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Paper 35

Overhead Equipment: Structures and Foundations

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1 Introduction

This Paper gives further details of the design of structures and foundations to meet the requirements broadly defined in Papers 6 and 8. The structures are of the single mast type on single or double track route and of the portal type on multi-track work, the use of headspans being precluded by the necessity of providing mechanical as well as electrical separation of the tracks. The single mast structures are designed for use with hinged cantilevers and the portals to support and register the catenary system using pulleys to allow weight tensioning, as described in Paper 33.

Wherever possible the masts are planted direct into cylindrical foundations, as described in Papers 7 and 36.

2 General Considerations

Structures are designed to withstand the horizontal, longitudinal and vertical loads imposed by the conductors under the wind and ice loadings quoted in Paper 6, without exceeding the working stresses of BS.449 (1956), although in later designs advantage is being taken of relaxations permitted by the 1959 edition.

3 Principles involved in the Design of Portal Structures

The design of portal structures, particularly the kneebraced type, is a subject on which there is not a great deal of published information. Their stability depends on the bending resistance of the various members, and the correct determination of the stresses due to the applied loads, requires consideration of the deformation of all members of the structure. For a portal structure with masts fixed at the base, the general method of solution used for an arch with fixed ends can be advantageously applied for any type of loading. The masts are assumed pinjointed to the bridge and the kneebraces pinjointed to the bridge and masts. Consider the structure cut at the centre of the bridge and let forces Ho, Vo and the moment Mo be introduced for the equilibrium of each half independently. Consider the horizontal deflection, vertical deflection and the slope at centre for each half of the structure independently due to Ho, Mo, Vo and the external loading. When Ho, Mo and Vo have been solved the structure is then statically determinate.

The results of the application of this method have been verified by type tests of structures from time to time and give results more economical in steelwork than those from approximate formulae.

4 Single Track Cantilever Masts

Broad flange beams planted direct into the foundations are normally used to support the hinged cantilevers. The sizes of masts and of cantilevers have been standardised to cover the wide variety of conditions as regards spans and clearance from rail varying from a minimum of 5 ft. $3\frac{3}{4}$ ins. to 10 ft. 0 ins. or more. The beams vary in size from 6 ins. × 25 lbs. to 8 ins. × 45 lbs. and the cantilever tubes which, in the original design are of copper clad steel, from $1\frac{1}{8}$ ins. diameter to $2\frac{3}{8}$ ins. diameter.

Tubes varying in diameter from $6\frac{5}{8}$ ins. to $9\frac{5}{8}$ ins. × 4(G) are also being used instead of broad flange beams.

5 Multi-Track Structures

5.1 *The Angle/Welded Rod Construction*

A special type of angle/welded rod construction has been designed which combines a good appearance with great strength and lends itself to mass production at an economical price by the use of special welding jigs. The general appearance of this type of structure is pleasing, giving an impression of lightness and also has the advantage of causing very little obstruction to sighting of signals.

This is illustrated in fig.1 (*a*) and although capable of resisting the along track forces arising from weight tensioning, is cheaper and lighter than the kneebraced lattice or B.F.B. structures used on former D.C. electrifications in this country.

The structure is constructed from a box section composed of four 2 ins. × 2 ins. angles with $\frac{5}{8}$ in. diameter continuous rod bracing welded to the toes of the angles. $\frac{5}{16}$ in. thickness of angle is used but in areas subject to atmospheric pollution the minimum thickness is increased to $\frac{3}{8}$ in. The bridge is made up of standard end sections and a number of centre sections of variable lengths which can be used to form structures spanning from 43 – 75 ft. This enables bulk ordering of steelwork which then becomes available at Site Stores for immediate erection.

The following table shows the distribution of the total bending moment due to the various loads for such a structure:—

Type of loading	*Load*	*per cent of Bridge B.M.*	*per cent of Mast B.M.*
Horizontal	2,800 lbs.	38·0	56·1
Wind on structure	9·5 lbs/ft.	2·5	6·7
Wt. of registration	120 lbs. each	7·7	4·5
Wt. of equipment	440 lbs. each	28·8	17·8
Wt. of structure	30 lbs/ft.	23·0	14·9
	Total	100·0%	100·0%

During the tests of a prototype, the structure withstood 2·25 times the maximum working loads without any signs of failure. The masts are provided with bolted bases thus ensuring the necessary accuracy in setting, obviating the difficulty of leaving a cored hole in the concrete foundations and reducing the risk of corrosion of the small steel sections. This structure is also supplied with hinged base double channel masts for attaching to viaducts etc., when it is essential that the loads on the foundations are kept to an absolute minimum.

5.2 *The Lattice Structures*

For structures spanning six to eight tracks with mast centres up to 100 ft. 0 ins., a type of lattice structure is used as shown in fig.1 (*b*). The depth of the bridge is 3 ft. 0 ins. and is composed of $2\frac{1}{2}$ ins. × $2\frac{1}{2}$ ins. × $\frac{3}{8}$ in. angles for the top boom and 3 ins. × $2\frac{1}{2}$ ins. × $\frac{3}{8}$ in. for the bottom boom with $2\frac{1}{2}$ ins. × $2\frac{1}{2}$ ins. × $\frac{3}{8}$ in. angle for vertical bracing with 2 ins. × 2 ins. × $\frac{3}{8}$ in. horizontal bracing. The mast is composed of two 12 ins. × 4 ins. BS channels 2 ft. 0 ins. overall along track.

