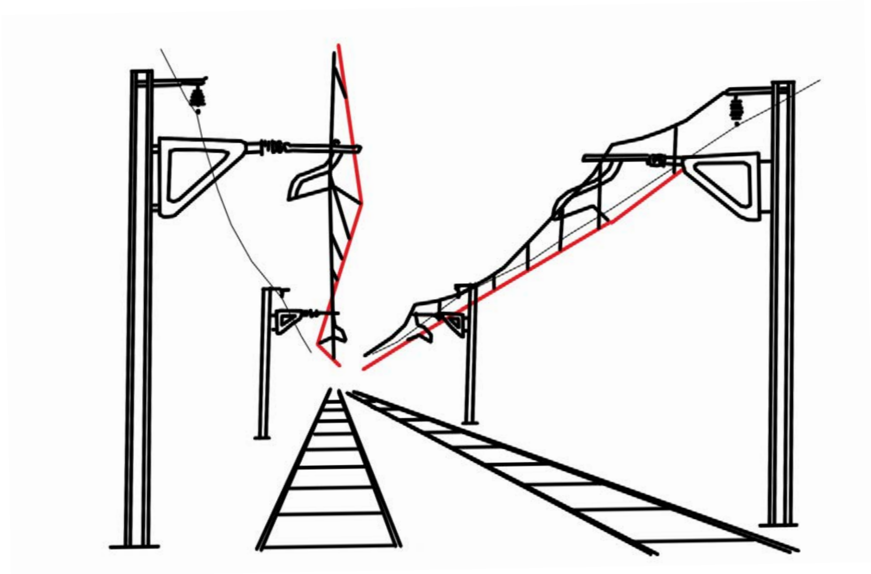


OLE in plan



OLE in elevation

The contact wire also runs in a zig-zag path above the track to avoid wearing a groove in the pantograph. The zig-zag - known as the **'stagger'** - is generally achieved by the use of **'pull-off' and 'pull on' arms** attached to the support structures.



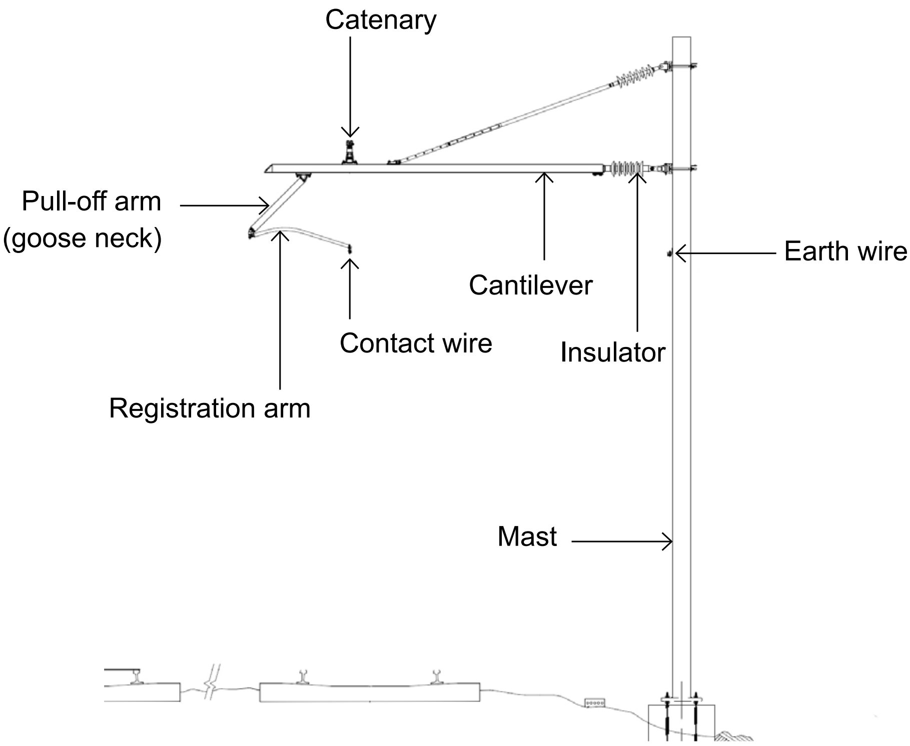
Stagger

Stagger of contact wire and catenary. Note also the pantograph on top of the train (photograph ©Graeme Bickerdike/Four by Three)

8.2 CANTILEVER MASTS

Where there are only one or two tracks, OLE is normally supported from lineside **masts** made of steel, under cantilevered arms. These structures are known as single track cantilevers (STC) and twin track cantilevers (TTC), as shown in the photographs over the page. In each case, the **catenary** cable and the **pull/push-off arms** supporting the **contact wire** are attached to the ends of the **cantilever**. Where the masts and cantilevers meet, **insulators** are required to separate the electrically live elements. The **earth wire** is normally attached to the **mast**.

Typically, the mast is of a type called 'H section', meaning that a slice through the mast has the shape of a capital H, though sometimes other forms might be used (see section 13.1.1).



An example of an OLE mast, cantilever and associated equipment (in this case, 'UK Master Series')

Newly installed UKMS 'single track cantilever' (STC) masts on the Edinburgh Glasgow Improvement Programme (EGIP) (photograph: ©Network Rail)

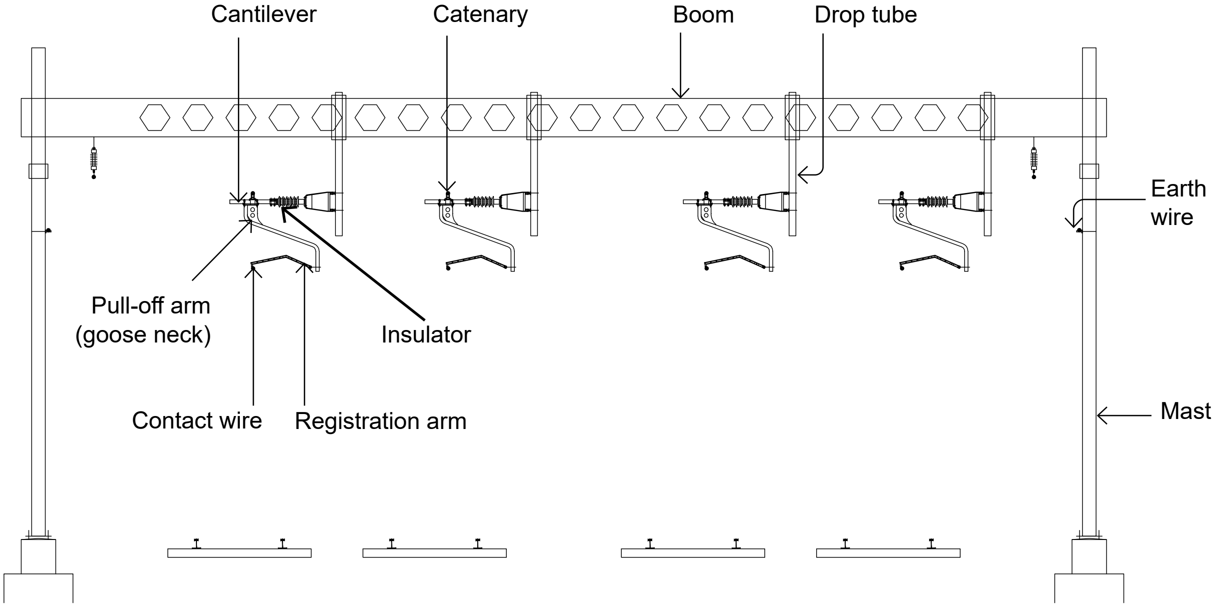
Twin track cantilevers (foreground) and single track cantilevers (background) installed for EGIP (photograph c Network Rail)

8.3 PORTAL FRAMES

Where there are more than two tracks, cantilever masts are not always feasible. Instead, a steel frame may be adopted, spanning the tracks. This is generally referred to as a **portal frame**.

The frame consists of masts joined by a horizontal **boom**, which might be H section, lattice or other forms, as shown below.

On frames, the cantilevers supporting the wires are attached to the boom by vertical members called **drop tubes**.



Portal frame OLE support structure (with "castellated" boom)

A typical portal frame made of H-section steel members (photograph: © Network Rail)

8.4 HEADSPANS

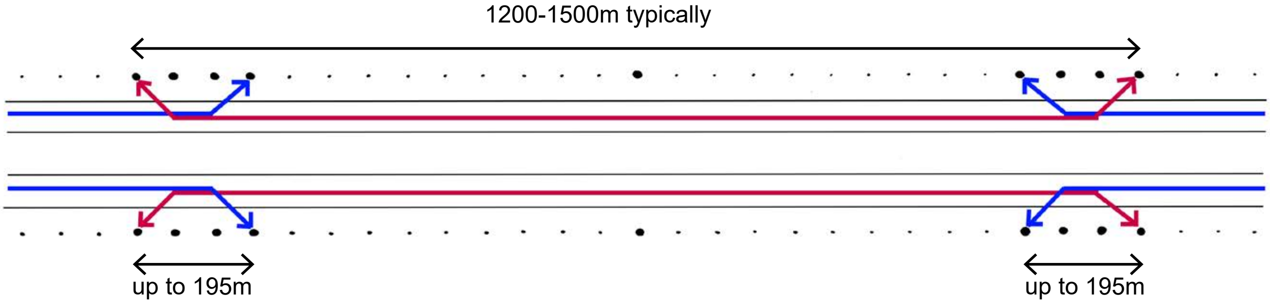
Earlier overhead electrification projects frequently used a system of wires spanning between masts either side of the tracks to support the OLE catenary and contact wires, instead of steel booms. These are known as 'headspans'. There have been difficulties with this system in practice, in particular because the OLE over each track is not independent of each other, which means there is a much greater risk that damage to the OLE over one track will affect all lines, resulting in much more extensive disruption than with other systems. As a consequence, headspans are now avoided except where slow train speeds reduce the risk of damage, such as in terminus stations. Here they may still be favoured because they are less visually obtrusive than other support methods (see section 13.6).

Headspans at Glasgow Queen Street Station. This type of support is now only favoured where trains move very slowly, such as depots or terminus stations (see section 13.6) (photograph: © Network Rail)

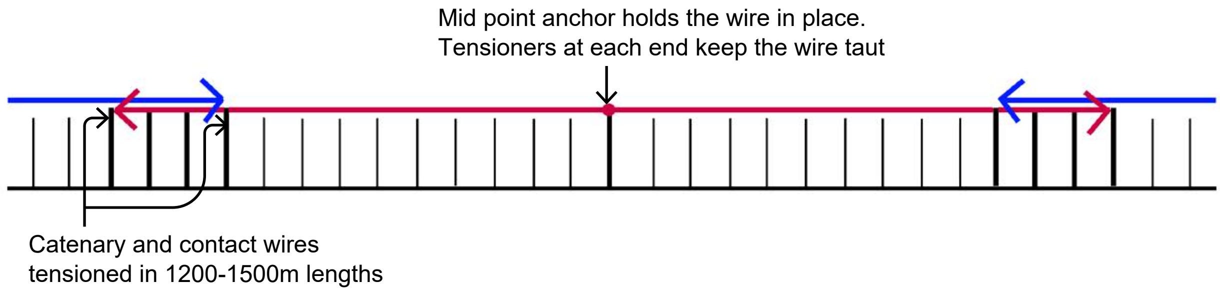
9.0 HOW OLE EQUIPMENT IS ARRANGED ALONG THE TRACK

9.1 TENSIONING

The catenary and contact wires are installed in lengths that are tensioned at either end in order to keep the contact wire as still as possible. This is so that a good contact is maintained with the pantograph at all times and in all conditions. The tensioned wires will generally be up to 1500m long. An overlap between the length of wires of between 150m and 195m is needed in order to provide a continuous supply of electricity to the trains.

