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UNIVERSIDAD PONTIFICIA
ICAI

DEGREE IN INDUSTRIAL TECHNOLOGIES ENGINEERING

FINAL DEGREE PROJECT

BASIC AND DETAIL ENGINEERING OF THE CATENARY SYSTEM DUE TO TRACK SWITCHES RENEWAL

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Madrid

June 2019

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Director: Ramos Rodríguez, Joaquín

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas

RESUMEN DEL PROYECTO

Como consecuencia de la renovación de las agujas, vía y otros elementos asociados de la plataforma ferroviaria, será necesario actualizar el sistema de electrificación existente. Para ello se analizará el sistema existente y se adoptará una solución de compromiso en el diseño, que tendrá en cuenta todas las variables implicadas y las posibles consecuencias. El proyecto consistirá en resolver un caso real en Reino Unido, teniendo que utilizar la normativa aplicable en dicho país.

La motivación primaria de este proyecto es la mejora del sistema de ferrocarril. Ya que la tecnología sigue mejorando día a día la posibilidad de introducir este progreso en el sistema bajo discusión deriva en este proyecto. Unos cambios en las medidas de las estructuras OLE, aun si son bastante simples, pueden implicar un cambio enorme tanto en la funcionalidad como en la eficacia del sistema de ferrocarril.

El primer capítulo será una pequeña introducción a la historia del ferrocarril y de la electrificación, prestando especial atención al papel de Reino Unido.

El primer paso como tal del proyecto se da en el segundo capítulo y será desarrollar una herramienta de cálculo en Excel con la que se calcularán diversos parámetros que se deben tener en cuenta a la hora de diseñar la renovación. Para llevarlos a cabo se obtendrá del plano disponible diversos valores, desde la altura de los cables de sustentación y de contacto a la distancia entre vanos. También se dispone de datos sobre curvatura de la vía, la influencia del viento y el kilometraje de la estación.

Con todos esos datos como base, se comienza a calcular todo lo necesario, empezando por el midspan offset, que básicamente es el desplazamiento lateral de la posición estática del cable en el punto medio entre dos puntos de registro. Es decir, es la posición horizontal de la barra de contacto en relación con el centro de la via del ferrocarril en cuestión teniendo en cuenta los efectos del viento. El valor ideal sería cero, valor que se puede conseguir fijando el descentramiento a su valor nominal en direcciones opuestas en estructuras sucesivas si se trata de estructuras tangentes. En este caso, la via es curva por lo que el procedimiento varía y el descentramiento se fija con un valor igual al de la versina.

Luego se calculan los efectos del viento, para lo cual se utiliza una de las normas de GEFF. Se procederá a la obtención de un buen número de coeficientes involucrados en este proceso. Una vez estén todos calculados se obtendrá el levantamiento del pantógrafo debido al viento para cada estructura.

A continuación, se calcula el efecto del descentramiento, que es la diferencia entre la desviación en el punto medio y la peor desviación en el cantón bajo las condiciones de viento dadas. Debido al descentramiento, es muy posible que la mayor desviación del cable de contacto no se de en el punto medio. Variara dependiendo del descentramiento en cada estructura.

Seguidamente, se calcula la desviación actual, que es la suma de los factores que ya se han explicado en líneas anteriores, y se compara con la desviación máxima permisible en cada estructura. Si la desviación es inferior a dicho máxima, se usará para el diseño. En caso contrario se utilizaría el valor de la máxima.

Por último, se estudiará el gradiente y la variación de tal. Esto se lleva a cabo para comprobar que la renovación se atañe a los requisitos pertinentes. Normalmente, durante el movimiento del tren hay un rango permitido de alza y caída del pantógrafo, que depende de su habilidad, ya que actúa como sistema de amortiguación. Los resultados obtenidos en este proyecto se adaptan y cumplen con dichas exigencias a la perfección.

El segundo capítulo se centra en el diseño de dicha renovación. Se comienza analizando el cambio de Mk1 a GEFF, el cual tiene varias ventajas, tato en velocidad como en seguridad. Además, como el aumento de tensión en la línea es tan solo de 1.3 kV, y normalmente este tipo de estructuras se dimensionan para soportar sobrecargas, la estructura se adapta correctamente al cambio.

Entonces se comentan los elementos que habría que cambiar debido al cambio de cables. Cabe destacar las barras de contacto de cruce, que se utiliza para obligar a ambos cables a moverse juntos, aunque admite cierto movimiento. Minimiza el riesgo de enganche asegurándose de que el cable que no sea levantado por el pantógrafo siga al que sí.

También se cambian los saltadores de corriente, que se usan en localizaciones donde dos o más cables coinciden. Su función es facilitar que fluya corriente de tracción de uno a otro en condiciones totalmente normales.

Una vez se ha realizado esto, se procede a diseñar cada estructura individualmente. Se estudia el plano particular, se analizan las referencias y se utilizan fotografías de la estructura real para facilitar el proceso. Entonces se proponen los soportes a cambiar y se diseñan todas las piezas necesarias para tal renovación.

Todo esto se utiliza para realizar en el capítulo 4 un documento que especifica la cantidad de piezas necesarias para llevar a cabo tal renovación. Se especifican tanto el total requerido de cada pieza como el necesario por estructura, para facilitar el trabajo del encargado de obtener las piezas.

Una vez se ha realizado una tabla con todas las piezas involucradas se utilizarán los presupuestos de Adif para realizar una estimación de los costes de la renovación propuesta.

En el quinto capítulo se diseñará el pendolado. Básicamente consiste en la introducción de ganchos de suspensión a lo largo de la via en los cables de contacto y de sustentación. Para ello se utilizará otra norma de GEFF para calcular el espaciado, la localización, el largo y el pandeo. También se calcularán las reducciones necesarias debido a que las alturas de los cables no son standard y a que hay un aislador de sección de alta velocidad entre dos de las estructuras.

Por último, en el sexto capítulo se calculará la distancia eléctrica entre el pantógrafo y la plataforma. Para ello se utilizará de nuevo otra norma de GEFF, en la que, conociendo la distancia, medida siempre paralelamente a la via, entre esta y la plataforma, se puede calcular la distancia deseada.

Para concluir este proyecto, se puede decir que la renovación ha sido un éxito total. La tecnología de catenaria utilizada anteriormente, Mk1, ha sido sustituida por la mas reciente, GEFF. Todas las diferencias entre ambos han sido analizadas y estudiadas buscando la mayor mejoría posible en la línea, que es con los sistemas GEFF ya que tienen algunas ventajas sobre el otro.

El objetivo del diseño era reducir al máximo los costes, ya que la renovación de este tipo de estaciones es realmente costosa. Puede implicar cortes de tráfico durante mucho tiempo o calles cerradas, que tienen un impacto directo en la sociedad, y el cambio de cables o soportes es realmente caro. Por estas razones, sólo se han sustituido los componentes esenciales. Todos ellos con éxito. Sólo había un soporte para el anclaje fijo que no era exactamente la solución perfecta, ya que el soporte utilizado es más largo de lo que realmente se necesita, pero como no había otra opción se puede utilizar perfectamente ya que es sólo un defecto visual y no tiene ningún impacto en las estructuras.

También cabe destacar que los resultados de la distancia eléctrica de seguridad muestran que las estructuras trabajan en las condiciones óptimas y dentro de los límites establecidos por las normas, lo que significa que ninguna medida suplementaria se tiene que tomar.

Para concluir, se ha hecho el proyecto según las especificaciones y las normas de Gran Bretaña, ocupándose de cada detalle lo que ha concluido en una renovación satisfactoria.

Las referencias utilizadas son o bien normas de GEFF en las que se han basado los cálculos o bien libros o artículos utilizados para conocer la historia del ferrocarril y de la electrificación.

PROJECT SUMMARY

Due to the renewal of the points, of the track and of other elements related with the railway infrastructure, it will be necessary to update the existing electrification system. Consequently, this system is analyzed to develop a compromise solution in the design, which takes into account any variables involved and the possible consequences. Particularly, this project will be focus on a real case at United Kingdom, having to use the British standards.

The primary motivation of this project is maintaining the improvement of the railway system. As it has been explained in the previous lines, as technology keeps upgrading day by day the possibility of introducing this advancement to the system under discussion leads to this project. A few changes at the OLE structures arrangements, even if they are rather simple, can imply a huge change in both the functionality and the efficiency of the railway system.

The renewal takes place at Colchester Station, and a layout has been developed in order to fulfil the client requirements. The approach taken in this case is focused on the support structures and everything related with these Overhead Line Equipment (OLE) elements, primarily affecting the structures placed at the railway crossover, which is the most critical zone.

Before proposing the layout, the existing system is analyzed in order to benefit from it, trying to optimize the amount of new items needed and also the number of them to be removed. The most remarkable change is the buffer stop, which is placed with a slightly different chainage.

To make all the adjustments that are required, the heights and the staggers records are checked. There are also a few more variables that must be studied or measured before the design, such as the curvature ratio and the span length, as all this data will be used in the further geometric calculations. The data is measured and it must be interpreted, so it is essential to clarify the sign convention that is going to be used. For example, staggers have two sign conventions, positive and negative, regarding on where the steady arm and the contact wire are placed in relation with the center line of the pantograph.

There are also other factors with direct impact on the design, as there is some necessary base information, which encompasses everything from the railway details (predicted worst case wind speeds, infrastructure and obstructions locations, station and level crossing details, feeding and switching and sectioning arrangements, signal positions and sighting details) to the environmental, planning and consents constraints.

The first chapter will be a small introduction to the railway history and the electrification evolution, paying special attention to all the developments at Great Britain.

The first real step of the project is to develop a calculation tool in Excel with which there will be calculated diverse parameters that must be taken into account at the time of designing the renewal. To calculate them a few values will be obtained of the available plane, from the height of the catenary and contact wires to the span length. Also there is some information on the track curvature, the wind speed and the mileage of the station.

With all this data, one begins to calculate everything necessary, beginning with the midspan offset. This is the lateral offset of the static wire position at the mid-point of two registration points. Basically, it is the horizontal position of the contact bar in relation to the track center line subject to the air conditions, between two registration points. The ideal value would be zero, which can be achieved by setting the stagger to the nominal value in opposite directions at successive structures if it is a tangent structure. If it is a curved track the procedure changes and the stagger should be set equal to the versine of the curve

Carrying on with the calculations, the next parameter to find is blow off. Basically, it indicates the amount through which the contact wire is moved at the midspan as a result of maximum wind conditions perpendicular to the track. So it is going to be calculated for the worst case possible.

Then, the stagger effect is calculated. Due to the stagger, the maximum contact wire deviation may not occur at the mid-span. Stagger effect is the difference between the deviation at midspan and the worst deviation in the span under wind conditions. However, the maximum deviation usually does not occur at the midspan. It will vary depending on the staggers between structures.

Once all these terms are obtained, actual deviation can be calculated. Basically, it is the sum of all of them. The values obtained will be compared with the maximum permissible deviation Y_M. This values will be decreasing 40 mm each meter that the contact wire is above the nominal value. If the value of actual deviation is higher than the corresponding one of maximum permissible deviation, then the actual deviation value will be substitute with the value of Y_M.

To end with the geometrical part of this project, the variation of the gradient is analyzed to see if the new variations introduced on the Overhead Contact System meet the requirements. During the train movement, there is a permissible rate of rise and fall of OLE which is constrained by the ability of the pantograph, which acts as a spring-mass-damper system, to follow the OLE. If the gradient obtained is above the target range, appropriate measures should be taken on the design until we obtain an allowable value that suits the stablished rate.

In the third chapter the first step is comparing both types of technology, Mk1 and GEFF. Basically, the main difference is a transition from compound to single sagged catenaries. The tension at GEFF systems, with standard parameters, is of 13.20 kN. It is a bit higher than the respective tension for the Mk1 system, but as these kind of structures are design to resist overloads the station will support the little increase of tension. However, this means that changing the wires will demand to adjust the auto tension system. The speed differs also a bit, GEFF is faster, and the wires are more secure, as the Mk1 wires are hazardous.

Then, the elements attached to the wires are changed. Starting with the cross contact bar, placed at any location where the cross over contact wire crosses over the main line contact wire and the piece is located at the main line contact wire. It constrains both wires to move together although it allows certain track movement, minimizing the hook over risk by ensuring that the wire run which is not being lifted by the pan follows the lifted wire.

Then the full current jumpers will be replaced. These jumpers, known as double drapes, are used when two or more wire runs meet at the same location. If it works correctly, there will be a flow of traction current from one to the other under normal conditions.

The last structure located at the wires that needs to be replaced is the high speed section insulator. This element is used in crossovers or, for exceptional occasions, where overlapping to create a sectioning point is not possible. As the main objective is maximizing both clearance to main line and horizontal clearance between different electrical sections, it should be located along the track center of the crossover.

The structures will now be design one by one. No modification is suggested for the down main line as part of the renewal works. For this part, old layouts and references are used. Also, pictures of the station are given in order to facilitate this process.

One of the most important conclusions of the designing process is the BOQ, at chapter 4. It consists on the development of a list of every single piece involved in the renewal process. At this list the reference of every single component is written and the number needed of each element is also given.

All the costs involved are obtained from the budgets generated by Adif, which is the administrator of the railway infrastructures at Spain and the borderline countries. They include all the costs for both supply and installation processes.

On chapter 5 the pendulum design is going to be developed. Basically, it consists of placing suspension hangers all along the different lines. In this case, they will be set at wires 84, R89 and R90, which are located at the up main line and at the up & down clancton. There are different things to choose or select. First of all, the space between them or the sag. Secondly, the length of these droppers. Although all the parameters are read from GEFF manuals, in this case due to the geometry of the lines it will be necessary to calculate some reductions to this length. One due to the non-standard heights of the system and another one because there is a high speed section insulator attached at wire R89 between structures B51-100 and B51-102.

Lastly, on chapter 6 the objective is measuring the clearance of the structures. There are several allowances and tolerances that must be taken into account while calculating the distance between a standing surface and live elements.

If for the final result is not possible to achieve a clearance greater than 3.5 m, there are some options to improve, such as taking into account the train body as a barrier for mitigation. However, for the station involved in this case it will not be necessary at all, as the results show that it is working at the optimal state.

To conclude this project, it can be said that the renewal has been completely successful. The catenary technology used before, Mk1, has been replaced by the most recent one, GEFF. All the differences between both have been analyzed and studied looking for the biggest improvement on the line, which is with the GEFF systems as it has a few advantages over the Mk1 system.

The aim of the design was to reduce the costs as much as possible, as the renewal of this kind of stations is really expensive. It can involve traffic cuts for a long time or closed streets, which have a direct impact on the society, and changing wires or supports is really expensive. For these reasons, only the essential components have been replaced. All of them successfully.

A bill of quantities was done also in order to facilitate the workers job. In this case, it was crucial to do a list very clear and organized were all the components involved in the different processes were detail. Then, it was possible to find an approximation of the cost of this renewal using the budgets of Adif.

Also, the gauging results show that the electrical clearance is working in the optimum conditions and within the limits stablished by the norms, which means that no extra measures need to be taken.

In conclusion, it has been done according to the specifications and the regulations of Great Britain, attending to every single detail resulting in a satisfactory renewal.

The references used along the project are GEFF manuals used for calculations or book and articles related with the history of the railway and the electrification.

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EQUATIONS

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1. Introduction

1.1. Railway history

The railway is a transport system of both people and goods on a fixed railway track. It has several advantages compared with other transport systems, such as the fuel consumption per kilometer covered, the lower environmental impact or the possibility of shipping massive loads, which all together make the railway essential and relevant nowadays.

But, when was the railway developed? The first appearance of a transport system related with it is dated in the 6th century B.C. and it was a small line used to transport boats, placing them over platforms. Slaves were forced to push the platforms along the 3 km line, which was constituted by rails dug into the rock. This line worked for 600 years and was placed at Corinth, Greece [1]. Numerous researches reveal that also at Egypt, Italy and Malta's islands there are archaeological remains of this guiding systems, with vestiges of complex changes of track.

Over the years, the furrows evolve to wood rails that were able to transport carts with flaps in the wheels to enable their guidance. However, it was not until the medieval at Europe that these systems reappeared again. There are some references in a few countries. In Germany at the showcase of the Freiburg Cathedral a railway is depicted [2] and in Austria, a funicular was built in 1515 at Hohensalzburg fortress. This line used wood rails and a hemp rope moved by humans or animals. It has been restored and modernized, and nowadays is still working, being one of the oldest systems to be operating [3].

However, the main development of the railway was executed at Great Britain. During the first half of 18th century some mines started to substitute the wooden rails for cast iron rails, as they discovered that the charging trolleys could be handled easier if the wheel's spin over a rail of metal sheets, just because the friction was less. These mines, where the wagons were used only to move the products to the closest waterway, were the first approach to what we call nowadays railway [4].

With the Industrial Revolution, at the beginning of the 19th century, it soon became apparent that more efficiency was needed at the transportation of raw materials and at the final product distribution.

Richard Trevithick was the engineer that, combining two mechanical principles, the driving force and the wheel's guidance, and adapting them into the steam machine, created the first locomotive. The conjectural model of the engine is shown at Figure 1. It was able to carry 10 tons for 15 km, at Pen & Darren foundry, at the south of Gales [5].

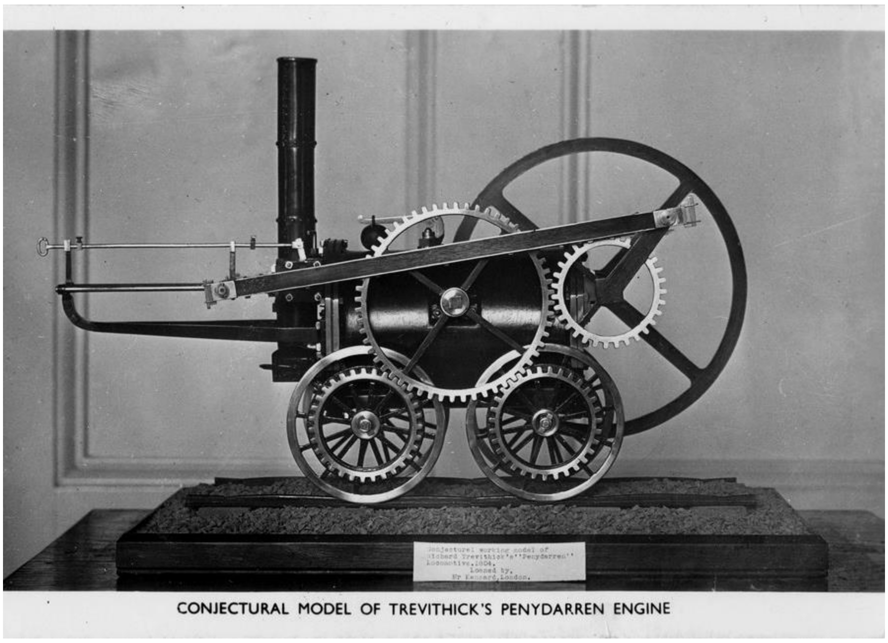

Figure 1. Model of Trevithick's engine

After this progress, the next two decades the railway development grew exponentially. The cast iron rails were design to withstand the weight of the steam locomotive, which was charged with the task of supplying the necessary power to drag trains. It was achieved by using rods to connect the wheels with the rails. This leads to the first railway line open to the public, Stockton-Darlington line, in northern England in 1825. Initially, it was used as a goods transport line, using horses as driving force, but it soon evolves and starts moving passengers. It was developed by the mechanical engineer George Stephenson, who in 1830 opened the first line for the transport of both goods and passengers which works absolutely with locomotives. It covered the distance Liverpool-Manchester [6].

During the following decades the railway expansion was outrageous, with more than 20.000 km around Europe. With the construction of railways, the transport in train soon became popular, although the expansion was guided by the interests of the industry until the second half of the 19th century. Basically, they were looking for the establishment of a network of railways that would allow the movement of big and heavy loads for a price that guarantee good benefits for the investors. In 1914 the railway network that we have nowadays was already built, except for the Scandinavian lands.

In the United States the railway development was powered by the British settlers, who were very interested in connecting the east coast with the inside zones of the country. The first passenger railway in these territories was inaugurated in 1830 at Charleston, South Carolina. Soon it started the expansion from East to West, as traders were convinced by the superiority of railways against other transport systems used until then, such as canals. They were impressed, not only by its high speed and by how straightforward the lines were, but by how this railway could work regardless of the weather conditions or the climate, while water lines could freeze during winter or decrease to unacceptable levels to sail during summer. In1850s decade, the important inversions were carried out through concessions by offering the necessary funds to British and American private companies, which developed the railway network all along the United States, exceeding Europe with more than 50.000 km [7].

After the 2nd World War, the construction of new railway lines in the developed world was focused on metropolitan lines or suburban railways. The two first countries to impulse these modern railways in 1960 were France and Japan. The development of modern long-distance passenger trains started with Japan ahead with the first train bullet, showing that the high speeds were possible. The French perfected its TGV (Train à Grande Vitesse, 'High speed train'). In 1994 four lines had been completed for TGV, which broadened the service of high-speed trains from Paris to the North and West of France and began the lines to the South and the Spanish border, ending by the end of this century. Italians and Germans have developed its own technology for the new railway lines for high speed and long distance that have already built and are expanding. The European Union desires to connect these new national lines to offer international travel by train of high speed without interruptions [8].

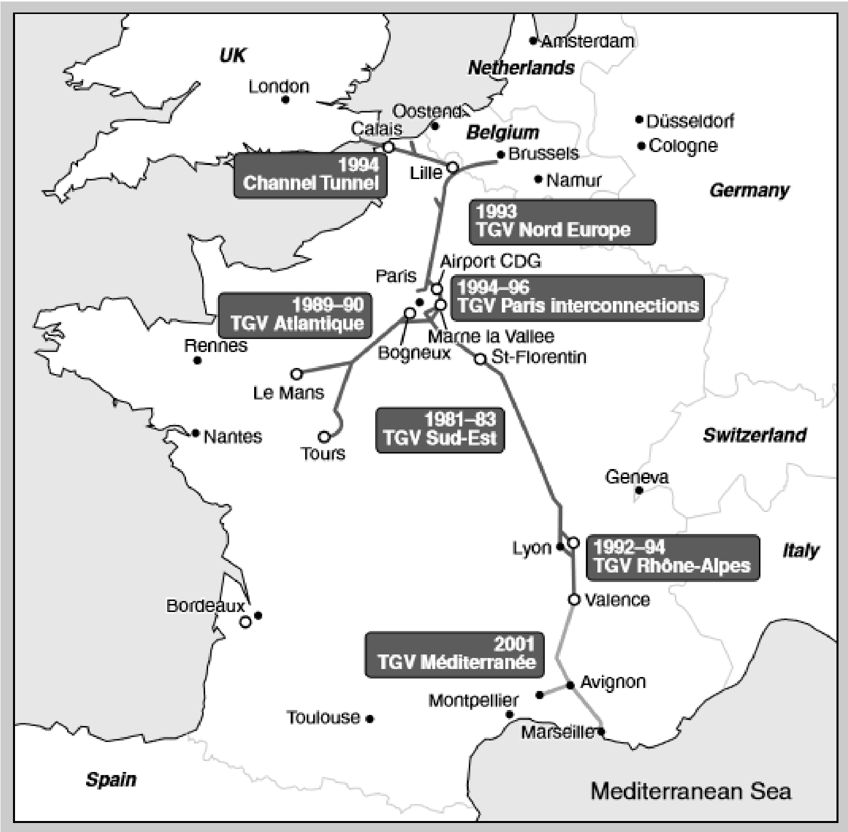

Figure 2. TGV High-speed Lines [9]

In the last quarter of the 20th century, desiring to avoid collapse in the road transport, the secondary cities could afford a system of urban rail thanks to the renaissance of trams from surface as economical and effective alternative to the high cost of building a traditional underground metro system.

1.2. Network Rail

In Great Britain almost the majority of the railway network is owned by the Network Rail, which is the infrastructure manager too. As a public entity it belongs to the Department for Transport, so it does not have shareholders. All the income is reinvested in the railroads [10].

Its primary clients are private train operating companies (TOCs), who are in charge of passenger transport, and freight operating companies (FOCs), responsible for providing train services on the facilities owned and maintained by the company. The first of September of 2014 the Network Rail became a public sector body [11].

Although the infrastructure is owned by the Network Rail, both passenger and goods are not included. Instead, it consists of several elements such as tracks, high voltage equipment, signs, tunnels and bridges or stations. In any case, it has various storage stocks.

Even though it has in its property more than 2,500 railroad stations, it runs just twenty of the most crowded and biggest. The rest are controlled and managed by private train operating companies [12].

Network Rail is usually confused with National Rail, but this one is not an organization, just a brand, which is basically, dedicated to explaining and promoting a large network of passenger railway services.

Since 1997, this service had an incredibly growth, doubling the number of passengers. For dealing with this phenomena, Network Rail is presently undertaking an improvement plan to the network, valued at more than 38 billion pounds. It includes several things as the electrification of the lines, the opening of new intercity trains or the construction of a new high speed line.

All this is recorded on the Strategic Business Plan that they evenly publish, were they detail policies, processes, plans, financial expenditure and other relevant information. In 2013 the last business plan was published [13]. It contains the division of the railway network into 10 operational routes. All of them have their own plans, published every single year. They cover a wide number of railroad lines, generally determined by the geographical conditions of the different areas. Moreover, they are subdivided into 17 strategic routes, each divided into Strategic Route Sections (SRS). A lot of information is included in the plans, where it is detailed geographical data of the different routes, major junctions and stations. Also, it covers the number of tracks, line speeds, electrification, capacity and other relevant details. Some predictions about the future demand and development of each route are included, as well as the expected expenditure and the maintenance and investment specifications.

In the present case, the line we are working at is the East Anglia Main Line.

1.3. Great Eastern Main Line

The Great Eastern Main Line is a 184.3 km railway line, being the primary one on the British railway system. It connects Liverpool Street station in Central London with several locations along east London and the East of England. In the following lines the evolution of this line will be explain, covering different stations. The line can be divided into Main line and Shenfield line.

The first one is composed of the outer suburban and inter-city services between Liverpool Street and Shenfield. There are numerous branch lines diverging at Romford, Shenfield, Witham, Marks Tey, Colchester, Ipswich, Stowmarket and Norwich, with through services going to a few locations. The same rails are used by all the services between Shenfield and Colchester [14].

Station	District	Branches
London Liverpool Street	City of London	
Stratford	Newham	
Romford	Havering	Romford to Up minster Line: Up minster
Shenfield	Brentwood	Shenfield to South end Line: South end Victoria / South minster
Ingatestone	Brentwood	
Chelmsford	Chelmsford	
Hatfield Peverel	Braintree	
Witham	Braintree	Braintree Branch Line: Braintree
Kelvedon	Braintree	
Marks Tey	Colchester	Gainsborough Line: Sudbury
Colchester	Colchester	Sunshine Coast Line: Colchester Town / Clacton-on-Sea / Walton-on-the-Naze
Manning tree	Tendring	Mayflower Line: Harwich Town
Ipswich	Ipswich	Felixstowe Branch Line: Felixstowe East Suffolk Line: Lowestoft
Needham Market	Mid Suffolk	
Stow market	Mid Suffolk	Ipswich to Ely Line: Ely / Cambridge
Diss	South Norfolk	
Norwich	Norwich	Wherry Lines: Great Yarmouth / Lowestoft Bittern Line: Sheringham Breckland Line: Cambridge

Table 1. Main Line route [15].

The second one is a high-frequency line which works on the slow lines from Liverpool Street to Shenfield serving suburban stations. The line is, for the most part, inside Greater London, with a pair of stations in the Brentwood district of Essex.

Station	Zone	District
London Liverpool Street	1	City of London
Stratford	3	Newham
Maryland	3	Newham
Forest Gate	3	Newham
Manor Park	¾	Newham
Ilford	4	Redbridge
Seven Kings	4	Redbridge
Goodmayes	4	Redbridge
Chadwell Heath	5	Redbridge
Romford	6	Havering
Gidea Park	6	Havering
Harold Wood	6	Havering
Brentwood	n/a	Brentwood
Shenfield	n/a	Brentwood

Table 2. Shenfield Line route [15].

In June 1839 the Eastern Counties Railway (ECR) raise the beginning section of the line at Devonshire Street in the East End of London and Romford, then in Essex [16]. Next, the Eastern Union Railway (EUR) built the part of line between Colchester and Ipswich, opening in June 1846 to passenger transportation. A few months later, the Ipswich and Bury Railway company, which is a sister company of the ECR, constructed a line to Bury St Edmunds [17].

To manage the increasing traffic during the late 19th century an expansion of the double track main line was needed and new tracks were incorporated. During 1854, between Bow Junction and Stratford an additional third track was built in order to improve the services that were running on the way to Stratford from London, Tilbury and South end Railway.

In November 1872 GER started building a permanent terminal at Liverpool Street. In order to comfort the high level station of Bishopsgate, the low level was used as a temporary terminal. When the construction was finished at November 1875, the original Bishopsgate station turned into a goods yard.

During the 1870s there was a fast development of the suburbia in the Forest Gate area, which leads to the expansion of the suburban trains at several platforms along Forest Gate, Ilford, Romford and Brentwood.

As the passenger traffic keep increasing within the years, a fourth track was added in 1877 between Bow junction and Stratford, and it was extended during the next years to other junctions like James Street junction in 1884 or Bethnal Green junction in 1891. Also, two tracks for goods were incorporated between Stratford and Maryland. The West Anglia Main Line benefits from this renovation time, as the basement warehousing related with Bishopsgate station built two extra tracks between Bethnal Green and Liverpool Street to improve the services rendered. The line ended being quadruplicated to Ilford and even out to Seven Kings in 1899.

There were a few projects to extend the quadruple track. Some were done in 1902, when the line was expanded from Seven Kings to Romford, others, due to the First World War, were delay until 1913, as the expansion out to Shenfield. The Fairlop Loop opened in 1903 and a lot of services were expanded onto it. The majority of them were looped back and round to the GEML at Stratford [18].

In 1923 the GER was aggregated to the London and North Eastern Railway (LNER). This organization ended with the inner-suburban operation by quadruplicating the tracks to Shenfield.

There were also electrification plans in the 1930s, focused on electrifying the suburban lines between Shenfield and Liverpool Street at 1500 V DC. Although they were started, the beginning of the Second World War stops all the projects, and it was not until 1949 that the electrification adaptation was concluded. In 1956 it was expanded to Chelmsford [19].

In 1955 the Modernization Plan proposed by the British Railways intend to standardized at 25 kV AC he overhead line systems. Nevertheless, because of the low clearances under bridges paths were electrified at 6.25 kV AC. Soon they realized, due to an extensive testing, that it was possible to tolerate the small electrical clearances with the 25 kV system. In consequence, the voltage was increased without making any change at all on the tracks along the route as there was no need of larger clearances. It took almost four years but in 1980 the line between Liverpool Street and South end Victoria was fully converted. In 1986 it was expanded up to Norwich [20].

The line up to Manning tree was integrated in 1986 into the South east Network. In the following decades, the First Great Eastern managed the suburban and medium services while the Anglia Railways run the fast mainline ones. Currently, all the services are conducted by the National Express East Anglia.

1.4. Traction history

For millennia, animal traction has been used. The origin of the use of animals for transport and for the tilling of the soil originally started in the ancient Mesopotamia and in Egypt. In this way, animal power has contributed to the cultural and economic development. Traction allows to obtain a better quality product and is less harmful for the fields. These are the main reasons why nowadays, despite of the evolution and expansion of agricultural mechanization, animal traction is still predominant in a few regions around the world, such as Asia, where it represents the 25% of the agricultural labors according to FAO's estimations [21].

Animal traction had also a huge impact on the railway development. Since the Ancient Mesopotamia, where animals were used to transport materials, to the medieval at Europe, where wood rail lines were used to pull a rope to move both persons and goods.

However, the application of the steam engine to railway transport was something revolutionary with a huge impact in the transport systems development. There are great figures involved with this achievement, starting with the pioneers Savery and Newcomen, continuing with James Watt and Richard Trevithick, who in 1804 built the first self-propelled vehicle on guide rails, and ending with George and Robert Stephenson. Both, father and son, constructed the locomotives that turn them into the major architects of the railway in England and elsewhere around the globe [22]. At the end of the 1820s the railway system was not restricted to intern transport at mines anymore, as it evolved into a more modern system where both goods and persons were transport. On the following decades private companies keep increasing the investment in the construction of new lines, building thousands of kilometers of rails to connect different places all around the world.

At the same time, investigations with static electricity and magnetism led to the origin of the first rotating electrical machines and to the transition from steam to electricity in the railway traction.

The birth of the electric traction is in 1879, when the company Siemens & Halske built a small electric locomotive for the Berlin Industrial exhibition. This locomotive was built for towing wagons with coal in the German mines, making a circular route of 300 meters and collecting current from a special rail located on the axis of the road [23].

At the end of the 19^{th} century occurs the great development of the trams, above all in the United States. The first tram with electric traction that ran in the world was performed in Europe by Siemens in 1881. A few years later, in 1888, occurs the great expansion of electric traction in the United States with 33 new railway power lines. This boom in lines construction ends with more than 23.000 kilometers of lines at the beginning of the 20^{th} century.

From the beginning of investigations in the field of electric traction, the possibility of applying this to the metropolitan resulted in the first metro line, opened in London in 1890. But not only metropolitan lines were updated. The rack railways, which are used in sections with very steep slopes, suffer a constant evolution since 1888, when in United States appeared the first locomotive with an electrical zip cart, especially in those countries which, like Switzerland, have a mountainous territory [24]. You can appreciate one at Figure 3.

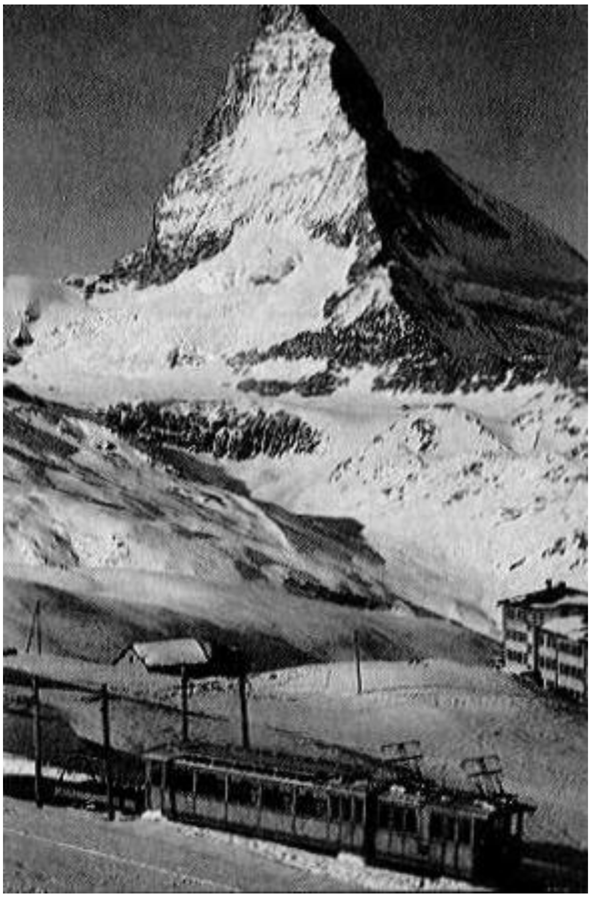

Figure 3. Cog railway at Gornergrat, Switzerland

The first appearance of the monorail is produced in the exhibition of Lyon in the year 1872, but it is not until 1898 in Germany when the monorail begins to operate on a railway line.

While all this advances are achieved, the electrical traction keeps evolving. From the first trials up to the real application of electricity to the railway traction, there has been a great development technical this type of traction. Electric locomotives grow in size, power, number of axes and increases its speed.

1.5. Electrification of the railway

When talking about the application of electricity to the railway traction, the first thing that comes to mind is the most common electrification system, which consist, mainly, in using an overhead cable (Overhead Line Equipment) connected to the train through a pantograph. There are various suspension systems depending on the requirements of the line under consideration. They provide different elasticity and require support arrangements due to the different support methodology provided. The suspension arrangement is dependent on the basic design selected as the design range to be installed. At its simplest, OLE can consist of a contact wire suspended directly from support structures. This is known as tramway or trolley OLE.

First of all, lets define elasticity. It is the amount of uplift experienced per unit of pantograph force at a particular location. An idealized OLE system would have uniform elasticity, but this is not possible, since every assembly attached to the contact wire reduces the elasticity at that point. The best that can be achieved is to limit the elasticity variation in the system to a level which allows for good current collection. Locations of excessively low elasticity are known as hard spots.

Although simplest in terms of engineering, the elasticity is typically zero at the support point; for this reason, it should be used only on very low speed lines for tram networks and heavy rail sidings, and structure spacing is small due to the lack of support by a catenary at midspan.

In order to improve the elasticity of the tram system a stitch can be added. Here the support is transferred to the stitch wire, which in turn suspends the contact wire. This is known as Stitched Tramway.

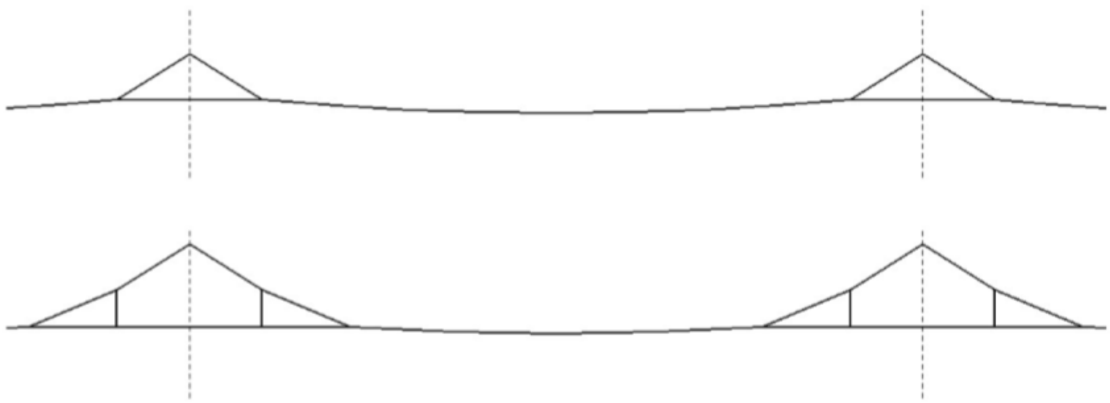

Figure 4. Stitched Tramway OLE

The stitch creates some elasticity at the support; allowing this suspension to be used on tram systems at speeds up to 80kph.

The next step is to create a suspension wire running the whole length of the system. The idea is having a catenary suspended between support points and the contact wire suspended from the catenary by vertical droppers. This is a simple catenary system as shown in Figure 5.

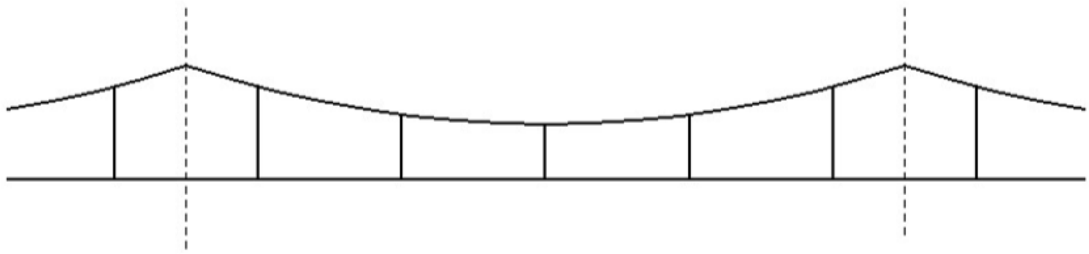

Figure 5. Simple catenary OLE

This system gives better elasticity at the support and is the simplest system adequate for mainline railways. It may be used on metros in the UK and heavy rail in Europe at speeds up to 120kph, but it is not used on heavy rail in the UK.

In an attempt to further reduce the elasticity variation, the next system uses pre-sagged contact wire. Rather than keeping the contact wire flat across the span, a deliberate amount of sag is introduced, typically, 1/1000 of the span length (i.e. the distance between structures).

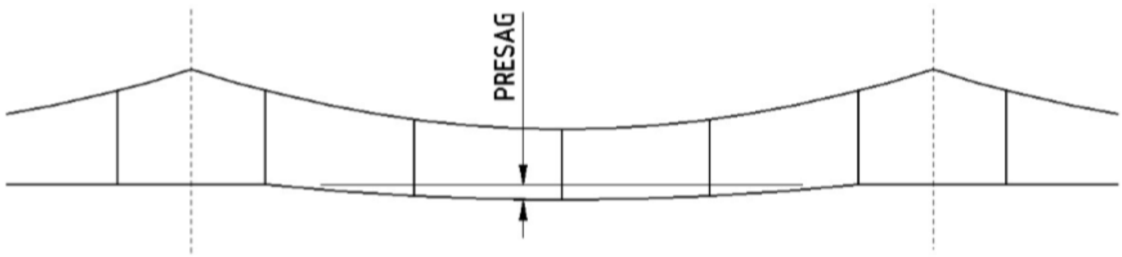

Figure 6. Pre-sagged simple catenary OLE

The purpose of the pre-sag is to compensate for the greater elasticity at the midspan, the uplifted contact wire position at midspan is closer to the uplifted position at the support. This system is standard in the UK and France for speeds up to 300kph.

It is also possible to introduce a stitch in simple catenary. The tension in the stitch can be set to reduce the elasticity at the support points even further. This system is used on high speed lines in Germany at speeds up to 300kph.

Figure 7. Stitched Simple Catenary

A further development is the introduction of a third wire – the auxiliary catenary. This gives us the compound catenary system.

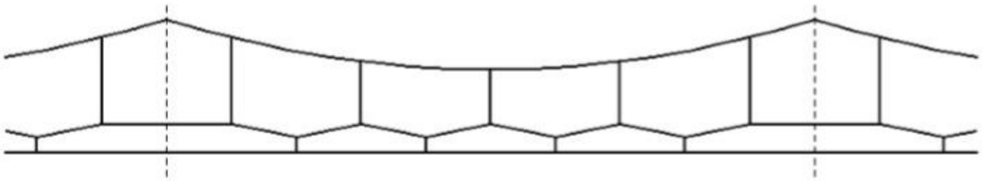

Figure 8. Compound catenary OLE

This also gives very low elasticity variation, and many of the first systems in the UK were compound. They have fallen out of favor in the UK due to the complexity and maintenance requirements, but some sections of UK OLE are still compound. Elsewhere in the world it is still widely used: notably in Japan, where the high speed Shinkansen lines make extensive use of compound equipment at speeds up to 300kph.

Anyways, in order to make this system work there are plenty of elements involved. First of all, feeder stations, which normally feed around neutral sections.

Secondly, both Track Sectioning Cabins and Locations, which are normally switch around neutral sections or around insulated overlaps. Neutral Sections consist of a short section of earthed OLE, with Automatic Power Control (APC) magnets placed either side of it to prevent traction power being drawn as a train moves through the neutral section. These systems are crucial to the operation of an electrified railway as they provide the capability to separate different phase supplies from a 3 phase supply. It is of paramount importance that no electric train be brought to a stand within the APC magnet limits, as the train would then be unable to move under its own power.

All switching and sectioning locations have DEPs (Designated Earthing Points) provided to give secondary protection against inadvertent energization and switch failure. This works by providing a fixed path for any potential to travel to earth by clipping a wire from a stalk on the live parts to a stalk on the earthed side.

Following, there are also Booster Transformers. They are provided on many AC electrified routes as part of the immunization system used to suppress interference with other electrical systems. BTs are configured so that the primary winding is connected across an electrical break in the wire run, usually at an overlap – known as a booster overlap. The secondary winding is connected across an electrical break in the RC. A pantograph coming to a stand in the booster overlap will short out the BT primary, and any current flowing in the section will flow through the pantograph head. This can be exacerbated by a small air gap to one of the wire runs, causing an electrical arc to be drawn. In extreme circumstances this can lead to contact wire being burned out and a dewirement.

Lastly, sometimes for dynamic performance reasons, electrical breaks in mainline running lines should be provided by means of a switched overlap, but if it is not practical to provide an overlap then Section Insulators are used to electrically separate electrical subsections. However, these section insulators are permissible only on crossovers, loops and sidings, due to their poor dynamic performance in running lines.

However, there are other electrification systems such as third rail. Method which consists of providing electric power to a railway train using a continuous rigid conductor placed alongside or between the rails of a railway track. It is used typically in a mass transit or rapid transit system, which has alignments in its own corridors, fully or almost fully segregated from the outside environment. In most cases, third rail systems supply direct current electricity.

Third rail systems are a means of providing electric traction power to railway trains, and they use an additional rail for the purpose. On most systems, the conductor rail is placed on the sleeper ends outside the running rails, but in some cases a central conductor rail is used. The conductor rail is supported on ceramic insulators or insulated brackets.

Nevertheless, this method is not common due to the disadvantages it presents. The most relevant one is the risk of electrocution for humans and animals. But there are a lot more. Using this method implicates a considerable increase of the horizontal space occupation and it requires to interrupt it in steps and level crossings. Moreover, it is not possible to apply AC current due to the skin effect and the Dc current is limited by the service voltage, between 500 and 800 volts. This restriction enforces to build the feeding stations much closer. Furthermore, it is a solution whose dynamic behavior is not as good as the catenary system ones and that does not allow to reach high speeds. The maximum speed is set at 160 kph, which is really low compared with the 300 kph of the catenary systems.

1.6. Electrification of British railways

It all started during the last years of the 19th century. Compared with the steam traction that was being used at that time, the electrification had a lot of advantages, tipping the scales in its favor. The main ones related with its quick acceleration and its power, which make of it an ideal system for urban, suburban and heavy freight trains.

The first OLE systems were used with passenger trams. These generally consisted of a simple single wire system, suspended from poles and buildings, and fed at low voltages. This was preferred to the previous 3rd rail systems, which had safety implications for on-street running.

The first twenty years of the 20th century saw these principles extended to mainline systems as the advantages of OLE over 3rd rail became clear. Voltages were increased due to the increasing distances covered. At the same time, more sophisticated suspension systems were required to maintain good current collection at increasing line speeds.

After the 2nd World War the railways' priority was rebuilding the battered infrastructure rather than funding new schemes. Unlike the UK, where overhead electrification proceeded only falteringly, the rest of Europe installed a large amount of 1500V DC after the war years, and much of this network still exists.

The 1950s saw increased interest in AC OLE. This was driven by the emergence of reliable industrial frequency AC technologies in the electricity supply industry. This meant that high voltage, long distance AC transmission, and by inference, intercity OLE systems, was now feasible. Across Europe, the 1500V DC standard was dropped in favor of 25kV at 50Hz AC.

The Lancaster to Heysham route, which had pioneered HV AC OLE in 1908, was converted from 25Hz to 50Hz in 1951 to serve as a test bed for industrial frequency supply. These tests confirmed the choice as the right one. A test scheme was installed between Colchester and Clacton in 1959. Various types of OLE were trialed, including simple and stitched, but compound was chosen as giving the best current collection at speed.

It was initially assumed that 25kV AC systems would require substantial electrical clearances to existing infrastructure. In the UK this would not be possible without reconstruction work, particularly for many bridges in the vicinity of large stations. For these areas a reduced voltage of 6.25kV was proposed. Trains would be dual voltage and switch between them on the move as necessary.

Experience on the lines out of Liverpool St, where the 1500V DC lines were converted to 6.25kV AC, showed that there was excessive caution in the standard clearances. Reduced and Special Reduced clearances were added, so that 25kV could be adopted throughout. The West Coast Mainline (WCML) electrification was the first large scale 25kV scheme in the UK. It was first proposed with 6.25kV sections, but was implemented fully at 25kV. The dual voltage locomotives which had been built for the route were modified to single voltage machines. The existing 6.25kV areas were then converted to 25kV throughout.

While all this renovation was happening at the UK, elsewhere in Europe the possibilities for higher speed passenger trains using electric traction began to be explored. The French state railway, SNCF, began a series of experimental runs in the 1950s using a modified 1500V DC system, with the line voltage increased to 1900V by means of mobile substations.

The tests showed the obstacles that needed to be overcome if speeds over 300kph were to become the norm. Frictional heat caused the pantographs to collapse, track damage was so great that derailment was only narrowly avoided.

Japan was the first country to build an electrified mainline railway from scratch. The Tokyo - Osaka Shinkansen opened in 1964. This was segregated from existing lines, and used 25kV 60Hz AC OLE rather than the 1500V DC used elsewhere in Japan. The line had no level crossings and was designed for continuous high speed with line speeds of up to 210kph.

The first TGV line between Paris and Lyon opened in 1981. Since then, additional lines have been opened, and the TGV concept has been exported to Germany (as the ICE), the US (the Acela) and the UK (the Channel Tunnel Rail Link).

Figure 9. Extreme gradients on the TGV at Tonnerre, France

2. Calculations and analysis of the Overhead Contact System geometry

The idea of this chapter is to study the geometry of the renewal that has been proposed and what is the impact on the station. There are plenty of factors to be calculated and analyzed in order to achieve the requirements stablished by the contractor and by the health and safety standards. In resume, this part aims to describe the basic Overhead Contact System geometry calculations that are required to demonstrate compliance to the Company Standard.

Let's start at the beginning. The layout used is shown at Annex I. From it a lot of relevant information will be obtain for the geometric calculations. From a global perspective, there are a lot of important aspects to take into account, such as the wind speed, which is 22.08 meters per second, the type of voltage along the different structures, which is a 25 kV Mark 1 Simple Auto Tension, or the different type of wires. However, the most important information is detailed for every single structure. At individual level, essential information used for calculations involves both the catenary and the contact wire height at the OLE structures, and the stagger and the span between these structures. The versine can be also obtained from the track design. Moreover, the layout shows where the fix anchors are placed, at what structures the designated earth points are set, which structures have knuckles and the location of the high speed section insulators and the cross contact bars. It will be really useful at a later stage, for the design and selection of the new supports.

To begin with the calculations, there are three reference values needed as it was said in earlier lines. It is needed to know the height of the contact and catenary wires and the stagger at every single structure. Also the span length is needed. The span length is defined as the distance between adjacent OLE structures (support and registration). Normally it is represented with an L, and it is used a lot at the calculations required when a needle renewal is done, as it is a key parameter due to its impact in the structures. If the span is reduced the blow off and the versine decrease, but it is possible that due to a smaller pan an extra structure is needed, which means that the costs will increase. So the key is to find the balance point.

With these parameters the midspan offset is calculated. This is the lateral offset of the static wire position at the mid-point of two registration points. Basically, it is the horizontal position of the contact bar in relation to the track center line subject to the air conditions, between two registration points. The ideal value would be zero, which can be achieved by setting the stagger to the nominal value in opposite directions at successive structures if it is a tangent structure. If it is a curved track the procedure changes and the stagger should be set equal to the versine of the curve [25].

Nevertheless, hardly ever versines are the same on consecutive spans. As staggers are shared between spans, setting the OLE is quite complicated, being a balanced challenge to fulfill the requirements of each span. And usually there are a lot of transitions between curved and tangent tracks, so it is a complex process.

Midspan offset can be calculated as:

$$O_M = \frac{S_2 + S_1}{2} \pm V \qquad (1)$$

Where

S_1, S_2 ≡ staggers at each end of span

V ≡ versine for the span

Following, as the versine, which is the measure of track curvature between two registration points, is given in the station plans, the track radius will be obtained. On Figure 10 it is represented.

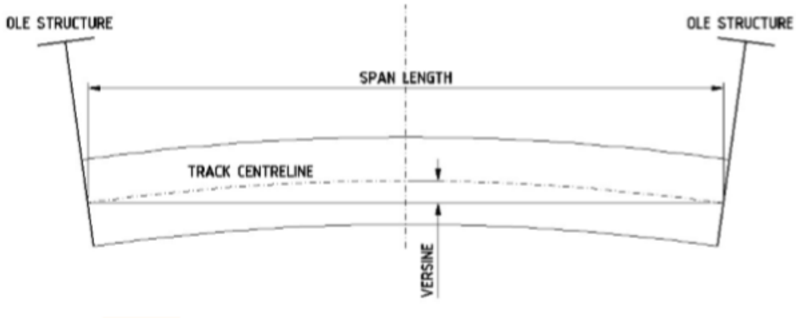

Figure 10. Versine between two OLE structures

The equation used to calculate the track radius is:

$$R = \frac{L^2}{8\,R} \tag{2}$$

Where

L ≡ span between OLE structures

V ≡ versine between two structures

Carrying on with the calculations, the next parameter to find is blow off. Basically, it indicates the amount through which the contact wire is moved at the midspan as a result of maximum wind conditions perpendicular to the track. So it is going to be calculated for the worst case possible [26].

First important measure is the wind speed, which is 22.08 meters per second. Then there are a few factors to select.

The first one is the seasonal factor C_{season}, which is taken as 1.0. It will always be one unless it is being used to calculate the lateral deflection of wires.

The second one is the altitude factor C_{alt}, which can be calculated as:

$$C_{alt} = 1 + 0.001\,A \qquad (3)$$

Where

A ≡ altitude of the station in meters above sea level

Using google maps Colchester's altitude is measured as 8 m. So the factor obtained is 1.008.

The third one is the wind direction factor and is picked from Figure 11 as 0.74:

Direction	0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
c_{dir}	0,78	0,73	0,73	0,74	0,73	0,80	0,85	0,93	1,00	0,99	0,91	0,82

NOTE 1 Interpolation may be used within Table NA.1.

NOTE 2 The directions are defined by angles from due North in a clockwise direction.

NOTE 3 Where the wind loading on a building is assessed only for orthogonal load cases, the maximum value of the factor for the directions that lie ± 45° either side of the normal to the face of the building is to be used.

NOTE 4 Conservatively, c_{dir} may be taken as 1,0 for all directions.

Figure 11. Directional factor, C_{dir}

The forth one is the probability factor C_{prob}, which shall be taken as 0.8143 at UK.

The last one is the orography factor C_o, which is 1 as the site is not on slope.

Once all this factors are obtained, the next step is calculating the real speed, which can be calculated as:

$$V_b = C_{dir} \cdot C_{season} \cdot C_{prob} \cdot C_{alt} \cdot \mathrm{v} = 13.42\ m/s \qquad (4)$$

Then, two more factors, the exposure ones, are obtained. In this case, both are read from Figure 12 and Figure 13. In order to read them three factors are used. The overhead clearance of contact wire relative to track level, which is 5, the upwind distance to the shoreline, which is 21.2 km, and the distance inside the town terrain, which is 3.4 km.

The values are 2 for the exposure factor and 0.77 for the correction one.

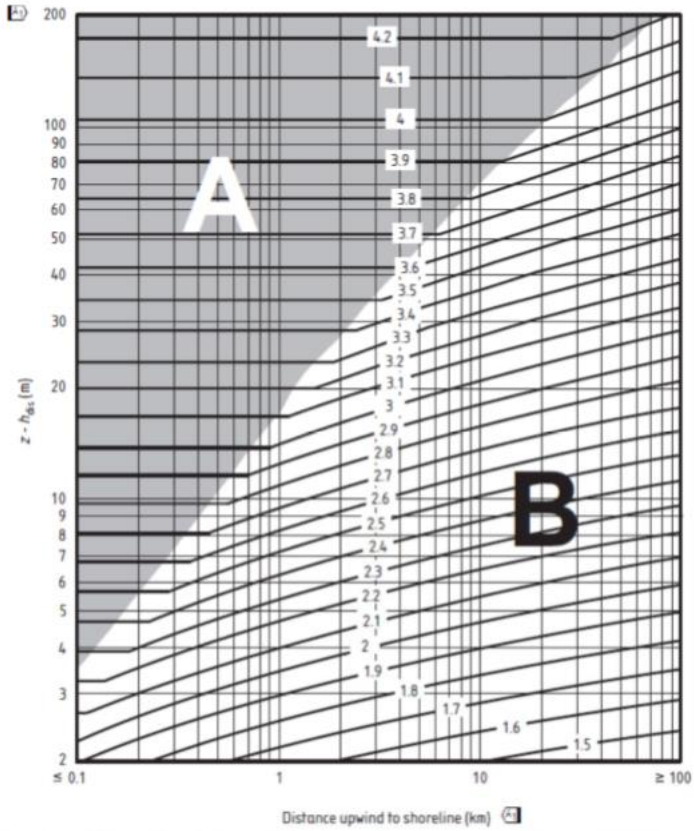

Figure 12. Values of exposure factor, $C_e(z)$, for sites in country terrain

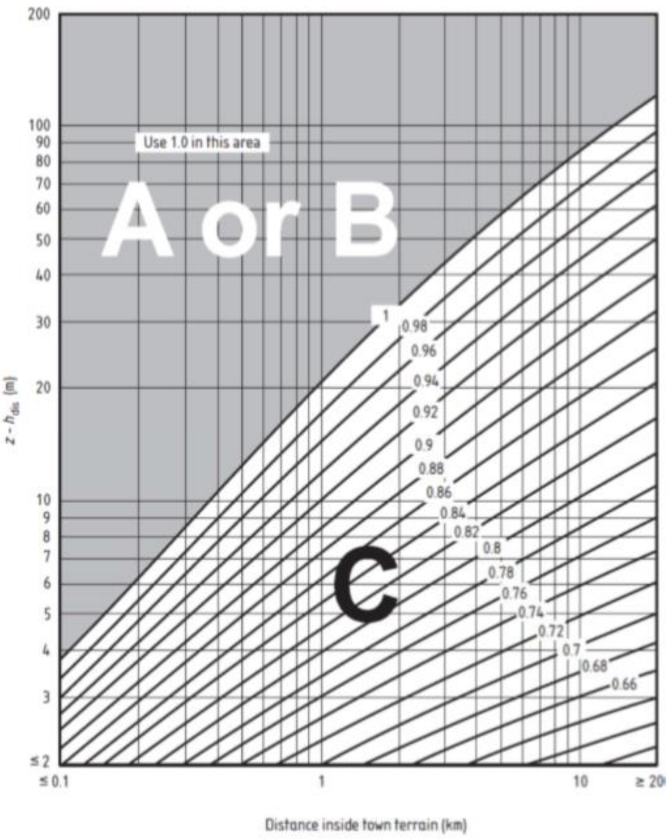

Figure 13. Values of exposure correction factor, $C_{e,T}$, for sites in town terrain

Both exposure factors are used to calculate the dynamic wind pressure, calculating first the basic velocity pressure as:

$$q_b = 0.613 \cdot {V_b}^2 = 110.26\, Nm^{-2} \tag{5}$$

And secondly the peak velocity pressure as:

$$q_p = C_e(z) \cdot C_{e,T}\, q_b = 169.8\, Nm^{-2} \tag{6}$$

The last but one step is to calculate the wind forces on conductors, which can be find as:

$$q_{WC} = q_p \cdot G_c \cdot d \cdot C_c \cdot cos^2 \phi = 1.25\, Nm^{-1} \tag{7}$$

Where

G_c ≡ Structural response factor for conductors is 0.75

d ≡ diameter of conductor wire (12.3 mm)

C_c ≡ Drag factor of conductor is 0.8

Φ ≡ angle of incidence of critical wind direction perpendicular to conductor, 0

Finally, the blow off can be calculated. There are two different cases, one for wires R84 and R112, with a 11.30 kN tension, and another one for wires R89 and R90, with an 8.91 kN tension. Both values read from the layout in Annex I. It is calculated as:

$$\beta = \frac{q_{\mathrm{WC}} \cdot L^2}{8 \cdot \mathrm{Tension}} \tag{8}$$

All the blow off results are displayed on Annex II.

Then, the stagger effect is calculated. Due to the stagger, the maximum contact wire deviation may not occur at the mid-span. Stagger effect is the difference between the deviation at midspan and the worst deviation in the span under wind conditions. However, the maximum deviation usually does not occur at the midspan. It will vary depending on the staggers between structures. Figure 14 and Figure 15 illustrate how the parameters defined in this chapter change according to the location of the staggers.

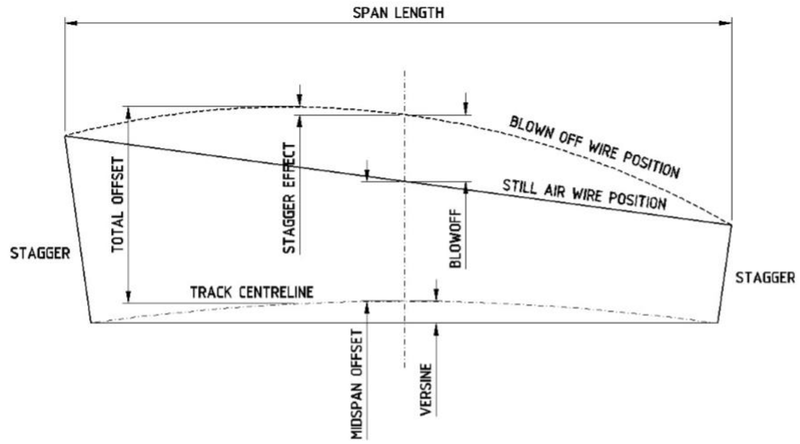

Figure 14. Midspan offset, blow off and stagger effect for staggers on same side of track

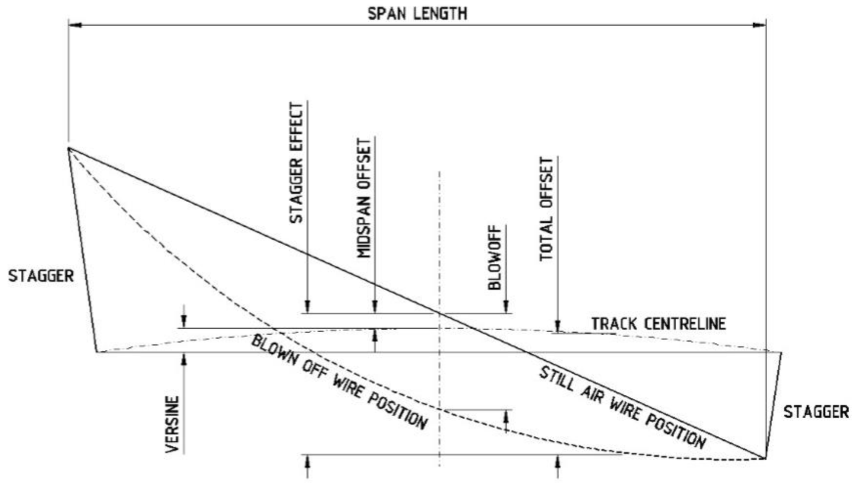

Figure 15. Midspan offset, blow off and stagger effect for staggers on opposite sides of track

Moreover, these staggers can be positive or negative. Positive when the contact wire is on the same side of the centerline of a static pantograph as the steady arm or negative if the contact wire is positioned on the opposite side of the centerline of a static pantograph as the steady arm. For an easier understanding, the stagger is positive under tension and negative under compression.

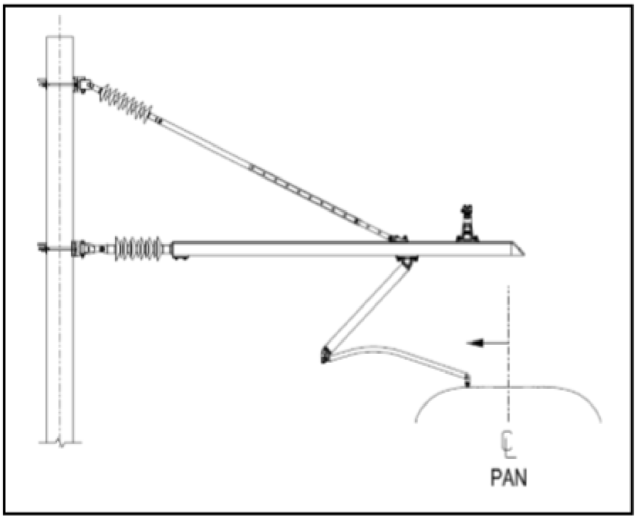

Figure 16. Positive stagger

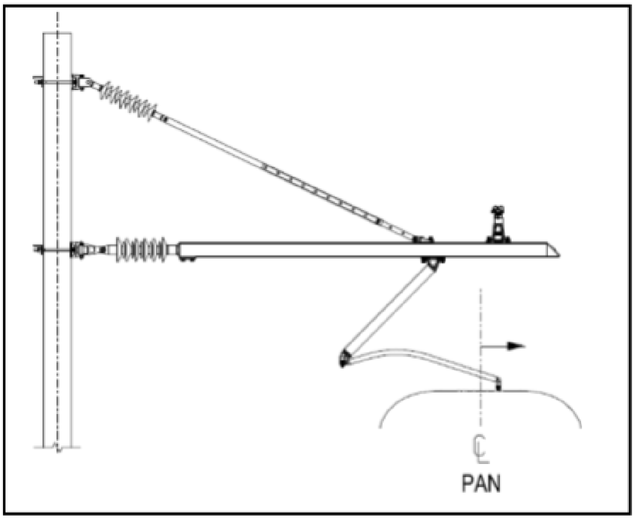

Figure 17. Negative stagger

Taking into account the situation between every two structures at Colchester's station, the stagger effect is calculated as:

$$E = \frac{(S_2 - S_1)^2}{16 \cdot (\beta - V)} \qquad (9)$$

Where

S_1, S_2 ≡ staggers at each end of span

V ≡ versine for the span

β ≡ blow off

It is important to highlight that this calculation will be valid as long as $(S_2 - S_1) < 4\,(\beta - V)$, otherwise the stagger effect will be null as the maximum deviation will occur at the structure.

The staggers also define the sweep ratio. During the course of travelling between two support points the contact wire will move across the pantograph (either from side to side or from one side to the centre line and back again). The distance this wire moves is the sweep and is calculated as:

$$W = S_1 + S_2 \quad or \quad W = 2V \tag{10}$$

Where

S_1, S_2 ≡ staggers at each end of span

V ≡ versine for the span

Once the sweep is estimated, the ratio of sweep to span length or sweep ratio can be obtained dividing it by the distance between spans. Usually, it is expressed as 1:x, e.g. 1:250 for 200mm of sweep throughout a 50 metre span.

Consequently, the found sweep ratio will be compared with the minimum and maximum defined at the majority of OLE systems. If the minimum sweep ratio is not met, there is a risk of excessive wear at one point in the span. If the maximum is exceeded, the wire moves too quickly across the pan and will begin to experience unwanted dynamic effects. However, in order to avoid nonsense results these criteria should be applied to a complete length of route.

Once all these terms are obtained, actual deviation can be calculated. Basically, it is the sum of all of them.

$$\mathrm{Y} = \beta + \mathrm{E} + \mathrm{M} + V \tag{11}$$

The values obtained will be compared with the maximum permissible deviation Y_M. This values will be decreasing 40 mm each meter that the contact wire is above the nominal value, so it is calculated, based upon the Mk1 OLE system, as:

$$Y_M = 400 - [(\mathrm{H} - 4700) \cdot 0.040] \tag{12}$$

If the value of actual deviation is higher than the corresponding one of maximum permissible deviation, then the actual deviation value will be substitute with the value of Y_M.

To end with the geometrical part of this project, the variation of the gradient is analyzed to see if the new variations introduced on the Overhead Contact System meet the requirements. Changes of gradient direction should be separated by a level span, and in the case of some high speed routes, by a ‘half-maximum’ span between the maximum gradient and the level span. This prevents any instantaneous reversal in pantograph travel, leading to loss of contact.

During the train movement, there is a permissible rate of rise and fall of OLE which is constrained by the ability of the pantograph, which acts as a spring-mass-damper system, to follow the OLE. If the gradient obtained is above the target range, appropriate measures should be taken on the design until we obtain an allowable value that suits the stablished rate.

This gradient is calculated between support points as:

$$G = \frac{L}{\Delta H} = \frac{L}{H_2 - H_1} \quad (13)$$

Where

L= span length between support points

H_1, H_2= contact wire height measured at the support points

The actual gradient can be represented as shown at Figure 18.

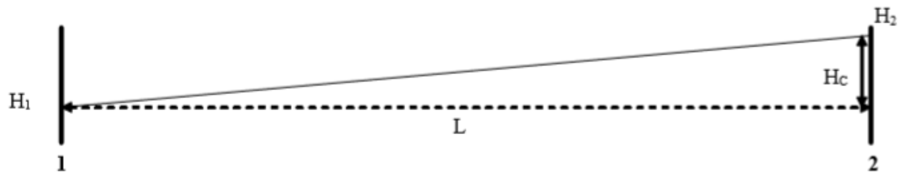

Figure 18. Actual gradient

Another thing to consider is the maximum gradient, which can be consider as the overall limit. Usually, the value allowed is defined as the line speed in mph multiplied by 5 (i.e. with 75 mph line speed the maximum grade would be 1:375). However, some administrations just set an absolute maximum gradient, i.e. a 0,4% (1 in 250).

The gradient sign can be both positive and negative relying upon the direction. So a negative value is just an indicator of a downward gradient. If changes of gradient direction occur, some arrangements will be made. Or a level span is introduced to separate both points, or rather, a half-maximum span between the maximum gradient and the level span for high speed routes. This measures can prevent the loss of contact caused by any instantaneous reversal in the pantograph during the ride.

Finally, the change in gradient is analyzed. The actual gradient variation should be equal to or greater than the maximum change in gradient, which is usually defined as 10 times the line speed in mph. Change in gradient can be positive or negative dependent upon direction. A negative value indicates a downward change in gradient

All the parameters explained on this chapter are calculated for the four wires and for all the structures at Annex II.

3. Design methodology

On this chapter all the structures affected by the renewal are going to be analyzed, and those who need to be change will be designed and selected according to the corresponding standards or regulations.

The main objective is to perform a renewal of the old structure taking advantage of the existing components. The supports and the lintel are going to withstand the different loads, so these pieces are the most expensive ones. Main reason why it will be intended to avoid the installation of new structures. Also, the modifications carried out on a railway station of certain size usually involve traffic cuts and much more time than renovating minor components.

The first step will be analyzing the old structure plans and studying if it is possible to find a connection with the modern manuals. Currently, the Great Eastern main line is being upgrade into GEFF, so the new manuals do not go along with the old ones, which are Mk1. Basically, the main difference is a transition from compound to single sagged catenaries. All the dimensions from the layouts are in feet and inches so it will be necessary to convert all the measures into millimeters, in order to select the new pieces of the structures.

There are some variations between Mk1and GEFF to consider. The tension at GEFF systems, with standard parameters, is of 13.20 kN. In the case of the Mk1 wires installed at the station that is being subject of study, the tensions are of 11.30 kN and 8.918 kN. This means that changing the wires will demand to adjust the auto tension system. It is not something too complicated but it is essential for the proper functioning of the station. The modification to be done is just a readjustment of the balance weight anchors according to the new tension, or, if these ones cannot be installed, the introduction of Tensorex units, devices in charge of maintaining mechanical tension in the OLE conductors [27].

The speed differs also a bit. The speed for the GEFF systems can reach the 160 kph, while the Mk1 systems will reach 176 kph if a single pantograph or 120 with a double headed one. However, as this line operates near a station the speed will be limited, running at less than 96kph. Even though, the staggers remain the same at both, with values of 230 for tangent tracks and 380 for the outside of the curve.

One last difference, and probably one of the most important ones is the wires materials. The GEFF wires are made of CuAg, material with very good resistance to corrosion and adapted to work with continuous loads at high temperatures. But the Mk1 wires are made of CdCu, which is hazardous and toxic. So, when changing the wires staff will need to wear specific protections, such as gloves and masks, and will not be able to drink or eat until they have finished working and they have done the cleaning procedure.

As the wires are going to be substitute, all the OLE elements placed on the wires need to be removed and if necessary replaced.

The second step, directly related with the first one, is changing the structures attached to the wires. Starting with the cross contact bar placed right after support B51-100. Basically, this structure is placed at any location where the cross over contact wire crosses over the main line contact wire and the piece is located at the main line contact wire. It constrains both wires to move together although it allows certain track movement, minimizing the hook over risk by ensuring that the wire run which is not being lifted by the pan follows the lifted wire.

If they are poorly designed or any mistake is done during the installation it can cause a hard spot, reason why for lines with speeds over 100 mph this structure is substitute with a specially-designed lightweight cross contact bar and appropriate droppering.

Then the full current jumpers will be replaced. These jumpers, known as double drapes, are used when two or more wire runs meet at the same location. If it works correctly, there will be a flow of traction current from one to the other under normal conditions.

Basically, they are made of a single copper conductor from the isolator or booster transformer to the catenary and two copper flexible stranded conductors from catenary to contact wire. As a full current jumper is going to be installed after structure B51-100, it will have two jumpers. All the clamps involved are twin bolt types.

The last structure located at the wires that needs to be replaced is the high speed section insulator located just before structure B51-102. This element is used in crossovers or, for exceptional occasions, where overlapping to create a sectioning point is not possible. As the main objective is maximizing both clearance to main line and horizontal clearance between different electrical sections, it should be located along the track center of the crossover. They are allowed just on crossovers, loops and sidings, because of their poor dynamic performance in running lines

The structures will now be design one by one. No modification is suggested for the down main line as part of the renewal works. All the changes will be done in up main or by pass lines.

The third step is designing ever single structure attending to which supports can be reused and which ones need to be replaced. Structure B51-91 reference is number 101, B51-96 reference is number 21 and B51-100 references are numbers 1 and 204. Then B51-105 reference number is 25 and the rest have reference number 2.

3.1. Design of structure B51-91

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure a picture is used as guidance.

Figure 19. Structure B51-91 (at the right of the picture)

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. At this structure, the support to renew is number 2, with a 76.2 mm stagger to the left and a contact wire height of 4876.8 mm. The height of the top boom is of 7924.8 mm. From the reference plans we obtain the width of the boom, which is 457.2 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The lintel space available for it is approximately 3 m wide, which is more than enough as the structure wide is less than 1.5 m. Also, it will be design to cover the distance between the highest point of the hole structure, the top boom, and the contact wire, which is 3048 mm.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected. It is referenced in Annex IV as 371.00244.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width, which is 457.2 mm, and the second one is related with the drop tube length needed. As the distance to cover is approximately 3 m and the registration tube adds 500 mm the chosen drop tube will be type 43 for the first position and type 250 for the second one. It is referenced in Annex IV as 348.00083.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type. It is referenced in Annex IV as 442.00096-2.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 300 – 460 mm type 30 is picked for both. Their references at Annex IV are 348.00067-2 and 433.00168 respectively.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the plate and taking into account that it has a thickness of 44.5 mm, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one. It is referenced in Annex IV as 396.00009.

All the selected elements are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.43.250)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.30)
- Support Bracket (433.00168.030)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm with Ring (442.00096-2.10)

3.2. Design of structure B51-96

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure two pictures are used as guidance.

Figure 20. B51-96 structure

Figure 21. B51 -96 AT structure

In this case, the objective is to designed the fixed anchor of the 2 wires that go through structure B51-96, which are wires 112 and 89. To start with, the measures are read from reference 21. The boom height is 1066.8 mm and its width is of 762 mm. The most restrictive parameter is going to be the thickness of both top and bottom booms, which is only 50.8 mm. With this value the available options are reduced drastically, being the best solution possible to design a fixed termination to catenary and contact wire, with an insulator attached to anchor structures with A frame. It is known that it has this frame due to the tower to the left of the given layout. It is shown at Figure 22.

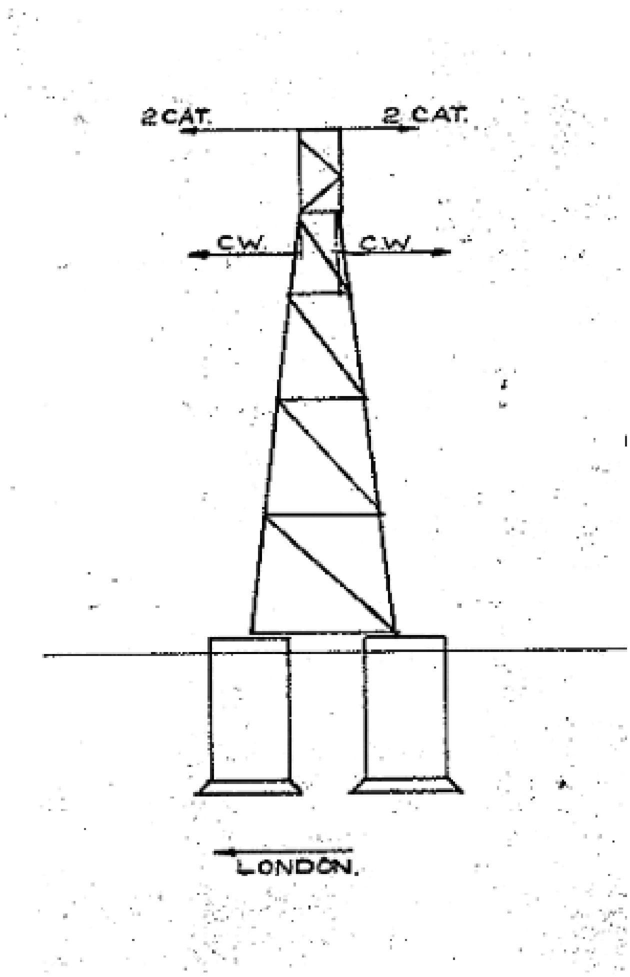

Figure 22. A frame reference

Before starting the selection, lets remark the difference between fixed terminations and midpoint anchors. For fixed terminations equipment the wire run is constrained at every support and therefore does not need further constraint while for auto tensioning equipment is constrained at the midpoint of the tension length by means of a Midpoint Anchor. Each half of the wire run is free to move according to ambient temperature.

In the given structures there are no balance weight anchors, but if in any structure affected there are any components of this type they must be readjust to achieve the new tension.

Now, let’s began with the selection. The first component to choose is the plate. This element has 4 holes for assemblies. Two of them for the vertical tube, which has a diameter of 120 mm, and that are separated 140 mm to have a bit of margin. The other two are for the boom. In this case the length to cover must be smaller than the corresponding value for factor B, so, as the boom has a thickness of 114.3 mm, the type selected is A200. To see all the factor references, go to see Annex IV, structure 523.00317.

Then, the 120 x 120 x 4.5 vertical tube can be chosen. Analyzing the references shown at Annex III, as the boom height is of 7112 mm and the contact wire height for the anchor support is 5257.8 mm, a suitable length to cover this distance is 1900 mm. So type 190 is selected. It is referenced in Annex IV as 523.00318.

The last component to design is the threaded bar M16 assembly. There are a lot of lengths available but, attending to the clamping range maximum distance allowance, to cover the 305 mm of boom width the one that fits best is type A160. It is referenced in Annex IV as 396.00011.

For this structure the designed components are:

- 120 x 120 x 4.5 Vertical Tube (523.00318.190)
- Plate (523. 00317.A200)
- Threaded Bar M16 Assembly (396. 00011.A160)

3.3. Design of structure B51-100

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure two pictures are used as guidance.

Figure 23. B51-100 structure

Figure 24. B51-100 FA

In this case there are two supports that are going to be changed. They correspond with supports 4 and 5 in the reference layout attached at Annex III. Both have the same characteristics and the same measures, so the same support will work for both. However, support 4 contact wire height is a bit higher, so maybe one component varies.

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. Support 4 has a 228.6 mm stagger to the left and a contact wire height of 4902.2 mm while support 5 has a 152.4 mm stagger to the right and a contact wire height of 4876.8 mm. The height of the top boom is of 7924.8 mm. From the reference plans we obtain the width of the boom, which is 457.2 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width and the second one is related with the drop tube length needed. As the distance to cover is approximately 3 m and the registration tube adds 500 mm the chosen drop tube will be type 43 for the first position and type 300/310 for the second one for supports 4 and 5 respectively.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 300 – 460 mm type 30 is picked for both.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3001, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one.

One extra thing to design for this structure is the designated earth points. Basically, they are locations where portable earths are applied to OLE to allow electrical isolations to be taken. The structure will be provided with DEP spigots to allow attachment of portable earths.