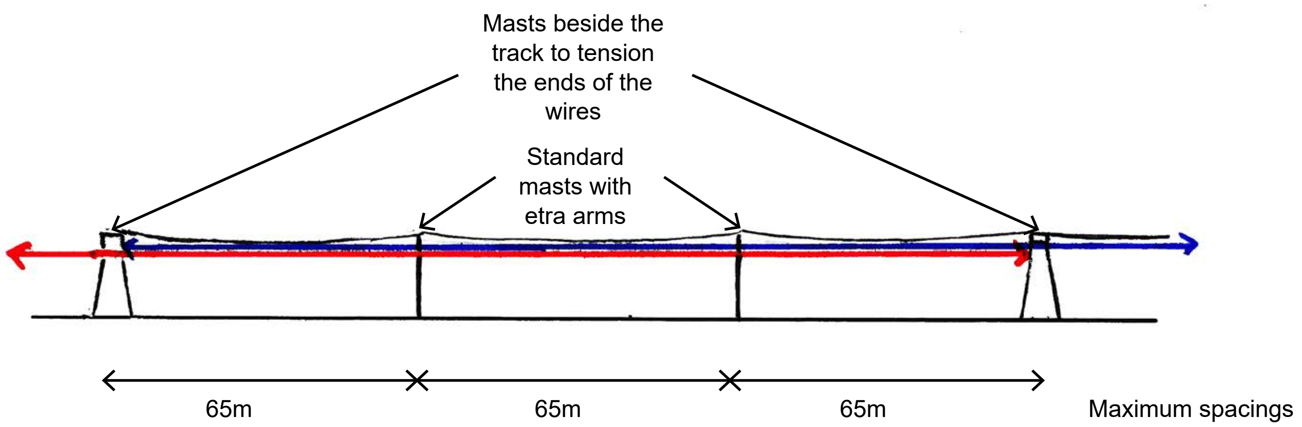


Plan



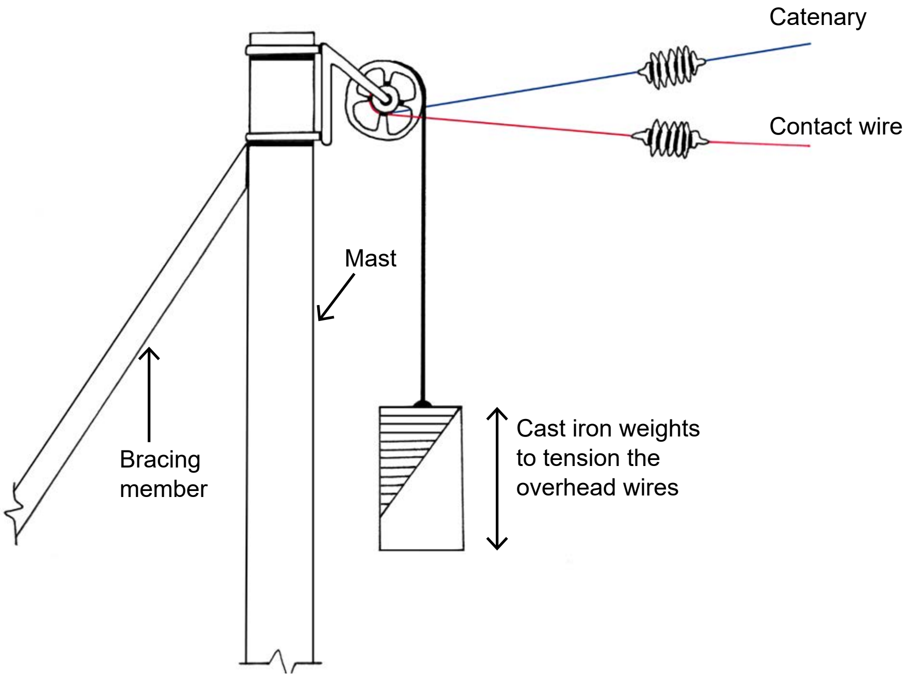
Section

Tensioning

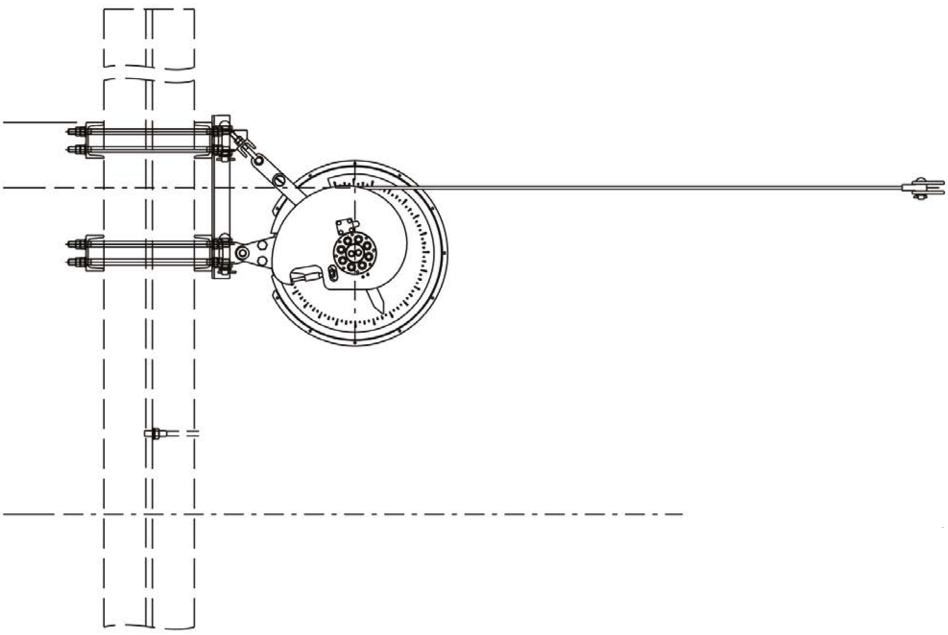


Overlapping

The conventional tensioning mechanism consists of a braced mast and iron weights, as shown below (a 'balance weight anchor'). However, this system is susceptible to mechanical problems and to vandalism that can cause service disruptions. Therefore new systems use a spring tensioning mechanism, as shown here (called 'tensorex'). Each wire needs two springs at each end (one for the catenary and one for the contact wire) and these are normally attached to masts beside the tracks. Historically, OLE in sidings was terminated without tensioning ('fixed termination'). This simpler system is still sometimes used for terminating platforms in stations.



Cast-iron balance weights, as traditionally used on UK railways (a 'balance weight anchor')



Spring tension device 'tensorex', as now used on electrification projects

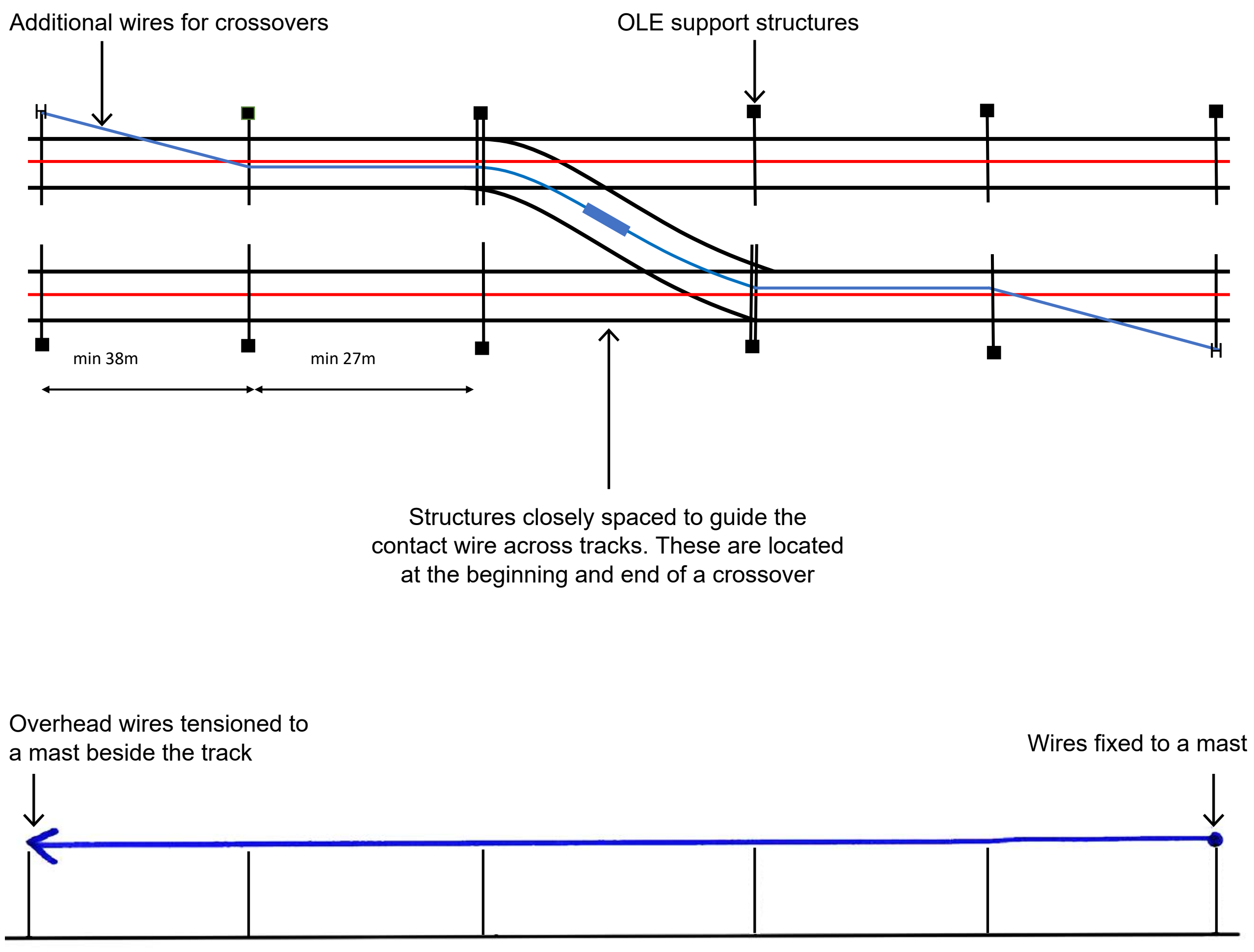
9.2 MID-POINT ANCHOR

At the mid-point along a tensioned length (plus or minus 15%), the wires are fixed in place. This is called the mid-point anchor and its purpose is to resist the effect of the friction caused by the passing pantograph trying to drag the contact wire forward. Mid-point anchor structures are usually single track cantilevers.

9.3 AT POINTS AND CROSS-OVERS

To ensure a continuous supply of power when a train switches from one track to another across points, or cross-overs, additional wires are provided. These are normally installed between five sets of supports, as shown below. They are fixed in position at one end and tensioned at the other using springs. Three of the supports are needed at the beginning, middle and end of the cross-over in order to direct the additional wires over the points.

This means that wherever there are points there have to be more and larger supporting structures and wires. This is exemplified by the approaches to major stations such as Glasgow Central or Edinburgh Waverley, where there is a profusion of gantry supporting the OLE.

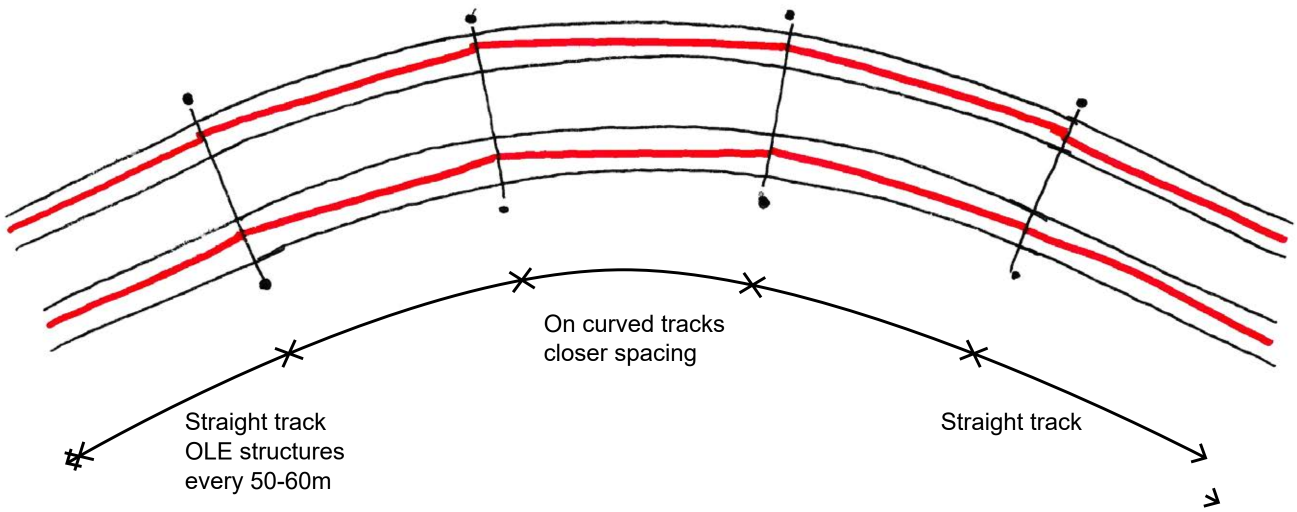


OLE at cross-overs (points)

9.4 AROUND BENDS AND CHANGES IN GRADIENT

OLE support structures are generally spaced 50–60m apart. Where the line goes around a bend, however, they may need to be more closely spaced so that the contact wire is kept in the right position for the pantograph.

A similar principle applies to vertical curves where track changes gradient, i.e. at the tops and bottoms of slopes.



OLE around bends

9.5 NEUTRAL SECTIONS

Neutral sections are electrical “gaps” in the OLE wiring, used to isolate sections of wiring for maintenance purposes and to separate lengths of line supplied with power from different feeder stations. This is necessary to avoid power from one feeder inadvertently passing via the OLE to another and thus bypassing National Grid’s control systems.

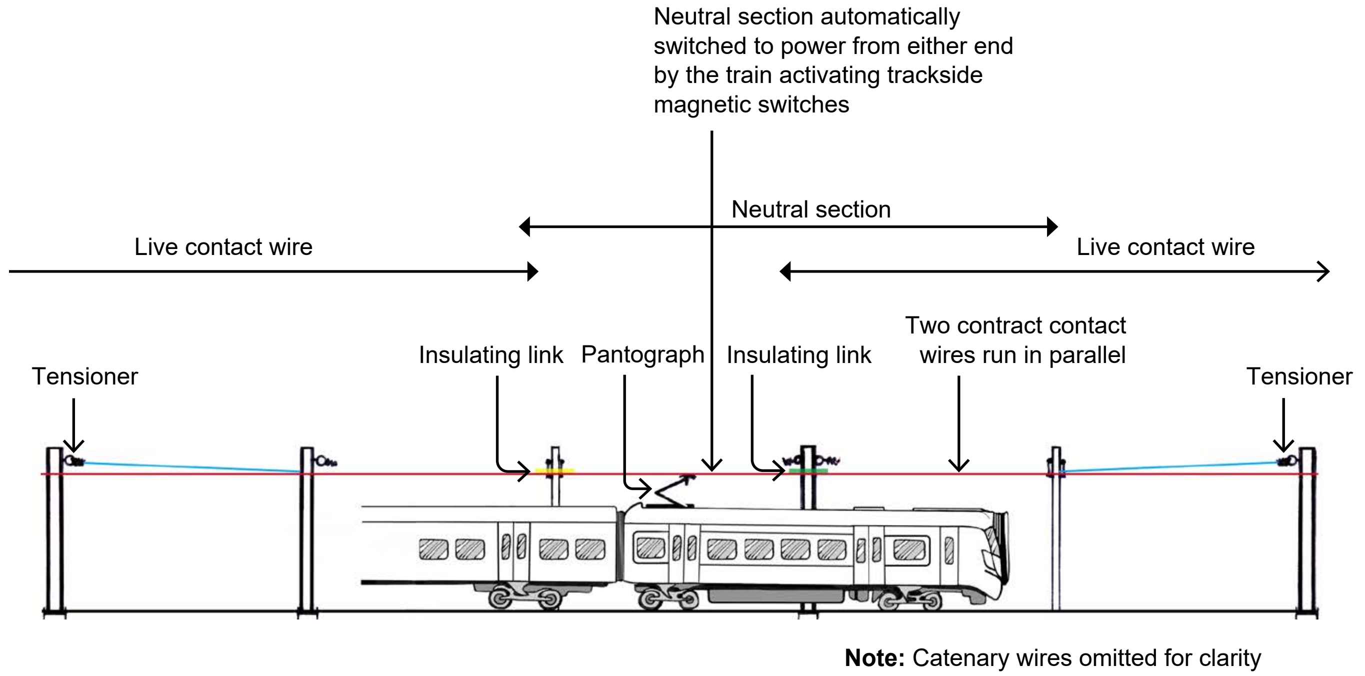
Neutral sections are formed by inserting short electrically-isolated or non-conducting elements between lengths of live contact wire, and fitting the catenary wire with insulators.

There are two basic types of neutral section, which are illustrated on the following page. The first is a full, “**switched**” neutral section, known as a ‘carrier wire’ neutral section. This is favoured where there are speeds of over 100mph. It consists of separate insulated lengths of contact wire in the overlap between two normal sections. The insulated neutral sections are connected to the normal contact wires by switches which are operated automatically by passing trains, thereby maintaining an unbroken electrical supply.

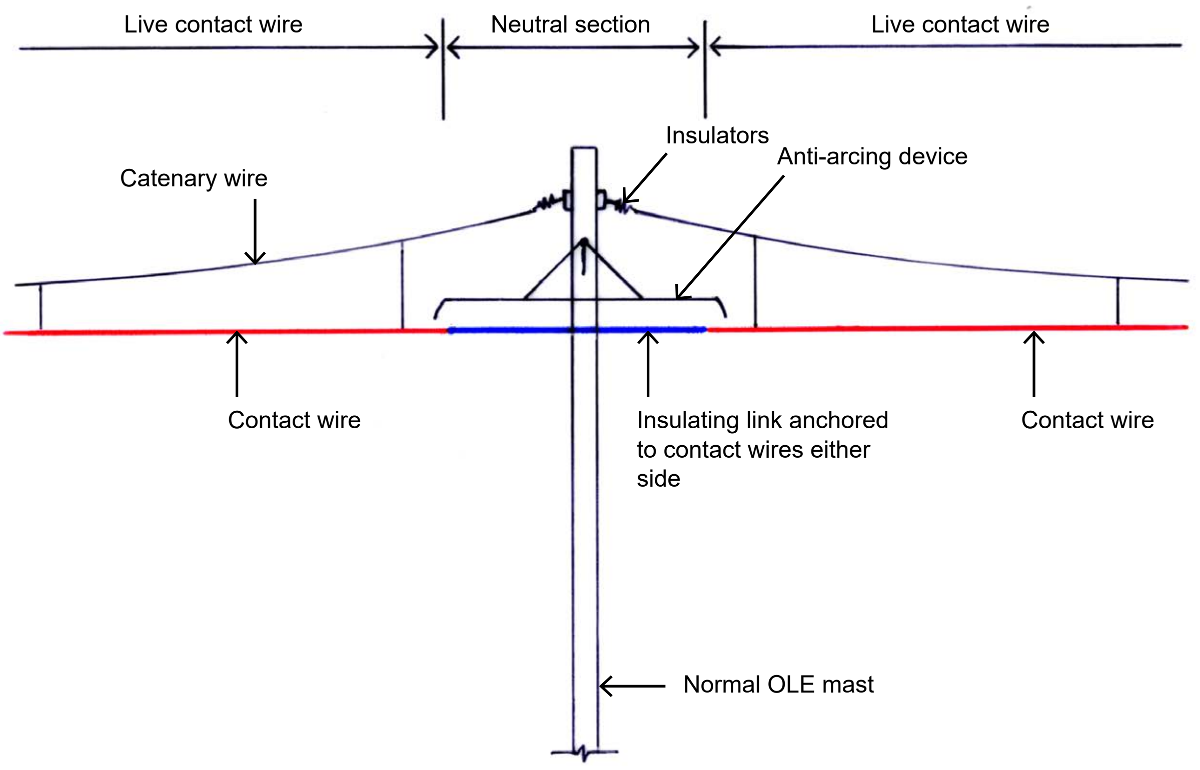
The second type of neutral section is a short length of non-conducting material spliced into the contact wire to enable local lengths of wire to be isolated, e.g. for maintenance work. This is known as an ‘in-line’ neutral section.

Neutral sections need to be sited away from junctions, signals or stations because any train that stops when its pantograph is on an isolated or insulated section will not have any power and will be unable to restart.

A full switched neutral section consists of an extended set of overlaps, together with an adjacent portacabin-sized switchgear cabinet; a short neutral section is attached to a standard single track cantilever mast and is less obtrusive. In sensitive landscapes or historic townscapes it is preferable for neutral sections to be sited in unobtrusive or screened locations because of the visual impact of the associated equipment.



Full switched neutral section



Short neutral section

10.0 OLE IN SENSITIVE LANDSCAPES

10.1 RAILWAYS IN THE LANDSCAPE

Railways pass through some of Scotland's most beautiful landscapes. Our acceptance that these lines now form part of the character of the countryside is both a testament to the skill of their Victorian engineers and a reflection of the extent to which the line of route is determined by topography and geology.

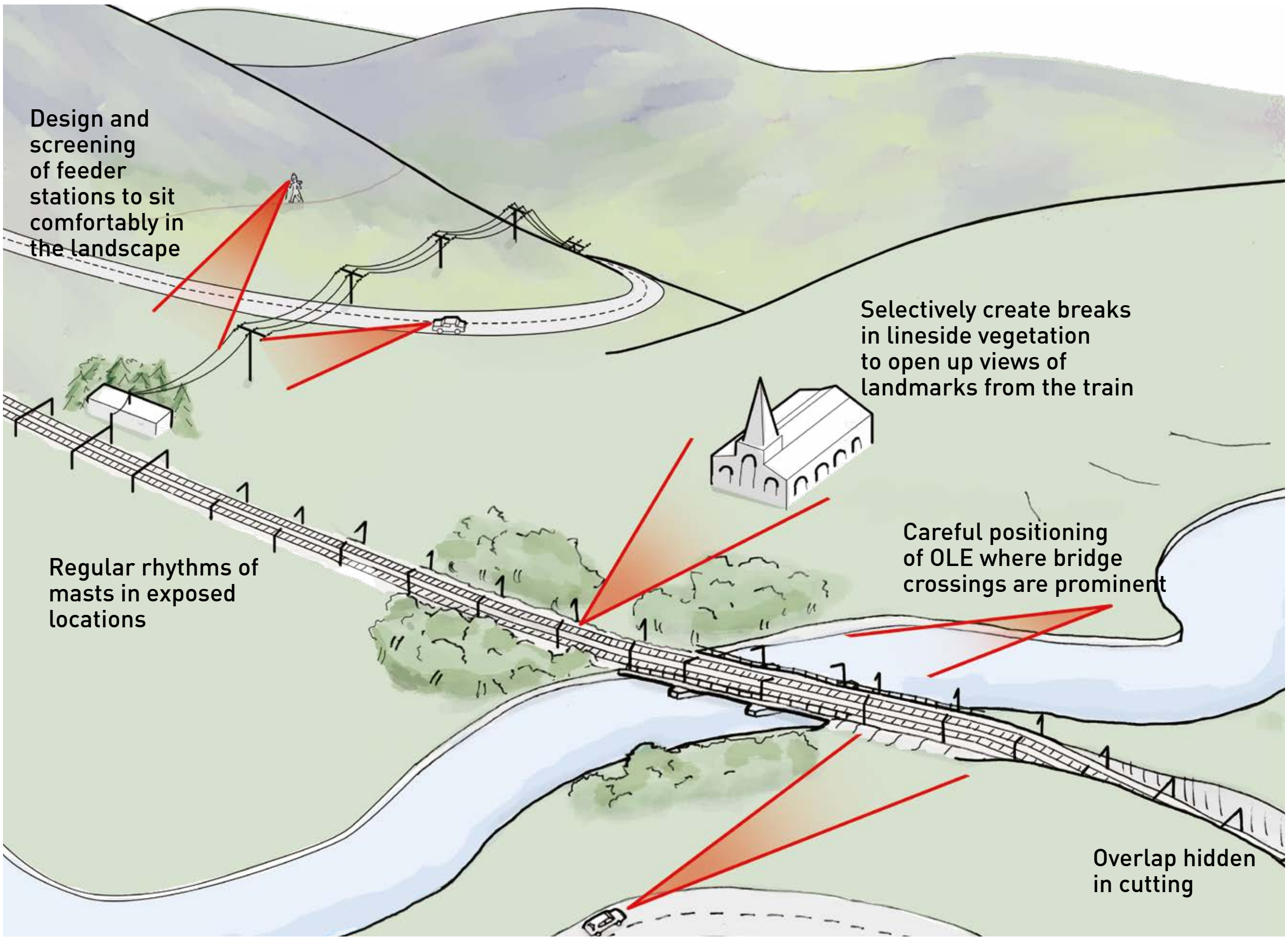
OLE has been installed for decades in some of the most beautiful parts of the UK, as the photographs on the following pages illustrate. We have learnt from this experience that the masts have little impact on our appreciation of these places, especially where lines consist of one or two tracks, and when viewed from a distance. When they are installed, galvanised steel OLE supports reflect the light, but with time they take on a dull patina that blends well with the tones of our landscape. In Denmark they use a weathering steel, whose natural rusted finish has similar benefits (see image at the bottom of p.27).

10.2 VEGETATION

In shorter views, electrification may make the railway more prominent because it is necessary to remove vegetation within 6 m of electrified tracks to avoid the risk of trees and shrubs interfering with or falling on the OLE, and reduce the risk of lineside fires caused by sparks. Sometimes it might be necessary to divert or modify utilities that cross the line, such as power lines, or gas and water pipes, to accommodate OLE.

10.3 DESIGN PRINCIPLES

Intelligent use of standard components can minimise the impact of OLE on sensitive landscapes. Consistency, simplicity and placement are key principles, illustrated in the sketch overleaf. There may be occasions in especially important locations where planting might be considered to screen more prominent equipment such as feeder stations, if these cannot be positioned in place such as cuttings that already offer cover. This is an approach being adopted by HS2.



OLE in sensitive landscapes

OLE on the West Coast Main Line at Wandel in Lanarkshire (photograph: © Jamie Squibbs)


OLE on the West Coast Main Line in the Lune Valley, Cumbria (photograph: © Gordon Edgar)


OLE on the West Coast Main Line in the Southern Uplands (photograph: © Georgesixth Dreamstime.com)

OLE on the East Coast Main Line as it skirts the Berwickshire coast (photograph: © Scott Borthwick)

OLE on a railway in Denmark, using weathered steel masts (photograph: © Network Rail)

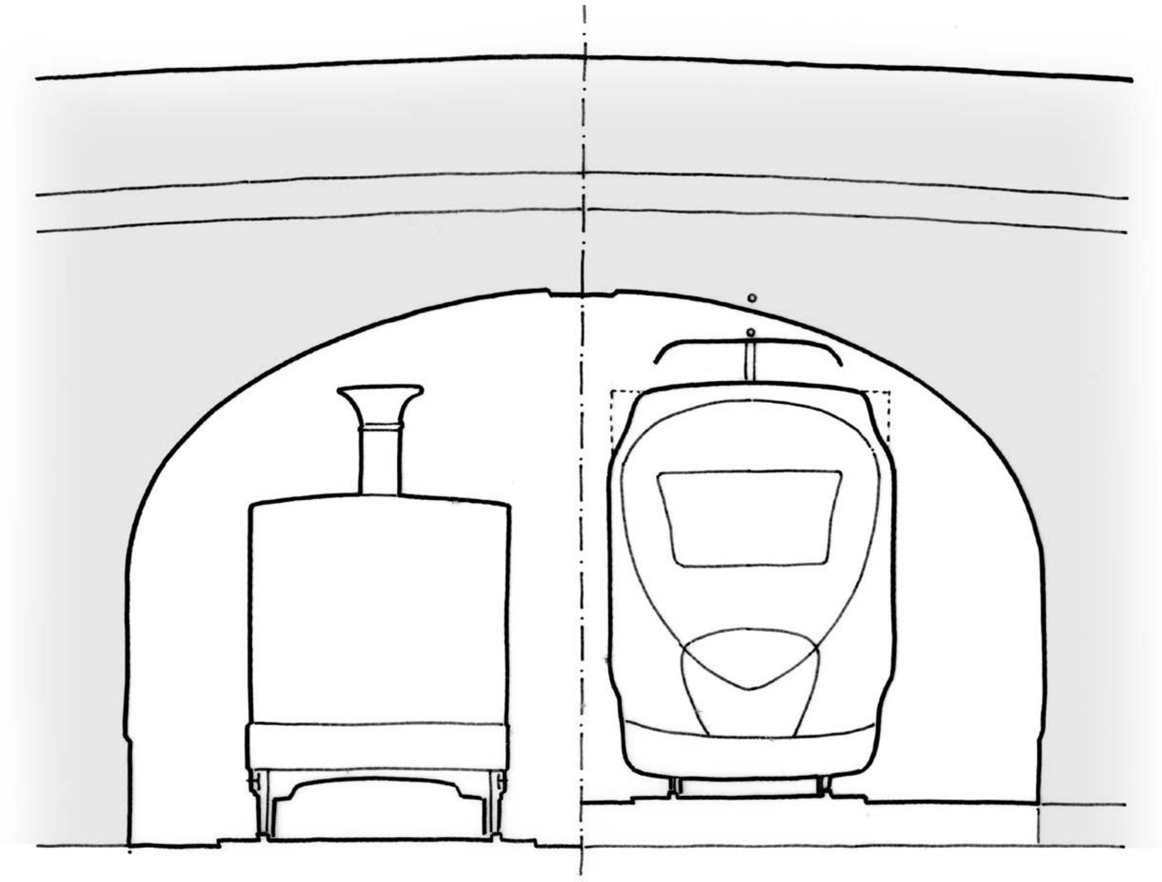
11.0 LOADING GAUGES AND BRIDGE CLEARANCES

11.1 OVERVIEW

The greatest engineering challenge to installing OLE on existing lines is getting it under bridges and through tunnels that were almost all constructed in the 19th or early 20th centuries with no thought of electrification in mind.