The only element to design is the earthing bolt assembly, and for the drop tube diameter that is used along the supports, type 12 is the one that fits best. It is referenced in Annex IV as 472.00057.

The las thing to design is the fixed anchor attached to the mast. In this case the support will be similar to the one used for structure B51-96, but in this case attached to the mast.

The first component to choose is the plate. This element has 4 holes for assemblies. Two of them for the vertical tube, which has a diameter of 120 mm, and that are separated 140 mm to have a bit of margin. The other two are for the boom. In this case the length to cover must be smaller than the corresponding value for factor B, so, as the boom has a thickness of 228.6 mm, the type selected is A240. To see all the factor references, go to see Annex IV, structure 523.00317.

Then, the 120 x 120 x 4.5 vertical tube can be chosen. Analyzing the references shown at Annex III, as the boom height is of 7924.8 mm and the contact wire height for the anchor support is 5181.6 mm, a suitable length to cover this distance is 2800 mm. So type 280 is selected.

The last component to design is the threaded bar M16 assembly. There are a lot of lengths available but, attending to the clamping range maximum distance allowance, to cover the 457.2 mm of boom width the one that fits best is type A160, with a clamping range of 470.

All the selected elements for supports 4 and 5 are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.43.300 / 348.00083.310)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.30)
- Support Bracket (433.00168.030)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm with Ring (442.00096-2.10)
- Earthing Bolt Assembly (472.00057.12)

For this structure the FA components are:

- 120 x 120 x 4.5 Vertical Tube (523.00318.280)
- Plate (523. 00317.A240)
- Threaded Bar M16 Assembly (396. 00011.A160)

3.4. Design of structure B51-102

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure a picture is used as guidance.

Figure 25. B51-102 structure

In this case there are four supports that are going to be changed. They correspond with supports 3,4,5 and 6 in the reference layout attached at Annex III.

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. Support 3 has a 228.6 mm stagger to the right and a contact wire height of 4876.8 mm. The height of the top boom is of 8382 mm. From the reference plans we obtain the width of the boom, which is 609.6 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width, which is 609.6 mm, and the second one is related with the drop tube length needed. As the distance to cover is approximately 3.5 m and the registration tube adds 500 mm the chosen drop tube will be type 53 for the first position and type 300 for the second one.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type. It is referenced in Annex IV as 442.00096-2.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 460 – 620 mm type 46 is picked for both. Their references at Annex IV are 348.00067-2 and 433.00168-2 respectively.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3002, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one.

Then supports 4 and 5 are designed. Both are just a pulley system so the design process is quite short, as is just a part of the support 3 selection that has already been done. The pieces to design, which are the long shank bolt M16 assemblies, the backing angle and the bracket support, are chosen in the same way.

Support 6 is a bit more complex. For this one a twin catenary support with a return conductor is proposed. This one has a 76.2 mm stagger to the right and a contact wire height of 4876.8 mm.

The first elements to select are the attachments frames below and above. Both depend on the boom width, which in this case is 609.6 mm, so type 53 is chosen for both. Their references at Annex IV are 353.00291 and 353.00291-1 respectively.

Next, the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3002, if the thickness of the attachment frame below, which is 10 mm, and the one of above, which is 10 mm, are added, it is obtained that type 26 will be the right one.

Now, the registration tube is selected. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected. But, in this case, due to the geometric of the given drop tube the right choice is using type 030.

Following, the dropping tube is design. In this case there is only one parameter to choose, related with the drop tube length needed. As the distance to cover is approximately 3.5 m and the registration tube adds 300 mm the chosen drop tube will be type 325. It is referenced in Annex IV as 348.00111.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type.

About the return conductor, there will be four pieces to design. It is important to take into account that the height of this return conductor is 6553.2 mm.

With that height to cover and knowing the width of the top boom, the chosen drop tube positions are type 53 for the first position and 180 for the second one. It is referenced in Annex IV as 348.00071.

Then, the return conductor insulator assembly attached to the mast will be designed. As the mast width is 304.8 mm, according to the layout specifications, the type that fits best the requirements is type 24. It is referenced in Annex IV as 472.00055.

The other pieces to select are the backing angle and the long shank bolt M16 assemblies. For the first one, the same type as the one chosen for the catenary support will be selected. For the second one, although the thickness varies a little bit, as this drop tube is 5 mm thicker, type 26 is still the best possible option.

One extra thing to design for this structure is the designated earth points. The only element to design is the earthing bolt assembly, and for the drop tube diameter that is used along the supports, type 12 is the one that fits best. It is referenced in Annex IV as 472.00057.

All the selected elements for support 3 are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.53.300)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm with Ring (442.00096-2.10)

For supports 4 and 5:

- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)

For support 6:

- 120 x 120 x 4.5 Drop Tube (348.00111.325)
- Long Shank Bolt M16 (396.00009.26)
- Attachment Frame Above (353.00291.53)
- Attachment Frame Above (353.00291.53)
- Ø48.3 Registration Tube (371.00244.030)
- Curved Registration Arm with Ring (442.00096-2.10)
- Curved Registration Arm with Ring (442.00096-2.10)

For the return conductor at support 6:

- 120 x 120 x 4.5 Drop Tube (348.00071.53.180)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Return Conductor Insulator Assembly (472.055.24)

DEPs:

- Earthing Bolt Assembly (472.00057.12)

3.5. Design of structure B51-103

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure a picture is used as guidance.

Figure 26. B51-103 structure

In this case there are three supports that are going to be changed. They correspond with supports 3,4 and 5 in the reference layout attached at Annex III. Supports 3 and 5 have the same characteristics and almost the same measures, so the same support will work for both. However, support 5 will have an extra element, as a return conductor will be added.

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. Support 3 has a 76.2 mm stagger to the right and a contact wire height of 4876.8 mm, while support 5 has a stagger of 203.2 to the right and the same contact wire height. The height of the top boom is of 8382 mm. From the reference plans we obtain the width of the boom, which is 609.6 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width, which is 609.6 mm, and the second one is related with the drop tube length needed. As the distance to cover is approximately 3.5 m and the registration tube adds 500 mm the chosen drop tube will be type 53 for the first position and type 300 for the second one.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 460 – 620 mm type 46 is picked for both.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3002, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one.

About the return conductor added for support five, there will be four pieces to design. It is important to take into account that the height of this return conductor is 6553.2 mm.

With that height to cover and knowing the width of the top boom, the chosen drop tube positions are type 53 for the first position and 180 for the second one.

Then, the return conductor insulator assembly attached to the mast will be designed. As the mast width is 304.8 mm, according to the layout specifications, the type that fits best the requirements is type 24.

The other pieces to select are the backing angle and the long shank bolt M16 assemblies. For the first one, the same type as the one chosen for the catenary support will be selected. For the second one, although the thickness varies a little bit, as this drop tube is 5 mm thicker, type 26 is still the best possible option.

Now let’s designed support number 4. In this case, a knuckle will be designed. This support is facing right and has 101.6 mm of stagger to the left. When there is no option of using a registration arm to achieve registration, normally at complex junctions or crossover areas, this component is used. As they introduce a hard spot onto the system because of the fact that they are unsupported and as they can lead to an excessive differential movement if the two wire runs move at different rates along-track with temperature, they are not preferred for heavy rail systems. However, they are extensively used on older systems in complex areas such as stations and junctions like this one at Colchester.

The selection of the pieces is already done, as the elements to design, the long shank bolt M16 assemblies, the backing angle and the support bracket are exactly the same as for supports 3 and 5.

All the selected elements for support 3 and 5 are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.53.300)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm with Ring (442.00096-2.10)

For the return conductor at support 5:

- 120 x 120 x 4.5 Drop Tube (348.00071.53.180)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Return Conductor Insulator Assembly (472.055.24)

For support 4:

- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)

3.6. Design of structure B51-105

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. For the correct design of the structure a picture is used as guidance.

Figure 27. B51-105 structure

In this case there are three supports that are going to be changed. They correspond with supports 3,4 and 5 in the reference layout attached at Annex III. Supports 3 and 5 have the same characteristics and the same measures, so the same support will work for both. However, support 5 will have an extra element, as a return conductor will be added.

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. Both supports have a 228.6 mm stagger to the right and a contact wire height of 4876.8 mm. The height of the top boom is of 8382 mm. From the reference plans we obtain the width of the boom, which is 609.6 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width, which is 609.6 mm, and the second one is related with the drop tube length needed. As the distance to cover is approximately 3.5 m and the registration tube adds 500 mm the chosen drop tube will be type 53 for the first position and type 300 for the second one.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 460 – 620 mm type 46 is picked for both.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3002, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one.

About the return conductor added for support five, there will be four pieces to design. It is important to take into account that the height of this return conductor is 6553.2 mm.

With that height to cover and knowing the width of the top boom, the chosen drop tube positions are type 53 for the first position and 180 for the second one.

Then, the return conductor insulator assembly attached to the mast will be designed. As the mast width is 304.8 mm, according to the layout specifications, the type that fits best the requirements is type 24.

The other pieces to select are the backing angle and the long shank bolt M16 assemblies. For the first one, the same type as the one chosen for the catenary support will be selected. For the second one, although the thickness varies a little bit, as this drop tube is 5 mm thicker, type 26 is still the best possible option.

Now let’s designed support number 4. In this case, the proposed structure is an under boom support with registration and push off plus a drop tube and a pulley. This support is facing right and has 304.8 mm of stagger to the left.

As the contact wire height for this one is 5486.4 mm the chosen drop tube will be selected as type 53 for the first position, to cover the boom width, and as type 290 for the length.

Then, the catenary support is going to be chosen. The first piece to design is the top mast bracket, which depends on the drop tube. For the one at issue, type MB100 covers the tube diameter, of 120 mm. It is referenced in Annex IV as 353.00304.

The second one is the registration tube, which covers two panels of the lintel. Every panel has a length of 1066.8 mm based on the reference details shown at Annex III, so the selected tube will be type 21. It is referenced in Annex IV as 353.00273.

Both thickness and width of the boom remain the same, so the support bracket, the backing angle and the long shank bolt M16 assemblies chosen for this support are exactly the same as for supports 3 and 5. These pieces are also applied to the pulley, as their design process is the same.

All the selected elements for support 3 and 5 are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.53.300)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm With Ring (442.00096-2.10)

For the return conductor at support 5:

- 120 x 120 x 4.5 Drop Tube (348.00071.53.180)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Return Conductor Insulator Assembly (472.055.24)

For support 4:

- Top Mast Bracket (353.00304.MB100)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (353.00273.21)
- 120 x 120 x 4.5 Drop Tube (348.00071.53.290)

3.7. Design of structure B51-106

For the design of this structure, the layout and the references used are attached on Annex III. The plans of the new supports are included at Annex IV. It is exactly the same as the structure before, so every single selection is designed as for structure B51-105. For the correct design of the structure a picture is used as guidance.

Figure 28. Structure B51-106

In this case there are three supports that are going to be changed. They correspond with supports 3,4 and 5 in the reference layout attached at Annex III. Supports 3 and 5 have the same characteristics and the same measures, so the same support will work for both. However, support 5 will have an extra element, as a return conductor will be added.

The first thing is reading the relevant measures from the layout and converting them into millimeters, as all the data is in feet and inches. Both supports have a 228.6 mm stagger to the right and a contact wire height of 4876.8 mm. The height of the top boom is of 8382 mm. From the reference plans we obtain the width of the boom, which is 609.6 mm.

With all these measures it is quite easy to select the correct support. Attending to the old structure details, the best one will be an under boom with pulley and registration. The suspension wire goes underneath the pulley, so it is very important to avoid changing its height, as it could disarrange the rest of structures along the canton. Over the top runs a steel wire, so the key lies in finding the correct height for this piece.

The first element to design is the registration tube. As a general rule, in order to avoid violent knocks on the pantograph due to a bad geometric arrangement the 050 type will be selected.

Next, the dropping tube. In this case there are two parameters to choose. The first one is related with the boom width, which is 609.6 mm, and the second one is related with the drop tube length needed. As the distance to cover is approximately 3.5 m and the registration tube adds 500 mm the chosen drop tube will be type 53 for the first position and type 300 for the second one.

Then, the curved registration arm with ring is design. In this case, it is written in several manuals that in order to keep the minimum deviation the chosen type will be type 10. There are some exceptions, but for the structures involved in this renewal there is no inconvenience in selecting that type.

Following, backing angle and support bracket can be selected at the same time, as both depend directly on the boom width. For booms between 460 – 620 mm type 46 is picked for both.

The last piece to select are the long shank bolt M16 assemblies. As the support is attached to the top boom, which has a thickness of 76.2 mm according to the reference 3002, if the thickness of the backing angle, which is 6 mm, and the one of the drop tube, which is 15 mm, are added, it is obtained that type 26 will be the right one.

About the return conductor added for support five, there will be four pieces to design. It is important to take into account that the height of this return conductor is 6553.2 mm.

With that height to cover and knowing the width of the top boom, the chosen drop tube positions are type 53 for the first position and 180 for the second one.

Then, the return conductor insulator assembly attached to the mast will be designed. As the mast width is 304.8 mm, according to the layout specifications, the type that fits best the requirements is type 24.

The other pieces to select are the backing angle and the long shank bolt M16 assemblies. For the first one, the same type as the one chosen for the catenary support will be selected. For the second one, although the thickness varies a little bit, as this drop tube is 5 mm thicker, type 26 is still the best possible option.

Now let’s designed support number 4. In this case, the proposed structure is an under boom support with registration and push off plus a drop tube and a pulley. This support is facing right and has 304.8 mm of stagger to the left.

As the contact wire height for this one is 5486.4 mm the chosen drop tube will be selected as type 53 for the first position, to cover the boom width, and as type 290 for the length.

Then, the catenary support is going to be chosen. The first piece to design is the top mast bracket, which depends on the drop tube. For the one at issue, type MB100 covers the tube diameter, of 120 mm.

The second one is the registration tube, which covers two panels of the lintel. Every panel has a length of 1066.8 mm based on the reference details shown at Annex III, so the selected tube will be type 21.

Both thickness and width of the boom remain the same, so the support bracket, the backing angle and the long shank bolt M16 assemblies chosen for this support are exactly the same as for supports 3 and 5. These pieces are also applied to the pulley, as their design process is the same.

All the selected elements for support 3 and 5 are shown at the next list:

- 120 x 120 x 4.5 Drop Tube (348.00083.53.300)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (371.00244.050)
- Curved Registration Arm With Ring (442.00096-2.10)

For the return conductor at support 5:

- 120 x 120 x 4.5 Drop Tube (348.00071.53.180)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Return Conductor Insulator Assembly (472.055.24)

For support 4:

- Top Mast Bracket (353.00304.MB100)
- Long Shank Bolt M16 (396.00009.26)
- 60 x 60 x 6 Backing Angle (348.00067-2.46)
- Support Bracket (433.00168-2.046)
- Ø48.3 Registration Tube (353.00273.21)
- 120 x 120 x 4.5 Drop Tube (348.00071.53.290)

4. Bill of quantities

One of the most important conclusions of the designing process is the BOQ. It consists on the development of a list of every single piece involved in the renewal process. At this list the reference of every single component is written and the number needed of each element is also given.

It is really important to avoid any possible mistake as this is one of the most important steps off the renewal process due to the relevancy of it. If any component is missing or the reference is incorrect it can lead to a geometrical failure or to an assembly problem.

Making it clear and simple will make the person in charge life easier and will accelerate the hole process of the renewal. For this reason, the table makes up the difference between the cost per structure and the cost per component. It is decision of the supervisor to choose which one will be use for the selection process.

All the costs involved are obtained from the budgets generated by Adif, which is the administrator of the railway infrastructures at Spain and the borderline countries. They include all the costs for both supply and installation processes.

The obtained BOQ is attached at Annex V.

5. Pendulum design

On this chapter the pendulum design is going to be developed. Basically, it consists of placing suspension hangers all along the different lines. In this case, they will be set at wires 84, R89 and R90, which are located at the up main line and at the up & down clancton.

There are different things to choose or select. First of all, the space between them or the sag. Both are read from the GEFF tables attached at Annex VI. The spacing is measured between the axes of the hangers.

The other parameter to obtain is the length of these droppers. It will be measured from the suspension wire to the contact wires. Although it can be read from the tables available at GEFF manuals, in this case due to the geometry of the lines it will be necessary to calculate some reductions to this length. They can be obtained using the next equation:

$$R = H_s - H_1 + (H_1 - H_2) \cdot \frac{x}{L} \tag{14}$$

Where:

R ≡ reduction in mm

H_s ≡ system height on which the table is based

H_1, H_2 ≡ distance between contact and suspension wires

x ≡ distance to the droppers from one end of span

L ≡ span length

For a better understanding watch Figure 29.

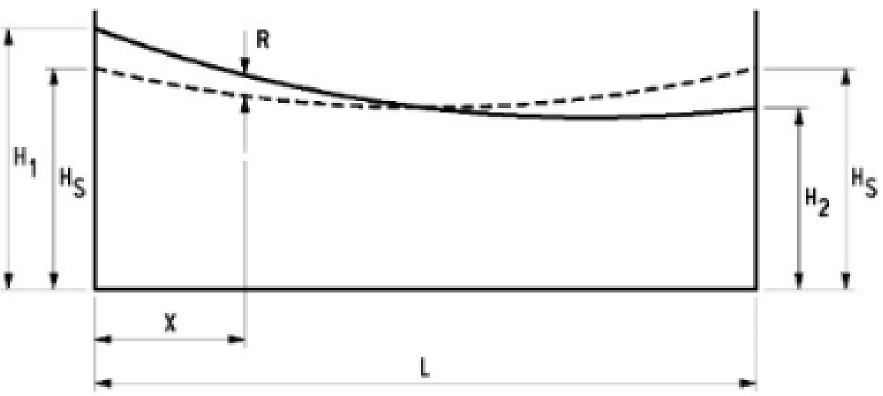

Figure 29. Adjustment for non-standard system heights

All the results obtained are attached at Annex VI.

One last reduction need to be calculated as there is a high speed section insulator attached at wire R89 between structures B51-100 and B51-102. This reduction must be added to the earlier ones, as they are complementary. In this case, the equation used is:

$$R = \frac{W \cdot x \cdot y}{T \cdot L} \cdot 1000 \qquad (15)$$

Where:

R ≡ reduction in mm

x, y ≡ distance of point load to end of span

W ≡ weight on point load (N)

T ≡ catenary tension (N)

L ≡ span length

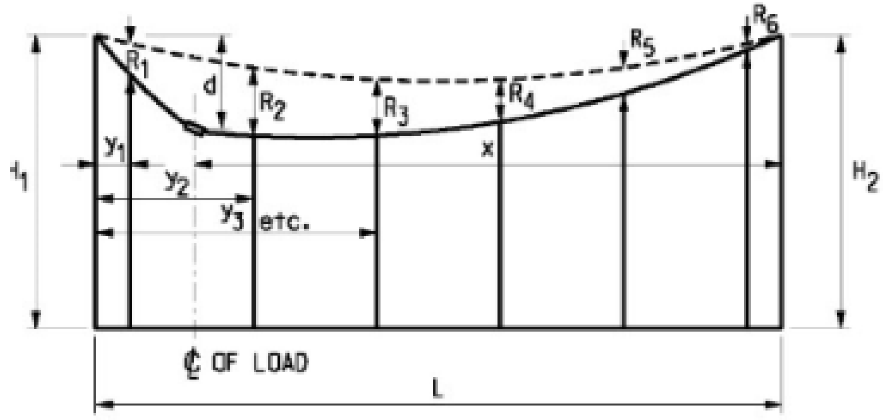

Figure 30. Adjustment for point load in span

For droppers to left of point load y is taken to the left hand end span and x to the right one. For droppers on the right is vice versa.

As the section insulator is placed closer to B51-102, the reduction along the corresponding six droppers will be different. The reductions obtained are:

R (HSSI)
22,37
77,17
131,96
186,76
241,56
89,47

Table 3. Reductions due to the section insulator

6. Platform Gauging

The main objective of this chapter is measuring the clearance of the structures. There are several allowances and tolerances that must be taken into account while calculating the distance between a standing surface and live elements. Figure 31 illustrates this process.

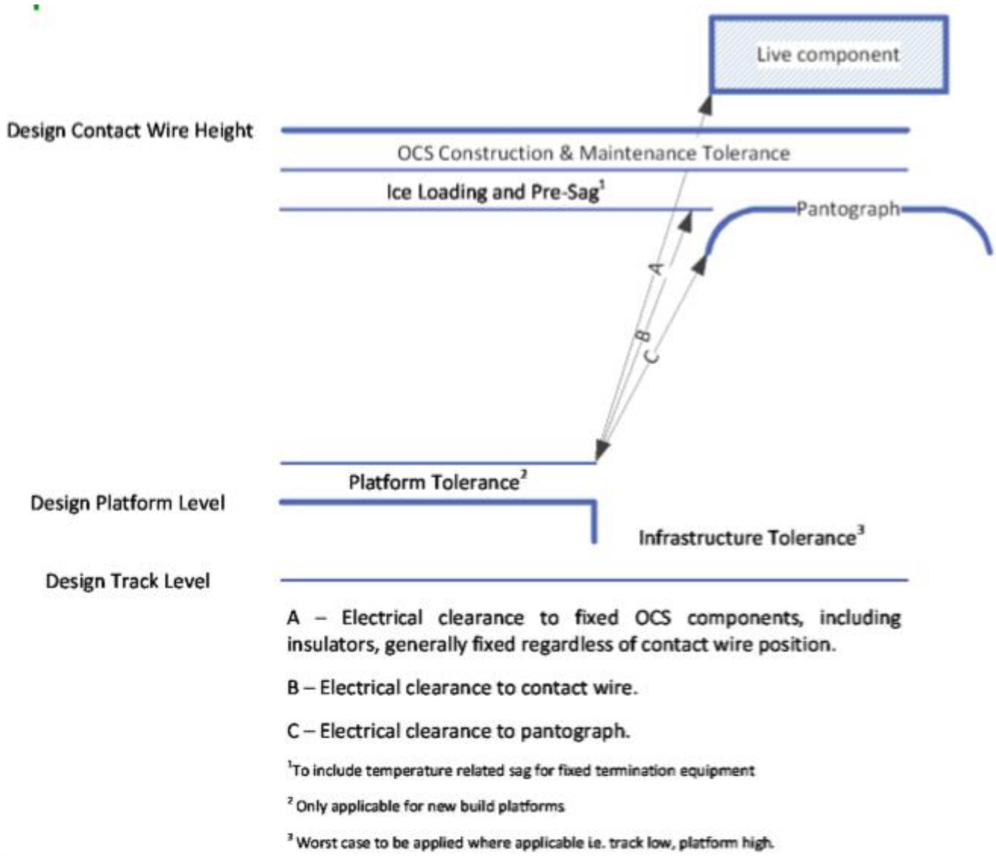

Figure 31. Calculation of clearances at public platform areas

In order to measure the clearance dimensions a straight line will be used from the platform edge to the nearest live part, of the infrastructure or of the pantograph. Platform, track and OCS related construction and maintenance tolerance are included in the measurement, although the uplift and the sway are discard. The track cant will also affect the clearance measures.

If for the final result is not possible to achieve a clearance greater than 3.5 m, there are some options to improve, such as taking into account the train body as a barrier for mitigation. However, for the station involved in this case it will not be necessary at all, as the results show that it is working at the optimal state [28].

It is calculated for two lines using the data from the layout at Annex I. This information is given in miles and feet, so the first thing to do is converting them into meters, as the Colchester's platform gauging reference tables use meters.

Then x and y are read from the data sheets. Both coordinates indicate the distance between the platform and the railway line, measured parallel to this last one.

Finally, using the contact wire height, the width of the railway track obtained from the layouts at Annex III and Figure 32 all the electrical clearances are calculated.

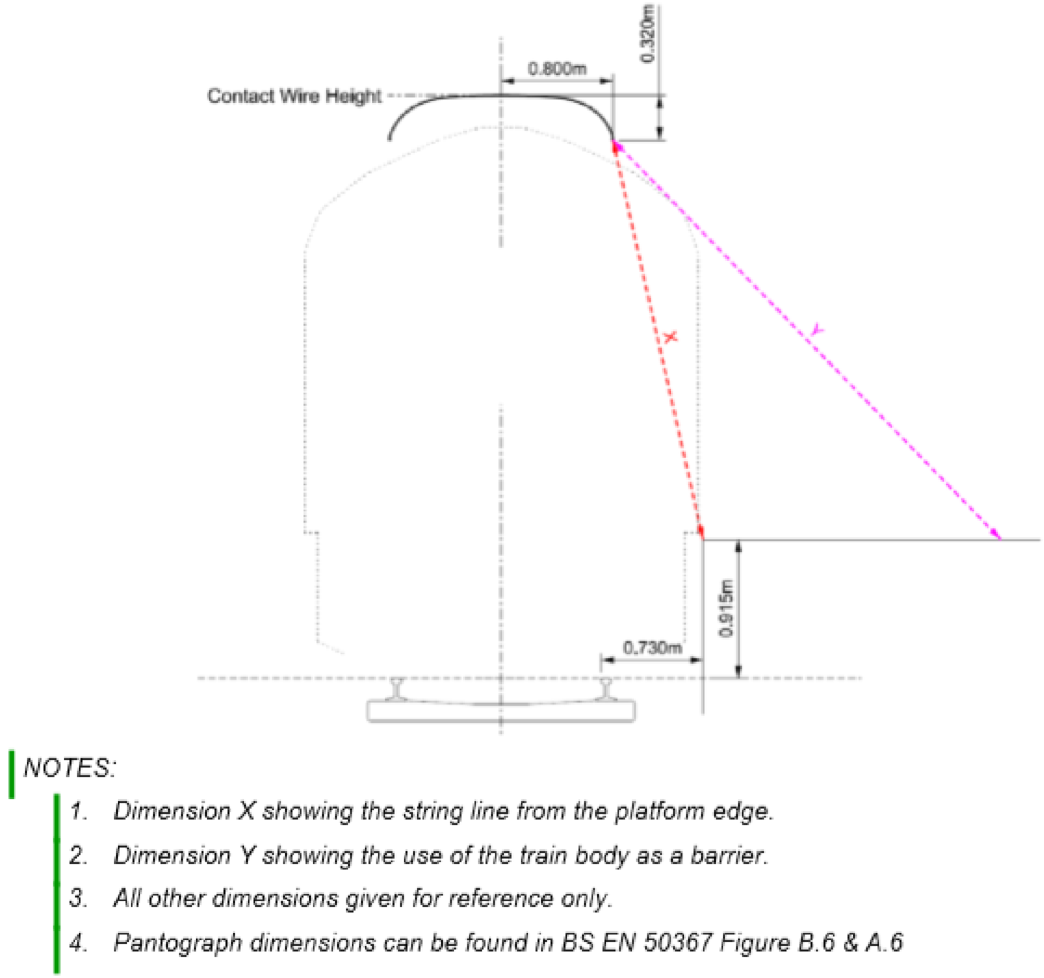

Figure 32. Overview of measurement points

It is not too complicated once all the distances are obtained from the layouts and the data sheets, as it is only calculating the distance between two points whose coordinates are known.

As it has already been said, it can be appreciated on the results that every electrical clearance is greater than 3.5 m, so there is no need of taking extra decisions.

The results for the up main line are attached on Table 4.

Location	Chainage (m)	Horiz (X)	Vert (Y)	Oversail (Z)	Coper Depth	x (m)
B 51 91	83.066,23	768	813	533	109	4,10
[redacted]						
B 51 96	83.120,18	767	919	472	106	4,00
[redacted]						
B 51 100	83.146,70	754	899	438	106	4,01
[redacted]						
B 51 102	83.203,39	763	899	467	104	3,97
[redacted]						
B 51 103	83.230,82	737	958	394	70	3,95
[redacted]						
B 51 105	83.281,42	751	907	447	104	4,01
[redacted]						
B 51 106	83.344,51	724	962	490	100	3,95

Table 4. Electrical clearance results for up main line

The results for the up & down clacton line are attached on Table 5.

Location	Chainage (m)	Horiz (X)	Vert (Y)	Oversail (Z)	Coper Depth	x (m)
B 51 100	83.146,70	754	899	438	106	4,01
[redacted]						
B 51 102	83.203,39	763	899	467	104	3,97
[redacted]						
B 51 103	83.230,82	737	958	394	70	3,95
[redacted]						
B 51 105	83.281,42	751	907	447	104	4,01
[redacted]						
B 51 106	83.344,51	724	962	490	100	3,95

Table 5. Electrical clearance results for up & down clacton line

7. Conclusions

To conclude this project, it can be said that the renewal has been completely successful. The catenary technology used before, Mk1, has been replaced by the most recent one, GEFF. All the differences between both have been analyzed and studied looking for the biggest improvement on the line, which is with the GEFF systems as it has a few advantages over the Mk1 system.

These advantages are present at different sectors, going from better properties, with wires carrying a bit more tension, to safer elements, as the material of the wires of the Mk1 were really toxic and harmful for the workers. Although there is a difference in the voltage carried by the wires, it is quite small, just a few kilovolts. So, as the whole installation was constructed for the worst case possible, design to support overload situations, it was possible to reuse the elements as they would resist the little increase off tension.

In order to accomplish this renewal a calculation tool was developed using excel in order to obtain all the necessary data to perform the different design processes. It covers different aspects of the line, from the geometrical calculations to the support hangers' parameters and the platform gauging.

The aim of the design was to reduce the costs as much as possible, as the renewal of this kind of stations is really expensive. It can involve traffic cuts for a long time or closed streets, which have a direct impact on the society, and changing wires or supports is really expensive. For these reasons, only the essential components have been replaced. All of them successfully. There was only a support for the fixed anchor which was not exactly the perfect solution, as the bracket used is longer than what is really need, but as there was no other choice it can be used perfectly as it is only a visual defect and it does not have any impact on the running lines. A bill of quantities was done also in order to facilitate the workers job. In this case, it was crucial to do a list very clear and organized were all the components involved in the different processes were detail. Then, it was possible to find an approximation of the cost of this renewal using the budgets of Adif.

Also, the gauging results show that the electrical clearance is working in the optimum conditions and within the limits stablished by the norms, which means that no extra measures need to be taken.

In conclusion, it has been done according to the specifications and the regulations of Great Britain, attending to every single detail resulting in a satisfactory renewal.

8. Future developments

Ideally, it would have been better to have a more global scope, concerning a bigger extension of the lines. Going further of the limits of Colchester's station would allow to study and analyze the impact of every single structure involved out of the limits of the station, which permits to evaluate the real impact of the renewal. However, it goes far beyond the level of a final degree project. In this project only a small renewal is taking place. In fact, performing a renewal of this caliber would imply a renewal of the whole canton.

Also, it would have been great to generate cross sections layouts, such as the old ones used at the design chapter. They can be developed using design tools such as micro station, and they are usually a standard requirement. As the elaboration of the plans of every single support involved is a lot of work, and it would request a lot of delineation hours it exceeds the requirements of a final degree project.

Finally, it should be noted that is quite complicated to gather information from the Mk1 systems. The majority of the layouts are really old and quite worn. Some were illegible. Some just were impossible to found. However, the GEFF system is completely different. There are plenty of manuals and references available, and all of them are clear, clean and organized, which allows an easier decision making process.

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ANNEX I

Colchester's station layout

On the next picture the layout is shown. However, for a better resolution use the link given below.

WINDSPEED	IN ACCORDANCE WITH NR/L2/CIV/072	22.08m/s

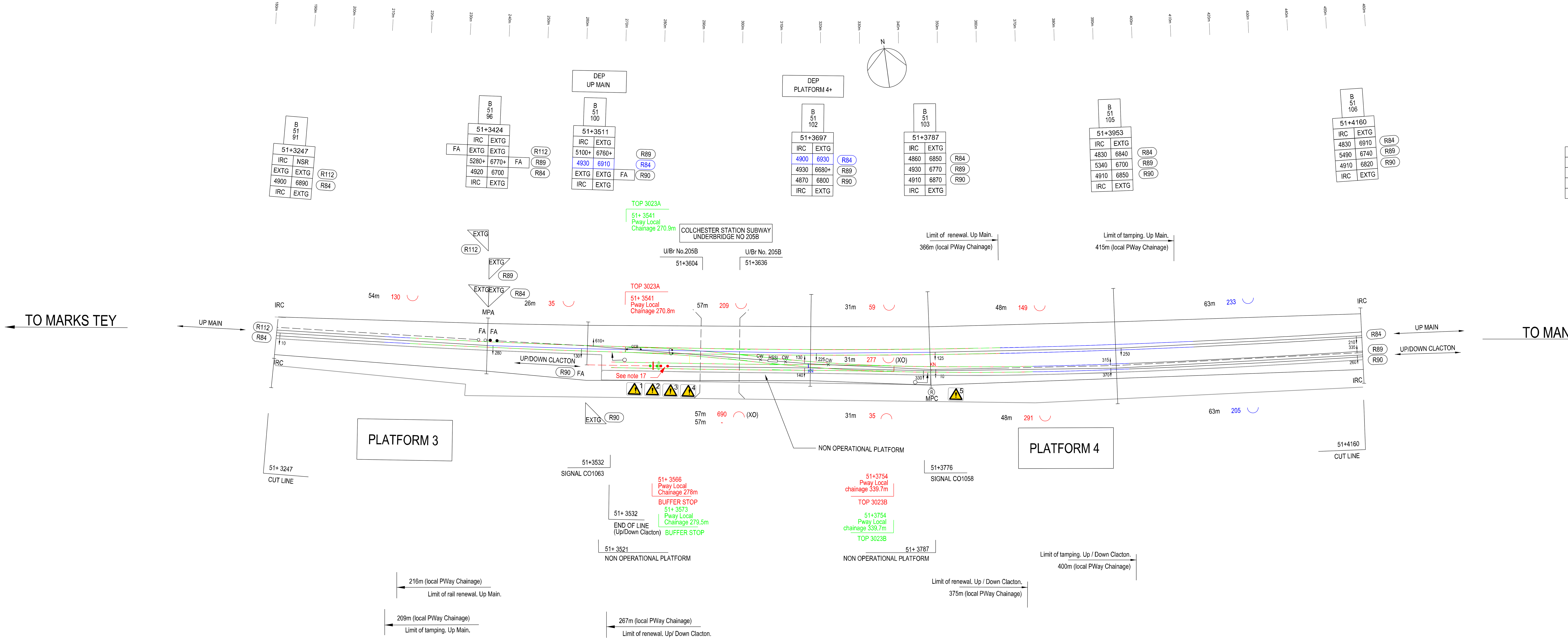
ABBREVIATIONS KEY:

ALT	ALTERNATE FEED
APC	AUTOMATIC POWER CONTROL MAGNET
ATFA	AUTO TRANSFORMER FEEDER ANCHOR
AUX	AUXILIARY CATENARY
BFA	BARE FEEDER ANCHOR
BWA	BALANCE WEIGHT ANCHOR
CAT	CATENARY
CONT	CONTENARY
CW	CONTACT WIRE
DEP	DESIGNATED EARTHING POINT
EWA	EARTH WIRE ANCHOR
EXTG	EXISTING
FA	FIXED ANCHOR (AT AND FT EQUIPMENTS)
HSSI	HIGH SPEED SECTION INSULATOR
IATF	INSULATED ATF
IKN	INSULATED KNUCKLE
IRC	INSULATED RC
KN	KNUCKLE
M	MOTORISED (FOR SWITCHES)
MPA	MID POINT ANCHOR
N/C	NORMALLY CLOSED
N/O	NORMALLY OPEN
NR	NOT REGISTERED
NS	NOT SUPPORTED
NSR	NOT SUPPORTED OR REGISTERED
RCA	RETURN CONDUCTOR ANCHOR
SSA	SELF SUPPORTING ANCHOR
SSSI	SLOW SPEED SECTION INSULATOR
SL	STRING LINE
TOP	TOE OF POINTS
TBC	TO BE CONFIRMED

COLOUR KEY:
BLACK - EXISTING ITEMS
RED - NEW ITEMS
GREEN - ITEMS TO BE REMOVED
BLUE - FINAL POSITION OF MODIFIED ITEMS

KEY:

ANCHORS: BALANCE WEIGHT, FIXED — BWA, FA
CUT-IN INSULATION: PORCELAIN, GLASS FIBRE
SECTION INSULATOR: HIGH SPEED, SLOW SPEED — HSSI, SSSI
SWITCH — SWITCH NUMBER
TAIL WIRE SPLICES: — TAIL
CW, CW/CAT, AUX, CONT — CW, CW/CAT, AUX, CONT
JUMPERS: EQUIPOTENTIAL, CURRENT CARRYING, IN-SPAN
BIAS WEIGHT — BIAS
WIRE RUN MARKERS: NUMBER, HALF TENSION LENGTH — XXX
SPAN, VERSINE — XXXXm XXX
TRACK
OLE WIRE RUNS:
IN RUNNING
OUT OF RUNNING
OTHER WIRES BARE / INSULATED
RC
ATF
BF
EW
OVERHEAD POWER LINES
BURIED SERVICES
CROSS CONTACT BAR — CCB
HAZARD TRIANGLE WITH REFERENCE TO SHE BOX



22.08m/s	22.08m/s

22.08m/s	WINDSPEED

Safety, Health and Environmental Information

Construction

1. During the permanent way works there is an increased risk of electrocution due to the differences in potential due to the removal of traction bonds.The contractor is to take particular care with any red bonds in the area.The contractor shall take appropriate measures to protect workers.

2. There is a risk from residual voltage in the return conductors. The contractor should use appropriate methods to confirm that this cabling is discharged prior to commencing any works on the return conductor.

3. The contractor shall dispose of any recovered equipment using an approved disposal method.

4. Cadmium copper equipment is present at site. Contractor to ensure staff do not smoke, eat or drink without thoroughly washing their hands. Suitable gloves are to be worn.

5. Red bond present within the site. Contractor to adopt safe working method.

WIRE RUN	TYPE	CW TYPE	CW TENSION	CAT TYPE	CAT TENSION	TENSION LENGTH
R84	MK1-02-AT-S-ST	107 sqmm Cad Cu	11.30KN	19/2.1 Cad Cu	8.195KN	EXTG
R112	MK1-02-AT-S-ST	107 sqmm Cad Cu	11.30KN	19/2.1 Cad Cu	8.195KN	EXTG
R89	MK1-00-AT-S	107 sqmm Cad Cu	8.91KN	19/2.1 Cad Cu	8.195KN	EXTG
R90	MK1-00-AT-S	107 sqmm Cad Cu	8.91KN	19/2.1 Cad Cu	8.195KN	EXTG

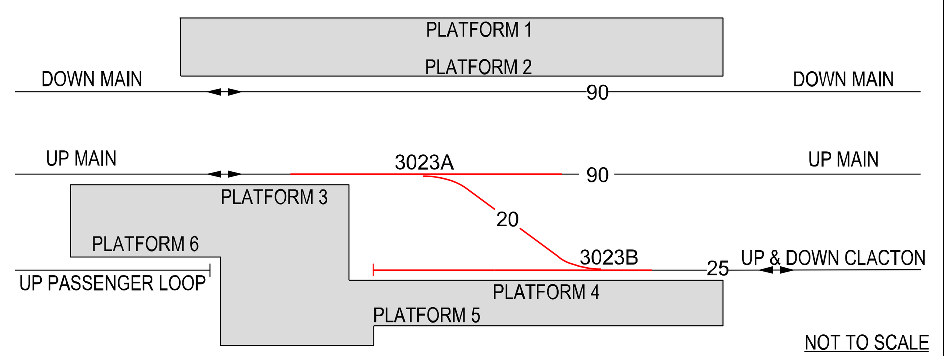
Notes:

16. The versine for span between structures B/51/100 and B/51/102 along Up/Down Clacton cannot be calculated because the road starts 21 feet after structure B/51/100.

17. The proposed location for Cut-in insulator is approximately 20m from the structure B51/100 and 2 m behind the proposed buffer stop location.

EXISTING & PROPOSED PSR DIAGRAM

COLCHESTER STATION



NOT TO SCALE

SAFETY, HEALTH AND ENVIRONMENTAL INFORMATION BOX

IT IS ASSUMED THAT WORKS ON THIS DRAWING WILL BE CARRIED OUT BY A COMPETENT CONTRACTOR WORKING, WHERE APPROPRIATE, TO AN APPROPRIATE METHOD STATEMENT

THIS DRAWING IS TO BE USED ONLY FOR THE PURPOSE OF ISSUE THAT IT WAS ISSUED FOR AND IS SUBJECT TO AMENDMENT

Notes:

1. The existing OLE Equipment type is 25kV Mark 1 Simple Auto Tension. Existing wire run details for catenary and contact wires have been taken from the site survey. However there are few UK1 components present on site from previous renewal works.
2. The area is classified as not polluted.
3. Heights and Staggers are shown in millimetres, Spans are in metres. All other dimensions are in millimetres unless otherwise stated.
4. Heights are shown to the nearest 10mm.
5. Staggers are shown to the nearest 5mm.
6. The North Arrow is indicative only.
7. The height and staggers and other unverified information marked with "+" values have been taken from record drawings or survey model.
8. The S&C installation team are to ensure that a pantograph equipped vehicle ensures that crossovers and overlaps are compliant and pantograph clearances are maintained .
9. All tension lengths remain unchanged as part of the design.
10. The structure locations have been obtained from the record drawings ECC/O/L246 Rev L and SE103d/LAY1 Rev 3.
11. No works have been proposed along the Down Main as part of the renewal works.
12. Down Main and Platform 1 & 2 has been omitted for clarity.

REVISION DETAILS	By / Checked	Approved	Date	Suffix

Purpose of Issue

FOR CONSTRUCTION

Client

Project Title

COLCHESTER 3023

Drawing Title

OVERHEAD LINE ELECTRIFICATION PROPOSED LAYOUT

Designed	Drawn	Checked	Approved	Date

URS Internal Project No.	Suitability: Fit for Construction	Engineering Manager
Scale @ 445 x 1261: 1:500 H/1:500 V	Zone / ELR / Mileage: LTN1 - 51M 49C to 51M 63C	

Drawing Number | Rev

ANNEX II

Colchester's station geometrical calculations

Location	Wire	Stagger (mm)	Contact wire height (mm)	Catenary height (mm)	Structure Span (m)	Track radius (m)	Versine (mm)	Midspan offset (mm)	Blow off (mm)	Stagger effect(mm)	Actual deviation(mm)	Ym (mm)	Contact wire gradient	Gradient variation
B 51 91	R112	10												
					54	2803,85	130							
B 51 96	R112	280												
B 51 91	R84	10	4900	6890										
					54	2803,85	130	275	40,42	-50,86	391,20	391,2	2700	
B 51 96	R84	280	4920	6700										15525,0
					23	1889,29	35	-130	7,33	0,00	390,80	390,8	2300	
B 51 100	R84	-610	4930	6910										-1040,5
					57								-1900	
B 51 102	R84	225	4900	6930										-1308,9
					31	2036,02	59	234	13,32	-13,68	292,64	392	-775	
B 51 103	R84	125	4860	6850										1503,0
					48	1932,89	149	316,5	31,94	-3,86	393,60	393,6	-1600	
B 51 105	R84	210	4830	6840										
					63	2129,29	233	463	55,02	-0,56	394,80	394,8		
B 51 106	R84	250	4830	6910										

Table 6. Up main line calculations

No calculations are done at Up passenger loop line as there is no need and no data, it is just an existing structure.

Location	Wire	
B 51 91	R112	**EXTG**
B 51 96	R112	**EXTG**

Table 7. Up passenger loop line calculations

Location	Wire	Stagger (mm)	Contact wire height (mm)	Catenary height (mm)	Structure Span (m)	Track radius (m)	Versine (mm)	Midspan offset (mm)	Blow off (mm)	Stagger effect (mm)	Actual deviation(mm)	Ym (mm)	Contact wire gradient	Gradient variation
B 51 96	R89	280	5280	6770										
					26	2414,29	35	-130	11,88	0,00	376,80	376,8	-144	
B 51 100	R89	-610	5100	6760										
								-370						
B 51 102	R89	-130	4930	6680										
					31	-3432,14	-35	-95	16,89	0,00	390,80	390,8		
B 51 103	R89	10	4930	6770										
					48	989,69	291	138,5	40,50	-26,35	374,40	374,4	117	
B 51 105	R89	-315	5340	6700										-162
					63	2420,12	205	-120	69,78	-0,18	154,59	368,4	420	
B 51 106	R89	-335	5490	6740										
B 51 102	R90	140	4870	6800										
					31	-3432,14	-35	200	16,89	0,00	391,60	391,6	775	
B 51 103	R90	330	4910	6870										
					48	989,69	291	641	40,50	-0,40	391,60	391,6		
B 51 105	R90	370	4910	6850										
					63	2420,12	205	520	69,78	-5,59	391,60	391,6		
B 51 106	R90	260	4910	6820										

Table 8. Up & Down Clancton line calculations

ANNEX III

Colchester's station structures layouts and references

For the design of structure B51-91:

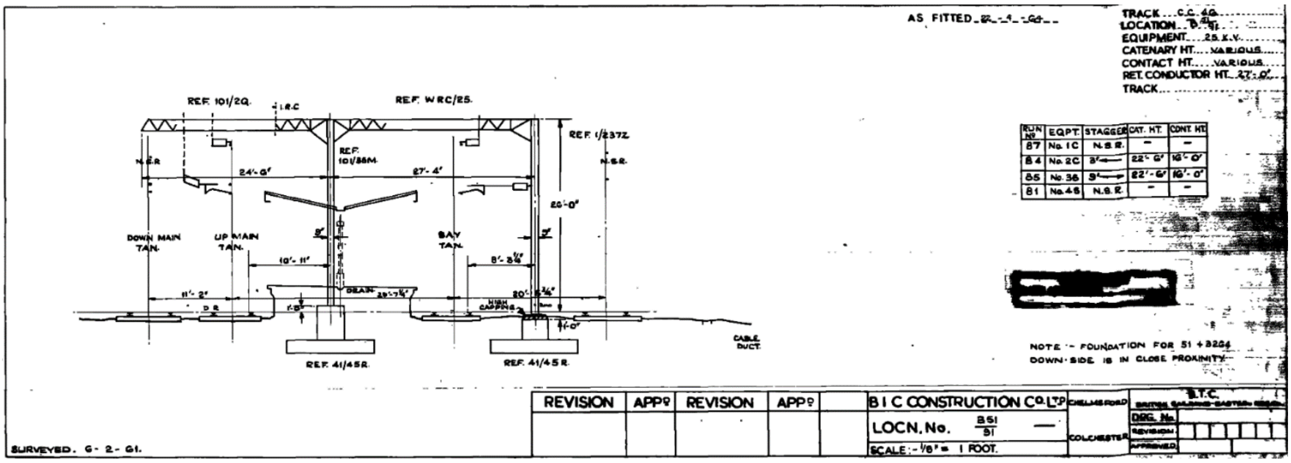


Figure 33. B51-91 layout

	WIRE (L TO R)					
	1		2		3	
STAGGER	N. S. R.		3" ←		9" →	
CANT.			¾" LEFT.		NIL	
CURVE.			TANGENT		TANGENT	
DESCRIPTION.	QTY	REF	QTY.	REF.	QTY	REF.
CATY. SUPP. S.P.S			1	13/3A	1	13/3A
CATY SUPP. ASSY.			1	201/0/2/4	1	201/0/2/2
CONT. REG ASSY			1	13/17A	1	14/4L
CONT. REG. S.P.S			1	304/47/5/4	1	302/0/1/2
CONT. REG. FITTING			1	AG2G		
CONT. REG. FITTING						
STEADY ARM.						
AUXILIARY CLIP.						
B.W. ANCH. S.P.S.						
B.W. GUIDE TUBE						
CANTILEVER ASSY						
TOP TIE ATTACH						
STRUT. ATTACH						
MAST ATTACH.						
B.W. FITTINGS.						
B.W. FITTINGS.						
35° STOP						
35° STOP.						
WASHER			2	⅝" Z		
BONDING STUD		V11873	2	V11873		
CAP FINIAL.		[illegible]				
BONDING ASSY		[illegible]	1 2	CF 453 CF 454		
BONDING MAST ATT.						
RET. CON. INSLTR			1	A1059		
RET. CON S.P.S.			1	13/1A		
No. PLATE		K11440	1	K11440		
No PLATE CLIP.		K11968	2	K11968		
No. PLATE PACK		[illegible]				

Figure 34. B51-91 old structure details

For the design of structure B51-96:

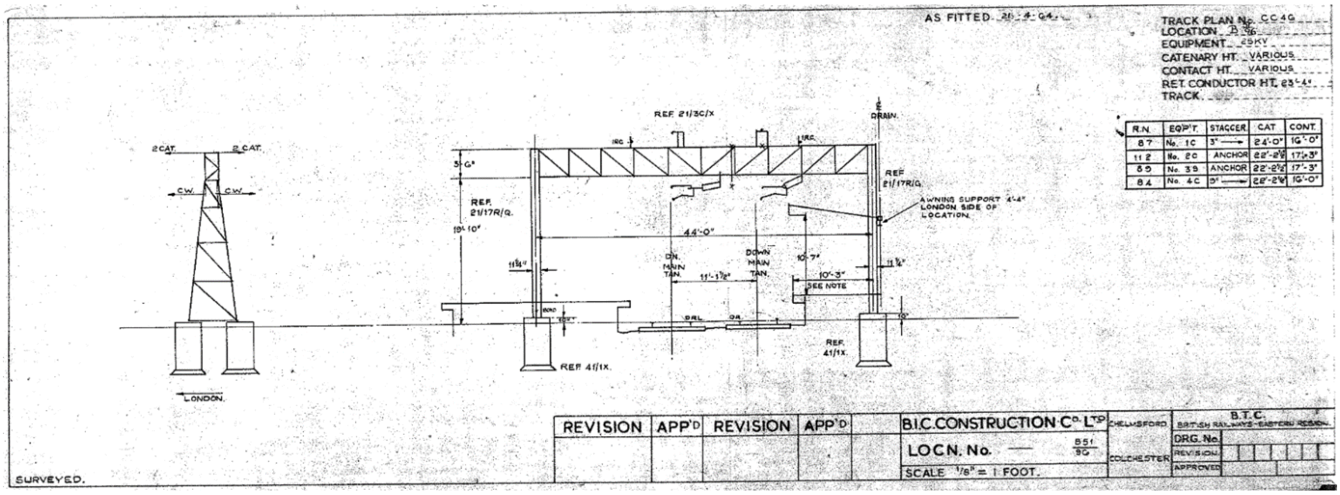


Figure 35. B51-96 layout

	WIRE L. TO R.							
	1		2		3		4	
STAGGER.	3" →		ANCHOR.		ANCHOR.		9" →	
CANT.	NIL						NIL.	
CURVE.	TANGENT						TANGENT	
DESCRIPTION.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.
CATY. SUPP. S.P.S.	1	11/5C					1	15/24N
CATY. SUPP. ASSY.	1	241/0/2/4					1	417/G0/4
CONT. REG. S.P.S.	1	13/2W/P					1	13/2W/P
CONT. REG. ASSY.	1 *	300/0/1/4					1 *	311/0/3/4
CONT. REG. FITTING	1	A8G5					1	A8G5
CONT. REG. FITTING								
STEADY ARM.								
AUXILIARY CLIP	1	93A					1	93A
B.W. ANCH. S.P.S.								
B.W. GUIDE TUBE.								
CANTILEVER ASSY.								
TOP TIE ATTACH.T								
STRUT ATTACH.T								
MAST ATTACH.T								
B.W. FITTINGS.								
B.W. FITTINGS.								
35° STOP.								
35° STOP.								
JUMPER S.P.S.							1	11/5C
AUXILIARY CLIP	1	A30					1	A30
CAT. ANCH.			1	401/0/0/2	1	401/0/0/2		
CONT. ANCH.			1	404/0/0/2	1	404/0/0/2		
ANCHOR ASSY.								
ANCHOR S.P.S.			1	315/38	1	315/38		
BONDING STUD	2	V11873		* SPL LESS A29				~~V11873~~
CAP FINIAL	~~1~~	~~A1020~~						~~A1020~~
BONDING ASSY.	1 / 1	C.F. 453 / C.F. 454						
WASHER	2	5/8" Z						
RET. CON. INS.L.TR	1	A1059					1	A1059
RET. CON. MAST ATT.	1	13/2W/S.					1	13/2W/S
No. PLATE	1	K11440						~~K11440~~
No. PLATE CLIP	2	K11968						~~K11968~~
No. PLATE PACK		~~K11587~~						~~K11587~~

Figure 36. B51-96 old structure details

For the design of structure B51-100:

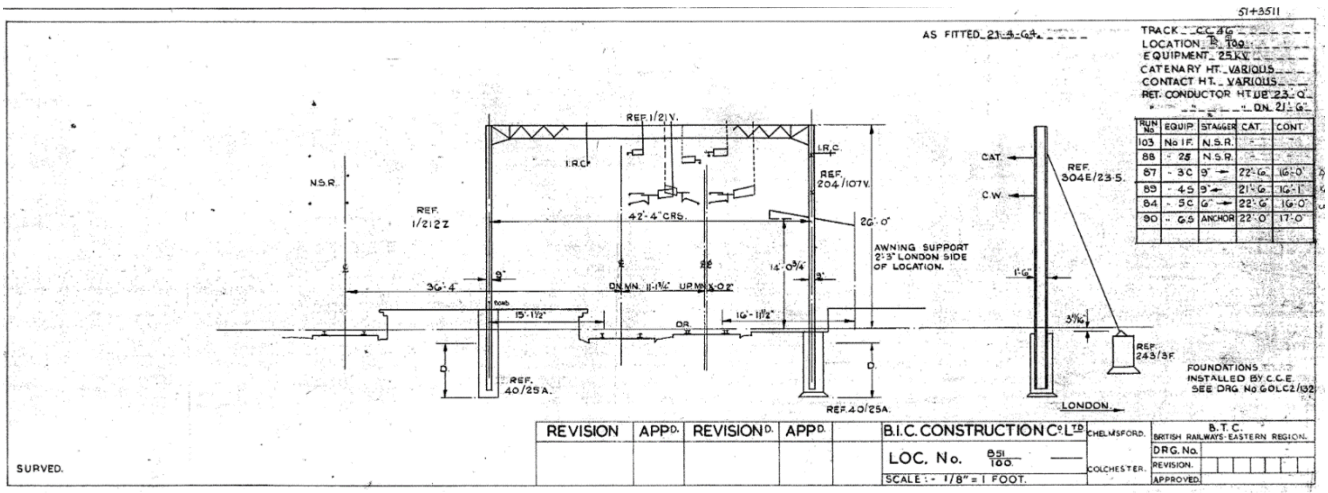


Figure 37. B51-100 layout

	WIRE (L TO R).								WIRE (L TO R).							
	1		2		3		4		5		6		7		8	
STAGGER	N.S.R		N.S.R		9" →		9" ←		6" →		ANCHOR					
CANT.					NIL		NIL		NIL							
CURVE.					TANGENT		TANGENT		TANGENT							
DESCRIPTION.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.
CAT. SUPP. S.P.S.					1	13/3A	1	13/5A	1	13/3A						
CATT. SUPP. ASSY.					1	201/0/2/4	1	201/0/2/2	1	201/0/2/4						
CONT. REG. ASSY.					1	304/47/5/4	1	301/0/5/2	1	304/47/5/4						
CONT. REG. S.P.S.					1	13/17A	1	13/17A	1	13/17A						
CONT. REG. FITTING					1	A626	1	A626	1	A626						
CONT. REG. FITTING																
STEADY ARM.																
AUXILIARY CLIP.					1	93A			1	93A						
B.W. ANCH. S.P.S.											1	215/11V				
B.W. ANCH TUBE.																
CANTILEVER ASSY.																
TOP TIE ATTACH.																
STRUT. ATTACH.																
MAST ATTACH.																
B.W FITTINGS.																
B.W. FITTINGS.																
35° STOP.																
35° STOP.																
CAT ANCH.											1 *	401/0/0/2				
CONT ANCH.											1 *	404/0/0/2				
P.G. CLAMP.									4	A28						
CUT INS.											1	532/0b/2				
EARTH ASSY.											1	AI7. A28. R484				
WASHER	2	⅝" Z								* S.P.L. LESS A22.						
BONDING STUD.		V11873			2	V11873		~~V11873~~								
CAP FINIAL		~~A1020~~						~~A1020~~								
BONDING ASSY.		~~[illegible]~~			2 2	CF453 CF454										
BONDING MAST ATT.																
RET. CON. INS. AIR					1	A1059					1	A1057				
RET. CON. S.P.S.					1	13/4A					1	18/4H/B/S.				
Nº PLATE.		~~K11440~~			1	K11440		~~K11440~~								
Nº PLATE CLIP.		~~K11968~~			2	K11968		~~K11958~~								
Nº. PLATE PACK.		~~K11687~~						~~K11687~~								

Figure 38. B51-100 old structure details

For the design of structure B51-102:

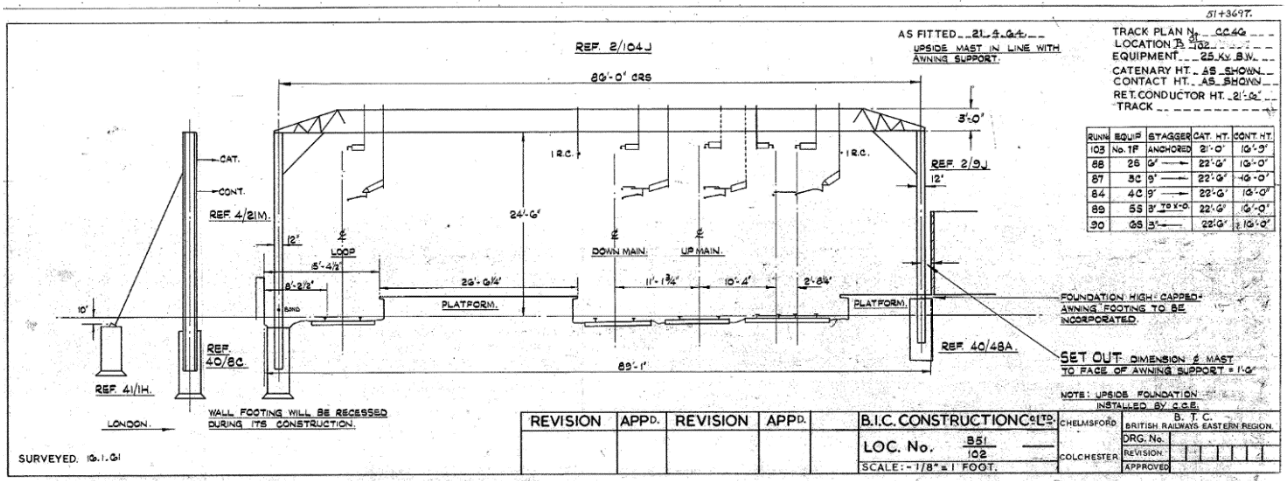


Figure 39. B51-102 structure

	WIRE (L TO R).															
	1		2		3		4		5		6		7		8	
STAGGER.	ANCHOR		6" ⟶		9" ⟶		9" ⟶		3" ⟵		3" ⟵					
CANT.			NIL.		2" LEFT.		2" LEFT.		NIL.		NIL.					
CURVE.																
DESCRIPTION.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.
CAT. SUPP. S.P.S.			1	13/103F	1	13/103F	1	13/103F	1	13/103F	1	13/103F				
CAT. SUPP. ASS'Y.			1	201/0/2/2	1	201/0/2/4	1	201/0/2/4	1	201/0/2/2	1	201/0/2/2				
CONT. REG. S.P.S.			1	13/112F	1	13/112F	1	13/112F				13/112F				
CONT. REG. ASS'Y.			1	311/0/1/2	1	304/47/5/4	1	304/47/5/4			1	311/0/5/2				
CONT. REG. FITTING.			1	A626A	1	A626	1	A626			1	A626				
CONT. REG. FITTING																
STEADY ARM.																
AUXILIARY CLIP.					1	93A	1	93A								
CANTILEVER ASSY.																
ANCHOR S.P.S.	2	215/12V														
ANCHOR FITT.																
ANCHOR FITT.																
CATY. ANCHOR.	1	401/0/0/00														
CONT. ANCHOR.	1	404/0/0/00														
P.G. CLAMP.	1	A28														
P.G. CLAMP.	1	A17														
ETH. CLAMP.	1	A484														
ETH. S.P.S.	1	18/48.														
KNUCKLE.									1	A1087B						
CONT. CLIP.									2	A40						
ANCHOR ASSY.																
CUT. INS.	1	533/00/0/00														
WASHER	2	5/8" Z														
BONDING STUD	2	V11873						~~V11873~~								
CAP FINIAL.		~~A1020~~						~~A1020~~								
BONDING ASSY.	1	CF 253 CF 252														
BONDING MAST ATT.																
RET. CON. INSL'R.					1	A1059					1	A1059				
RET. CON. MAST ATT.					1	13/104F					1	13/104F				
No. PLATE.	1	K11440						~~K11440~~								
No. PLATE CLIP	2	K11968						~~K11968~~								
No. PLATE PACK.		~~K11587~~						~~K11587~~								

Figure 40. B51-102 old structure details

For the design of structure B51-103:

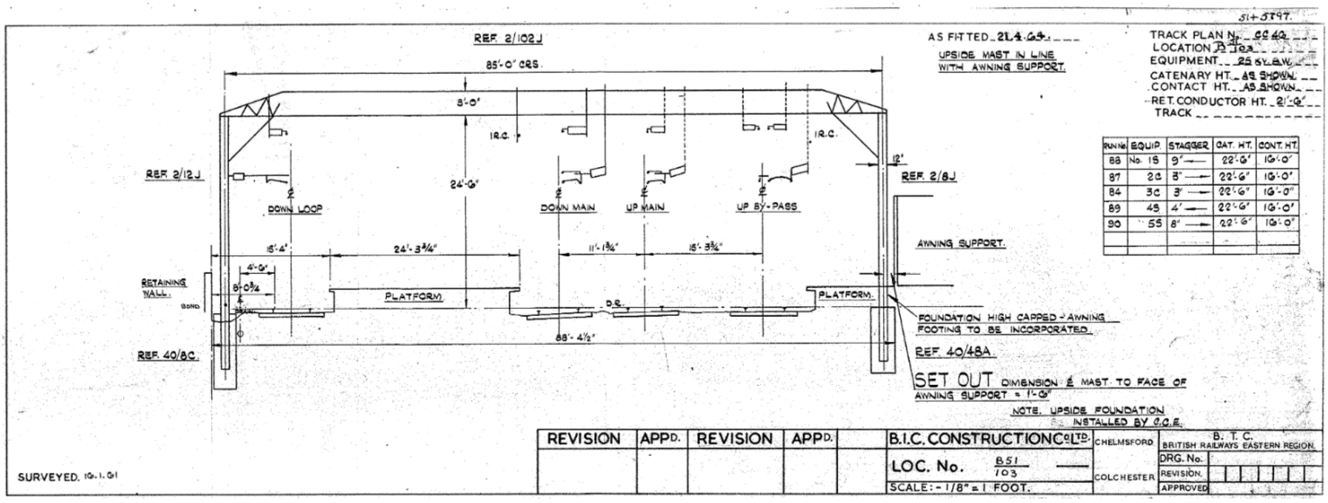


Figure 41. B51-103 layout

	WIRE (L TO R) 1		2		3		4		5		6		7		8	
STAGGER	9" ←		3" →		3" →		4" ←		8" →							
CANT	NIL		2" LEFT		2" LEFT		NIL		NIL							
CURVE	—		—		—		—		—							
DESCRIPTION	QTY	REF.	QTY	REF.	QTY	REF.	QTY.	REF.	QTY.	REF.	QTY	REF.	QTY	REF.	QTY	REF.
CAT. SUPP. S.P.S.	1	13/3P	1	13/103F	1	13/103F	1	13/103F	1	13/103F						
CAT. SUPP. ASSY.	1	201/0/2/2	1	201/0/2/4	1	201/0/2/4	1	201/0/2/2	1	201/0/2/2						
CONT. REG. S.P.S.	1	14/9L	1	13/112F	1	13/112F			1	13/112F						
CONT. REG. ASSY.	1	302/0/1/2	1	304/47/5/4	1	304/47/5/4			1*	311/0/3/2						
CONT. REG. FITTING			1	AG2G	1	AG2G			1	AG2GA						
CONT. REG. FITTING																
STEADY ARM									1	A39						
AUXILIARY CLIP			1	93A	1	93A										
CANTILEVER ASSY.																
KNUCKLE							1	AGG								
									* SPL LESS A913C.							
WASHER	2	5/8" Z														
BONDING STUD.	2	V11873						~~V11873~~								
CAP FINIAL.		~~A1020~~						~~A1020~~								
BONDING ASSY.	1/2	CF 453 / CF 432														
BONDING MAST ATT.																
RET. CON. INSL'R.	1	A1059							1	A1059						
RET. CON. MAST ATT.	1	13/104F														
No. PLATE.	1	K11440						~~K11440~~								
No. PLATE CLIP	2	K11968						~~K11968~~								
No. PLATE PACK		~~K11587~~						~~K11587~~								

Figure 42. B51-103 old structure details

For the design of structure B51-105:

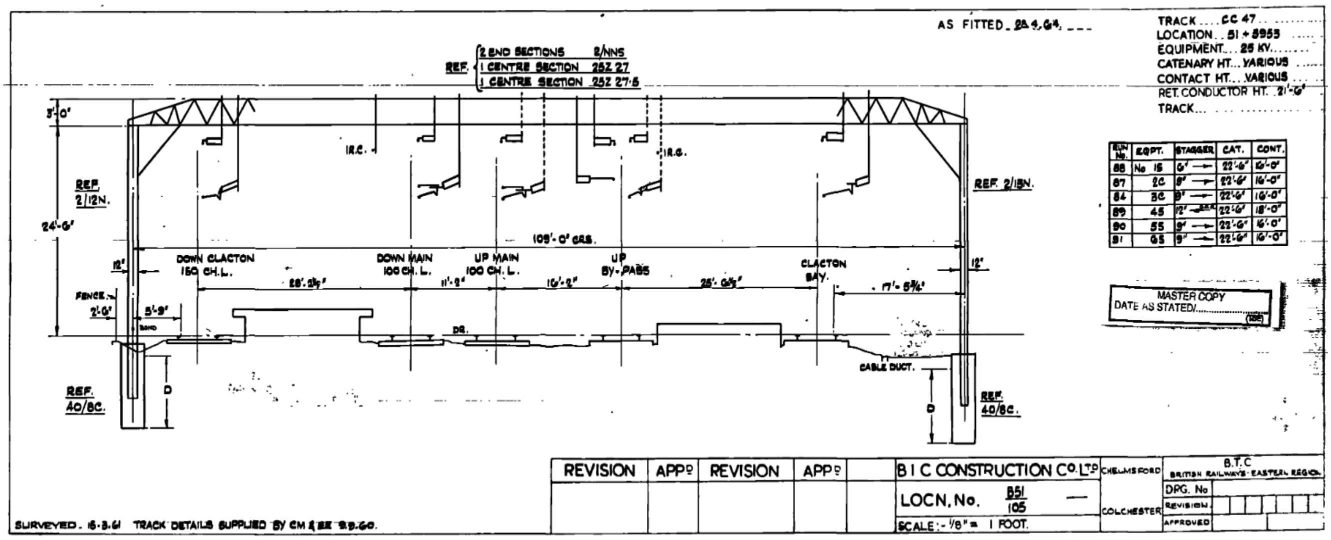


Figure 43. B51-105 layout

	WIRE (L TO R)															
	1		2		3		4		5		6		7		8.	
STAGGER	6" →		9" →		9" →		12" →		9' →		9' →					
CANT.	NIL															
CURVE.	150 CH. L.		100 CH. L.		100 CH. L.											
DESCRIPTION	QTY	REF	QTY	REF	QTY	REF.	QTY	REF.	QTY	REF	QTY	REF	QTY	REF.	QTY	REF.
CATY. SUPP S P S	1	13/103F	1	13/103F	1	13/103F	1	13/103F	1	13/103F	1	13/103F.				
CATY SUPP. ASSY.	1	201/0/2/2	1	201/0/2/4	1	201/0/2/4	1	201/0/2/2	1	201/0/2/2	1	201/0/2/2				
CONT. REG ASSY	1	311/0/1/2	1	304/47/5/4	1	304/47/5/4	1	326/0/2/2	1	* 311/0/1/2	1	301/0/1/2				
CONT. REG. S.P.S	1	13/112F	1	13/112F	1	13/112F	1	13/113F	1	13/112F	1	13/112F				
CONT REG FITTING	1	A626A	1	A626	1	A626	1	A865	1	A626A	1	A626				
CONT REG FITTING																
STEADY ARM.									1	A39						
AUXILIARY CLIP.			~~1~~	~~93A~~	~~1~~	~~93A~~										
B.W. ANCH. S.P.S																
B.W GUIDE TUBE																
CANTILEVER ASSY																
TOP TIE ATTACH												* SPL	LESS	A913C.		
STRUT. ATTACH																
MAST ATTACH																
B.W. FITTINGS																
B.W. FITTINGS																
35° STOP																
35° STOP.																
WASHER	2	5/8" Z														
BONDING STUD	2	V11 873.						~~V11873~~								
CAP FINIAL.		~~A1020~~						~~A1020.~~								
BONDING ASSY	1 1	CF 453. CF 454.														
BONDING MAST ATT.																
RET. CON. INSLTR	1	A1059							1	A1059						
RET. CON MAST ATT.	1	13/105F														
No PLATE	1	K11 440.						~~K11440~~								
No PLATE CLIP.	2	K11 968.						~~K11968~~								
No. PLATE PACK		~~K11 687~~						~~K11687.~~								

Figure 44. B51-105 old structure details

For the design of structure B51-106:

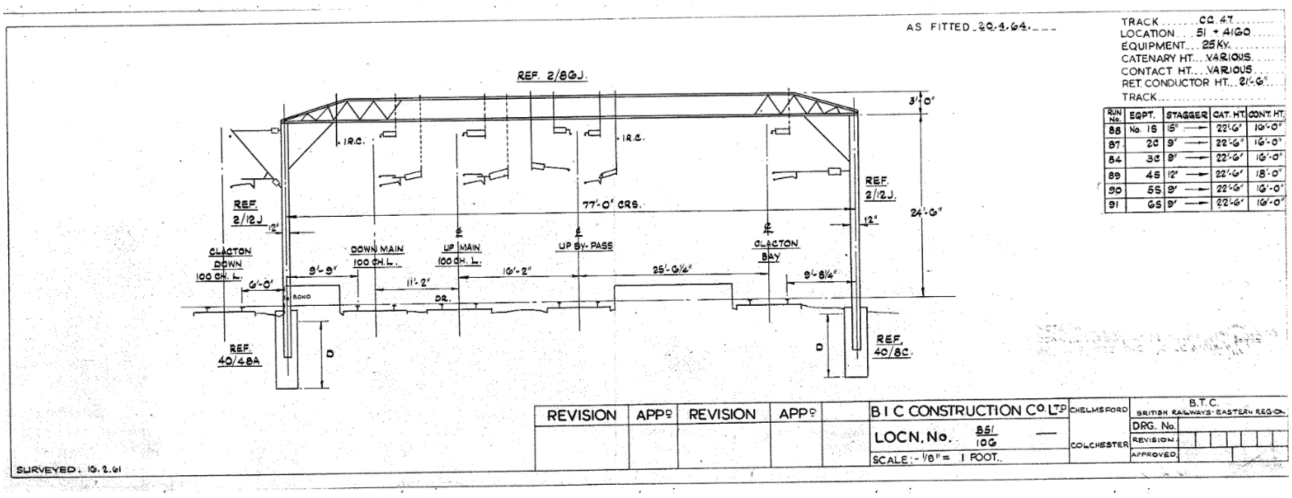


Figure 45. B51-106 layout

	WIRE (L TO R) 1		2		3		4		WIRE (L TO R) 5		6		7		8	
STAGGER	15' →		9" →		9" →		12' ←		9" →		9" →					
CANT.	NIL															
CURVE.	100 CH. L.		100 CH. L.		100 CH. L.											
DESCRIPTION.	QTY.	REF.	QTY.	REF.	QTY	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.	QTY.	REF.
CATY. SUPP. S.P.S			1	13/103F	1	13/103F	1	13/103F	1	13/103F	1	13/103F				
CATY SUPP. ASSY.			1	201/0/2/4	1	201/0/2/4	1	201/0/2/2	1	201/0/2/2	1	201/0/2/2				
CONT. REG. S.P.S.			1	13/112F	1	13/112F	1	13/113F	1	13/112F	1	114/10Z				
CONT. REG. ASSY			1	304/47/5/4	1	304/47/5/4	1	326/0/2/2	1	*311/0/1/2	1	346/0/1/2				
CONT. REG. FITTING			1	A626	1	A626	1	A663	1	A626A						
CONT. REG. FITTING																
STEADY ARM.									1	A39						
AUXILIARY CLIP.			~~1~~	~~93A~~	~~1~~	~~93A~~										
B.W. ANCH. S.P.S.														*SPL LESS	A9/3C.	
B.W. GUIDE TUBE																
CANTILEVER ASSY.	1	0/0/1/2														
TOP TIE ATTACH	1	A271														
STRUT. ATTACH	1	A269														
MAST ATTACH	1	14/146														
B.W. FITTINGS																
B.W. FITTINGS																
35° STOP																
35° STOP.																
WASHER	2	5/8" Z														
BONDING STUD	2	V11 873.						~~V 11 873.~~								
CAP FINIAL.		~~A 1020.~~						~~A 1020.~~								
BONDING ASSY.	2 2	C.F. 453. C.F. 454														
BONDING MAST ATT.																
RET. CON. INSLTR	1	A 1059							1	A1059						
RET. CON. MAST ATT.	1	13/6P														
No. PLATE.	1	K 11 440.						~~K11 440.~~								
No. PLATE CLIP.	2	K 11 968.						~~K11 968.~~								
No. PLATE PACK		~~K 11 587.~~						~~K11 587.~~								

Figure 46. B51-106 old structure details

References:

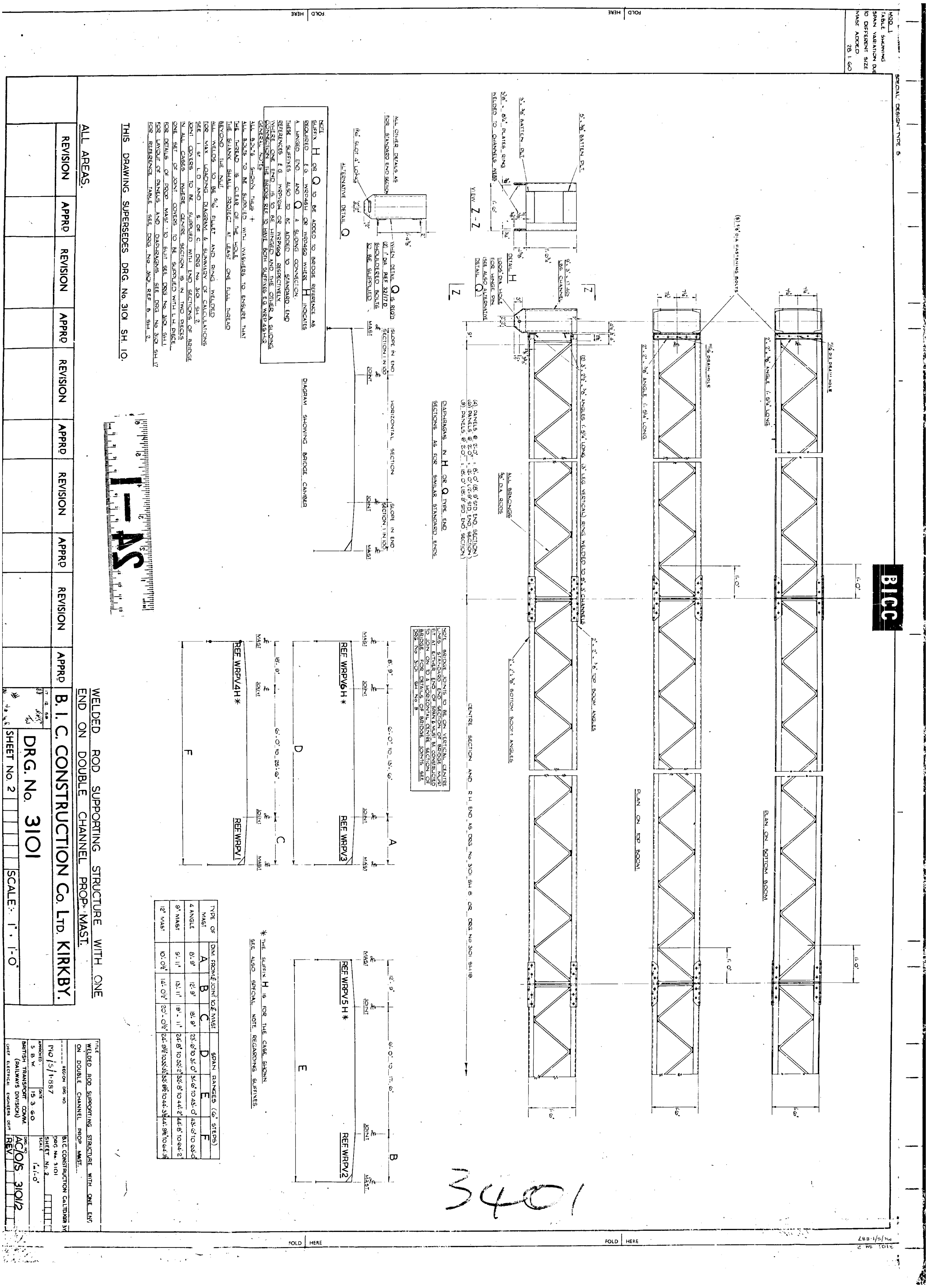


Figure 47. Reference 101

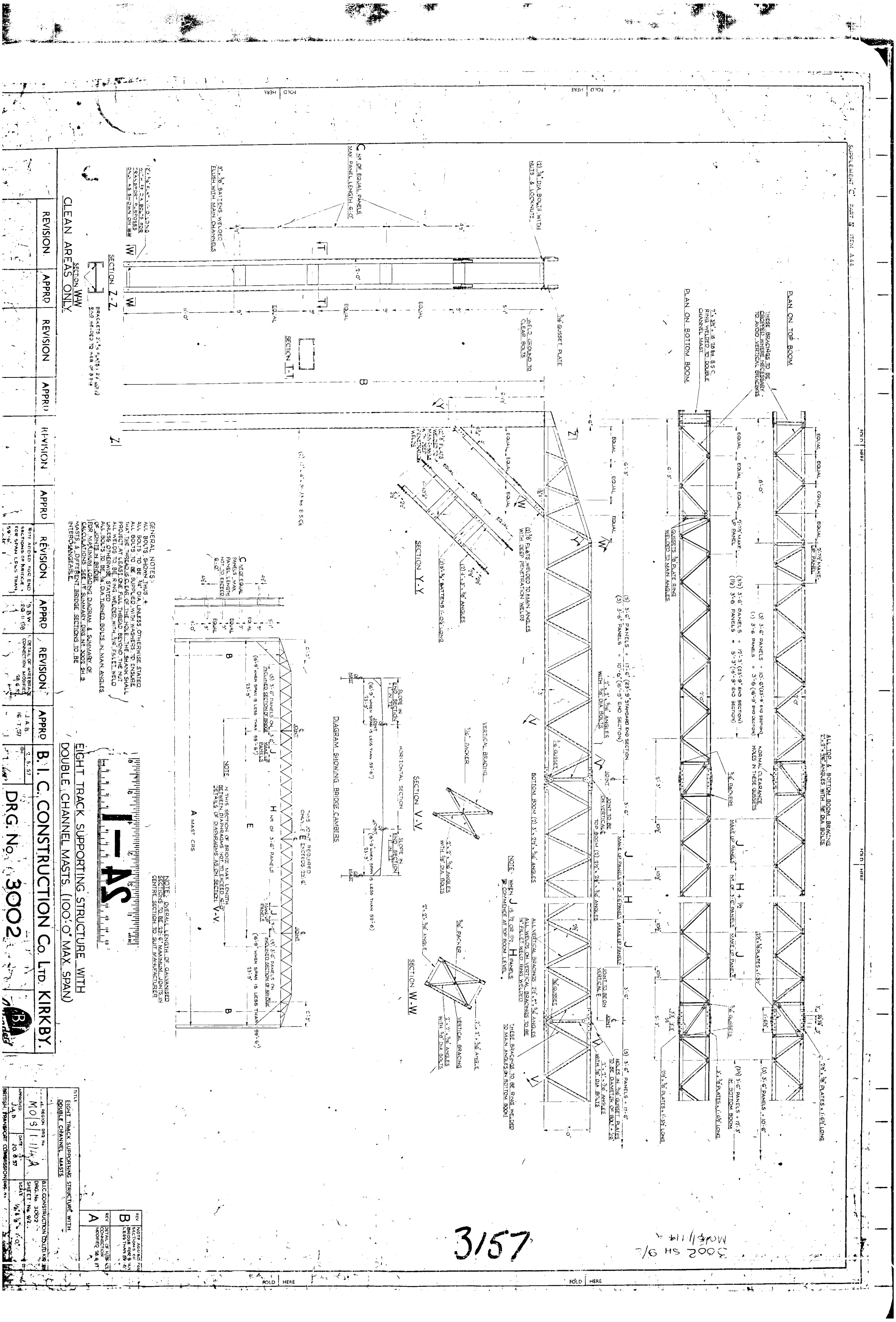


Figure 48. Reference 2

SUPPLEMENT 'C' PART IV ITEM A 44

1ST REFERENCE TABLE FOR 8 TRACK SUPPORTING STRUCTURE WITH DOUBLE CHANNEL MASTS DRG. No. 3002 SHEET 9

NOTES.