11.2 HISTORICAL BACKGROUND

Passenger carriages were originally derived from stage coach superstructures set on railway wagon undercarriages. These, together with the height of steam locomotive chimneys, determined the height and width of bridges and tunnels needed to allow trains to pass safely through. These dimensions became industry-wide standards early in the history of the railways, and so succeeding generations of locomotive and trains have had to be designed to fit these original profiles, known as 'loading gauges'. This is why UK trains are smaller than on the continent where railways were built later and for large trains.



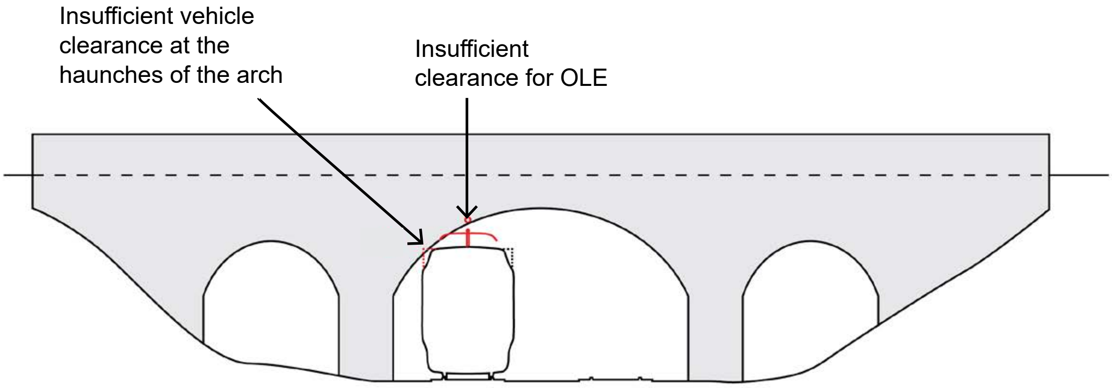
1840
- lower train
- little ballast
- poor drainage

2021
- taller trains, swaying at up to 125mph
- OLE wires and electrical clearance
- greater ballast depth, for track stability and improved drainage

Gauge clearance: then and now

11.3 REQUIREMENTS FOR OLE

Electrification brings significant changes. The trains have pantographs on their roofs and, above this, there must be space for the wires themselves. New electric trains cannot be made lower so that the OLE wires can be fitted into the existing space because trains already in service need to be able to run as well. So greater height is needed at bridges and tunnels, particularly those with arched profiles.

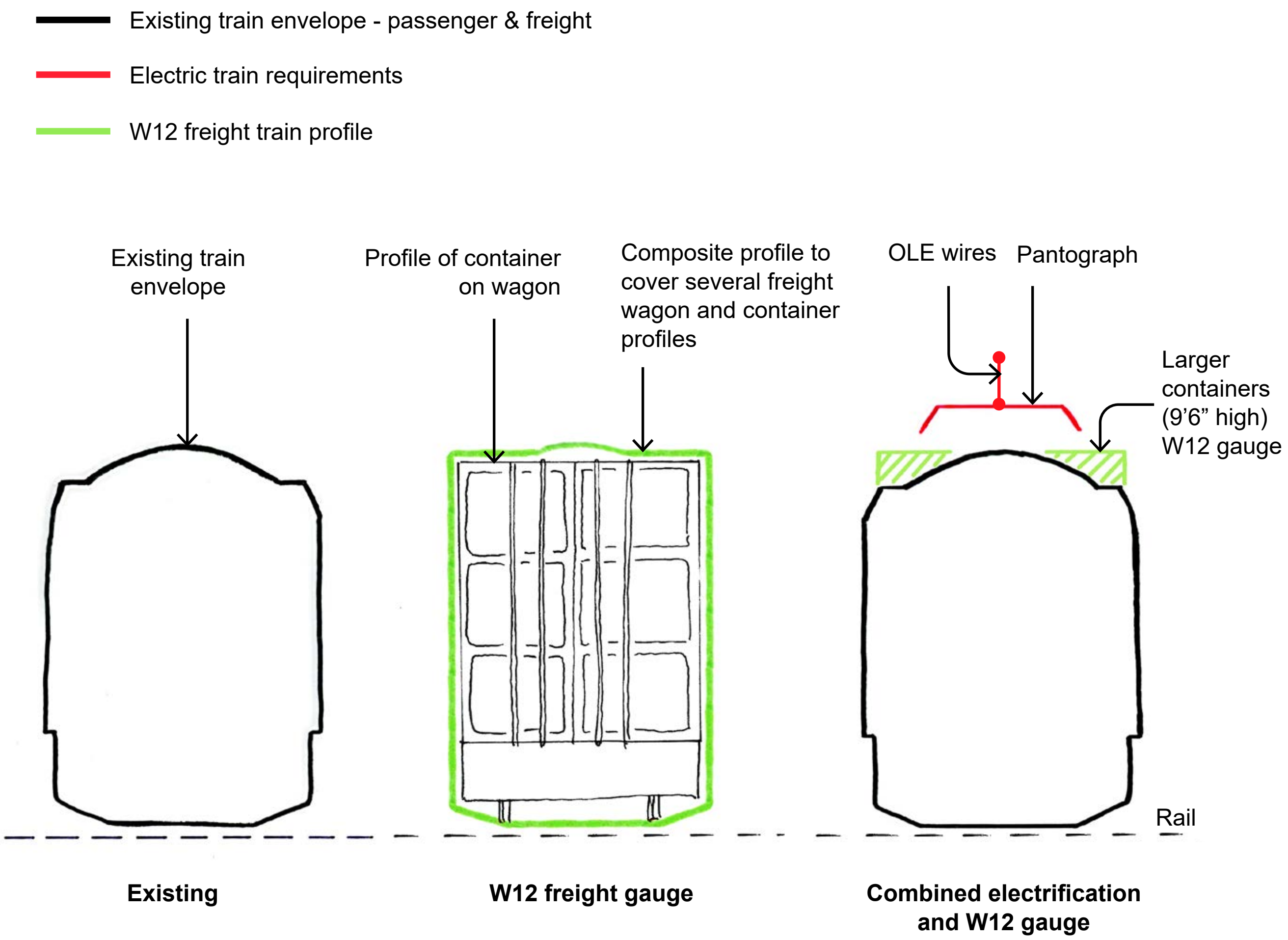


Typical constraints for the installation of OLE wires under an existing bridge

11.4 REQUIREMENTS FOR IMPROVED FREIGHT TRAINS

At the same time as the track and structures are being modified to accommodate electrification, the opportunity may also be taken to allow for larger freight trains. International shipping containers come in two standard sizes, 2.6m high x 2.44m wide and 2.9m high x 2.5m wide. These are too large to be carried on most UK railway lines without specialist wagons. Therefore, a larger profile, known as W12 gauge, is being adopted to facilitate the more efficient transport of containers by rail, helping to reducing the number of diesel-powered lorries on our roads.

Arched structures tend to conflict with the top corners of the container profile.



Gauge profile requirements

11.5 CLEARANCE TO BRIDGES AND TUNNELS

The amount of clearance (safety space) needed between the train, OLE and bridge, station or tunnel can depend on the nature and condition of the track and the trackbed, the amount the train can sway and bounce, the accuracy within which the positions of the track and OLE wires are maintained and the risks of accidental short-circuiting. There are a number of categories of clearance, in order of decreasing height, which are shown in the diagram below:

1. Reinforced insulation static (clearance between live OLE equipment and bridge or other structure: min 600mm)

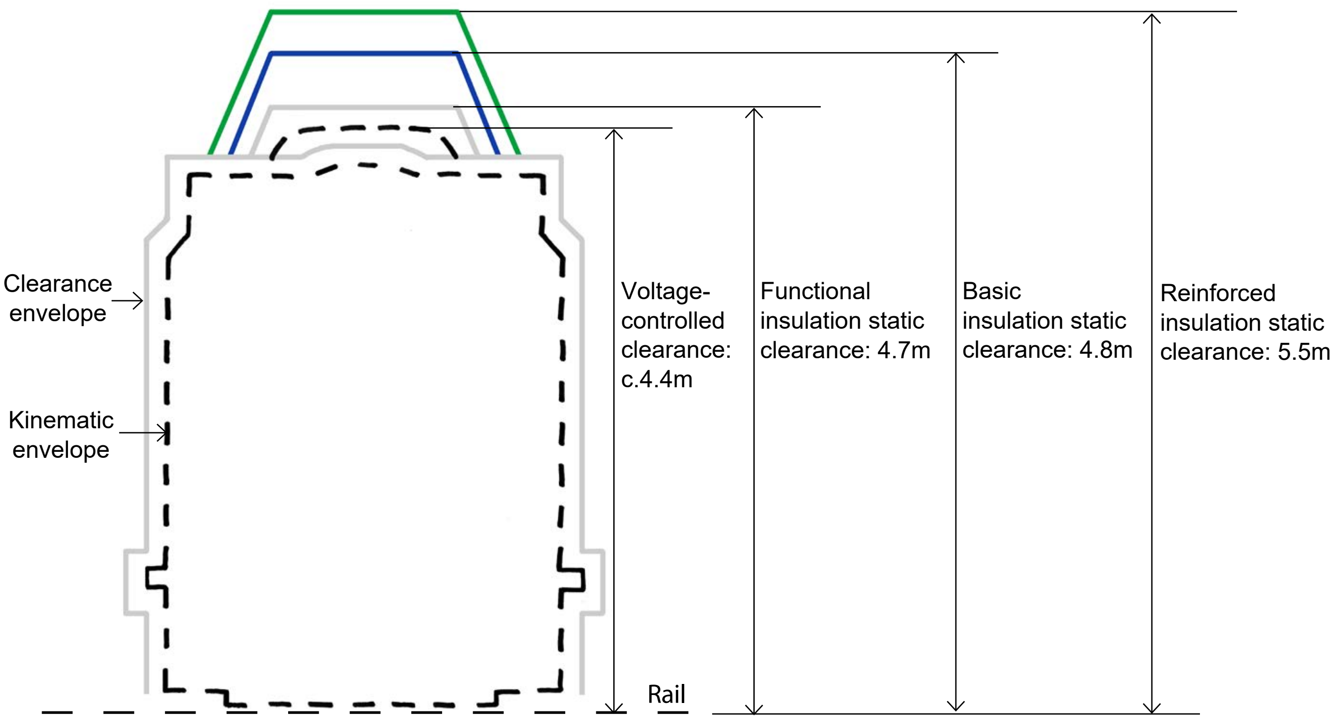
2. Basic insulation static (clearance as above: 370-599mm)

3. Functional insulation static (clearance as above: 270-369mm)

4. Voltage-controlled clearances (clearance as above: 70-269mm, see section 13.3)

'Free running' OLE allows the OLE wires to pass under bridges without any attachment; 'fitted OLE 'needs the wires to be held in position by attaching them to the underside of the bridge or tunnel by 'bridge arms', but this allows the clearance to be reduced.

Functional insulation static clearances and voltage controlled clearances have tight tolerances that require the track and OLE wiring to be monitored and adjusted much more frequently in order to keep close control over their positions. This is more expensive, but (subject to risk assessment) may be accepted because the costs and disruption associated with replacing bridges are high (see section 13.3).