BRIDGE & MASTS WILL BE DENOTED BY SEPARATE REFERENCES ON THE CROSS SECTIONS. ON ALL CROSS SECTIONS THE BRIDGE WILL BE DENOTED BY ONE SINGLE REFERENCE. THE BRIDGE HOWEVER IS IN THREE SECTIONS OR MORE. THE TWO STANDARD END SECTIONS OF THE BRIDGE (23'-9" LONG) ARE TO BE MARKED REF 2/J. THE CENTRE SECTION OR SECTIONS OF THE BRIDGE WILL BE MARKED THE SAME AS THE REFERENCE GIVEN ON THE CROSS SECTION, e.g. REF 2/56J.

THE KNEEBRACE IS TO BE SUPPLIED WITH THE MAST. BOLTS FOR CONNECTION OF BRIDGE TO MAST AND KNEEBRACE TO BRIDGE TO BE SUPPLIED WITH MASTS. JOINT COVERS TO BE SUPPLIED WITH CENTRE SECTIONS OF BRIDGE.

WHEN SPAN OF BRIDGE IS LESS THAN 59'-6" CRS, THE TWO END SECTIONS TO BE 16'-9" LONG & MARKED 2/JJ. THE CENTRE SECTION OR SECTIONS OF THE BRIDGE WILL BE MARKED THE SAME AS THE REF GIVEN ON THE CROSS-SECTION e.g. REF 2/136J.

MASTS

REF	B	C	BASE	WT. (lbs.)
2/1J	20'-6	1	PLAIN	1602
2/2J	21'-6	1	PLAIN	1668
2/3J	22'-6	1	PLAIN	1730
2/4J	23'-6	2	PLAIN	1823
2/5J	24'-6	2	PLAIN	1884
2/6J	25'-6	2	PLAIN	1948
2/7J	26'-6	2	PLAIN	2011
2/8J	27'-6	2	PLAIN	2073
2/9J	28-6	2	PLAIN	2134
2/10J	29'-6	3	PLAIN	2230
2/11J	30'-6	3	PLAIN	2292
2/12J	31'-6	3	PLAIN	2354
2/13J	32'-6	3	PLAIN	2420
2/14J	33'-6	3	PLAIN	2480
2/15J	34'-6	3	PLAIN	2540
2/16J	35'-6	4	PLAIN	2630
2/17J	36'-6	4	PLAIN	2691
2/18J	37'-6	4	PLAIN	2753
2/19J	38'-6	4	PLAIN	2815

NOTE. (PLAIN BASES) MASTS FROM 15'-6" TO LESS THAN 20'-6" LONG TO BE AS 2/1J (20'-6") BUT 11'-0" DIMENSION REDUCED TO SUIT MAST LENGTH (6'-0" MIN.) FOR MASTS FROM 11'-10" TO LESS THAN 15'-6" 'C' TO BE NIL.

REF	B	C	BASE	WT. (lbs.)
2/20J	17'-6"	1	PLAIN	1412
2/21J	18'-6"	1	PLAIN	1475
2/22J	19'-6"	1	PLAIN	1537
2/23J	15'-6"	1	PLAIN	1286
2/24J	16'-6"	1	PLAIN	1348
2/25J	14'-6"	NIL	PLAIN	1192
2/26J	13'-6"	NIL	PLAIN	1129
2/27J	12'-6"	NIL	PLAIN	1067

BRIDGES

REF	A	E	H	J	WT (lbs)	REF	A	E	H	J	WT. (lbs.)
2/51J	59'-6"	12'-0"	NIL	1	3439	2/101J	84'-6	37'-0	7	1	4914
2/52J	60'-0"	12'-6"	NIL	1	3455	2/102J	85'-0	37'-6"	8	1/2	4930
2/53J	60'-6"	13'-0"	1	1/2	3471	2/103J	85'-6	38'-0	8	1/2	4947
2/54J	61'-0"	13'-6"	1	1/2	3487	2/104J	86'-0	38'-6"	9	NIL	4962
2/55J	61'-6"	14'-0"	2	NIL	3503	2/105J	86'-6	39'-0"	7	1 1/2	5044
2/56J	62'-0"	14'-6"	NIL	1 1/2	3586	2/106J	87'-0	39'-6	7	1 1/2	5063
2/57J	62'-6	15'-0"	NIL	1 1/2	3605	2/107J	87'-6	40'-0	8	1	5076
2/58J	63'-0"	15'-6"	1	1	3618	2/108J	88'-0	40'-6	8	1	5093
2/59J	63'-6	16'-0"	1	1	3666	2/109J	88'-6	41'-0	9	1/2	5108
2/60J	64'-0"	16'-6"	2	1/2	3683	2/110J	89'-0	41'-6	9	1/2	5126
2/61J	64'-6"	17'-0"	2	1/2	3698	2/111J	89'-6	42'-0	10	NIL	5141
2/62J	65'-0"	17'-6"	3	NIL	3715	2/112J	90'-0"	42'-6"	8	1 1/2	5223
2/63J	65'-6	18'-0"	1	1 1/2	3797	2/113J	90'-6	43'-0	8	1 1/2	5242
2/64J	66'-0"	18'-6	1	1 1/2	3816	2/114J	91'-0	43'-6	9	1	5255
2/65J	66'-6"	19'-0	2	1	3829	2/115J	91'-6	44'-0	9	1	5271
2/66J	67'-0"	19'-6"	2	1	3845	2/116J	92'-0	44'-6"	10	1/2	5288
2/67J	67'-6"	20'-0"	3	1/2	3861	2/117J	92'-6	45'-0"	10	1/2	5302
2/68J	68'-0"	20'-6"	3	1/2	3877	2/118J	93'-0"	45'-6	11	NIL	5320
2/69J	68'-6"	21'-0"	4	NIL	3893	2/119J	93'-6"	46'-0	9	1 1/2	5401
2/70J	69'-0"	21'-6"	2	1 1/2	3976	2/120J	94'-0"	46'-6"	9	1 1/2	5421
2/71J	69'-6	22'-0"	2	1 1/2	3995	2/121J	94-6"	47'-0	10	1	5437
2/72J	70'-0"	22'-6"	3	1	4008	2/122J	95'-0	47'-6	10	1	5450
2/73J	70'-6"	23'-0"	3	1	4024	2/123J	95'-6	48'-0	11	1/2	5466
2/74J	71'-0"	23'-6"	4	1/2	4040	2/124J	96'-0	48'-6"	11	1/2	5515
2/75J	71'-6"	24'-0"	4	1/2	4056	2/125J	96'-6"	49'-0"	12	NIL	5531
2/76J	72'-0"	24'-6"	5	NIL	4072	2/126J	97'-0	49'-6"	10	1 1/2	5613
2/77J	72'-6"	25'-0"	3	1 1/2	4154	2/127J	97'-6"	50'-0	10	1 1/2	5632
2/78J	73'-0	25'-6"	3	1 1/2	4173	2/128J	98'-0"	50'-6	11	1	5645
2/79J	73'-6"	26'-0"	4	1	4186	2/129J	98'-6"	51'-0	11	1	5661
2/80J	74'-0"	26'-6	4	1	4202	2/130J	99'-0"	51'-6	12	1/2	5678
2/81J	74'-6	27'-0"	5	1/2	4218	2/131J	99'-6	52'-0	12	1/2	5694
2/82J	75'-0	27'-6"	5	1/2	4235	2/132J	100'-0	52'-6	13	NIL	5710
2/83J	75'-6"	28'-0"	6	NIL	4250	2/133J	58'-0"	24'-6	5	NIL	3311
2/84J	76'-0"	28'-6"	4	1 1/2	4333	2/134J	57'-0"	23'-6	4	1/2	3254
2/85J	76'-6	29'-0	4	1 1/2	4351	2/135J	59'-0"	25'-6"	3	1 1/2	3486
2/86J	77'-0"	29'-6"	5	1	4365	2/136J	58'-6"	25'-0"	3	1 1/2	3436
2/87J	77'-6"	30'-0	5	1	4524	2/137J	57'-6"	24'-0"	4	1/2	3337
2/88J	78'-0"	30'-6"	6	1/2	4540	2/138J	56'-6"	23'-0"	3	1	3302
2/89J	78'-6"	31'-0	6	1/2	4556	2/139J	56'-0"	22'-6"	3	1	3275
2/90J	79'-0"	31'-6	7	NIL	4571	2/140J	55'-6"	22'-0"	2	1 1/2	3272
2/91J	79'-6"	32'-0	5	1 1/2	4654	2/141J	55'-0"	21'-6"	2	1 1/2	3257
2/92J	80'-0"	32'-6"	5	1 1/2	4706	2/142J	54'-6"	21'-0"	4	NIL	3162
2/93J	80'-6"	33'-0"	6	1	4719	2/143J	54'-0"	20'-6"	3	1/2	3154
2/94J	81'-0"	33'-6"	6	1	4735	2/144J	53'-6"	20'-0"	3	1/2	3134
2/95J	81'-6"	34'-0"	7	1/2	4751	2/145J	53'-0"	19'-6"	2	1	3125
2/96J	82'-0"	34'-6"	7	1/2	4767	2/146J	52'-6"	19'-0"	2	1	3111
2/97J	82'-6"	35'-0"	8	NIL	4783	2/147J	52'-0"	18'-6"	1	1 1/2	3110
2/98J	83'-0"	35'-6"	6	1 1/2	4866	2/148J	51'-6"	18'-0"	1	1 1/2	3082
2/99J	83'-6"	36'-0"	6	1 1/2	4885	2/149J	51'-0"	17'-6"	3	NIL	2994
2/100J	84'-0"	36'-6"	7	1	4898	2/150J	50'-6"	17'-0"	2	1/2	2982

FOR FURTHER REFS SEE 2ND R.F. TABLE

CLEAN AREAS ONLY.

B.I.C. CONSTRUCTION Co. Ltd. KIRKBY.

DRG. No. 3002. REF. J.

SHEET No. 9/2

H.10260

Figure 49. Reference 2 details

1636

SUPPLEMENT "C" PART IV ITEM A44.

2nd REFERENCE TABLE FOR 8 TRACK SUPPORTING STRUCTURE WITH DOUBLE CHANNEL MASTS. DRG No. 3002 SH.9

CLEAN AREAS ONLY.

NOTES.

BRIDGE AND MASTS WILL BE DENOTED BY SEPARATE REFERENCES ON THE CROSS-SECTIONS. ON ALL CROSS-SECTIONS, THE BRIDGE WILL BE DENOTED BY ONE SINGLE REFERENCE THE BRIDGE HOWEVER IS IN THREE SECTIONS OR MORE. THE TWO STANDARD END SECTIONS (23'-9" LONG) ARE TO BE MARKED REF 2/N. THE CENTRE SECTION OR SECTIONS OF THE BRIDGE WILL BE MARKED THE SAME AS THE REFERENCE GIVEN ON THE CROSS-SECTION, e.g. REF 2/152J THE KNEEBRACE IS TO BE SUPPLIED WITH THE MAST. BOLTS FOR CONNECTION OF BRIDGE TO MAST AND KNEEBRACE TO BRIDGE, TO BE SUPPLIED WITH MASTS. JOINT COVERS TO BE SUPPLIED WITH CENTRE SECTIONS OF BRIDGE.

WHEN SPAN OF BRIDGE IS LESS THAN 59'-6" CRS THE END SECTIONS TO BE 16'-9" LONG & MARKED 2/JJ THE CENTRE SECTION OR SECTIONS OF THE BRIDGE WILL BE MARKED THE SAME AS THE REFERENCES GIVEN ON THE CROSS-SECTION e.g. REF 2/136J.

MASTS.

REF	B	C	BASE	WT (lbs)
2/200J	30'-0"	4	31/1J	2684
2/201J	29'-6"	4	31/1J	2653
2/202J	29'-0"	4	31/1J	2622
2/203J	28'-6"	4	31/1J	2591
2/204J	28'-0"	4	31/1J	2560
2/205J	27'-6"	4	31/1J	2529
2/206J	27'-0"	3	31/1J	2467
2/207J	26'-6"	3	31/1J	2436
2/208J	26'-0"	3	31/1J	2405
2/209J	25'-6"	3	31/1J	2374
2/210J	25'-0"	3	31/1J	2343
2/211J	24'-6"	3	31/1J	2312
2/212J	24'-0"	3	31/1J	2281
2/213J	23'-6"	3	31/1J	2250
2/214J	23'-0"	3	31/1J	2210
2/215J	22'-6"	3	31/1J	2188
2/216J	22'-0"	3	31/1J	2157
2/217J	21'-6"	3	31/1J	2120
2/218J	21'-0"	3	31/1J	2005
2/219J	20'-6"	2	31/1J	2033
2/220J	20'-0"	2	31/1J	2002
2/221J	19'-6"	2	31/1J	1971
2/222J	19'-0"	2	31/1J	1940
2/223J	18'-6"	2	31/1J	1909
2/224J	18'-0"	2	31/1J	1878
2/225J	17'-6"	2	31/1J	1847
2/226J	17'-0"	2	31/1J	1816
2/227J	16'-6"	2	31/1J	1785
2/228J	16'-0"	2	31/1J	1754
2/229J	15'-6"	2	31/1J	1723
2/230J	15'-0"	2	31/1J	1692
2/231J				
2/232J				
2/233J				
2/234J				
2/235J				
2/236J				
2/237J				
2/238J				
2/239J				
2/240J				
2/241J				
2/242J				
2/243J				
2/244J				
2/245J				
2/246J				
2/247J				
2/248J				
2/249J				

MASTS.

REF	B	C	BASE	WT (lbs)
2/250J				
2/251J				
2/252J				
2/253J				
2/254J				
2/255J				
2/256J				
2/257J				
2/258J				
2/259J				
2/260J				
2/261J				
2/262J				
2/263J				
2/264J				
2/265J				
2/266J				
2/267J				
2/268J				
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2/294J				
2/295J				
2/296J				
2/297J				
2/298J				
2/299J				

BRIDGES.

REF	A	E	H	J	WT (lbs)
[redacted]					
2/151J	50'-0"	16'-6"	2	1/2	2965
2/152J	49'-6"	16'-0"	1	1	2951
2/153J	49'-0"	15'-6"	1	1	2936
2/154J	48'-6"	15'-0"	NIL	1/2	2924
2/155J	48'-0"	14'-6"	NIL	1/2	2908
2/156J	47'-6"	14'-0"	2	NIL	[illegible]
2/157J	47'-0"	13'-6"	1	1/2	2808
2/158J	46'-6"	13'-0"	1	1/2	2792
2/159J	46'-0"	12'-6"	NIL	1	2779
2/160J	45'-6"	12'-0"	NIL	1	2764
2/161J	40'-6"	7'-0"	NIL	NIL	2646
2/162J					
2/163J					
2/164J					
2/165J					
2/166J					
2/167J					
2/168J					
2/169J					
2/170J					
2/171J					
2/172J					
2/173J					
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2/193J					
2/194J					
2/195J					
2/196J					
2/197J					
2/198J					
2/199J					

REVISION | APPR'D | REVISION | APPR'D | REVISION | APPR'D | REVISION | APPR'D | REVISION | APPR'D

B.I.C. CONSTRUCTION Co. LTD. KIRKBY.

DRG. No. 3002 REF J.

CONTINUED.

TITLE. 2nd REFERENCE TABLE FOR 8 TRACK SUPPORTING STRUCTURE WITH DOUBLE CHANNEL MASTS

B.I.C.C. Co. LTD KIRKBY. DRG No. 3002 REF J. SHEET No. 9.

REGION DRG No

APPROVED S.B.W. DATE 20.11.58. SCALE.

BRITISH TRANSPORT COMMN RAILWAYS DIVISION CHIEF ELEC. ENG. DEPT. DRG No

REV A | REV B

FOLD HERE

Figure 50. Details for reference 2

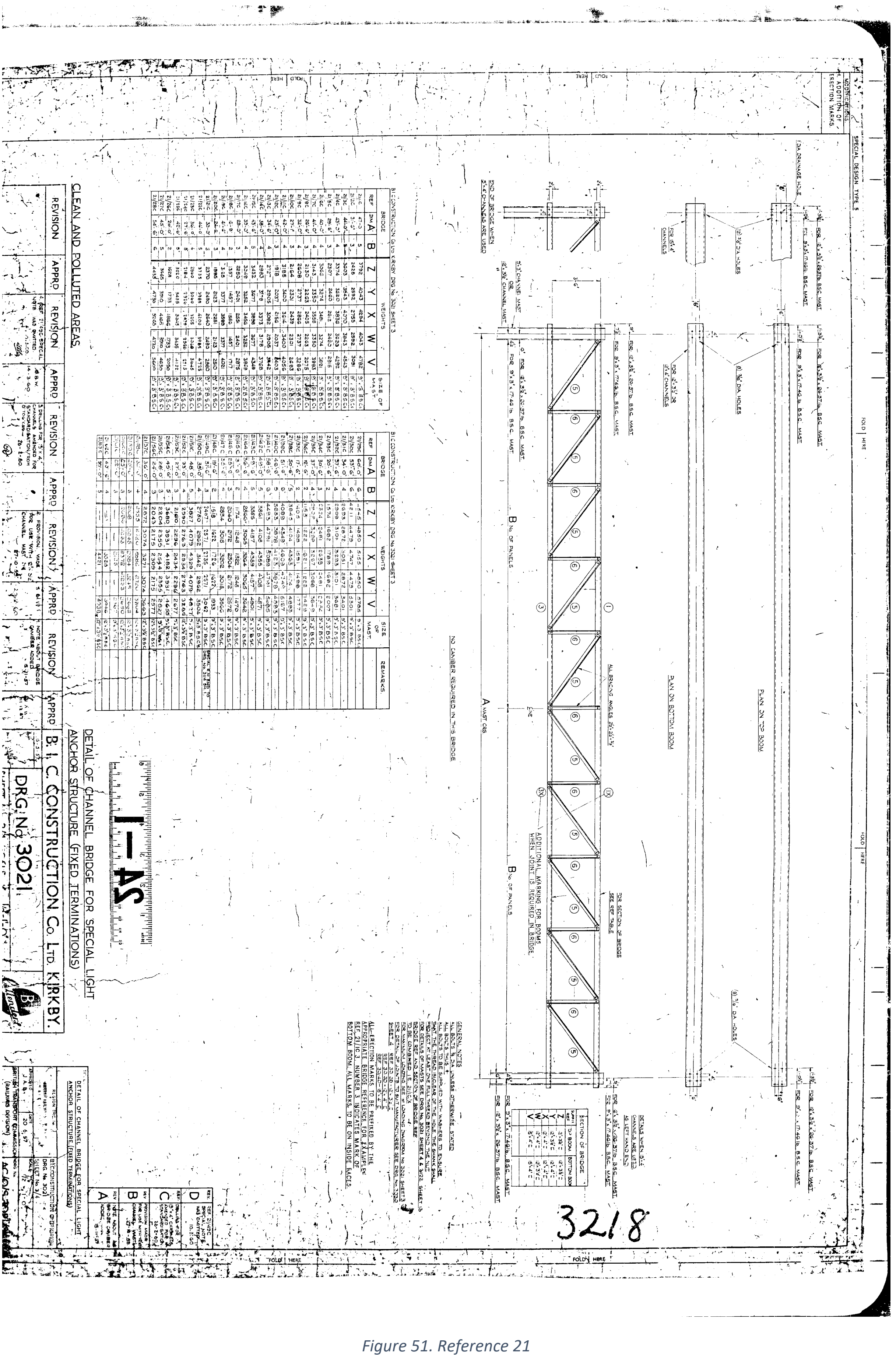


Figure 51. Reference 21

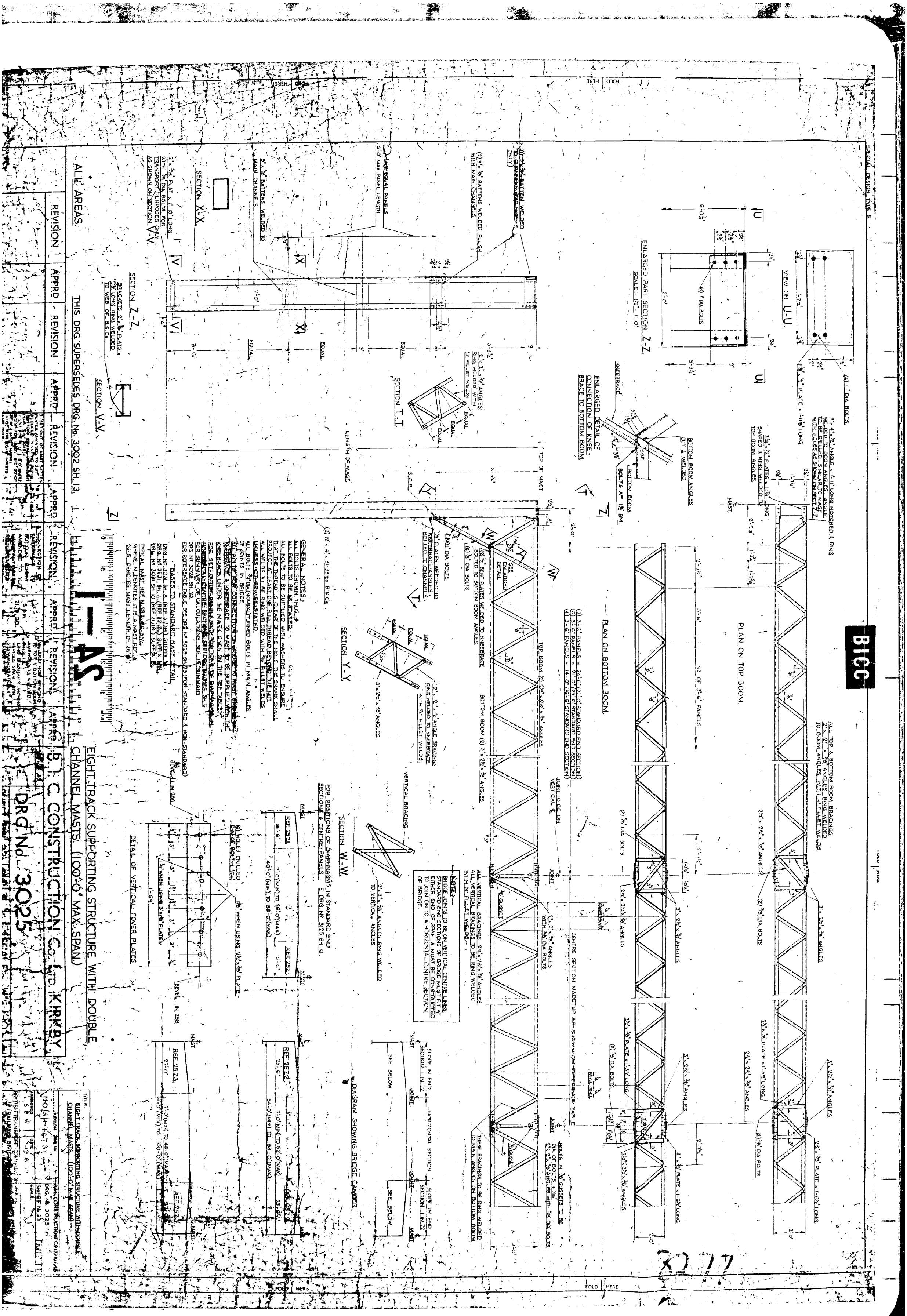


Figure 52. Reference 25

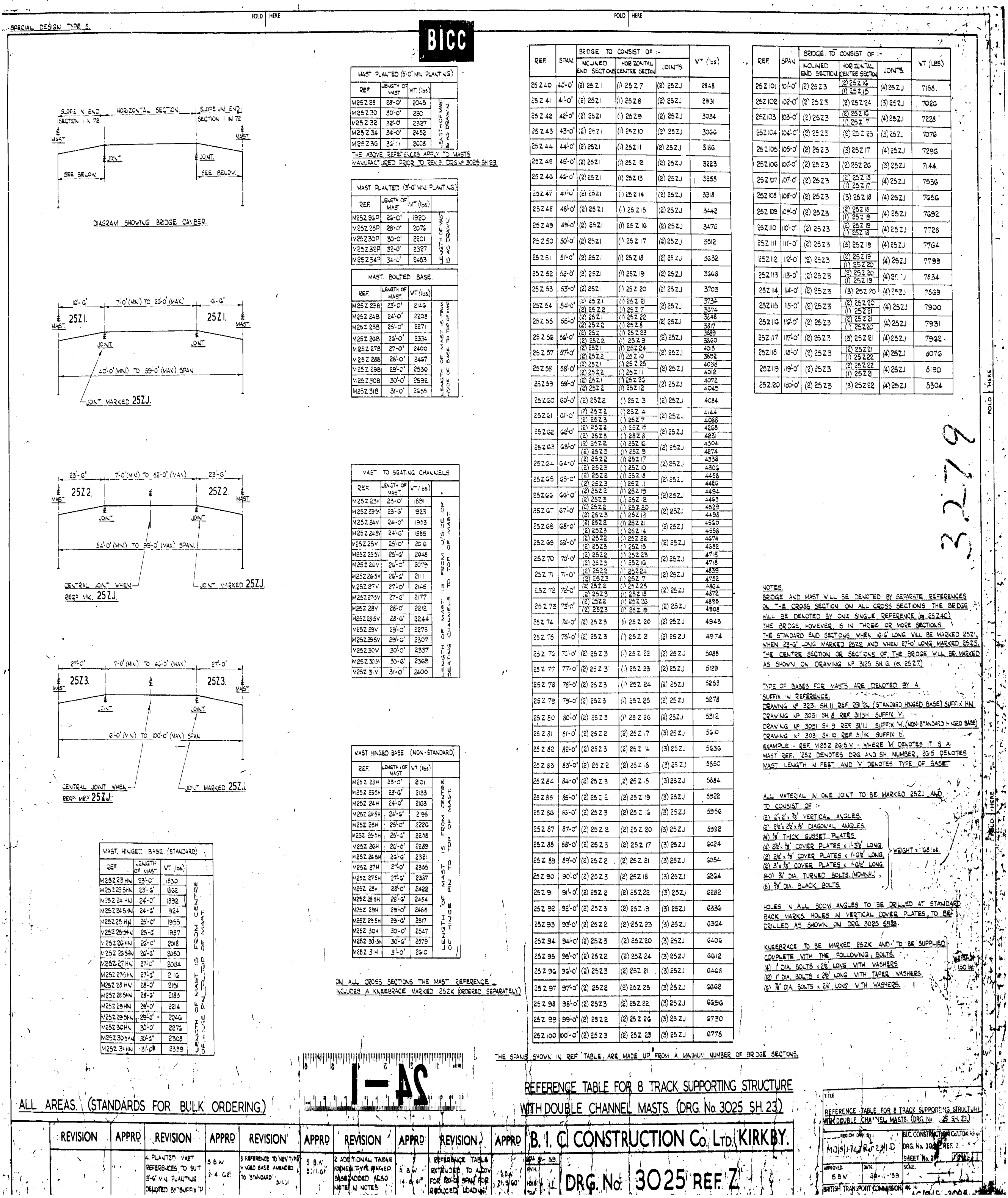


Figure 53. Details for reference 25

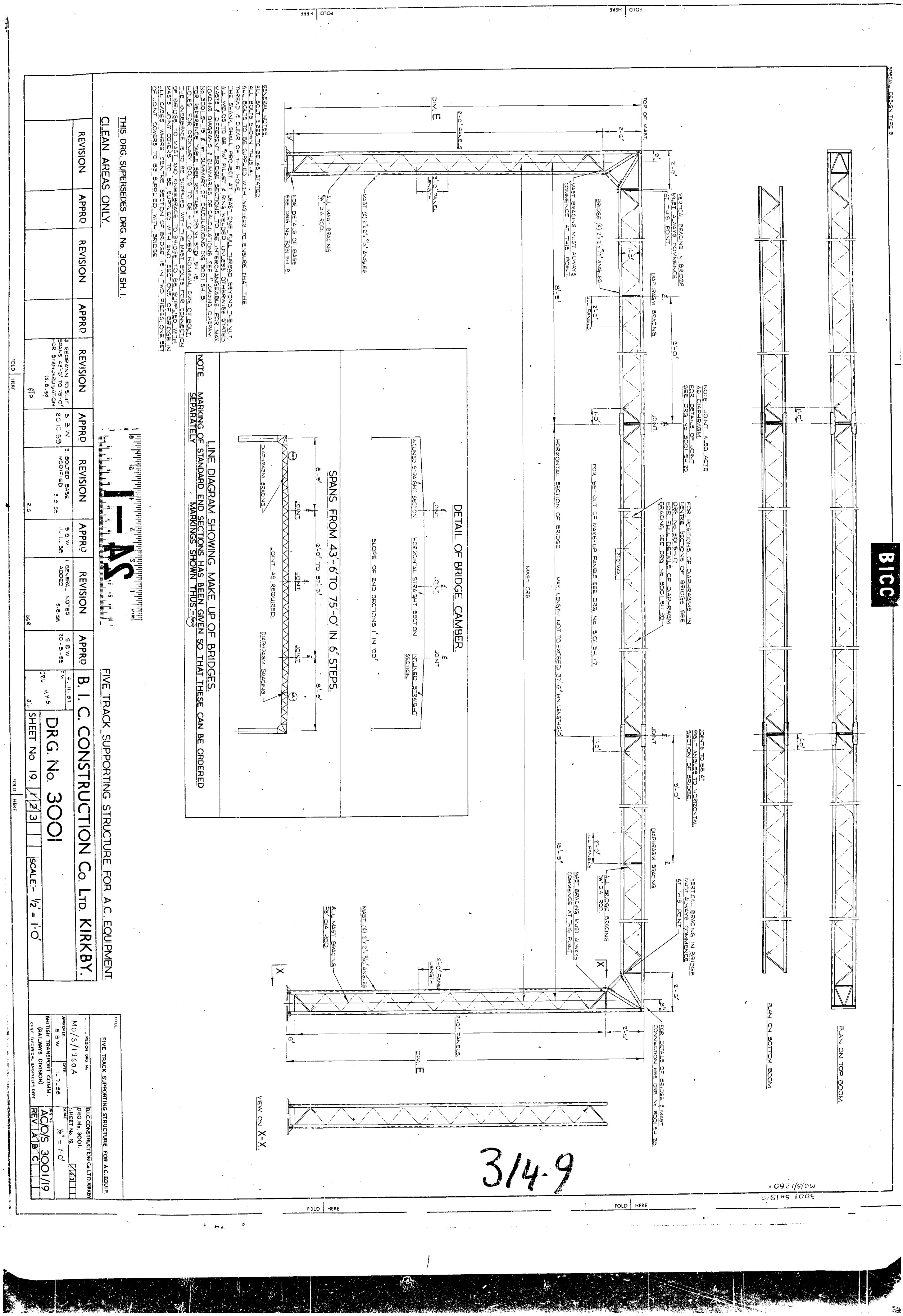
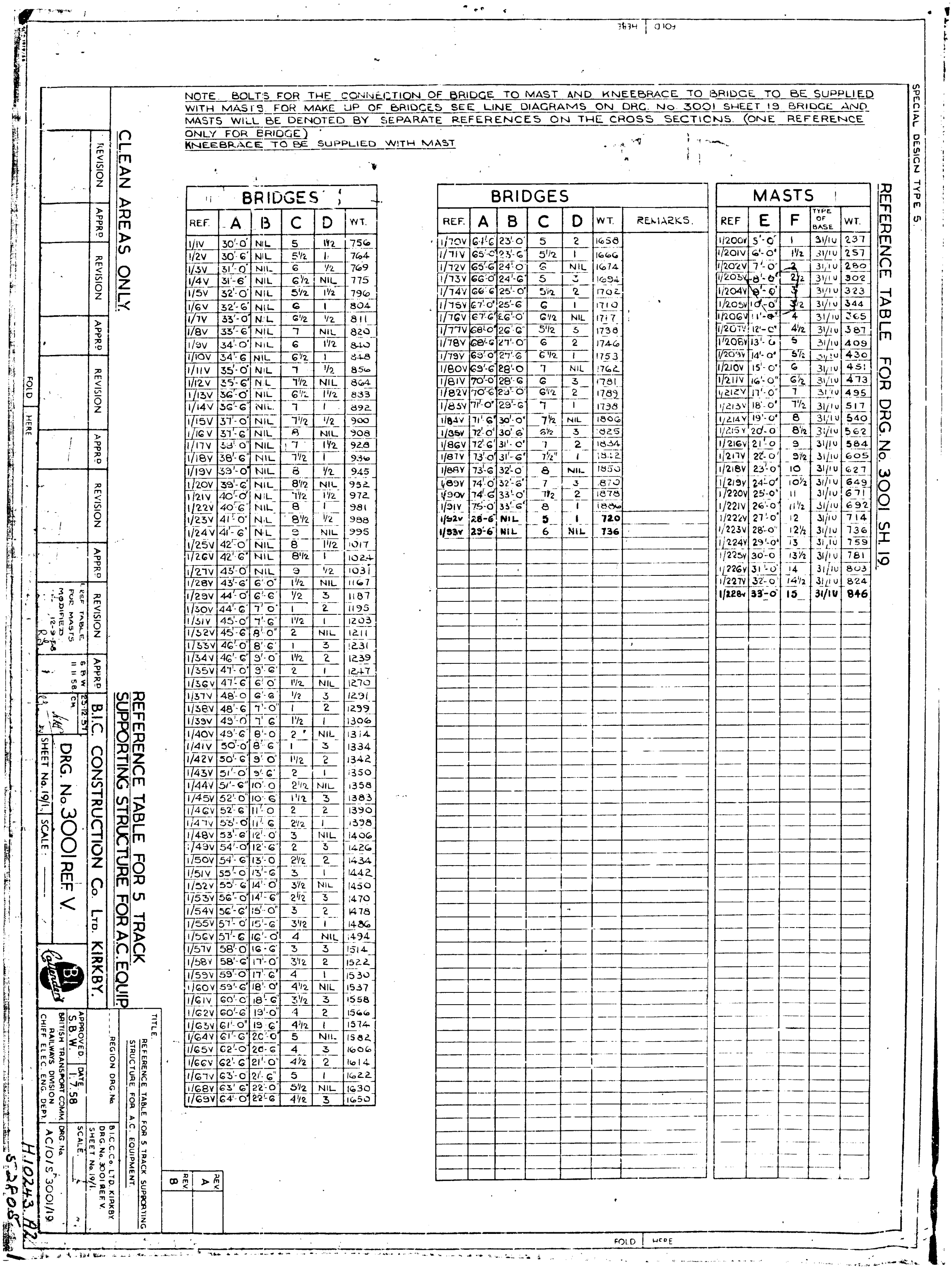


Figure 54. Reference 1



NOTE. BOLTS FOR THE CONNECTION OF BRIDGE TO MAST AND KNEEBRACE TO BRIDGE TO BE SUPPLIED WITH MASTS. FOR MAKE UP OF BRIDGES SEE LINE DIAGRAMS ON DRG. No 3001 SHEET 19. BRIDGE AND MASTS WILL BE DENOTED BY SEPARATE REFERENCES ON THE CROSS SECTIONS. (ONE REFERENCE ONLY FOR BRIDGE)
KNEEBRACE TO BE SUPPLIED WITH MAST

BRIDGES

REF.	A	B	C	D	WT.
1/1V	30'-0"	NIL	5	1½	756
1/2V	30'-6"	NIL	5½	1	764
1/3V	31'-0"	NIL	6	½	769
1/4V	31'-6"	NIL	6½	NIL	775
1/5V	32'-0"	NIL	5½	1½	796
1/6V	32'-6"	NIL	6	1	804
1/7V	33'-0"	NIL	6½	½	811
1/8V	33'-6"	NIL	7	NIL	820
1/9V	34'-0"	NIL	6	1½	840
1/10V	34'-6	NIL	6½	1	848
1/11V	35'-0"	NIL	7	½	856
1/12V	35'-6"	NIL	7½	NIL	864
1/13V	36'-0"	NIL	6½	1½	833
1/14V	36'-6"	NIL	7	1	892
1/15V	37'-0"	NIL	7½	½	900
1/16V	37'-6"	NIL	8	NIL	908
1/17V	38'-0"	NIL	7	1½	928
1/18V	38'-6"	NIL	7½	1	936
1/19V	39'-0"	NIL	8	½	945
1/20V	39'-6"	NIL	8½	NIL	952
1/21V	40'-0"	NIL	7½	1½	972
1/22V	40'-6"	NIL	8	1	981
1/23V	41'-0"	NIL	8½	½	988
1/24V	41'-6"	NIL	9	NIL	995
1/25V	42'-0"	NIL	8	1½	1017
1/26V	42'-6"	NIL	8½	1	1024
1/27V	43'-0"	NIL	9	½	1031
1/28V	43'-6"	6'-0"	1½	NIL	1167
1/29V	44'-0"	6'-6"	½	3	1187
1/30V	44'-6"	7'-0"	1	2	1195
1/31V	45'-0"	7'-6"	1½	1	1203
1/32V	45'-6"	8'-0"	2	NIL	1211
1/33V	46'-0"	8'-6"	1	3	1231
1/34V	46'-6"	9'-0"	1½	2	1239
1/35V	47'-0"	9'-6"	2	1	1247
1/36V	47'-6"	6'-0"	1½	NIL	1270
1/37V	48'-0	6'-6"	½	3	1291
1/38V	48'-6	7'-0"	1	2	1299
1/39V	49'-0"	7'-6"	1½	1	1306
1/40V	49'-6"	8'-0	2	NIL	1314
1/41V	50'-0"	8'-6"	1	3	1334
1/42V	50'-6"	9'-0"	1½	2	1342
1/43V	51'-0"	9'-6"	2	1	1350
1/44V	51'-6"	10'-0	2½	NIL	1358
1/45V	52'-0"	10'-6	1½	3	1383
1/46V	52'-6"	11'-0	2	2	1390
1/47V	53'-0"	11'-6	2½	1	1398
1/48V	53'-6"	12'-0"	3	NIL	1406
1/49V	54'-0"	12'-6"	2	3	1426
1/50V	54'-6"	13'-0	2½	2	1434
1/51V	55'-0	13'-6"	3	1	1442
1/52V	55'-6"	14'-0"	3½	NIL	1450
1/53V	56'-0"	14'-6"	2½	3	1470
1/54V	56'-6"	15'-0"	3	2	1478
1/55V	57'-0"	15'-6"	3½	1	1486
1/56V	57'-6	16'-0"	4	NIL	1494
1/57V	58'-0"	16'-6"	3	3	1514
1/58V	58'-6"	17'-0"	3½	2	1522
1/59V	59'-0"	17'-6"	4	1	1530
1/60V	59'-6"	18'-0"	4½	NIL	1537
1/61V	60'-0"	18'-6"	3½	3	1558
1/62V	60'-6"	19'-0"	4	2	1566
1/63V	61'-0"	19'-6"	4½	1	1574
1/64V	61'-6"	20'-0"	5	NIL	1582
1/65V	62'-0"	20'-6"	4	3	1606
1/66V	62'-6"	21'-0"	4½	2	1614
1/67V	63'-0"	21'-6"	5	1	1622
1/68V	63'-6"	22'-0"	5½	NIL	1630
1/69V	64'-0"	22'-6"	4½	3	1650