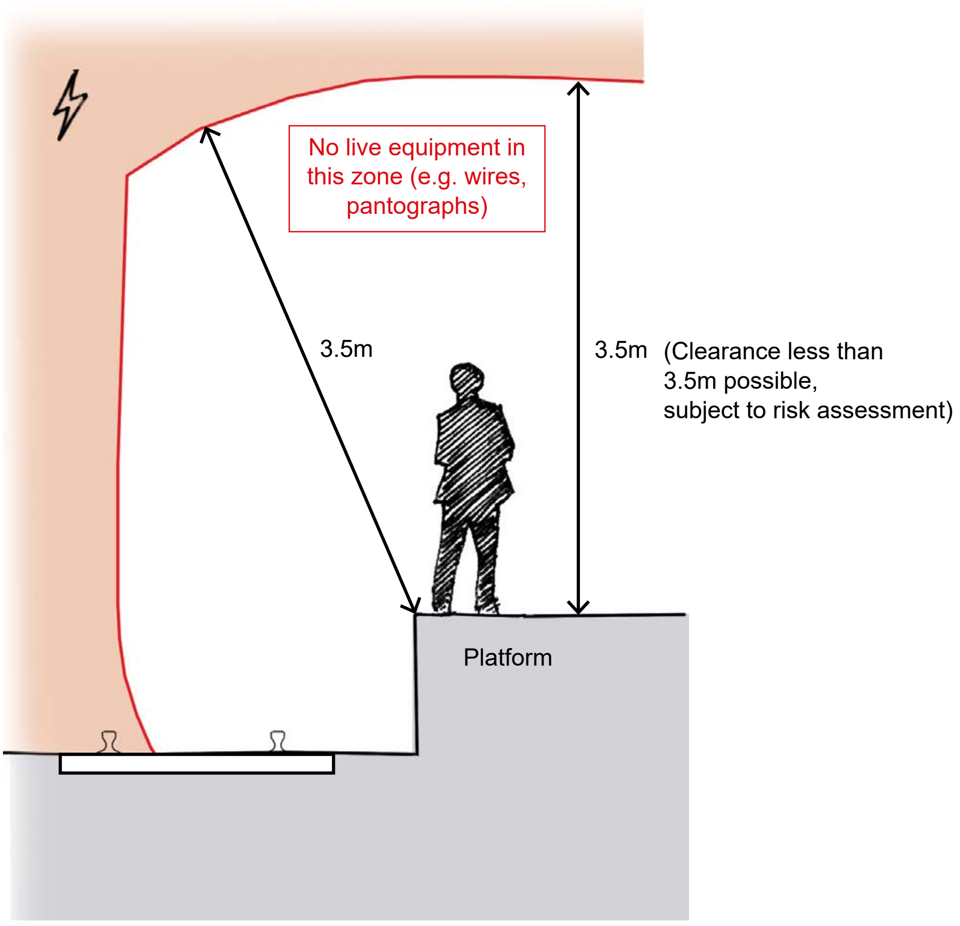


Different electrical clearances

12.0 THE SAFETY OF PASSENGERS AND STAFF

12.1 CLEARANCE TO LIVE ELECTRICAL EQUIPMENT

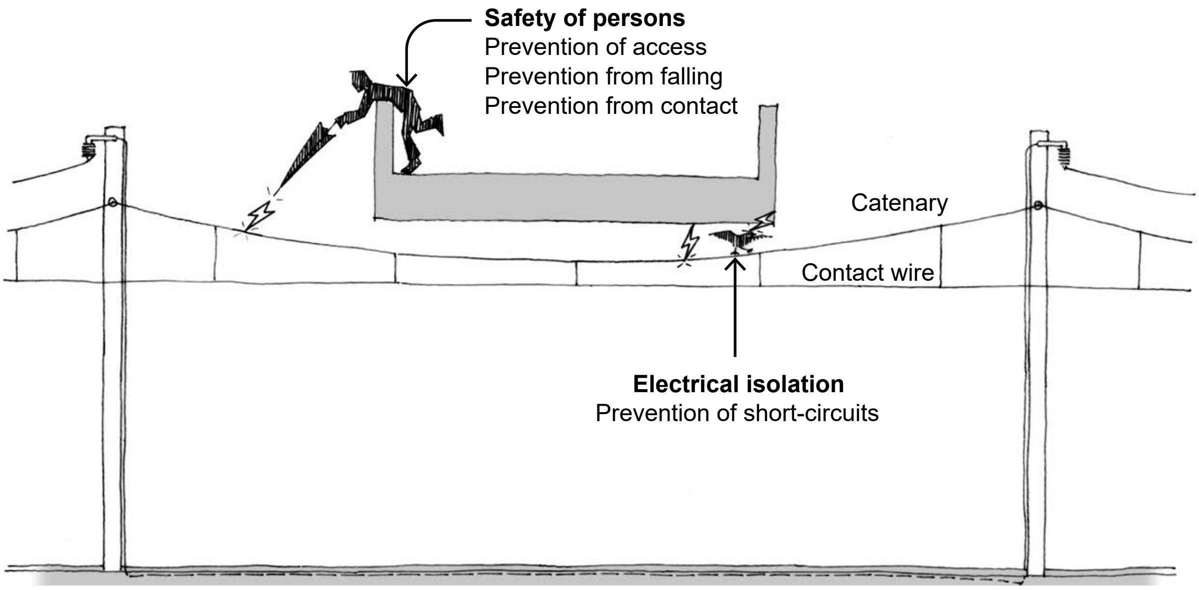
Chapter 11 established the required clearances for trains. This section looks at the clearances required to reduce the risk of people coming into contact with 25,000V OLE. The diagram below shows requirements for minimum clearances in public areas such as station platforms. These clearances are measured from the closest standing surface to the closest live electrical parts of the OLE, including the pantograph on the train.



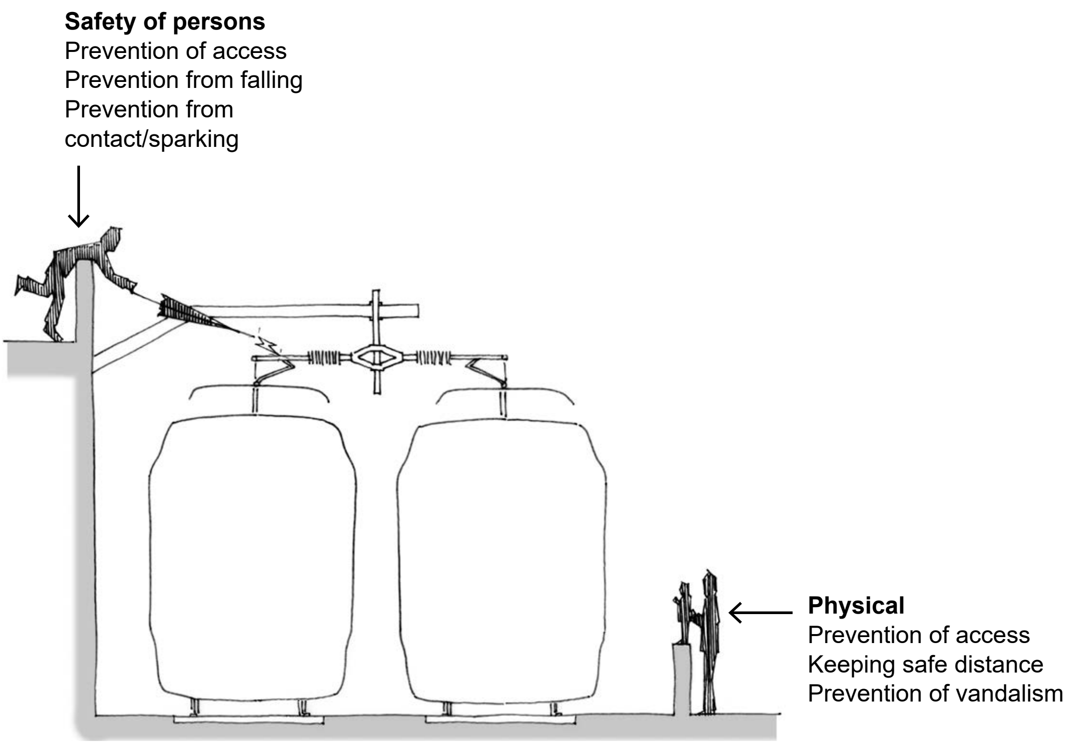
Public safety: electrical clearances in public areas

12.2 BRIDGE AND WALL PARAPETS

Network Rail has a legal obligation to take reasonable steps to prevent people from accidentally or otherwise falling onto OLE:



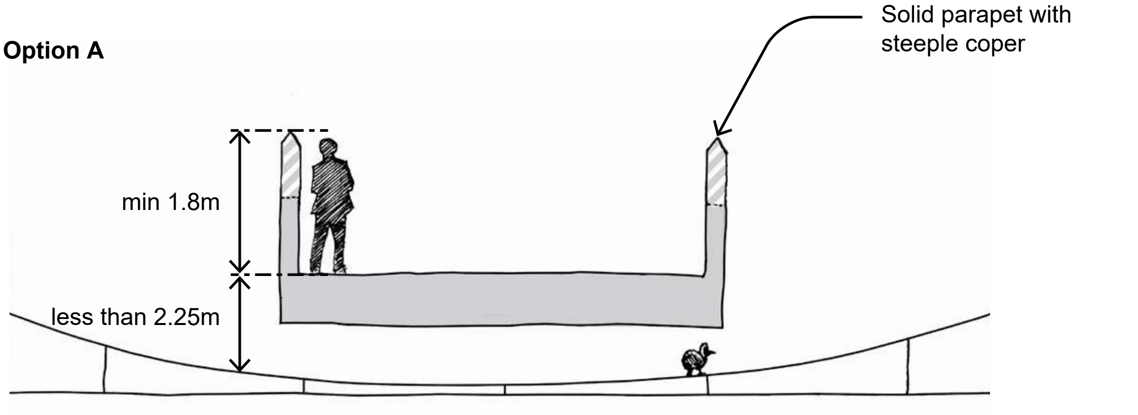
Public safety: bridges over OLE

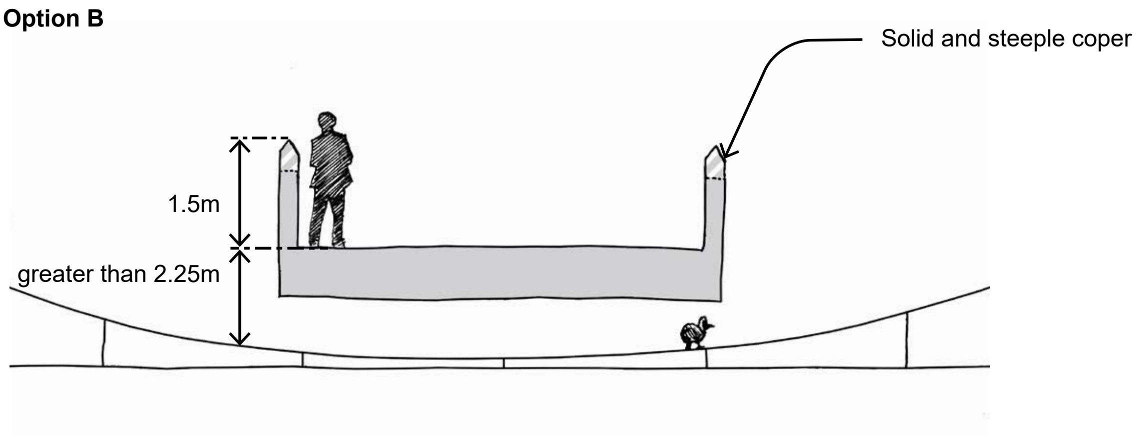


Public safety: lineside

12.2.1 BRIDGES

Where a railway line is being electrified under existing bridges, Network Rail requires the bridge parapets to be difficult to climb, stand or walk on, with a smooth inner face without hand or foot holds. Measures are also required to deter access to the outside face/ledges of overbridges. On the decarbonisation programme, these requirements can be achieved in two ways:

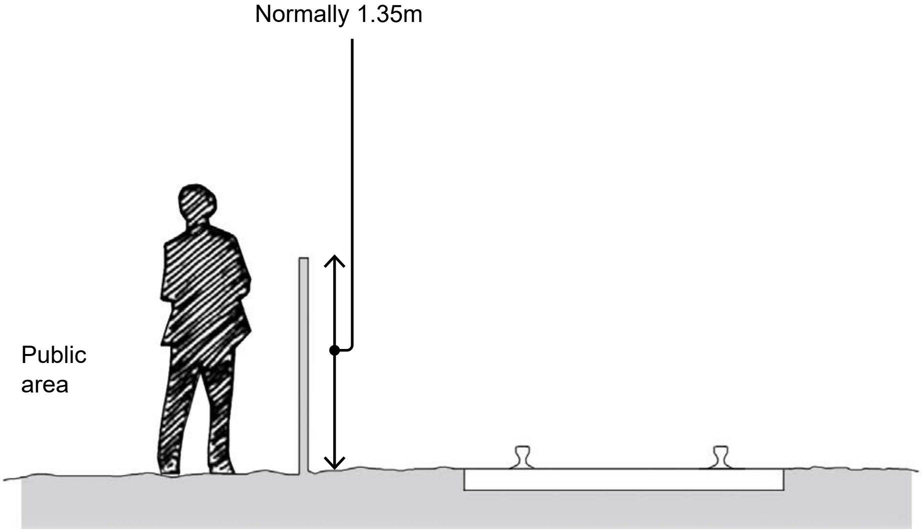




The Rainhill Skew Bridge near Liverpool was designed by George Stephenson as part of the pioneering Liverpool and Manchester Railway in 1830. Recently, the line was electrified and the bridge parapets sympathetically raised. In time, the stone will weather to the same colour (photograph: © Network Rail)

12.2.2 LINESIDE

In locations other than bridges, a safe distance from live electrical equipment must be maintained using appropriate fences or barriers. For boundary walls and fences alongside the track in areas considered to have a low risk of trespass or vandalism, such as many rural districts, the height requirement is 1.35m, as shown on the diagram below. Barriers 1.85m high are used close to OLE wiring and where there is a high risk of vandalism or trespass, as well as near schools and playgrounds.



Trackside boundaries

At Linlithgow, boundary walls were sympathetically raised to protect the public from the OLE installed as part of the Edinburgh Glasgow Improvement Programme (EGIP) (photograph: © Network Rail)

13.0 INSTALLING OLE ON DIFFERENT TYPES OF STRUCTURE

13.1 STATIONS

The principal matters that designers must consider when installing OLE at stations come under four headings:

13.1.1 OLE AND PLATFORM CANOPIES

Historic canopies usually extend out beyond the platform edge (to overlap with carriages) and therefore may need to be cut back to satisfy required clearances to the train, OLE and live electrical equipment. As the example of Stirling Station illustrated below, demonstrates, it is usually possible to achieve this in ways that are sympathetic to the historic form of canopies, with results that are imperceptible to the public.

OLE masts might need to be positioned on platforms if there is not sufficient space between tracks for them, and they may have to be punched through canopies if the canopies are longer than the maximum possible spacing between OLE supports. In such cases, to the person standing beneath a canopy, the visual intrusion of OLE is surprisingly limited because their upward view is constrained by the canopy, as long as masts are located with consideration to their relationship to platform buildings and canopy structures.

At a more detailed level, metal structures such as canopies must be earthed. Typically, this is achieved by attaching a small cable from the base of columns to devices below the platform. If canopies are not electrically continuous, additional cables might be installed at roof level to link up the separate metal elements.

The canopies at Category A Stirling Station have been trimmed to accommodate OLE (photograph: © Alan Baxter)

13.1.2 OLE ON PLATFORMS

Where there are open platforms, the visual impact of OLE can be reduced by carefully ordering the equipment into regularly-spaced supports of consistent design. The following photograph shows this principle applied at Stirling Station.

As the example of Stirling demonstrates, standard OLE support structures used harmoniously in this way are a highly effective solution for historic stations. Occasionally, however, round masts (known as 'circular hollow section' or CHS) have been installed where it has been judged that the smoother profile would mitigate the visual impact of the OLE on listed stations (and also viaducts, as show in section 13.6). When applying modern design standards, these masts are no smaller or slimmer than standard masts, and in many circumstances – such as longer views – any visual benefit of CHS is negligible.

Stirling Station from the air, showing how the OLE on the platforms has been carefully ordered to create a harmonious visual effect, in contrast to the OLE on the other side of the road bridge (photograph: © Network Rail)

13.1.3 OLE IN TRAIN SHEDS

For stations with train sheds, it may be desirable to attach the OLE to the roof structure, as at listed stations such as Edinburgh Waverley, Glasgow Central and London Kings Cross. This avoids the need for masts. The visual consequences may not be as one would imagine; a visit to any of the above stations reveals that, if done sensitively, fixing OLE to a Victorian train shed has remarkably little impact on its architecture, or the appreciation of it, because the wires are lost amongst the ironwork of the roof.

13.1.4 OLE AND STATION APPROACHES

Whilst OLE can be sympathetically integrated into stations, the complex and extensive trackwork and pointwork on the approaches to major stations can require equally complex and extensive OLE supports at the end of the platforms and beyond. Because of the requirements set out in chapter 9, this in unavoidable.

In other instances, platforms may have to be altered or rebuilt as a consequence of track lowering or slewing associated with overcoming clearance issues at nearby bridges.

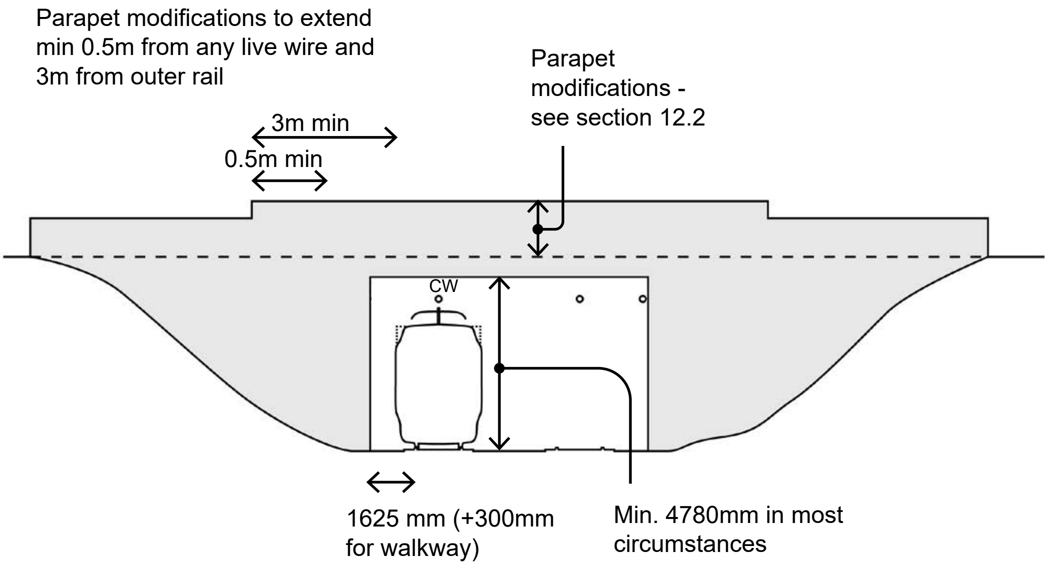
The OLE at Glasgow Central Station is imperceptible against the backdrop of the trainshed steelwork (photograph: © Alan Baxter)

13.2 OVERBRIDGES

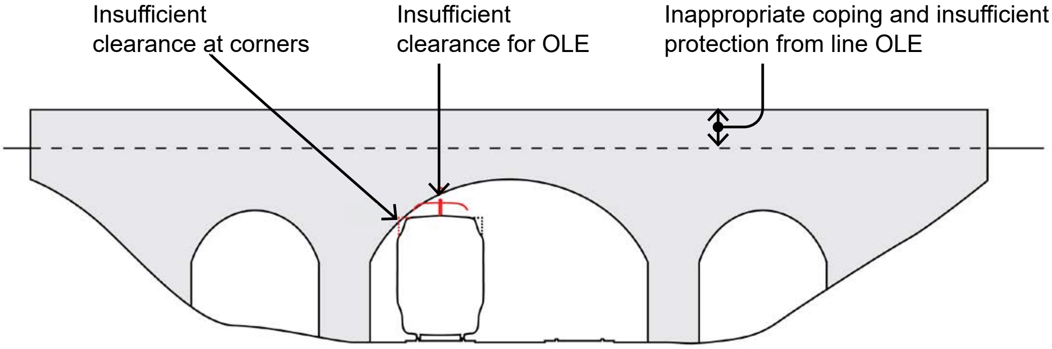
When installing OLE along historic railway lines, the biggest engineering challenge is fitting it under the existing bridges. The key issues are:

- insufficient clearance at the top corners of the loading gauge
- insufficient clearance for OLE wires
- insufficient parapet heights

These two diagrams show, first, the general requirements that must be met, and, second, typical issues with historic bridges:



Requirements



Typical constraints

13.3 SOLUTIONS FOR PROBLEMATIC OVERBRIDGES

Historically, typically a third of electrification project expenditure is allocated to reconstructing and modifying tunnels, bridges and stations to allow the installation of OLE and / or create loading gauge clearance. So engineers are keen to minimise this where they can.

Fortunately a number of options are now available. Building on experience gained across the country over the last decade, and taking advantage of the latest advances, the rolling programme in decarbonisation will normally follow a sequence of options when considering works to any one bridge or other obstacle along a route. This starts by reducing the distance between the contact wire and the catenary supporting it – known as the 'system height'. By narrowing this, up to 1.3m in height can be saved, depending on factors such as the proximity of mid-point anchors, overlaps, etc. If this is insufficient, the next step is:

13.3.1 MINIMISE CLEARANCES – VOLTAGE-CONTROLLED CLEARANCE

The first choice is voltage-controlled clearance, or VCC, a new approach developed by Network Rail and industry partners on the Great Western electrification project, which avoids the need for expensive bridge reconstructions or track lowers by minimising the clearance required. The photograph below illustrates the tight clearances that are possible using VCC.

This is achieved by a combination of measures including surge arrestors, insulated bridge arms (OLE arms attached to the underside of the bridge), twin insulated contact wires and the application of a special electric resistant paint to the soffit of the bridge.

(In the past, neutral sections have occasionally been employed to reduce clearances. However, because VCC is a simpler and more flexible approach, with much less visually intrusive kit, that allows trains to pass at higher speeds, neutral sections are no longer a favoured means of reducing clearances under bridges.)

The Intersector Bridge in Cardiff, where new techniques where pioneered to reduce OLE clearances and therefore avoid a very expensive bridge replacement (photograph: © Network Rail)

13.3.2 BRIDGE RECONSTRUCTION

Depending on the architectural and historical significance of the bridge under consideration, reconstruction might be the next option. Reconstruction could either involve complete replacement of the bridge or reconstruction of just the span over the tracks, supported on the existing abutments.

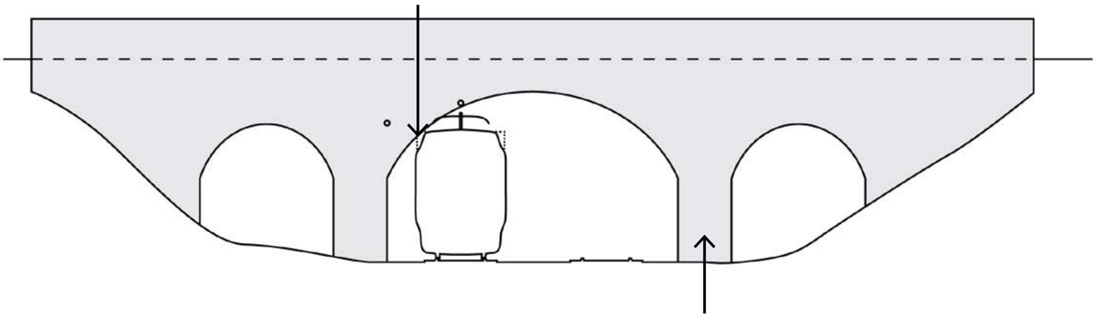
Depending on the layout of the bridge, the design of the replacement deck may provide this desired clearance without re-profiling road approaches, though the impact on buried services remains.

Typical reconstruction of a railway bridge (photograph: © Network Rail)

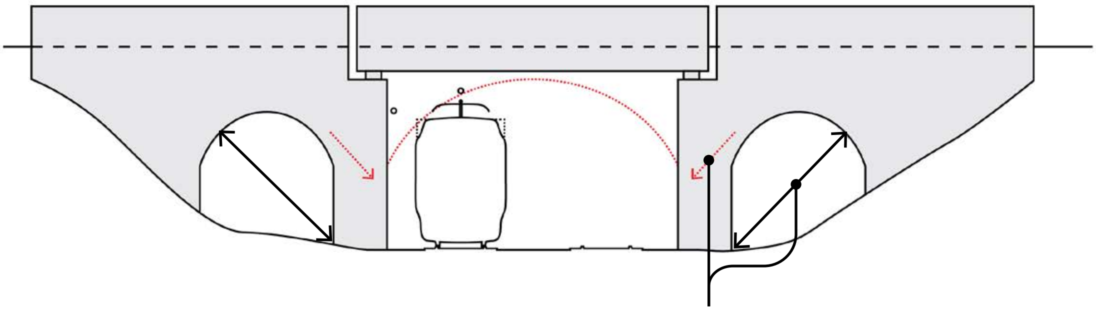
Some multi-arch bridges have slender piers. Removing the main arch could destabilise these piers. In some such cases additional reinforcement (typically, concrete) might need to be installed within the side arches, as shown below.

Further, reconstruction will have a major impact on any services and public utilities, such as telecoms, buried in the bridge. These are surprisingly numerous and most road bridges contain several. Altering and possibly temporarily severing these can be expensive. These can also cause significant disruption to local travel.

Finally, all of these works require careful design to aesthetically integrate the new span and parapet alterations with the surviving elements of the existing bridge.



Bridge before reconstruction



Bridge following insertion of new deck

13.3.3 BRIDGE JACKING

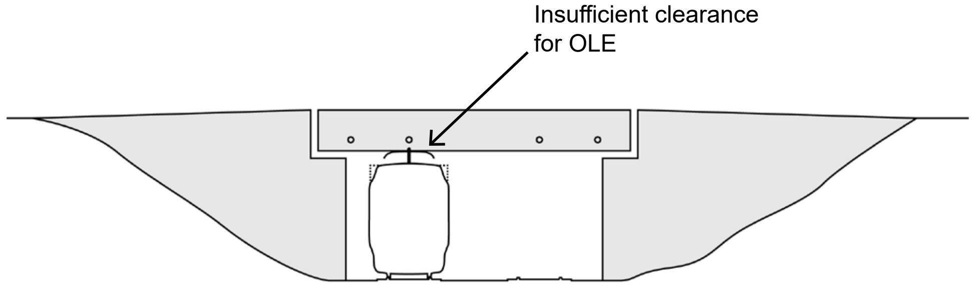
An alternative approach is to jack the bridge. This is a relatively commonplace undertaking on the rail network where bridges have a level steel or concrete deck, as shown in the diagram below. Even so, there are significant implications:

- reprofiling approach roads and possibly junctions to suit the new level, sometimes over considerable distances

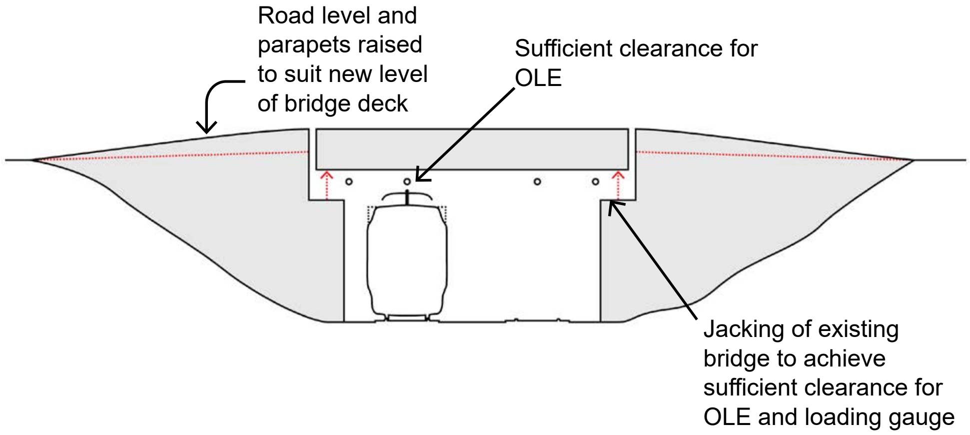
- impact on services and public utilities, as for bridge reconstruction.

Most historic railway bridges are brick or stone arched structures. Experimental jacking of a single-arch brick bridge was trialled over a closed railway line in 2016, but the concept remains entirely unproven on an operational railway or with a multispan bridge, or one containing services and public utilities.

The methodology involves cutting through the abutments and inserting jacks. The central section and its parapets are then raised by 300mm or more above the abutments. Other repairs and masonry replacement once the jacking was completed would be necessary, together with necessary extensions and alterations to the parapets to protect the public from the OLE installed beneath. The results will alter the appearance of the bridge.