BRIDGES

REF.	A	B	C	D	WT.	REMARKS.
1/70V	64'-6"	23'-0"	5	2	1658	
1/71V	65'-0"	23'-6"	5½	1	1666	
1/72V	65'-6"	24'-0"	6	NIL	1674	
1/73V	66'-0"	24'-6"	5	3	1694	
1/74V	66'-6"	25'-0"	5½	2	1702	
1/75V	67'-0"	25'-6"	6	1	1710	
1/76V	67'-6"	26'-0"	6½	NIL	1717	
1/77V	68'-0"	26'-6"	5½	3	1738	
1/78V	68'-6"	27'-0"	6	2	1746	
1/79V	69'-0"	27'-6"	6½	1	1753	
1/80V	69'-6"	28'-0	7	NIL	1762	
1/81V	70'-0"	28'-6	6	3	1781	
1/82V	70'-6"	29'-0"	6½	2	1789	
1/83V	71'-0"	29'-6"	7	1	1798	
1/84V	71'-6"	30'-0"	7½	NIL	1806	
1/85V	72'-0"	30'-6"	6½	3	1825	
1/86V	72'-6"	31'-0"	7	2	1834	
1/87V	73'-0"	31'-6"	7½"	1	1842	
1/88V	73'-6"	32'-0"	8	NIL	1850	
1/89V	74'-0"	32'-6"	7	3	1870	
1/90V	74'-6"	33'-0"	7½	2	1878	
1/91V	75'-0"	33'-6"	8	1	1886	
1/92V	28'-6"	NIL	5	1	720	
1/93V	29'-6"	NIL	6	NIL	736	

MASTS

REF	E	F	TYPE OF BASE	WT.
1/200V	5'-0"	1	31/1U	237
1/201V	6'-0"	1½	31/1U	257
1/202V	7'-0"	2	31/1U	280
1/203V	8'-0"	2½	31/1U	302
1/204V	9'-0"	3	31/1U	323
1/205V	10'-0"	3½	31/1U	344
1/206V	11'-0"	4	31/1U	365
1/207V	12'-0"	4½	31/1U	387
1/208V	13'-0	5	31/1U	409
1/209V	14'-0"	5½	31/1U	430
1/210V	15'-0"	6	31/1U	451
1/211V	16'-0"	6½	31/1U	473
1/212V	17'-0"	7	31/1U	495
1/213V	18'-0"	7½	31/1U	517
1/214V	19'-0"	8	31/1U	540
1/215V	20'-0	8½	31/1U	562
1/216V	21'-0	9	31/1U	584
1/217V	22'-0"	9½	31/1U	605
1/218V	23'-0"	10	31/1U	627
1/219V	24'-0"	10½	31/1U	649
1/220V	25'-0"	11	31/1U	671
1/221V	26'-0"	11½	31/1U	692
1/222V	27'-0"	12	31/1U	714
1/223V	28'-0"	12½	31/1U	736
1/224V	29'-0"	13	31/1U	759
1/225V	30'-0	13½	31/1U	781
1/226V	31'-0"	14	31/1U	803
1/227V	32'-0"	14½	31/1U	824
1/228V	33'-0"	15	31/1U	846

Figure 55. Reference 1 details

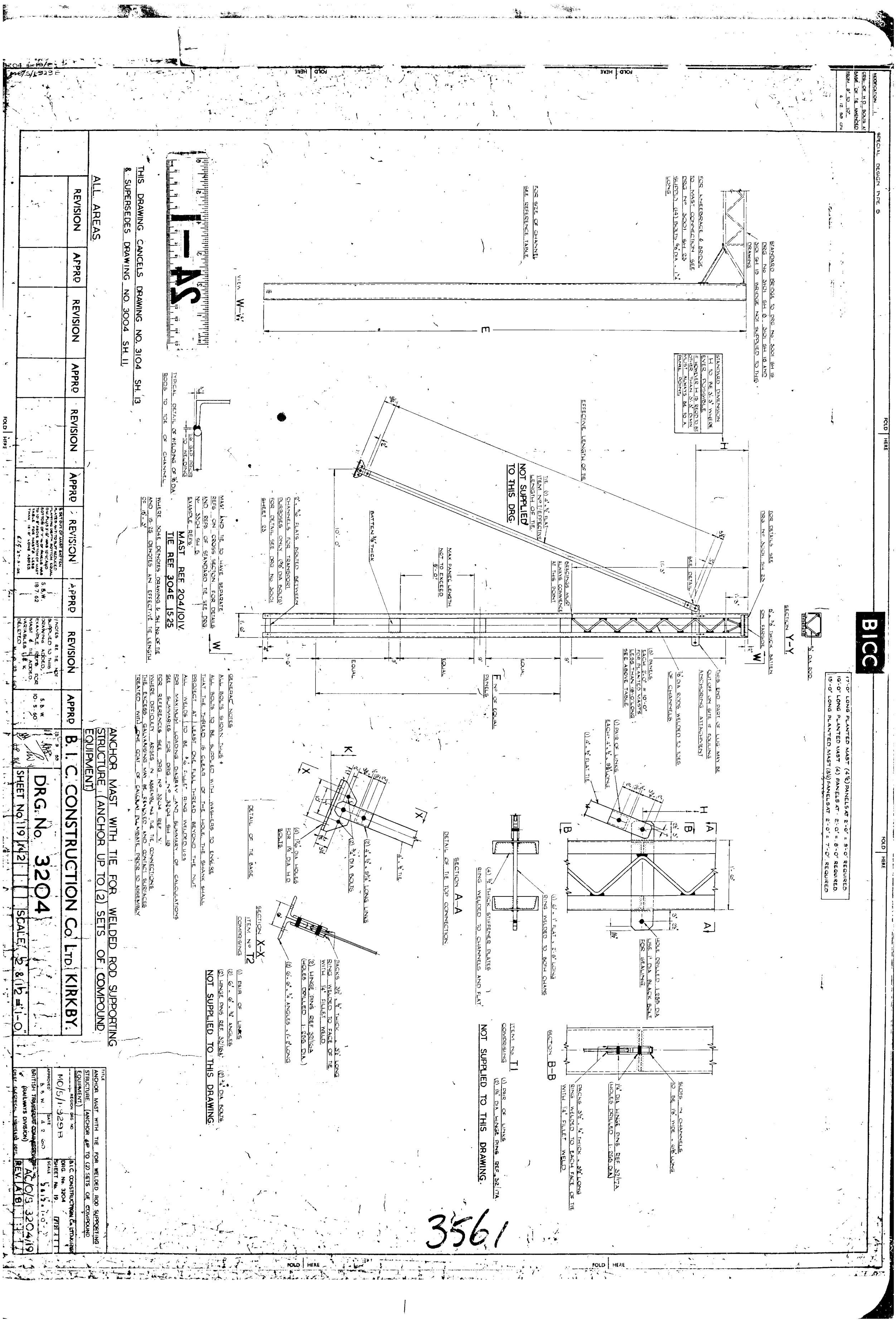


Figure 56. Reference 204

ANNEX IV

OLE components layouts

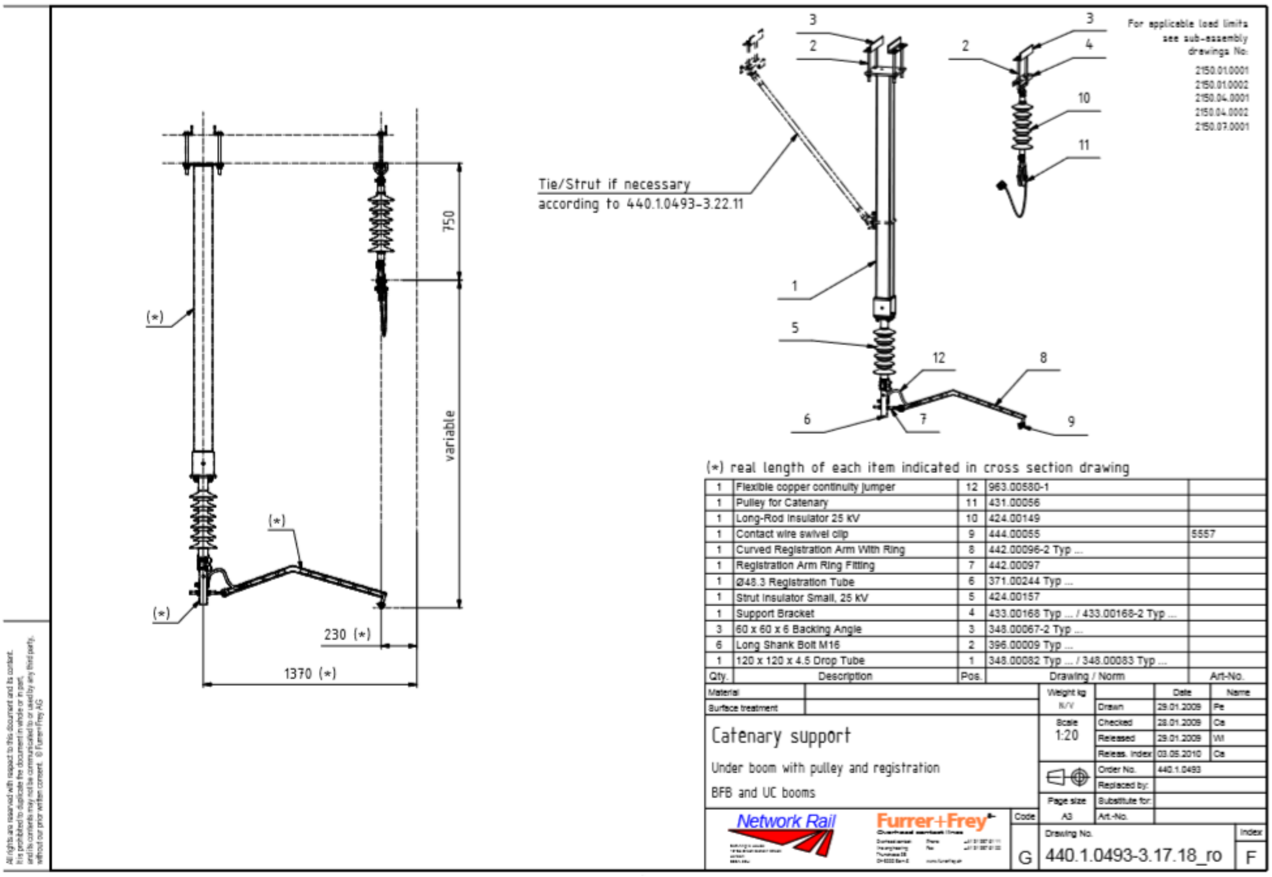


Figure 57. Catenary Support layout

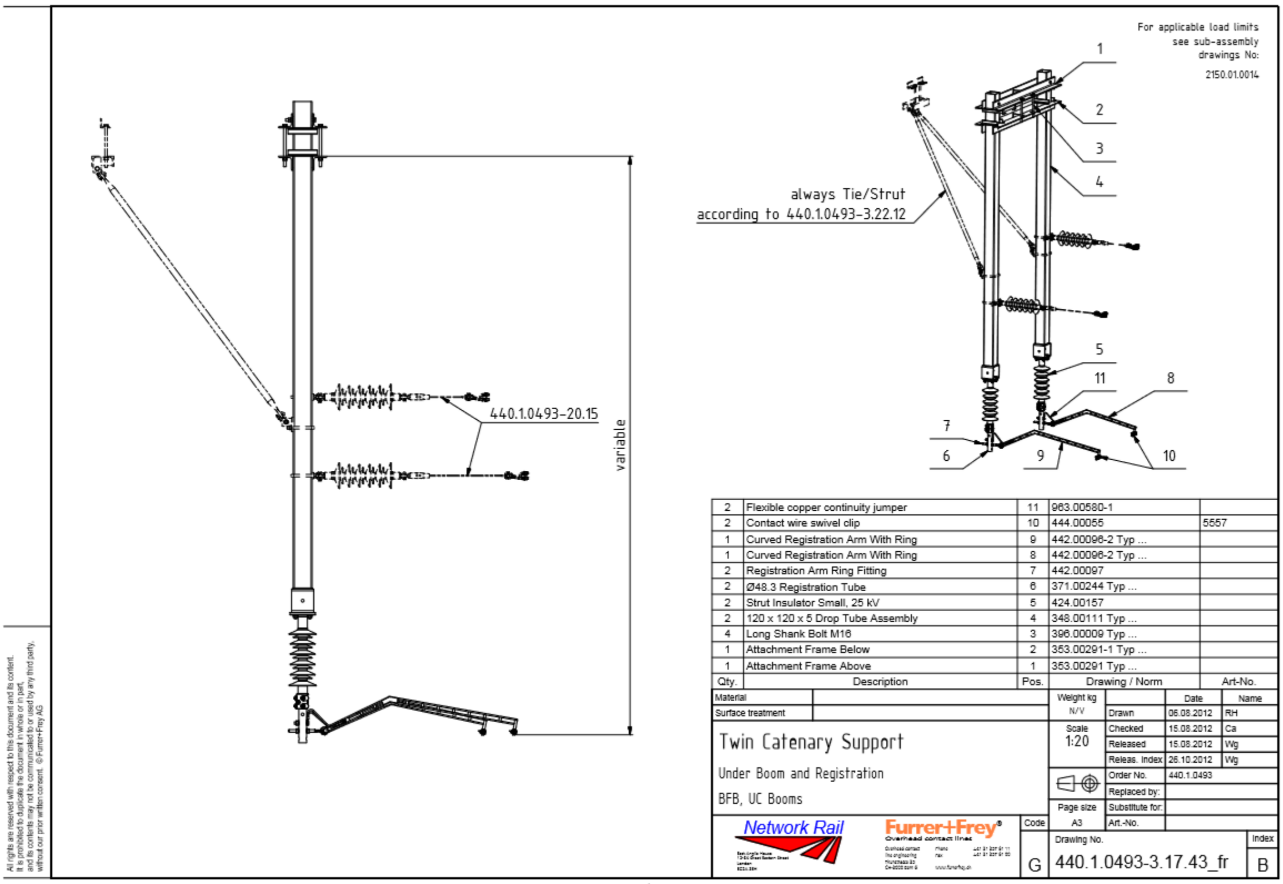


Figure 58. Twin Catenary Support layout

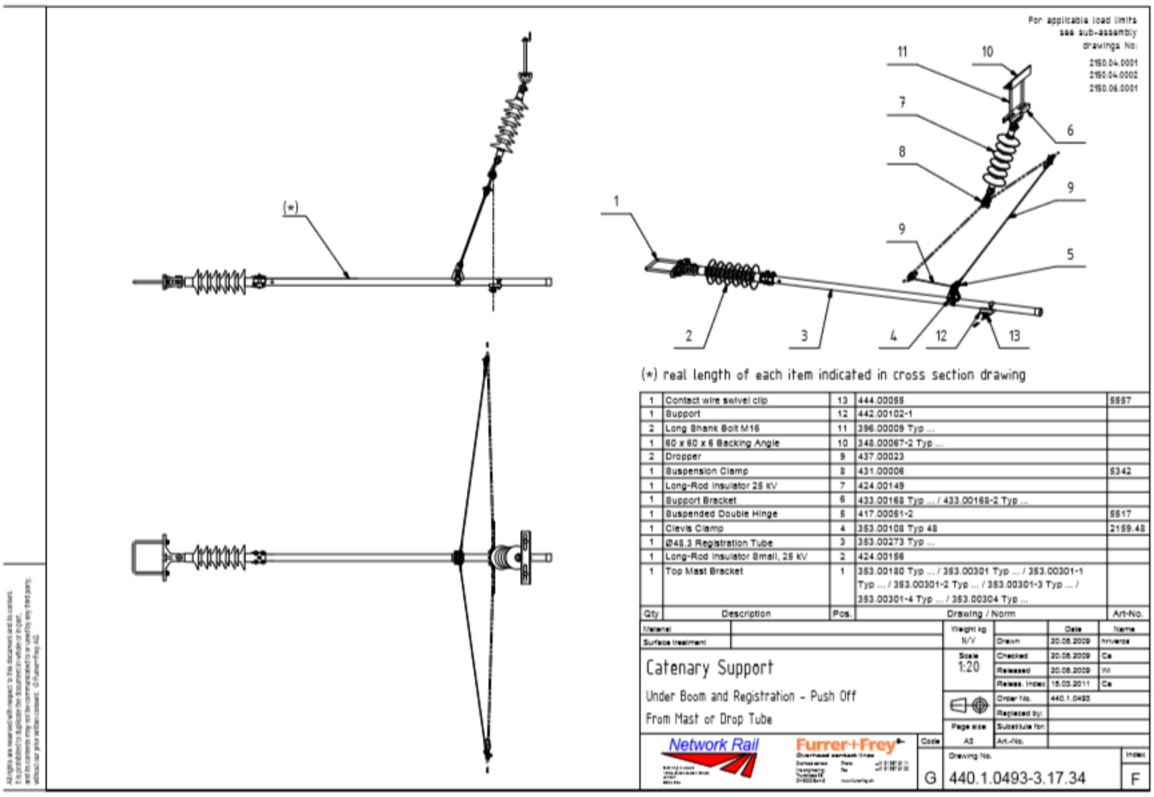


Figure 59. Catenary Support layout

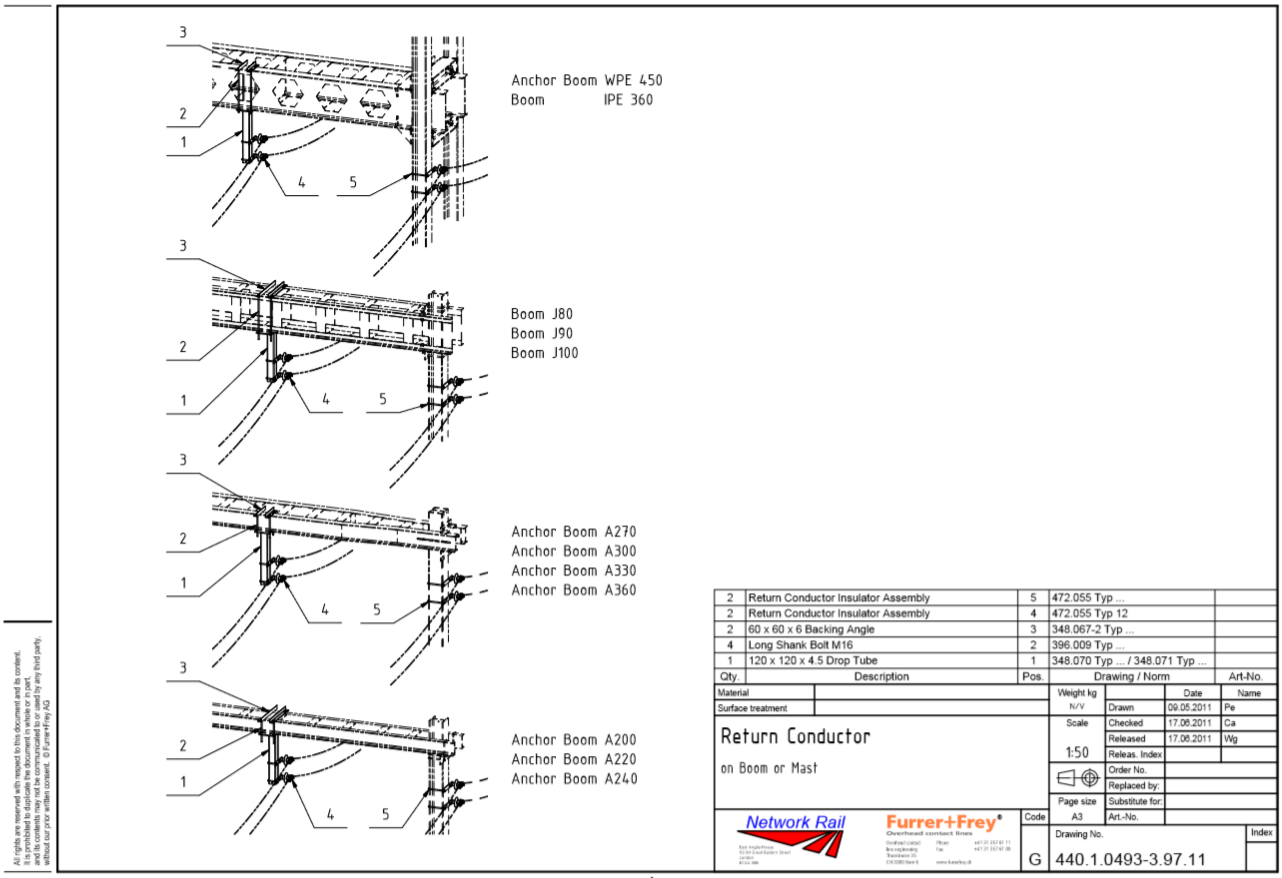


Figure 60. Return Conductor layout

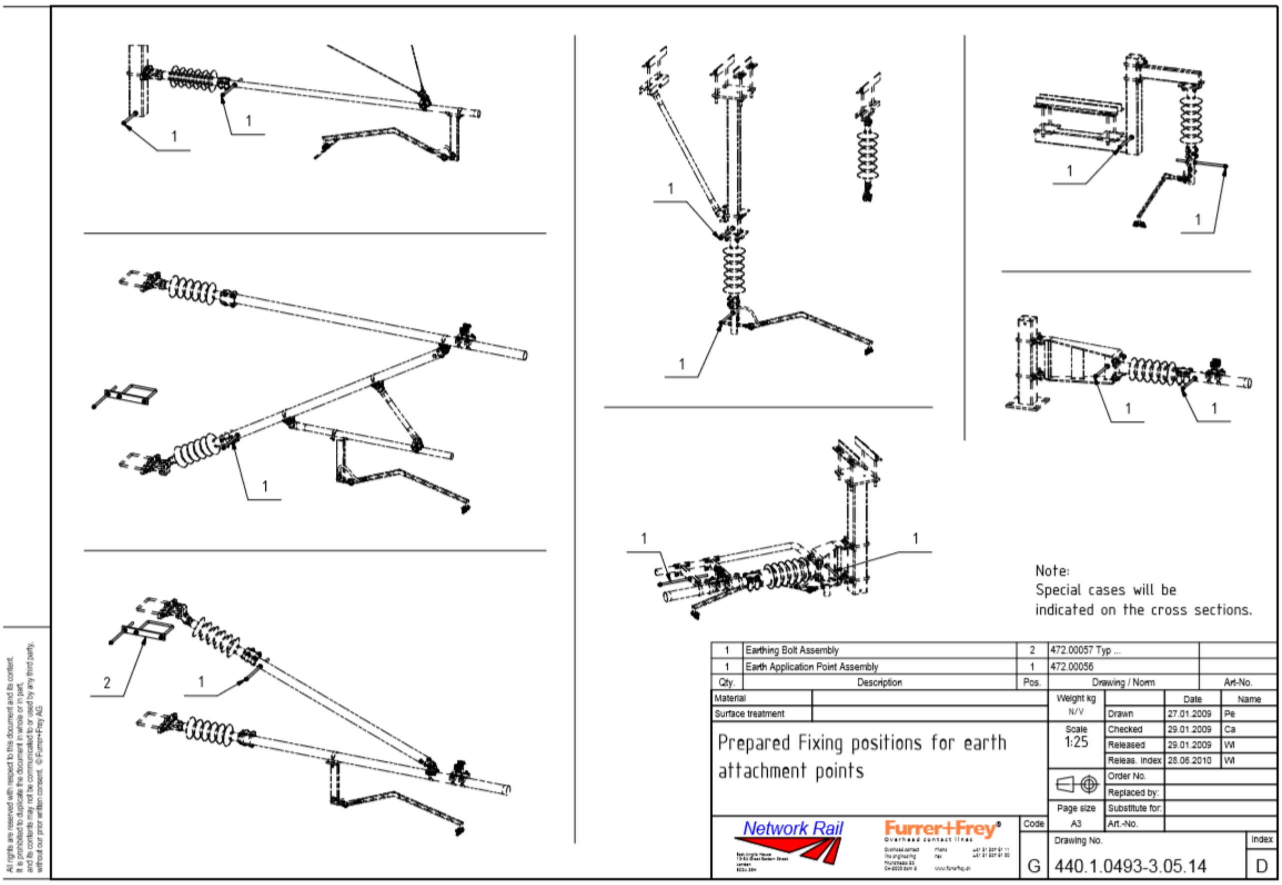


Figure 61. Prepared Fixing positions for earth attachment points

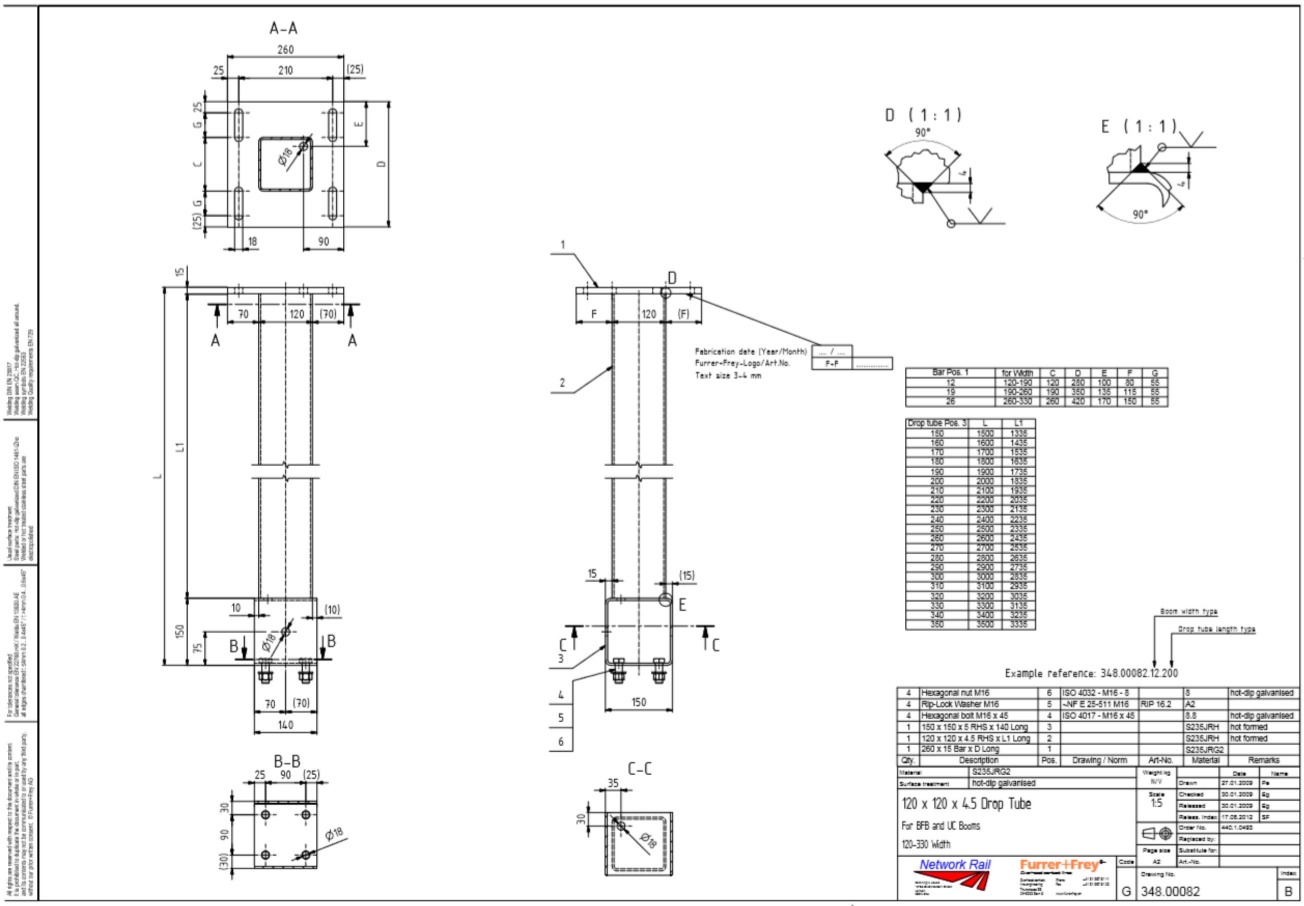


Figure 62. Drop Tube layout a

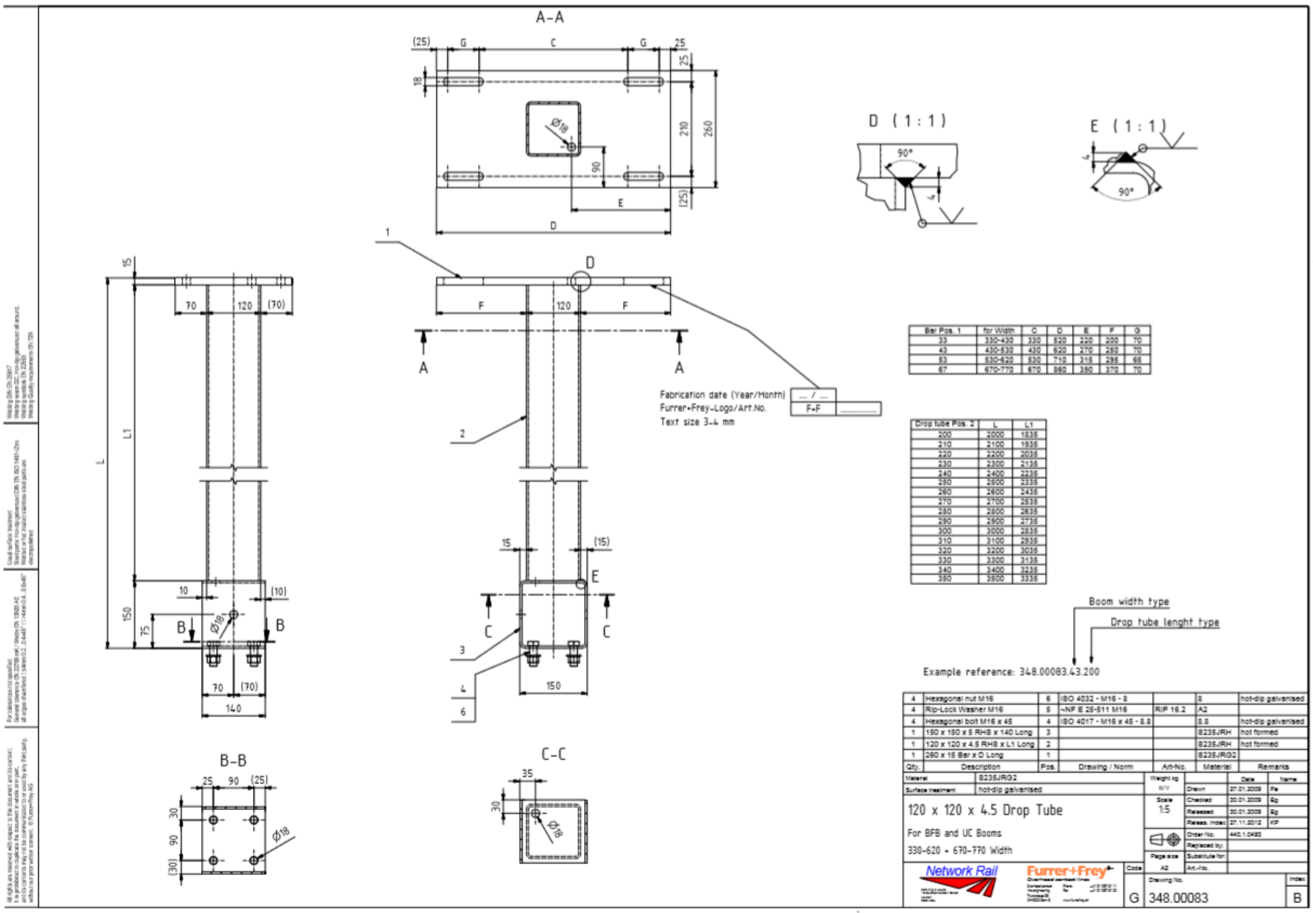


Figure 63. Drop Tube Layout b

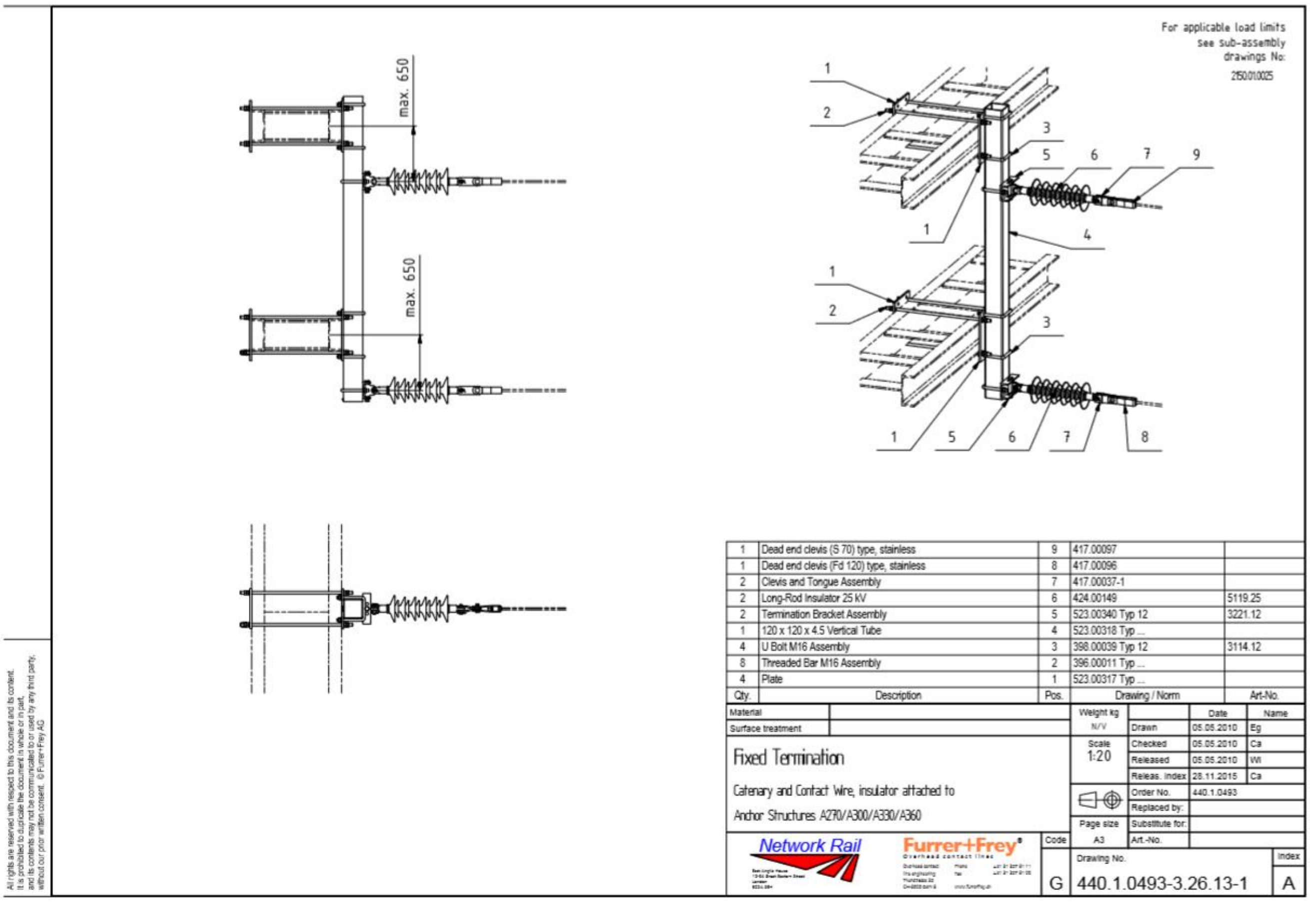
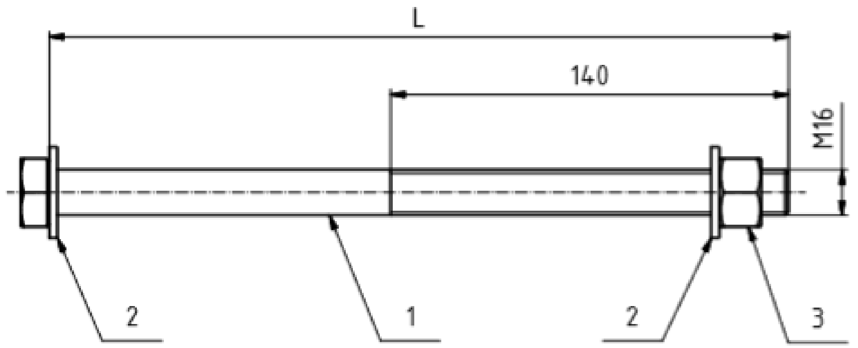


Figure 64. Fixed Termination layout



Type	Article	L	Long shank bolt M16 (Pos. 1)
396.00009 Typ 26	3251.26	260	396.00004 Typ 26
396.00009 Typ 30	3251.30	300	396.00004 Typ 30
396.00009 Typ 34	3251.34	340	396.00004 Typ 34
396.00009 Typ 38	3251.38	380	396.00004 Typ 38
396.00009 Typ 50	3251.50	500	396.00004 Typ 50
396.00009 Typ 62	3251.62	620	396.00004 Typ 62
396.00009 Typ 74	3251.74	740	396.00004 Typ 74

Typ

Example reference: 3251.50

Qty.	Description	Pos.	Drawing / Norm	Art-No.	Material	Remarks
1	Hexagonal nut M16	3	ISO 4032 - M16 - 8		8	hot-dip galvanised
2	Rip-Lock Washer M16	2	~NF E 25-511 M16	RIP 16.2	A2	
1	Long shank bolt M16 Fabrication	1	396.00004 Typ ...		S235JRG2	hot-dip galvanised

Material		Weight kg		Date	Name
Surface treatment	see table	N/V	Drawn	14.04.2009	RH
		Scale 1:2	Checked	15.04.2009	Eg
			Released	15.04.2009	Eg
			Releas. Index	24.11.2015	KP
			Order No.	440.1.0493	
			Replaced by:		
		Page size	Substitute for:	396.00002	
	Code	A4	Art.-No.	3251	