Before



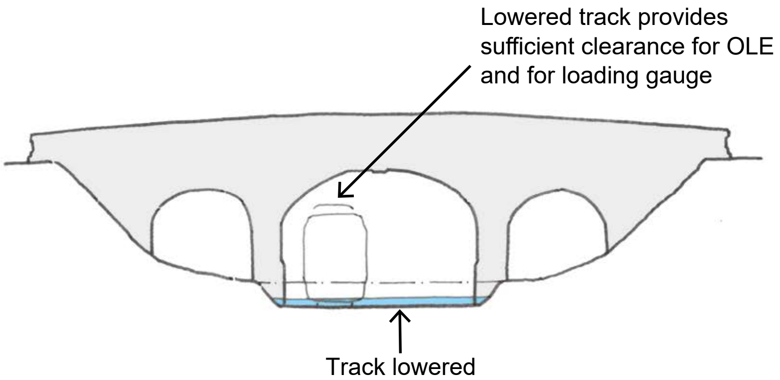
After

Jacking a beam or girder bridge

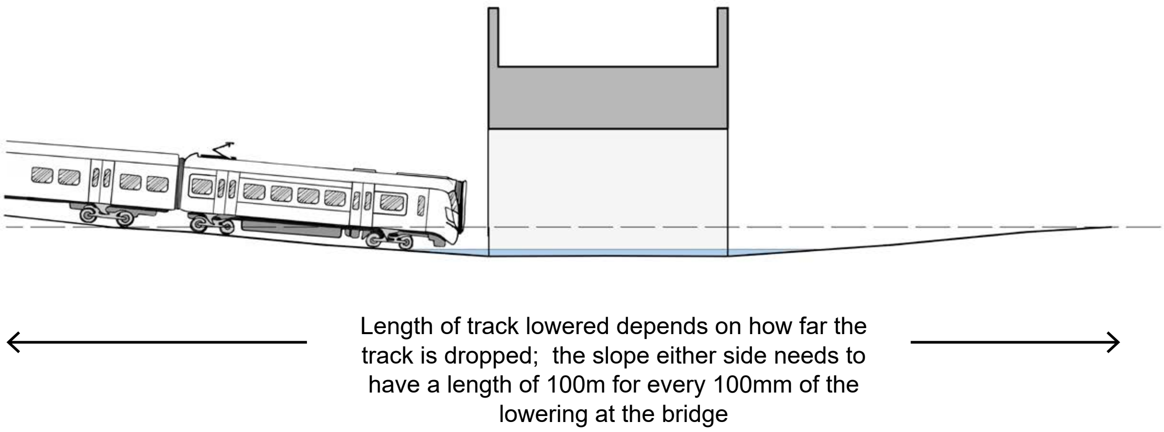
13.3.4 TRACK LOWERING AND SLEWING

If the bridge is listed, or if reconstruction is not feasible or cost effective, the next option is to lower the track, or 'slew' it sideways, or both. The principle of **track lowering** is shown here:

Sequence
1. Lift track
2. Lower ballast and trackbed
3. Relay track to new lowered level



Elevation of bridge



Section through bridge

Lowering track under a bridge

When considering track lowering, a number of factors must be taken into account:

- The lowered track needs to slope down under the bridge and back up again. The slopes need to be sufficiently gentle that passengers do not notice them and track wear is not significantly increased. Slopes may be as shallow as 1 in 1000, which means that many metres of track may have to be re-laid, which is expensive, time consuming and can cause disruption. Steeper slopes may be designed which shorten the extent of track to be lowered, but the maintenance implications of these needs to be evaluated.

- It may be possible to lower the track by up to approximately 150mm without the need to take up and replace the track, using special equipment. However, if the track has to be lowered by more than c. 150mm or if the track bed is in poor condition, the existing track needs to be lifted, the underlying ballast and track bed re-profiled to the new level, and then the track re-laid. This is much more expensive and disruptive.

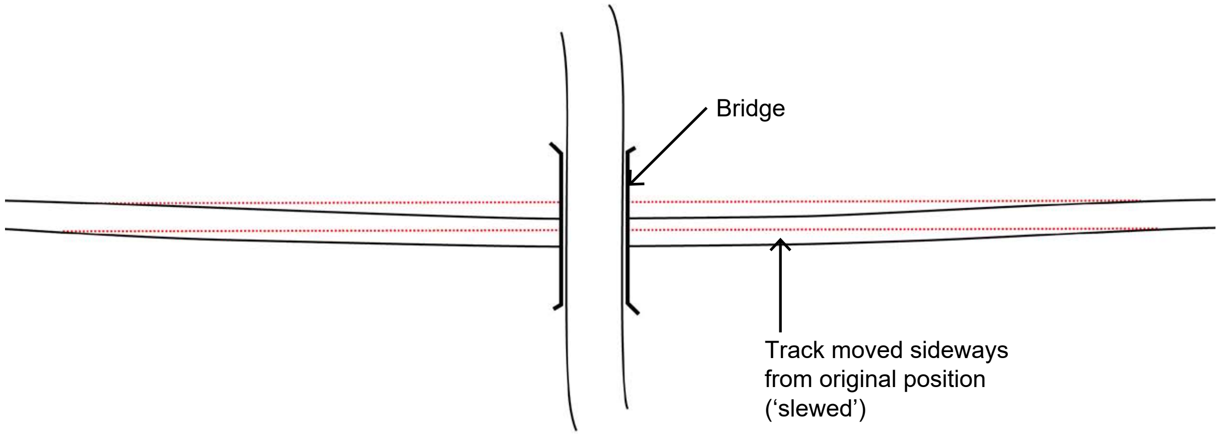
- If nearby stations, junctions or points are affected, the costs are greater still. For example, platforms may have to be lowered to match the new track level, which can be extremely expensive.

- Track lowering can give rise to significant problems with drainage, for example in the bottom of a cutting. Improved gravity drainage of the track bed may be needed and the pipes may have to run some considerable distance to a suitable discharge point. Installation of pumped drainage may appear to be a potential solution, but the pumps would be used infrequently and are therefore highly likely to fail when needed. Some lengths of track are already particularly prone to flooding causing disruption to train services. In such cases, track lowering would increase the risk of flooding and disruption and is therefore unacceptable.

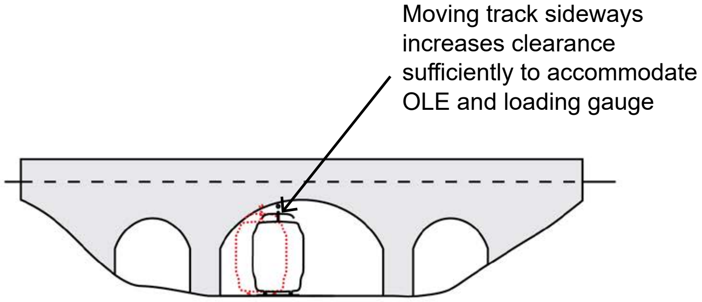
The use of track slab, where the rails are supported on a continuous concrete base instead of sleepers and ballast, can allow the rails to be lowered by 50–100mm, due to its thinner construction and its more accurate control of the track position. However, the concrete slab needs to be broken up and re-made if in the future the alignment or level of the track needs to be adjusted. This is much more expensive than minor adjustments to ballasted track, so the use of track slab is normally avoided.

Water collecting at low points on the network causes many thousands of 'delay minutes' each year (photograph: ©Network Rail)

Track slewing means moving the track sideways in order to create greater clearances, as shown below. Many of the drawbacks of track lowering also apply to slewing. The extent of slewing is limited by the need to maintain passing clearances to adjacent structures and trains.



Plan



Elevation

Track Slewing

13.4 FOOTBRIDGES

Many historic footbridges cross railway lines where electrification is being considered, both in stations and elsewhere.

Typically, these are lightweight Victorian and Edwardian structures built to standard designs with trellis pattern wrought-iron balustrades, cast-iron columns and half landings.

These present electrification teams with substantial challenges. First, they are often too low to install OLE beneath them. Second, the parapets are not of the required height and have gaps in them, so do not meet requirements for preventing people from accidentally being electrocuted. Third, the basic design does not normally meet modern safety and accessibility standards. Finally, at many stations these issues are compounded by the way in which the footbridge relates to or is physically integrated with the platforms and other station structures.

In some circumstances it may be possible to retain aspects of historic footbridges. At Stirling Station, the footbridge was jacked up, though the interfaces with the canopies and station buildings made this far from straightforward. At Edinburgh Waverley, because the footbridge is within a controlled, internal environment (where vandalism is not a significant risk), it was possible to install glass parapets inside the original ironwork.

Footbridge at Edinburgh Waverley Station (Category A) modified with glazed barrier to protect the public from the OLE passing beneath (photograph: © Alan Baxter Ltd)

In other instances, for example where Network Rail is also improving accessibility so that all passengers, including those who cannot use stairs, are able to access all platforms, it is not possible to retain existing footbridges. Where a replacement footbridge is therefore necessary, a range of design approaches and materials are available to suit the specific circumstances, especially where the station or location is historic or of greater landscape sensitivity. Photographs below illustrate two examples.

New level access footbridge at Dunblane Station (Cat B) in place prior to the installation of OLE. The redundant listed historic footbridge in the background has since been dismantled and re-erected for reuse at Bridge of Dun Station on the Caledonian Heritage Railway (photograph: © Network Rail)

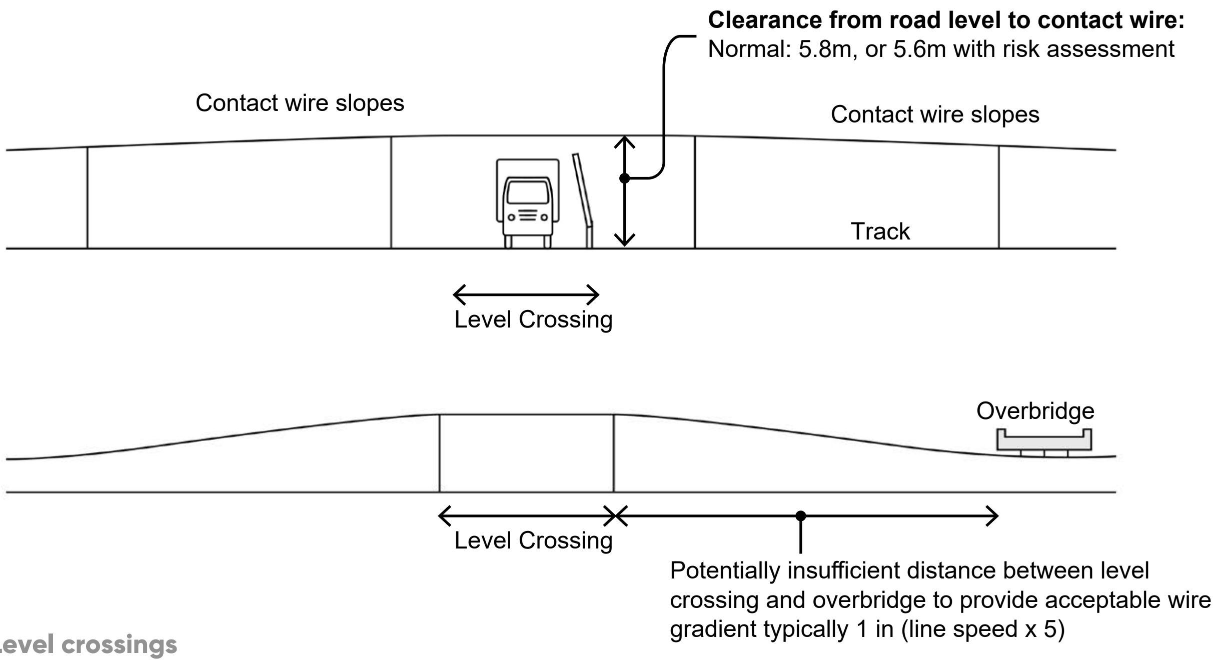
Timber footbridge installed on the Borders Railway near Gorebridge, where the use of timber helps to blend the bridge with its setting. A similar style bridge has also been used in Princes Street Gardens near Edinburgh Waverley station (photograph: © Network Rail)

13.5 LEVEL CROSSINGS

OLE wires rise to their highest point at level crossings, to provide sufficient headroom for lorries to use them. If the road is a designated high load route, a larger clearance is needed.

The normal height of the contact wire is 4.7m above rail level, and the minimum is approximately 4.1m to get under a bridge. The normal height of the wire at a level crossing is 5.8m, so the contact wire may need to climb approx. 1.7m between an overbridge and a level crossing. This could be a problem when these are located near together because the contact wire can only climb at a certain gradient if adequate and safe contact is to be maintained with the pantograph. This raises a significant issue for the design of OLE in general, which is that existing structures cannot always be thought of in isolation: works proposed to address the problems in one location can have consequences for other structures along the line, because of the distances involved in OLE engineering.

Footpath and bridleway crossings have a minimum clearance of 5.2m, but otherwise the same issues apply.



Level crossings

Level crossings - note how the pantograph on the train is extended to reach the raised contact wire (photograph: © Philip Hilbert)

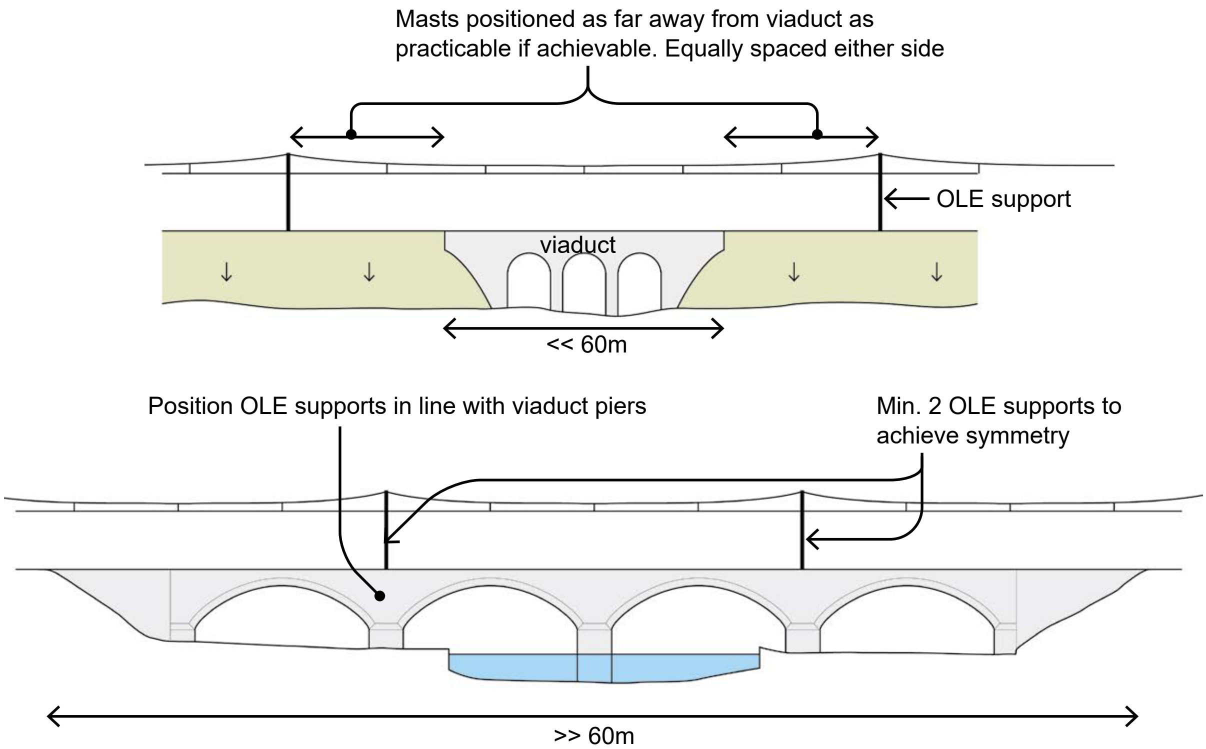
13.6 UNDERBRIDGES AND VIADUCTS

There are unlikely to be problems providing sufficient clearance to install OLE over underbridges and viaducts unless other objects such as electricity transmission wires interfere.

The majority of underbridges are **short structures of one, two or three spans**. Because the distance between OLE supports is approximately 50-60 metres, in most cases it should be possible for the OLE to span these bridges without positioning masts or frames on them or adjacent to them. This is good design practice and is especially important where the setting of the bridge is sensitive because it is historically or architecturally significant, or it forms part of an attractive townscape or landscape scene.

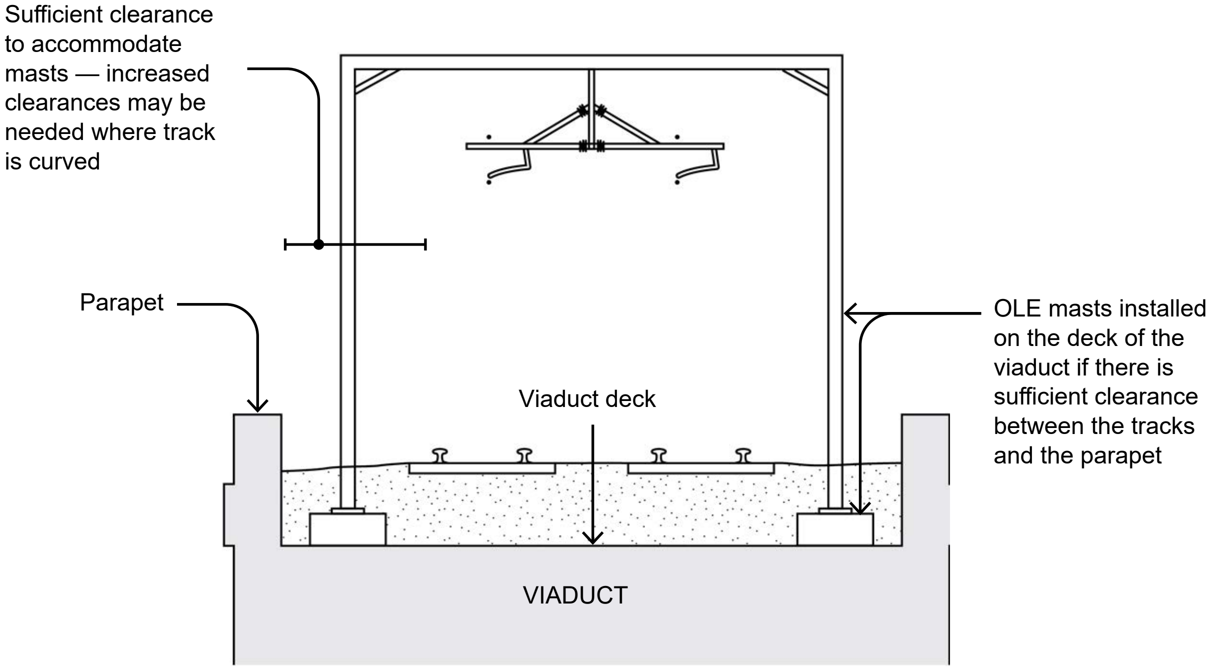
Any bridge or viaduct longer than about 60 metres will need to have supports erected on it. If the viaduct is of architectural or historical interest, for example if it is listed, it may be appropriate to erect bespoke designs that respond to the particular character of the structure and its setting, or create a cleaner, less visually disruptive profile. This has been done before, for example on Stephenson's Royal Border Bridge at Berwick-upon-Tweed and Brunel's Maidenhead Railway Bridge (see illustrations on the following pages).

There are two issues to consider in such circumstances. First, the spacing of the masts or portal frames should reflect the structural and architectural rhythm of the viaduct, even if this means positioning them more closely than technically necessary, as shown below. Second, the distance between the tracks and parapets will determine if it is possible to install masts on the bridge deck, as shown in the diagram on the following page. This is the simplest and least intrusive solution; an example is Maidenhead Railway Bridge. Where there is insufficient clearance between parapet and track and where parapets are sufficiently wide, supports can be embedded within the parapet, as shown on the following page. The Grade I listed Sankey Viaduct near Liverpool is an example of where this has been achieved, by locally rebuilding the parapets around the masts. Where neither of these solutions are possible because the viaduct has both a narrow deck and thin or no parapet walls, masts should be fixed to the elevations of the viaduct, as shown on p.55. The Royal Border Bridge is an example of where this necessity has been handled with some elegance.



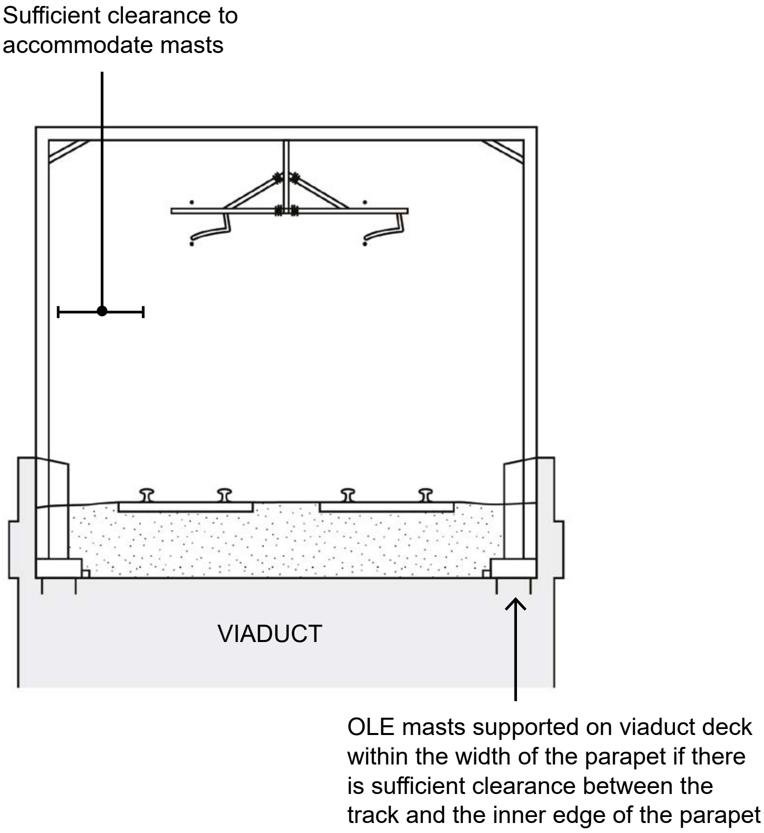
Spacing of OLE masts on viaducts

Masts on viaducts: on the deck, in board of the parapets



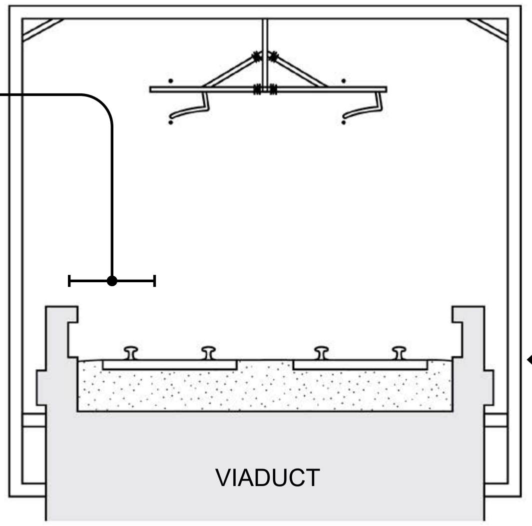
Maidenhead Railway Bridge, Great Western Main Line (Grade I). New OLE supports (photograph: © Alan Baxter Ltd)

Masts on viaducts: embedded within the parapets



Sankey Viaduct, St Helens (Grade I) OLE installed in 2015 (photograph: © St Helens Star)

Masts on viaducts: attached to the face of the piers



Royal Border Bridge, Berwick-upon-Tweed (Grade II*). OLE installed c. 1989 (photograph: © flickr.com/photos/forest_pines)

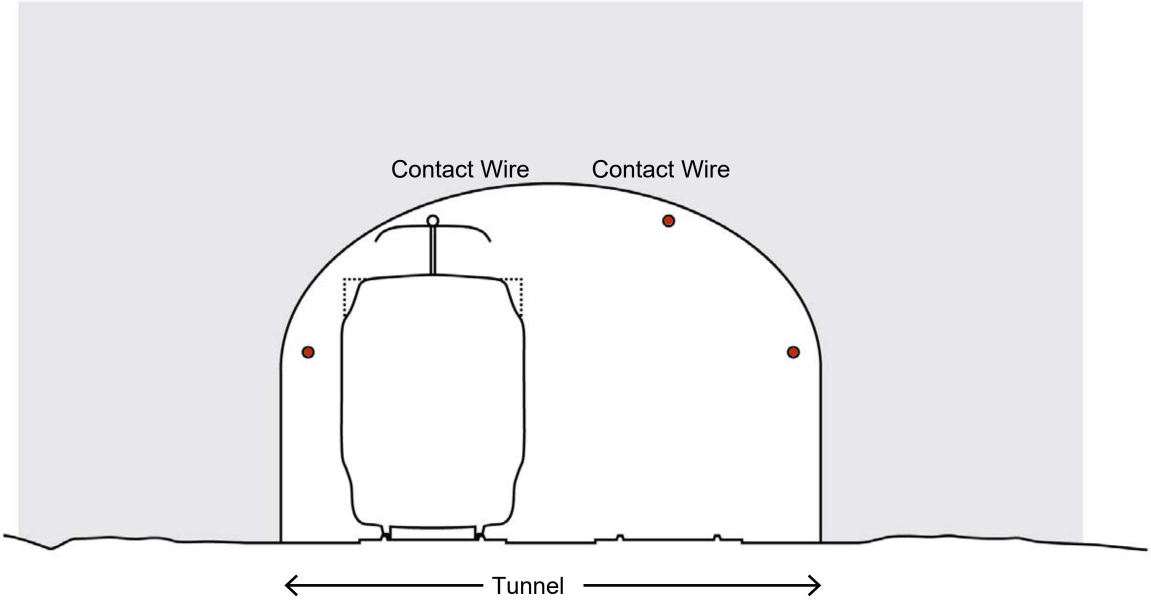
13.7 TUNNELS

The principles and issues for inserting OLE into tunnels are similar to those for overbridges. Therefore, voltage controlled clearance, conductor beam technology, track lowering and track slewing are potential options if there is insufficient clearance within the bore of a tunnel. The main concern, however, is to avoid fixing OLE to the face of tunnel portals if these are of architectural or historical interest. In most instances this can be achieved by using fixings just inside the tunnel mouth, hidden in shadow. Normally, the nearest mast to the portal can be positioned 25 metres away.

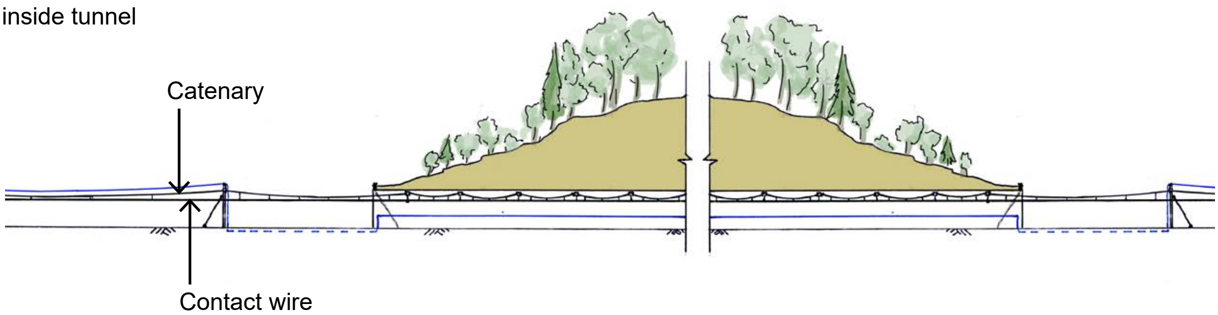
When tunnels are shorter than the length of tensioned wire, tensioning of the catenary and contact wire is undertaken in the normal manner outside the tunnel at either end. Care should be taken to position overlaps as far as practicable from historic portals.

If a tunnel is longer than about 1200m, the tensioning of the wires needs to be done within the tunnel, which can be quite complex because of the physical restrictions and environmental conditions.

The English portal of the Severn Tunnel (Grade II*), with OLE installed as part of the Great Western Electrification Programme. The OLE support in the foreground was necessary to avoid attaching the OLE to the stonework of the historic portal (photograph: © Furrer+Freyer)



Running wires and cables through tunnels



Running OLE wires through tunnels

Alan Baxter

SCOTLAND'S RAILWAY
BETTER IN THE MAKING

14.0 CONCLUSION

This Guide began by saying that, though the principle of overhead line electrification equipment is simple, the reality is complex. Yet an understanding of at least some of this engineering is helpful to all those who have an interest in the current electrification projects.

We hope that this document has been a useful introduction to these engineering issues, and you finish it with a better understanding of why electrification equipment must look the way it does, and why structures on the railway may need to be altered to accommodate it.

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