Long Shank Bolt M16 Assembly

with 2 Rip Lock Washers and 1 Hexagonal Nut

Network Rail

Furrer+Frey®
Overhead contact lines

Code	Drawing No.	Index
G	396.00009	D

Figure 65. Long Shank Bolt M16 Assembly layout

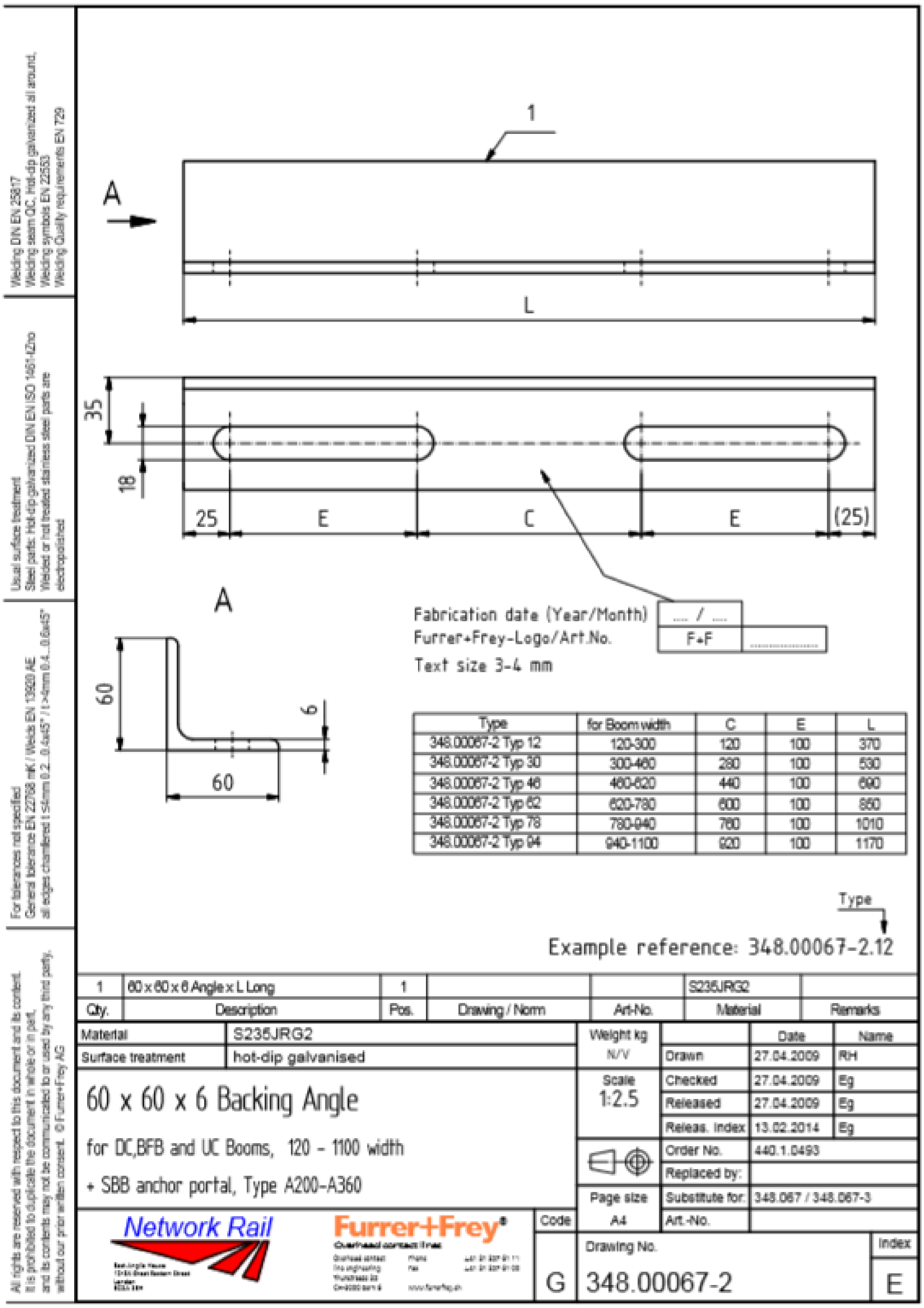


Figure 66. Backing Angle layout

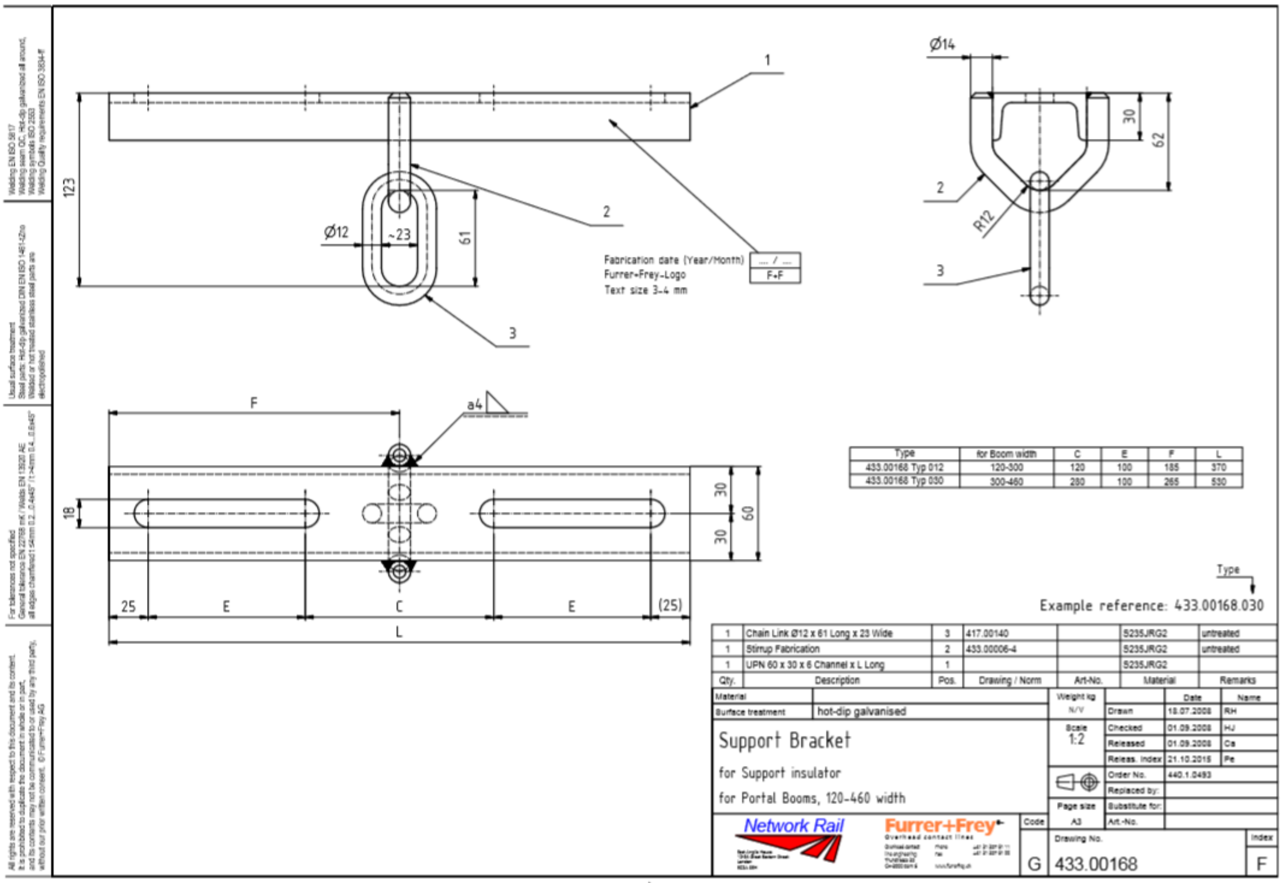


Figure 67. Support Bracket layout a

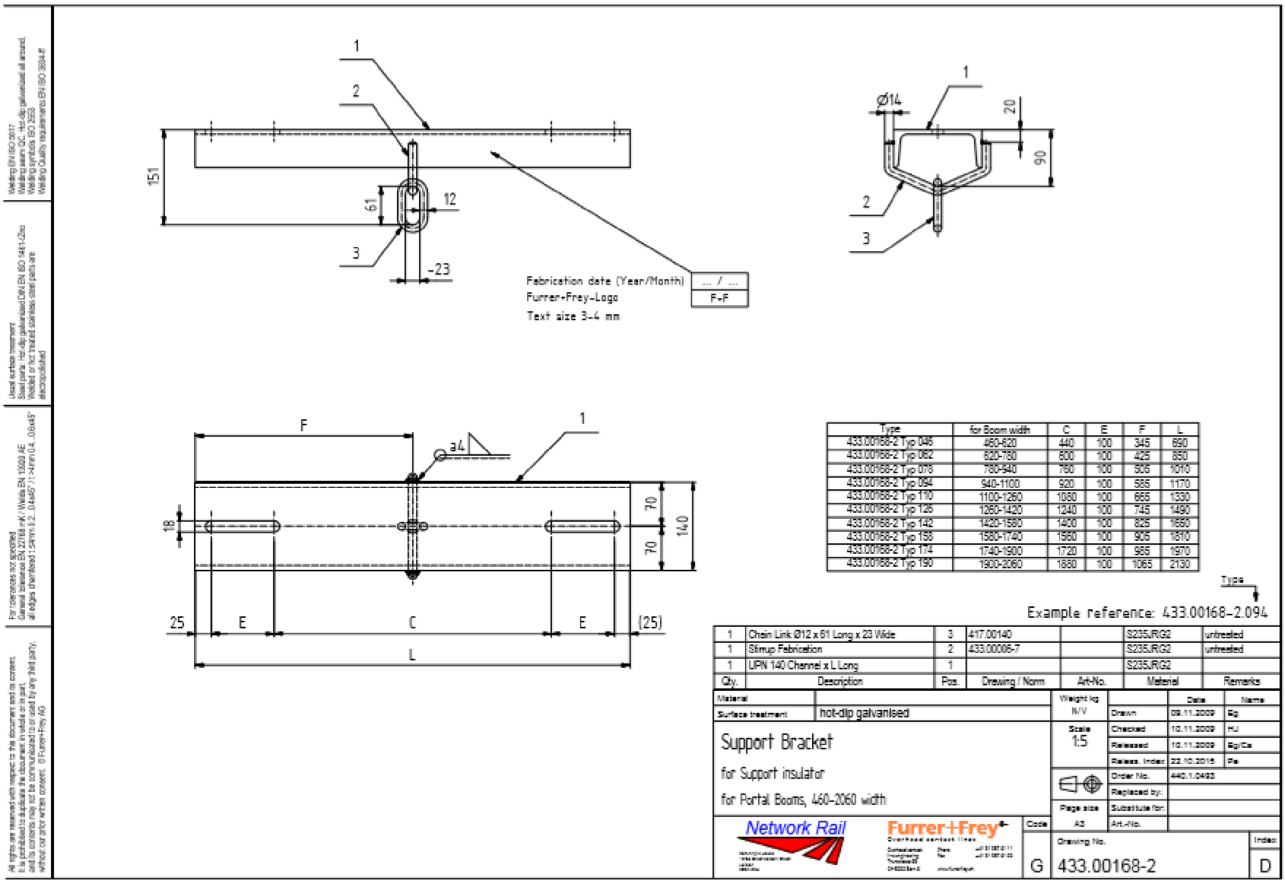


Figure 68. Support Bracket layout b

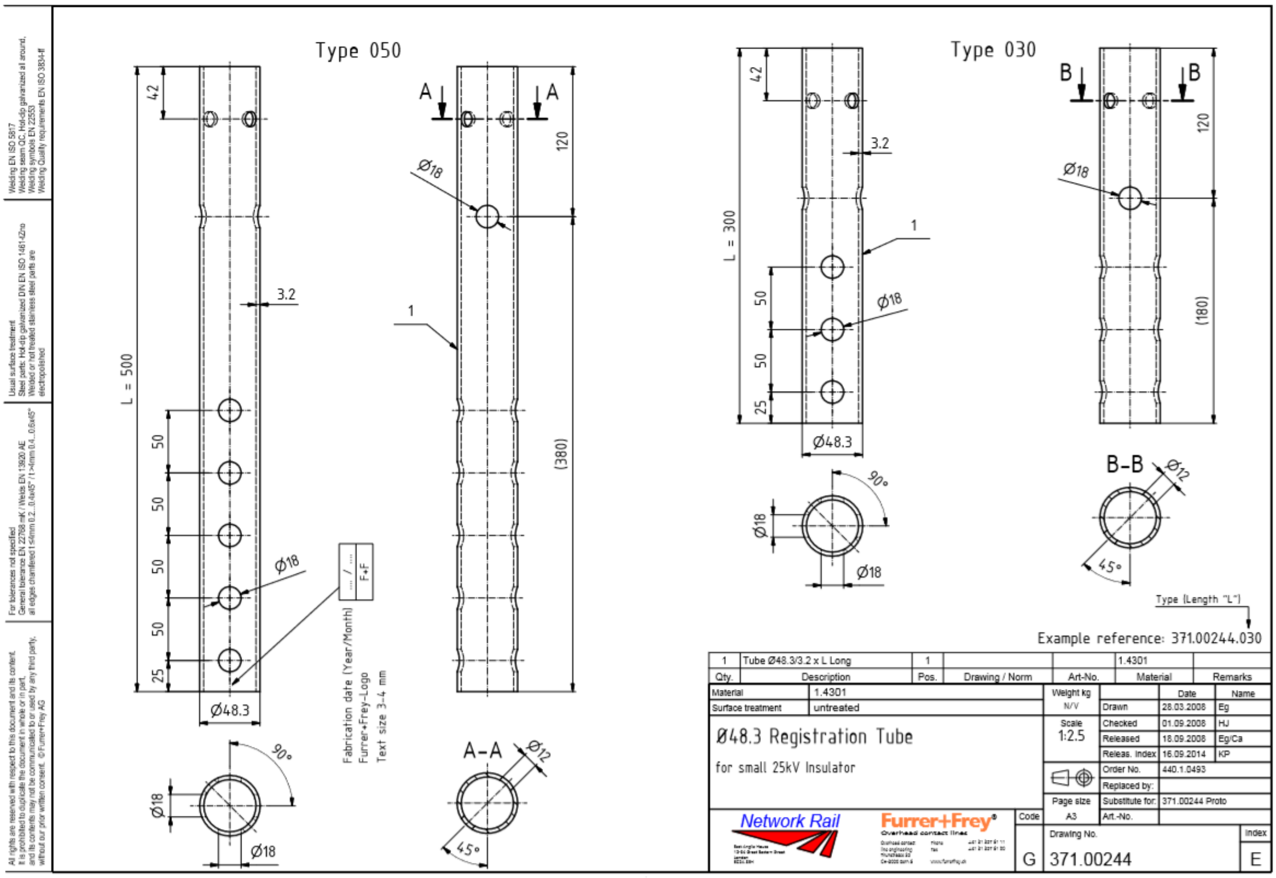


Figure 69. Registration Tube layout

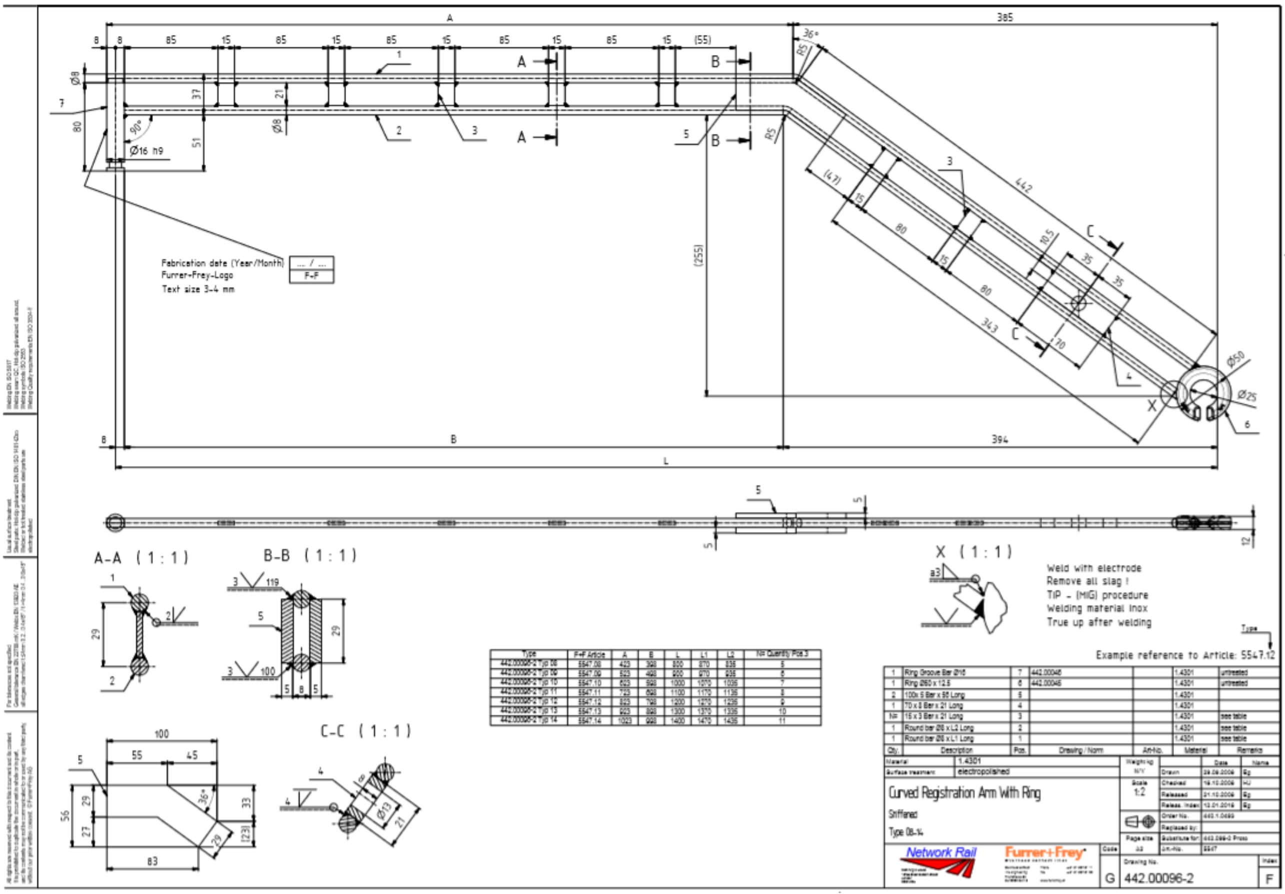


Figure 70. Curved Registration Arm with Ring layout

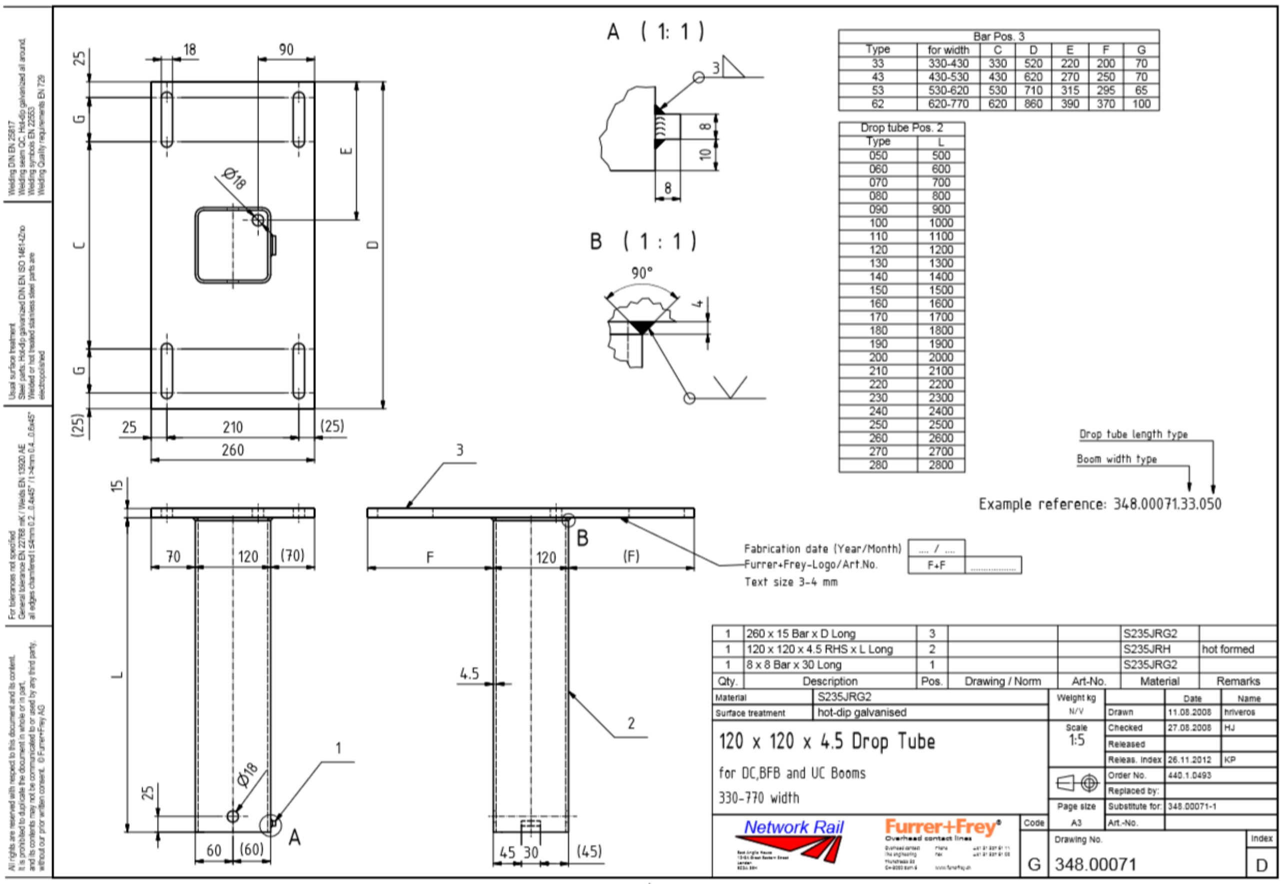
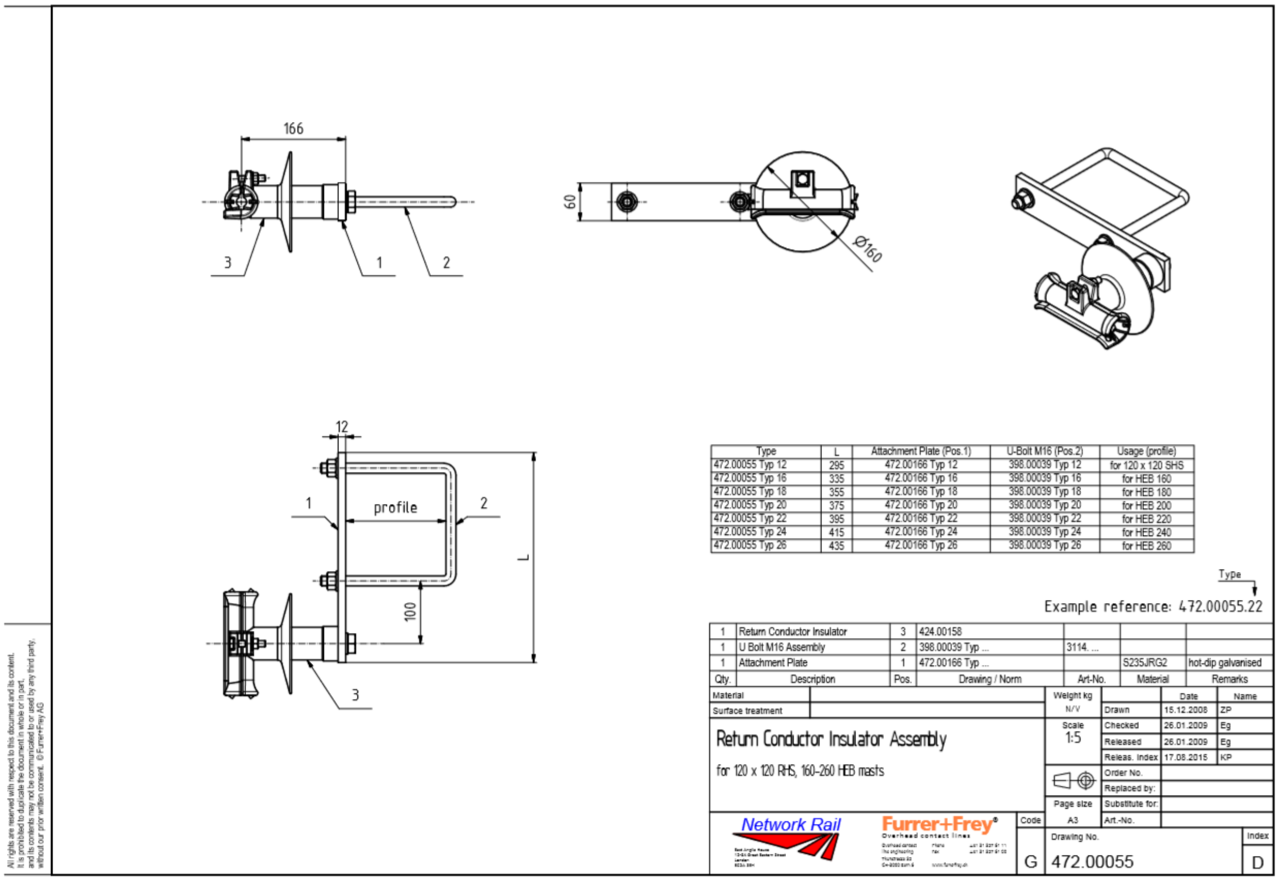


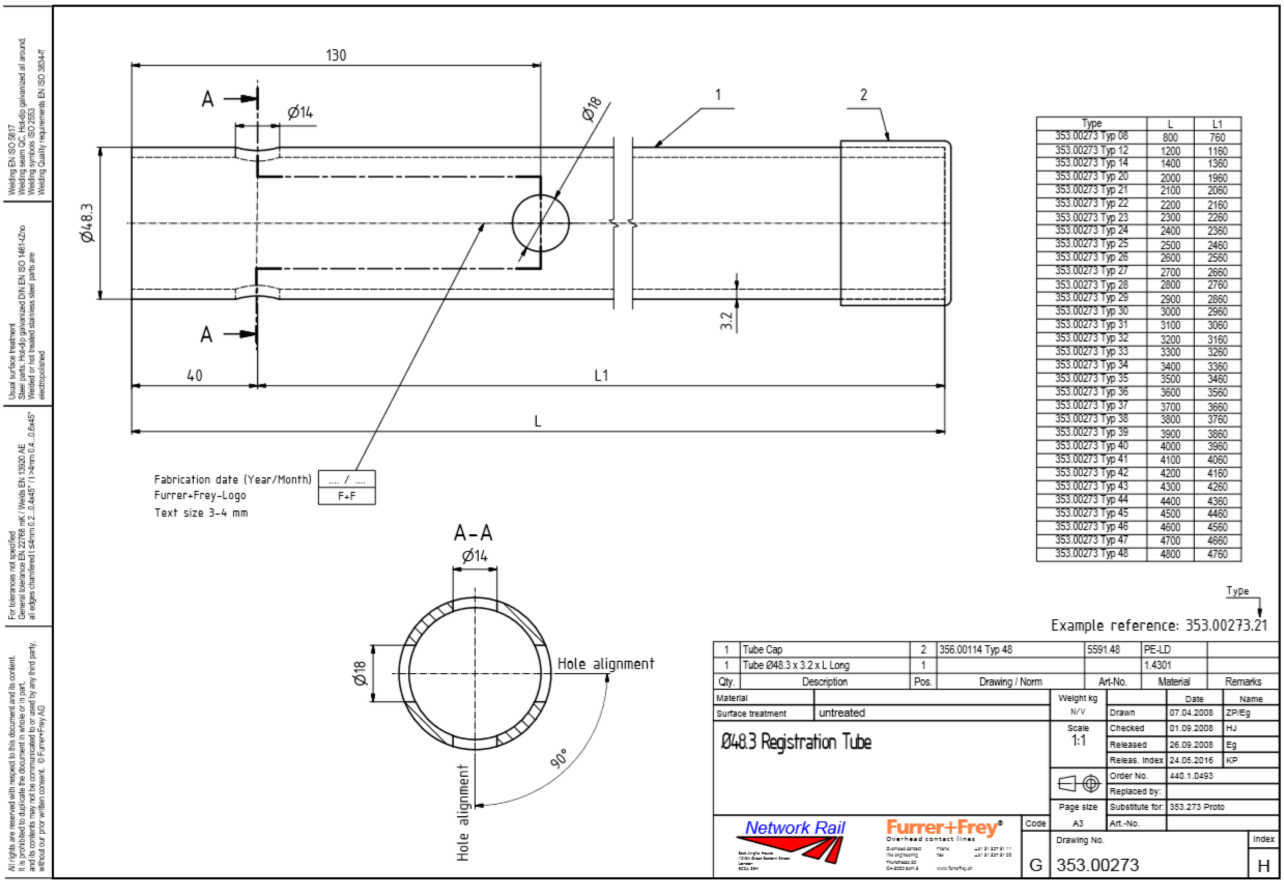
Figure 71. Drop Tube layout



Type	L	Attachment Plate (Pos.1)	U-Bolt M16 (Pos.2)	Usage (profile)
472.00055 Typ 12	295	472.00166 Typ 12	398.00039 Typ 12	for 120 x 120 SHS
472.00055 Typ 16	335	472.00166 Typ 16	398.00039 Typ 16	for HEB 160
472.00055 Typ 18	355	472.00166 Typ 18	398.00039 Typ 18	for HEB 180
472.00055 Typ 20	375	472.00166 Typ 20	398.00039 Typ 20	for HEB 200
472.00055 Typ 22	395	472.00166 Typ 22	398.00039 Typ 22	for HEB 220
472.00055 Typ 24	415	472.00166 Typ 24	398.00039 Typ 24	for HEB 240
472.00055 Typ 26	435	472.00166 Typ 26	398.00039 Typ 26	for HEB 260

Qty.	Description	Pos.	Drawing / Norm	Art-No.	Material	Remarks
1	Return Conductor Insulator	3	424.00158			
1	U Bolt M16 Assembly	2	398.00039 Typ ...	3114. ...		
1	Attachment Plate	1	472.00166 Typ ...		S235JRG2	hot-dip galvanised

Figure 72. Return Conductor Insulator Assembly



Type	L	L1
353.00273 Typ 08	800	760
353.00273 Typ 12	1200	1160
353.00273 Typ 14	1400	1360
353.00273 Typ 20	2000	1960
353.00273 Typ 21	2100	2060
353.00273 Typ 22	2200	2160
353.00273 Typ 23	2300	2260
353.00273 Typ 24	2400	2360
353.00273 Typ 25	2500	2460
353.00273 Typ 26	2600	2560
353.00273 Typ 27	2700	2660
353.00273 Typ 28	2800	2760
353.00273 Typ 29	2900	2860
353.00273 Typ 30	3000	2960
353.00273 Typ 31	3100	3060
353.00273 Typ 32	3200	3160
353.00273 Typ 33	3300	3260
353.00273 Typ 34	3400	3360
353.00273 Typ 35	3500	3460
353.00273 Typ 36	3600	3560
353.00273 Typ 37	3700	3660
353.00273 Typ 38	3800	3760
353.00273 Typ 39	3900	3860
353.00273 Typ 40	4000	3960
353.00273 Typ 41	4100	4060
353.00273 Typ 42	4200	4160
353.00273 Typ 43	4300	4260
353.00273 Typ 44	4400	4360
353.00273 Typ 45	4500	4460
353.00273 Typ 46	4600	4560
353.00273 Typ 47	4700	4660
353.00273 Typ 48	4800	4760

Qty.	Description	Pos.	Drawing / Norm	Art-No.	Material	Remarks
1	Tube Cap	2	356.00114 Typ 48	5591.48	PE-LD	
1	Tube Ø48.3 x 3.2 x L Long	1			1.4301	

Figure 73. Registration Tube layout

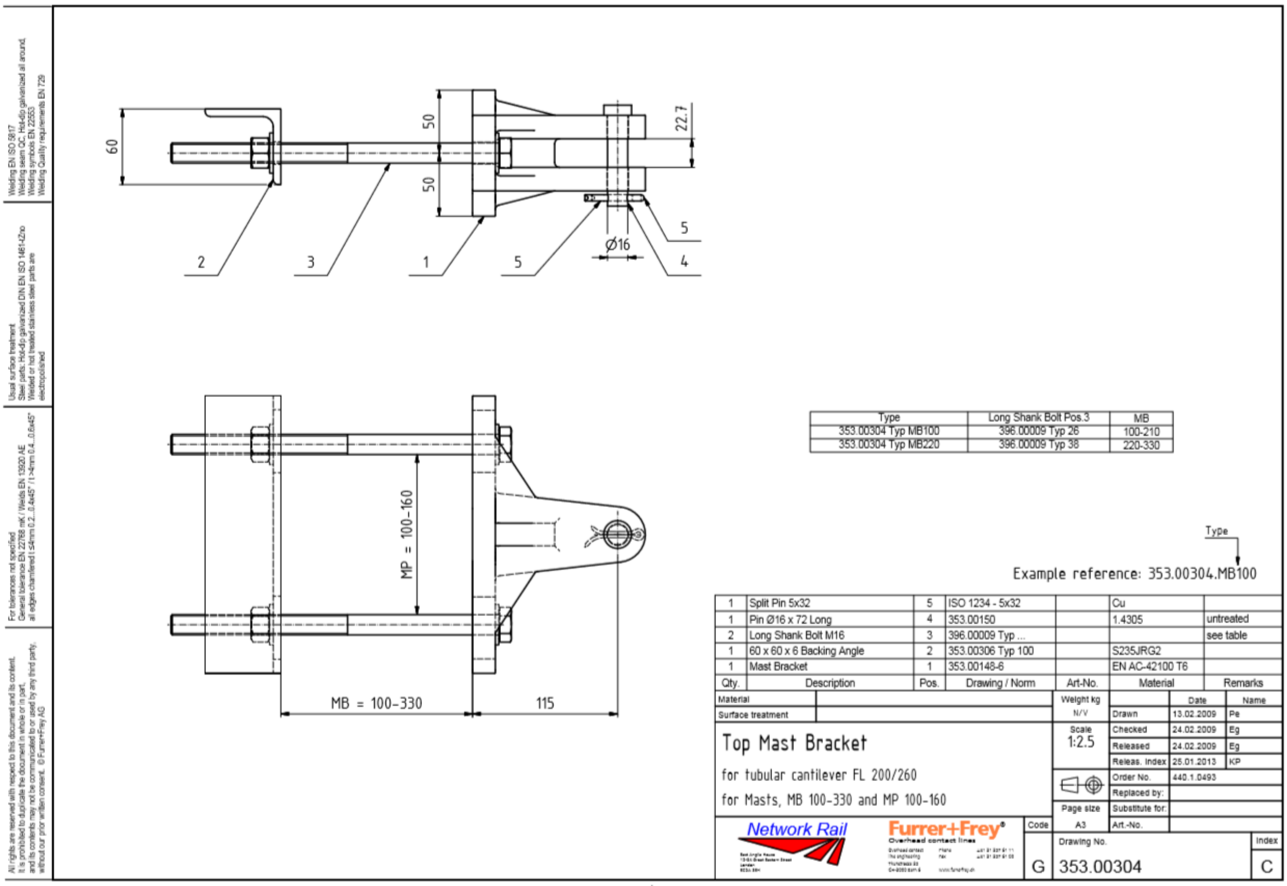


Figure 74. Top Mast Bracket layout

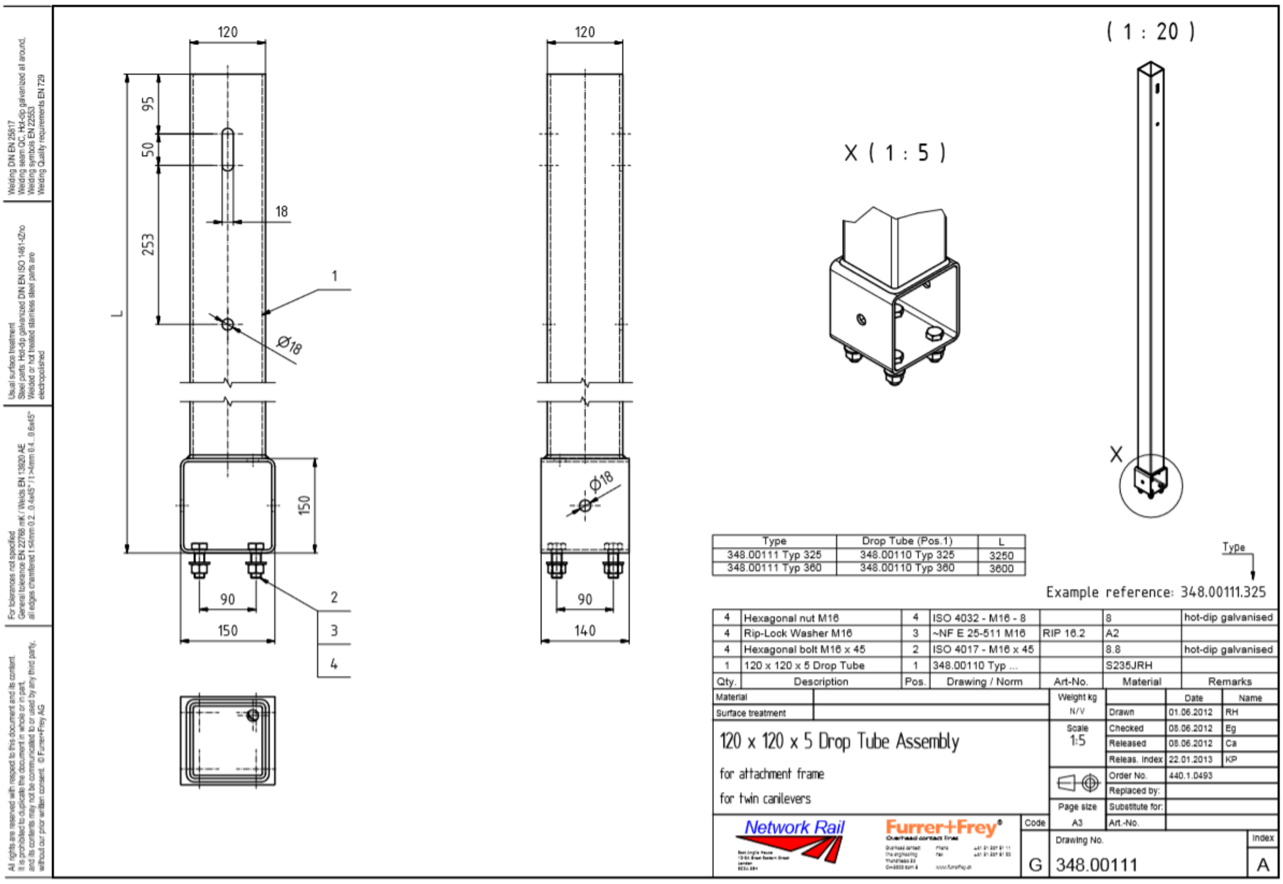


Figure 75. 120 x 120 x 5 Drop Tube Assembly layout

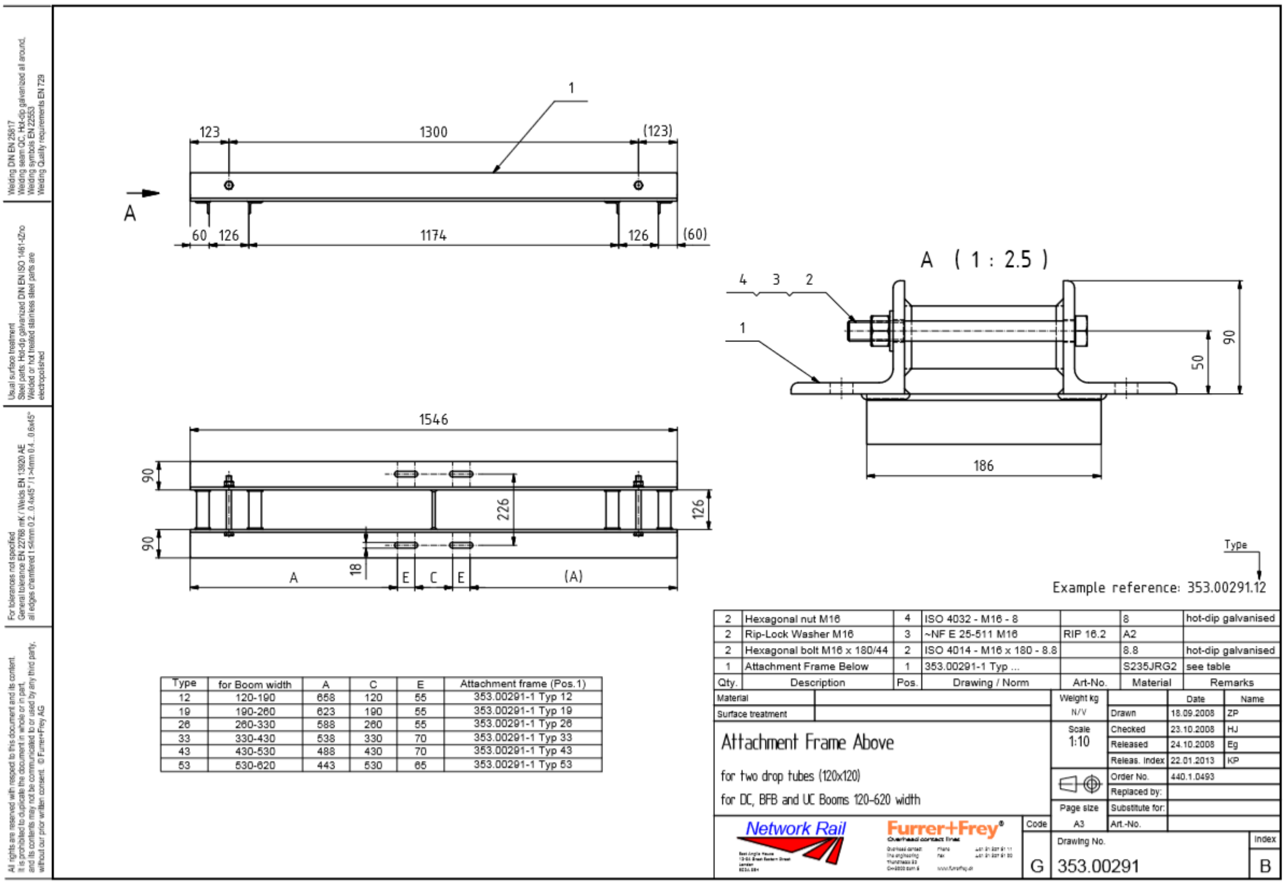


Figure 76. Attachment Frame Above layout

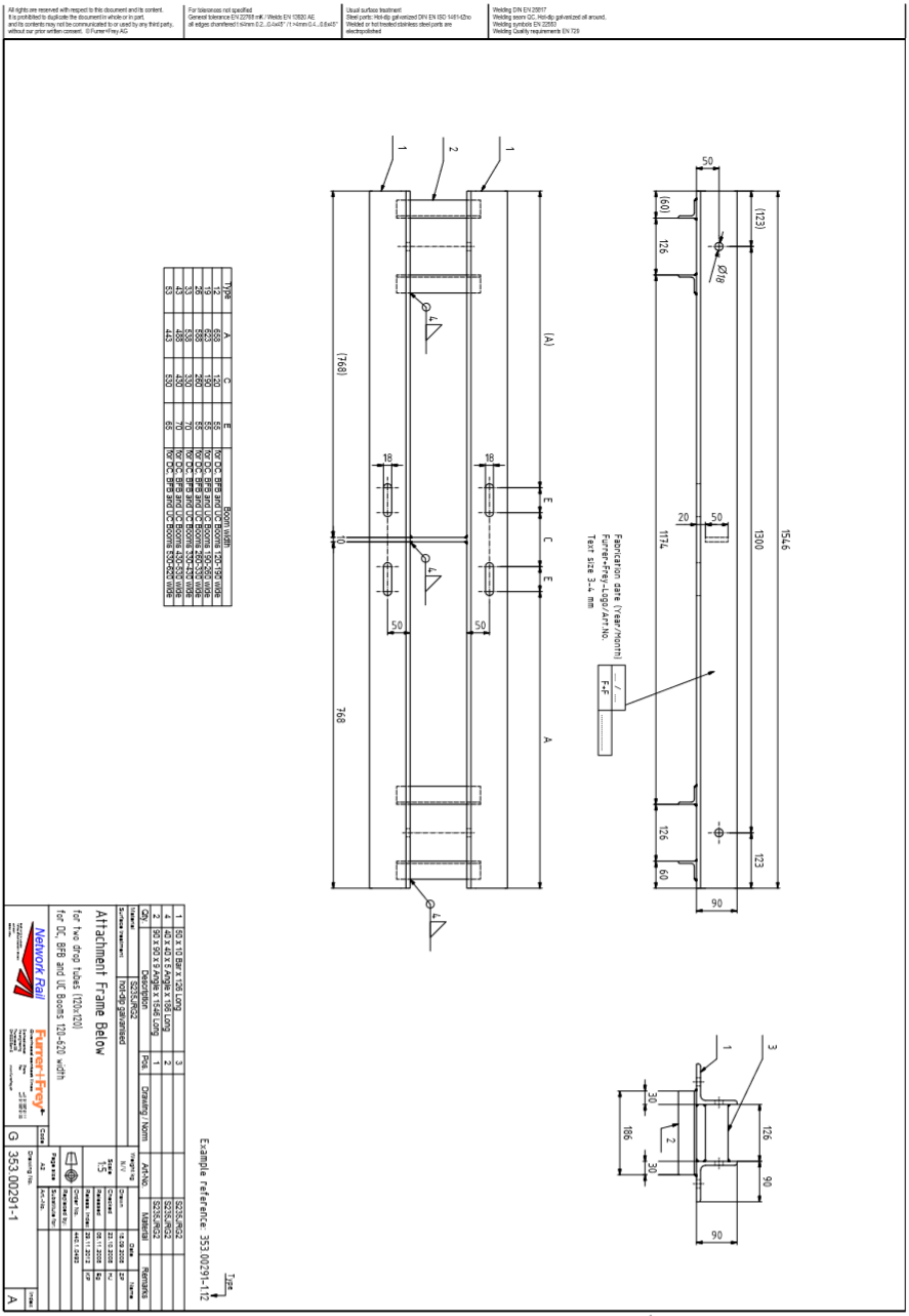


Figure 77. Attachment Frame Below layout

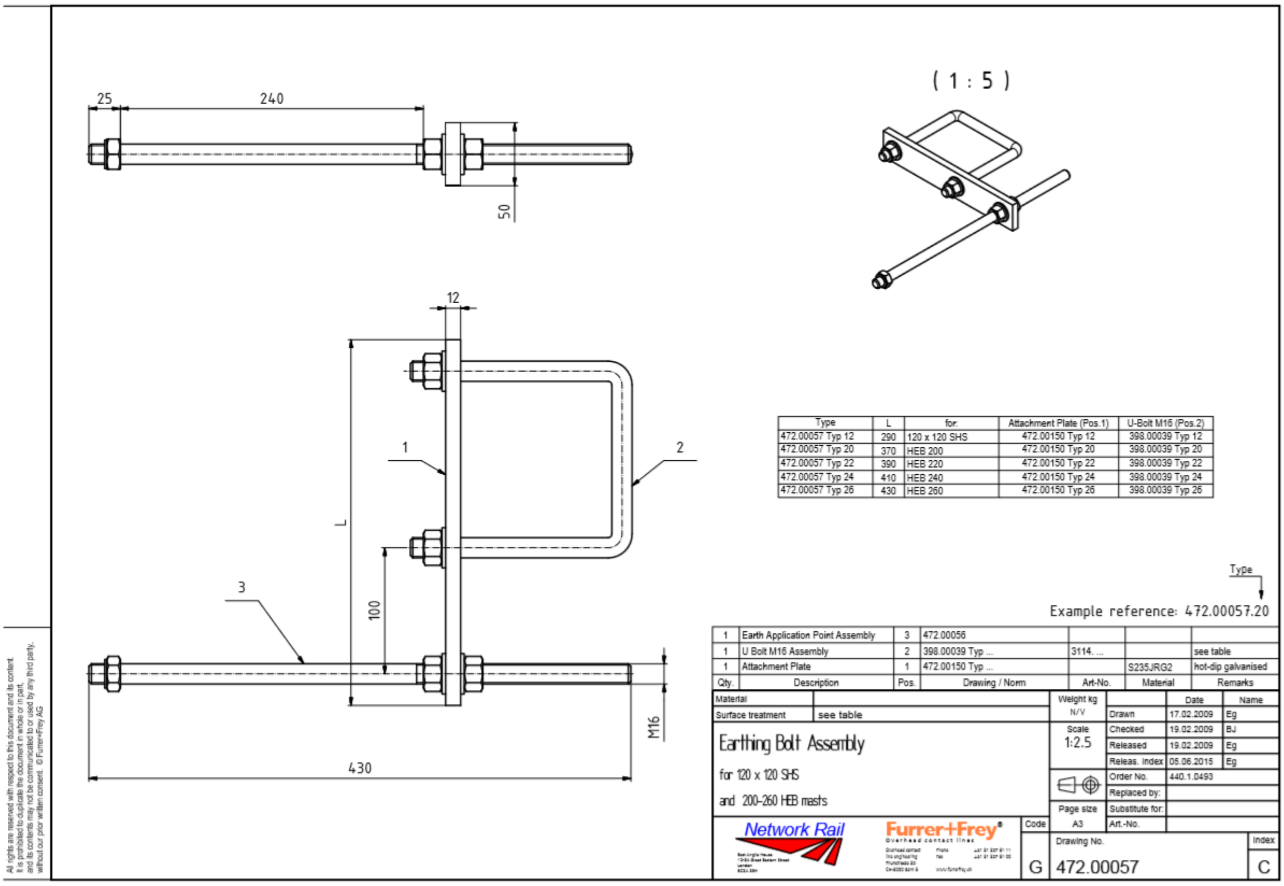


Figure 78. Earthing Bolt Assembly layout

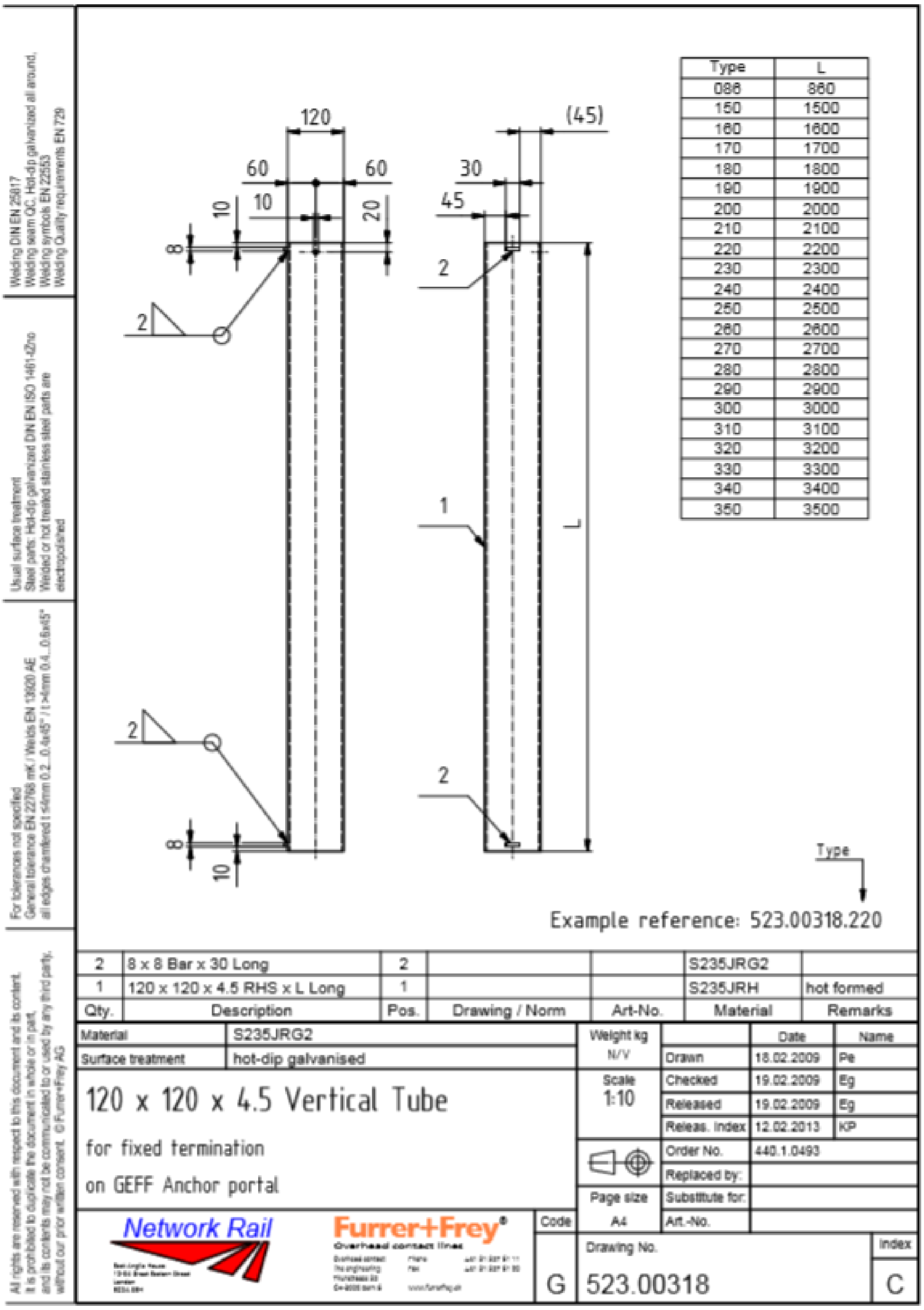


Figure 79. 120 x 120 x 4.5 Vertical Tube layout

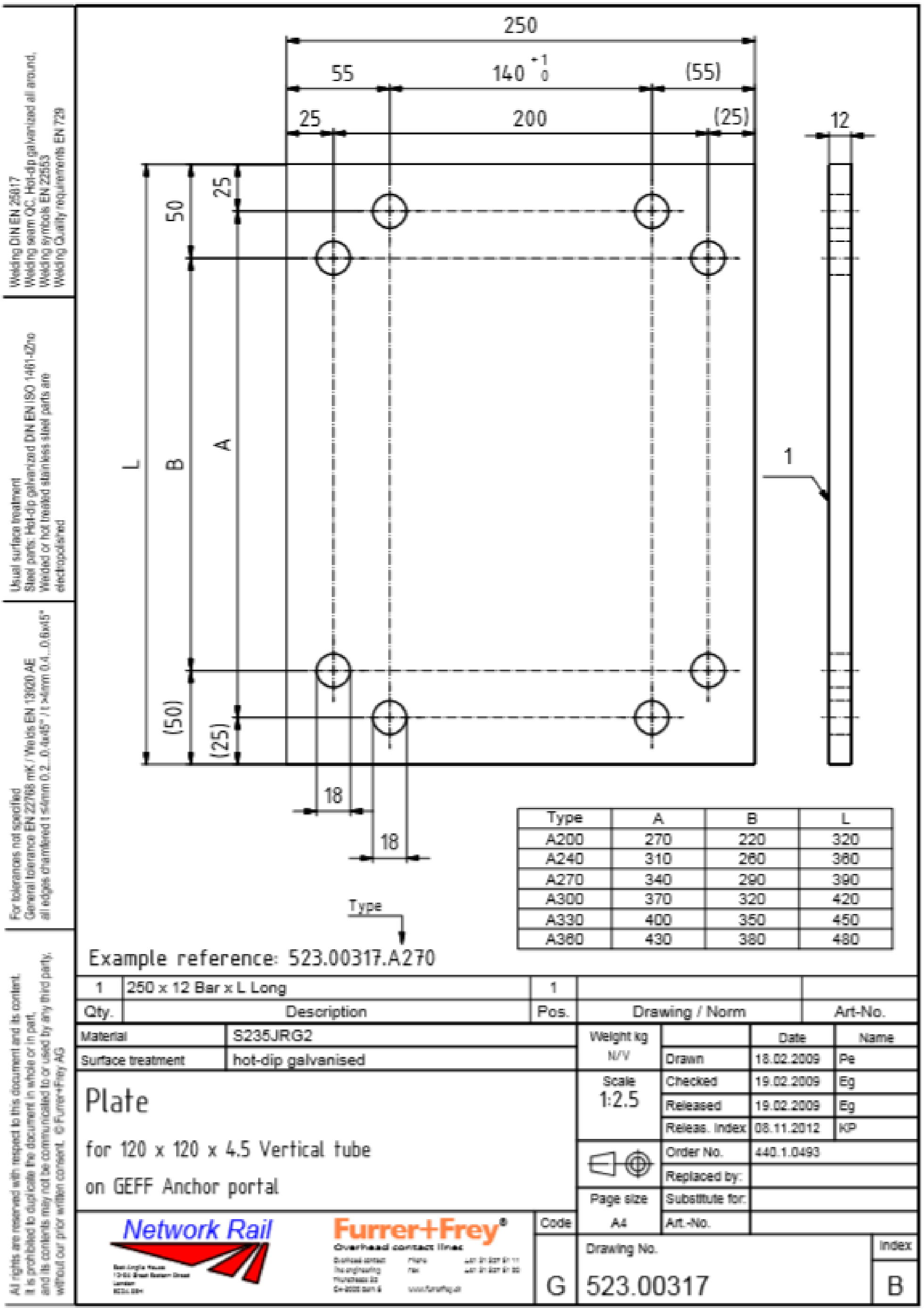
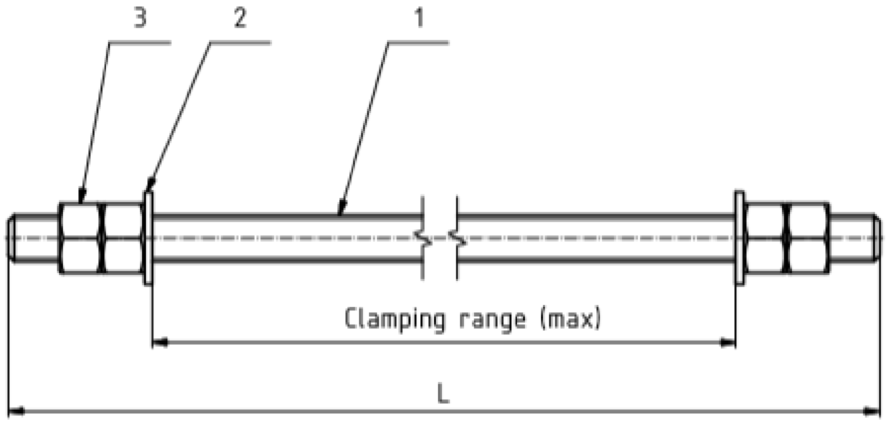


Figure 80. Plate layout

Welding DIN EN 25817
Welding seam QC. Hot-dip galvanized all around,
Welding symbols EN 22553
Welding Quality requirements EN 729

Usual surface treatment
Steel parts: Hot-dip galvanized DIN EN ISO 1461-tZn
Welded or not treated stainless steel parts are
electropolished

For tolerances not specified
General tolerance EN 22768 mK / Welds EN 13920 AE
all edges chamfered t<4mm 0.2...0.4x45° / t>4mm 0.4...0.6x45°



Type	L	For boom	Clamping range max.
396.00011 Typ A160	550	A160	470
396.00011 Typ A200	700	A200	620
396.00011 Typ A240	900	A240 - A360	820
396.00011 Typ WPE450	1200	WPE 450	1120

Type

Example reference: 396.00011.A240

(*) Molybe 7.01.000 / Cresacoat C 112

Qty.	Description	Pos.	Drawing / Norm	Art-No.	Material	Remarks
4	Hexagonal nut M16	3	ISO 4032 - M16 - A2		A2	(*)
2	Rip-Lock Washer M16	2	~NF E 25-511 M16	RIP 16.2	A2	
1	Threaded Bar M16 x L Long	1			A2-70	DIN 975

Material
Surface treatment

Threaded Bar M16 Assembly

on GEFF Anchor portal / WPE450

Weight kg N/V
Scale 1:2
Page size A4

	Date	Name
Drawn	04.05.2009	Pe
Checked	08.05.2009	HJ
Released	11.05.2009	Eg
Releas. Index	05.03.2013	KP
Order No.		
Replaced by:		
Substitute for:		
Art.-No.		

Network Rail

Furrer+Frey®

Code G

Drawing No. 396.00011

Index E

Figure 81. Threaded Bar M16 Assembly

ANNEX V

BOQ

Components	Cost	B51-91	B51-96	B51-100			B51-102				B51-103			B51-105			B51-106			Total cost per component
		Support 2	FA	Support 4	FA	Support 5	Support 3	Support 4	Support 5	Support 6	Support 3	Support 4	Support 5	Support 3	Support 4	Support 5	Support 3	Support 4	Support 5	
120 x 120 x 4.5 Drop Tube	6467,83	1	0	1	0	1	1	0	0	0	1	0	2	1	1	2	1	1	2	97017,45
Long Shank Bolt M16	970,2	6	0	6	0	6	6	2	2	4	6	2	10	6	4	10	6	4	10	87318
60 x 60 x 6 Backing Angle	1940,36	3	0	3	0	3	3	1	1	0	3	1	5	3	2	5	3	2	5	83435,48
Support Bracket	4365,9	1	0	1	0	1	1	1	1	0	1	1	1	1	2	1	1	2	1	74220,3
Strut Insulator Small, 25 kV	5619,45	1	0	1	0	1	1	0	0	2	1	0	1	1	0	1	1	0	1	67433,4
Ø48.3 Registration Tube	5675,67	1	0	1	0	1	1	0	0	2	1	0	1	1	1	1	1	1	1	79459,38
Registration Arm Ring Fitting	2837,835	1	0	1	0	1	1	0	0	2	1	0	1	1	0	1	1	0	1	34054,02
Curved Registration Arm With Ring	3405,402	1	0	1	0	1	1	0	0	2	1	0	1	1	0	1	1	0	1	40864,824
Contact wire swivel clip	3746,34	1	0	1	0	1	1	0	0	2	1	0	1	1	1	1	1	1	1	52448,76
Long-Rod Insulator 25 kV	5844,29	1	2	1	2	1	1	1	1	0	1	1	1	1	2	1	1	2	1	122730,09
Pulley for Catenary	4870,242	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	73053,63
Flexible copper continuity jumper	5112,17	1	0	1	0	1	1	0	0	2	1	0	1	1	0	1	1	0	1	61346,04
Return Conductor Insulator Assembly	4389,85	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	0	0	4	52678,2
Top Mast Bracket	3744,39	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	7488,78
Long Rod Insulator Small, 25 kV	13112,05	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	26224,1
Clevis Clamp	4973,13	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	9946,26
Suspended Double Hinge	12432,815	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	24865,63
Suspension Clamp	7459,7	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	14919,4
Dropper	4703,4	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	18813,6
Support	9406,83	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	18813,66
120 x 120 x 5 Drop Tube Assembly	8234,32	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	8234,32
Attachment Frame Above	12542,44	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	12542,44
Attachment Frame Below	12542,44	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	12542,44
Earthing Bolt Assembly	6344,6	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	25378,4
Earth Application Point Assembly	8610,6	0	0	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	34442,4
U Bolt M16 Assembly	1164,24	0	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9313,92
120 x 120 x 4.5 Vertical Tube	2023,02	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4046,04
Threaded Bar M16 Assembly	2247,804	0	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	35964,864
Plate	1881,366	0	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15050,928
Termination Bracket Assembly	3135,61	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12542,44
Clevis and Tongue Assembly	3802,6	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15210,4
Dead end clevis (S 70) type, stainless	3.993	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7985,44
Dead end clevis (Fd 120) type, stainless	4880	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9760
Total cost per stucture		59587,409	66625,596	215710,814			217413,927				169924,76			260441,265			260441,265			

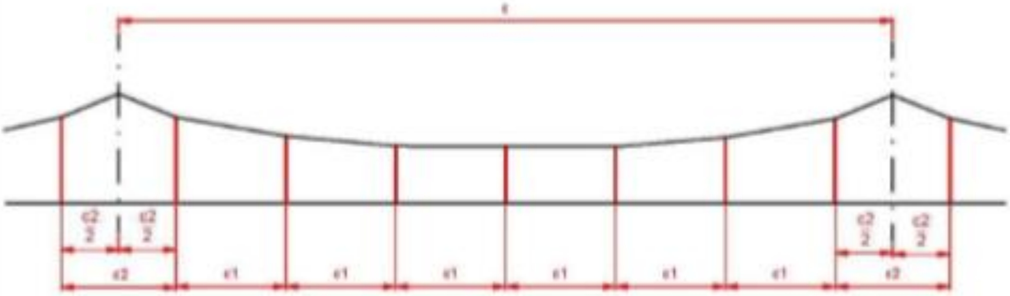
Table 9. BOQ

ANNEX VI

Suspension hangers GEFF reference and results

Dropper allocation:
The first dropper is located at c2/2=4m from the support. Further droppers are spaced equally according to the tables below. Maximum number of droppers per span is 7.
See Drawings 440.1.0493-3.01.02 and .03 for Dropper Lengths.

Dropper spacing is calculated with the following formula:
$c1 = (c - c2) \div (n_{droppers} - 1)$



Dropper Spacing

c = 73 - 66m (7 Droppers)			
c [m]	c1 [m]	c2 [m]	c2/2 [m]
73	10.83	8.00	4.00
72	10.67	8.00	4.00
71	10.50	8.00	4.00
70	10.33	8.00	4.00
69	10.17	8.00	4.00
68	10.00	8.00	4.00
67	9.83	8.00	4.00
66	9.67	8.00	4.00

c = 65 - 55m (6 Droppers)			
c [m]	c1 [m]	c2 [m]	c2/2 [m]
65	11.40	8.00	4.00
64	11.20	8.00	4.00
63	11.00	8.00	4.00
62	10.80	8.00	4.00
61	10.60	8.00	4.00
60	10.40	8.00	4.00
59	10.20	8.00	4.00
58	10.00	8.00	4.00
57	9.80	8.00	4.00
56	9.60	8.00	4.00
55	9.40	8.00	4.00

c = 54 - 43m (5 Droppers)			
c [m]	c1 [m]	c2 [m]	c2/2 [m]
54	11.50	8.00	4.00
53	11.25	8.00	4.00
52	11.00	8.00	4.00
51	10.75	8.00	4.00
50	10.50	8.00	4.00
49	10.25	8.00	4.00
48	10.00	8.00	4.00
47	9.75	8.00	4.00
46	9.50	8.00	4.00
45	9.25	8.00	4.00
44	9.00	8.00	4.00
43	8.75	8.00	4.00

c = 42 - 32m (4 Droppers)			
c [m]	c1 [m]	c2 [m]	c2/2 [m]
42	11.33	8.00	4.00
41	11.00	8.00	4.00
40	10.67	8.00	4.00
39	10.33	8.00	4.00
38	10.00	8.00	4.00
37	9.67	8.00	4.00
36	9.33	8.00	4.00
35	9.00	8.00	4.00
34	8.67	8.00	4.00
33	8.33	8.00	4.00
32	8.00	8.00	4.00

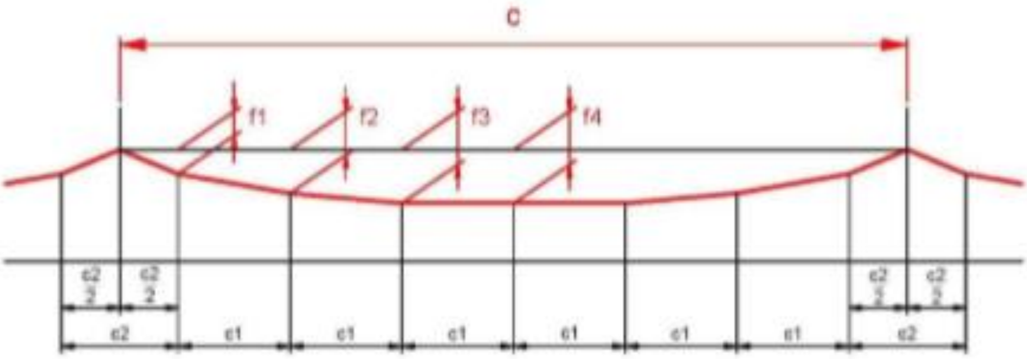
c = 31 - 22m (3 Droppers)			
c [m]	c1 [m]	c2 [m]	c2/2 [m]
31	11.50	8.00	4.00
30	11.00	8.00	4.00
29	10.50	8.00	4.00
28	10.00	8.00	4.00
27	9.50	8.00	4.00
26	9.00	8.00	4.00
25	8.50	8.00	4.00
24	8.00	8.00	4.00
23	7.50	8.00	4.00
22	7.00	8.00	4.00

Basic data:

Catenary	70mm2 Bz II 0.597 kg/m 12.0 kN
Contact wire	120mm2 CuAg 1.067 kg/m 13.2 kN

Material	Standard	Weight kg		Date	Name
Surface treatment		N/V	Drawn	14.04.2009	hriveros
Dropper Allocation and Spacing		Scale	Checked		
			Released	11.05.2009	Wi
			Releas. Index		
			Order No.	440.1.0493	
			Replace by:		
		Size	Substitute for:		
Network Rail	Furrer+Frey® Overhead contact lines	A4	Art.-No.		
Code G	Drawing No. 440.1.0493-3.01.01			Index	

Figure 82. Dropper allocation and spacing reference



Basic data

Catenary tension	12.0 kN (constant)
Linear weight of Catenary	0.597 kg/m

Sag of Catenary under load

c = 73 - 66m (7 Droppers)				
c [m]	f1 [m]	f2 [m]	f3 [m]	f4 [m]
73	0.206	0.624	0.875	0.959
72	0.203	0.609	0.852	0.933
71	0.200	0.594	0.829	0.908
70	0.198	0.579	0.807	0.883
69	0.195	0.564	0.785	0.859
68	0.192	0.549	0.763	0.835
67	0.189	0.535	0.742	0.811
66	0.187	0.521	0.721	0.788

c = 65 - 55m (6 Droppers)				
c [m]	f1 [m]	f2 [m]	f3 [m]	f4 [m]
65	0.183	0.553	0.738	
64	0.180	0.537	0.716	
63	0.177	0.522	0.695	
62	0.175	0.507	0.673	
61	0.172	0.492	0.653	
60	0.169	0.478	0.632	
59	0.166	0.463	0.612	
58	0.164	0.449	0.592	
57	0.161	0.435	0.573	
56	0.158	0.422	0.553	
55	0.155	0.408	0.535	

c = 54 - 43m (5 Droppers)				
c [m]	f1 [m]	f2 [m]	f3 [m]	f4 [m]
54	0.152	0.434	0.528	
53	0.149	0.419	0.509	
52	0.146	0.405	0.491	
51	0.143	0.390	0.473	
50	0.141	0.376	0.455	
49	0.138	0.363	0.438	
48	0.135	0.349	0.421	
47	0.132	0.336	0.404	
46	0.129	0.323	0.388	
45	0.127	0.310	0.372	
44	0.124	0.298	0.356	
43	0.121	0.286	0.341	

c = 42 - 32m (4 Droppers)				
c [m]	f1 [m]	f2 [m]	f3 [m]	f4 [m]
42	0.118	0.300		
41	0.115	0.287		
40	0.112	0.274		
39	0.109	0.262		
38	0.106	0.249		
37	0.104	0.237		
36	0.101	0.226		
35	0.098	0.214		
34	0.095	0.203		
33	0.093	0.192		
32	0.090	0.182		

c = 31 - 22m (3 Droppers)				
c [m]	f1 [m]	f2 [m]	f3 [m]	f4 [m]
31	0.086	0.180		
30	0.083	0.170		
29	0.081	0.159		
28	0.078	0.149		
27	0.075	0.140		
26	0.072	0.130		
25	0.070	0.121		
24	0.067	0.113		
23	0.064	0.105		
22	0.061	0.097		

Material	Standard	Weight kg		Date	Name
Surface treatment		N/V	Drawn	14.04.2009	hriveros
		Scale	Checked		
			Released	12.05.2009	WI
			Releas. Index		
			Order No.	440.1.0493	
			Replace by:		
		Size	Substitute for:		
Code		A4	Art.-No.		

Sag of Catenary 70mm² BzII, Tensioned at 12kN, and Loaded With A Contact Wire of 120mm²

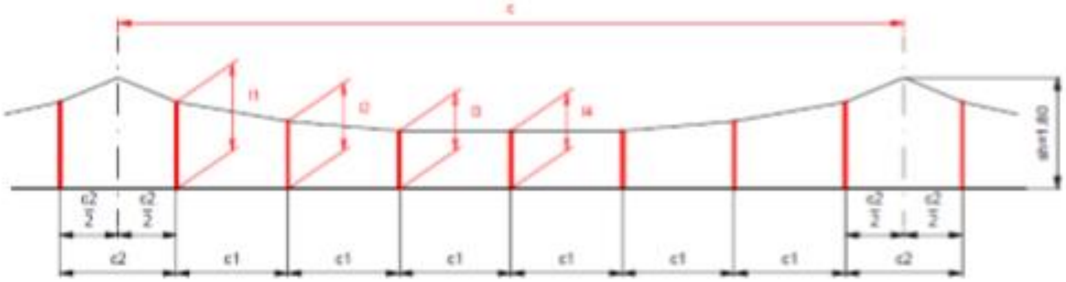
Network Rail

Furrer+Frey®
Overhead contact lines

Drawing No. G 440.1.0493-3.01.05 Index

Figure 83. Sag reference

The tables below show the dropper lengths for an encumbrance of 1.80m.
See Drawing 440.1.0493-3.01.01 for Dropper Spacing.



Catenary of 70mm2 BzII, automatically tensioned at 12kN, and loaded with droppers and a contact wire of 120mm2 CuAg0.1

Dropper length

c = 73 - 66m (7 Droppers)				
c [m]	l1 [m]	l2 [m]	l3 [m]	l4 [m]
73	1.594	1.176	0.925	0.841
72	1.597	1.191	0.948	0.867
71	1.600	1.206	0.971	0.892
70	1.602	1.221	0.993	0.917
69	1.605	1.236	1.015	0.941
68	1.608	1.251	1.037	0.965
67	1.611	1.265	1.058	0.989
66	1.613	1.279	1.079	1.012

c = 65 - 55m (6 Droppers)				
c [m]	l1 [m]	l2 [m]	l3 [m]	l4 [m]
65	1.617	1.247	1.062	
64	1.620	1.263	1.084	
63	1.623	1.278	1.105	
62	1.625	1.293	1.127	
61	1.628	1.308	1.147	
60	1.631	1.322	1.168	
59	1.634	1.337	1.188	
58	1.636	1.351	1.208	
57	1.639	1.365	1.227	
56	1.642	1.378	1.247	
55	1.645	1.392	1.265	

c = 54 - 43m (5 Droppers)				
c [m]	l1 [m]	l2 [m]	l3 [m]	l4 [m]
54	1.648	1.366	1.272	
53	1.651	1.381	1.291	
52	1.654	1.396	1.309	
51	1.657	1.410	1.327	
50	1.659	1.424	1.345	
49	1.662	1.437	1.362	
48	1.665	1.451	1.379	
47	1.668	1.464	1.396	
46	1.671	1.477	1.412	
45	1.673	1.490	1.428	
44	1.676	1.502	1.444	
43	1.679	1.514	1.459	

c = 42 - 32m (4 Droppers)				
c [m]	l1 [m]	l2 [m]	l3 [m]	l4 [m]
42	1.683	1.500		
41	1.685	1.513		
40	1.688	1.526		
39	1.691	1.538		
38	1.694	1.551		
37	1.696	1.563		
36	1.699	1.574		
35	1.702	1.586		
34	1.705	1.597		
33	1.707	1.608		
32	1.710	1.618		

c = 31 - 22m (3 Droppers)				
c [m]	l1 [m]	l2 [m]	l3 [m]	l4 [m]
31	1.714	1.620		
30	1.717	1.630		
29	1.719	1.641		
28	1.722	1.651		
27	1.725	1.660		
26	1.728	1.670		
25	1.730	1.679		
24	1.733	1.687		
23	1.736	1.695		
22	1.739	1.703		

Material	Standard	Weight kg		Date	Name
Surface treatment		N/V	Drawn	16.04.2009	hriveros
		Scale	Checked		
			Released	12.05.2009	Wi
			Releas. Index		
			Order No.	440.1.0493	
			Replace by		
		Size	Substitute for		
		A4	Art.-No.		

Dropper Length for Encumbrance of 1.80m

Network Rail

Furrer+Frey® Overhead contact lines

Code: G

Drawing No. 440.1.0493-3.01.03

Index

Figure 84. Dropper length reference

Wire	Location	Contact wire height (mm)	Catenary height (mm)	Structure Span (m)	c1 (m)	c2 (m)	number of droppers	l1 (m)	l2 (m)	l3 (m)	R1 (mm)	R2 (mm)	R3 (mm)	l1c (m)	l2c (m)	l3c (m)	f1 (m)	f2 (m)	f3 (m)
R84	B 51 91	4900	6890																
				54	11,5	8	5	1,654	0,866	0,772	-174,44	-129,72	-85,00	1,48	0,74	0,69	0,15	0,43	0,53
R84	B 51 96	4920	6700																
				26	9	8	3	1,228	1,17		-10,77	-80,00		1,22	1,09		0,07	0,13	
R84	B 51 100	4930	6910																
				57	9,8	8	6	1,139	0,865	0,727	-183,51	-192,11	-200,70	0,96	0,67	0,53	0,16	0,44	0,57
R84	B 51 102	4900	6930																
				31	11,5	8	3	1,214	1,12		-224,84	-210,00		0,99	0,91		0,09	0,18	
R84	B 51 103	4860	6850																
				48	10	8	5	1,165	0,951	0,879	-191,67	-195,83	-200,00	0,97	0,76	0,68	0,14	0,35	0,42
R84	B 51 105	4830	6840																
				63	11	8	6	1,123	0,778	0,605	-214,44	-226,67	-238,89	0,91	0,55	0,37	0,18	0,52	0,70
R84	B 51 106	4830	6910																

Figure 85. Wire 84 results

Wire	Location	Contact wire height (mm)	Catenary height (mm)	Structure Span (m)	c1 (m)	c2 (m)	umber of droppe	l1 (m)	l2 (m)	l3 (m)	R1 (mm)	R2 (mm)	R3 (mm)	l1c (m)	l2c (m)	l3c (m)	f1 (m)	f2 (m)	f3 (m)
R89	B 51 96	5280	6770																
				26	9	8	3	1,228	1,17		283,85	225,00		1,51	1,40		0,07	0,13	
R89	B 51 100	5100	6760																
				57	9,8	8	6	1,139	0,865	0,727	133,68	118,21	102,74	1,27	0,98	0,83	0,16	0,44	0,57
R89	B 51 102	4930	6680																
				31	11,5	8	3	1,214	1,12		38,39	5,00		1,25	1,13		0,09	0,18	
R89	B 51 103	4930	6770																
				48	10	8	5	1,165	0,951	0,879	0,00	100,00	200,00	1,17	1,05	1,08	0,14	0,35	0,42
R89	B 51 105	5340	6700																
				63	11	8	6	1,123	0,778	0,605	446,98	466,19	485,40	1,57	1,24	1,09	0,18	0,52	0,70
R89	B 51 106	5490	6740																

Figure 86. Wire R89 results

Wire	Location	t wire height	nary height (	ucture Span (	c1 (m)	c2 (m)	nber of dropp	l1 (m)	l2 (m)	l3 (m)	R1 (mm)	R2 (mm)	R3 (mm)	l1c (m)	l2c (m)	l3c (m)	f1 (m)	f2 (m)	f3 (m)
R90	B 51 102	4870	6800																
				31	11,5	8	3	1,214	1,12		-133,87	-145,00		1,08	0,98		0,09	0,18	
R90	B 51 103	4910	6870																
				48	10	8	5	1,165	0,951	0,879	-158,33	-154,17	-150,00	1,01	0,80	0,73	0,14	0,35	0,42
R90	B 51 105	4910	6850																
				63	11	8	6	1,123	0,778	0,605	-138,10	-132,86	-127,62	0,98	0,65	0,48	0,18	0,52	0,70
R90	B 51 106	4910	6820																

Figure 87. Wire R90 results