This structure is used chiefly in junctions where the masts are normally positioned between tracks and where the very limited clearances dictate the use of channels. Another advantage of this type of mast over the conventional four angle lattice type is that it facilitates the attachment of a tie or strut for anchoring purposes. Except for the joints where turned bolts are used in the main boom angles, this structure is an all welded construction. The connection between the bridge kneebrace and the mast lends itself to speedy erection. Advantage has been taken of providing standard end sections of the bridge with centre sections of variable lengths, thus enabling bulk ordering and stock piling.

The masts of this structure can be supplied with planted, bolted or hinged bases to suit the precise site condition.

Other single span supporting structures are used for spans between 100 ft. 0 ins. to 150 ft. 0 ins., 150 ft. 0 ins. to 180 ft. 0 ins. Such structures are of the lattice girder type with masts composed either of two British Standard channels or two Rolled Steel joists.

5.3 *Compound Structures*

Compound supporting structures of two, three or four spans are also used. These are made up of the standard units of the particular type of supporting structure, i.e. the welded rod type or the lattice type and are used where it is possible to place the centre mast between tracks.

5.4 *Cambers*

A camber is provided on all multi-track structures by sloping the end sections only, leaving the centre portion horizontal. This method is more economic than cambering to a definite radius throughout and enables bulk ordering to be used extensively.

5.5 *Structures for Fixed Equipment*

In areas where fixed equipment is permitted so that structures are not required to resist any along track torsional load from the equipment, they are constructed from Broad Flange Beams with kneebraces for spans up to 72 ft. 0 ins. Multi-track cantilevers are also used in such areas. These may be either supported on single masts or formed by extensions to portion structure bridges.

6 Anchoring Structures

For two-track construction an independent anchor mast or a mast with an anchor tie is used to terminate the equipment at each end of the tension length. A set of cast iron balance weights which are free to move up and down the mast is used at a ratio of 3 to 1 to balance the tension in the equipment. An automatic stop is brought into operation in the event of broken wires.

For multi-track work a fabricated anchor structure is used to terminate the equipment. For balance weight tensioned equipment the catenary and contact wire are terminated on an equalising plate to which is attached a terminating strand over the track, this strand is then taken round a pulley and across the bridge to the balance weights which are normally inside the masts on both sides of the track. The structure used is the conventional design, i.e. a lattice box girder bridge composed of angles with 'A' frame mast of BS Channels and angle bracing.

For fixed equipment a similar structure but without balance weights is used.

The terminal load for each set of equipment is 2·4 tons.

7 Mid-point Anchor Structure

For normal tension lengths it is necessary to provide a mid-point anchor where the catenary is anchored to avoid the whole length of equipment piling up at one end. Cantilevers furthest away from the mid-point may swing as much as 1 ft. 6 ins. in either direction with temperature variation.

Mid-point anchor structures are designed to resist an along track load of 1,400 lbs. for one or two catenaries in addition to the normal horizontal and vertical loads. The along-track load is taken as the no-load tension in the catenary in the event of a broken wire in the span.

The bridge and masts for a two-track Mid-point Anchor are composed of two 9 ins. × 3 ins. × 17·46 lbs. channels.

The bridge of a four-track structure is 1 ft. 8 ins. deep composed of 9 ins. × 3 ins. × 17·46 lbs. channels with $\frac{5}{8}$ in. diameter rod bracing welded to the toes of the channels. The masts are constructed from 12 ins. × $3\frac{1}{2}$ ins. channels with battens.

8 Structures in Salt Subsidence Areas

For the Sandbach area of the Manchester – Crewe electrification, it was necessary to develop structures to cater for both vertical and horizontal movement of the ground due to subsidence caused by brine pumping, the average annual movement being 12 ins. vertical and 3 ins. horizontal.

Four parallel tracks are subject to this subsidence and because of the constant track lifting which will be needed in future, as in the past, it has been necessary to design the overhead equipment to maintain the contact wire within the maximum and minimum heights above rail level. Portal structures spanning the tracks have been developed (fig.1 (*c*)) which can be raised on the masts which are initially extended above the level of the spans. The connection between the masts and the spans are through hinged and sliding joints to allow for individual movements of the masts due to subsidence.

Track lifting can be undertaken without recourse to major work on the overhead equipment within the following limits:—

(*a*) By installing the overhead contact wire at 18 ft. 0 ins. instead of the normal 16 ft. 0 ins., track lifting can be carried out for some two – three years without any adjustment to the overhead equipment.

(*b*) When this limit has been reached the structure bridge can be raised on the mast connections a further 4 ft. 0 ins., thus allowing for a further period of four – six years of track lifting.

(*c*) For lifting beyond this stage, it will be necessary to lift the complete structures bodily and to facilitate this, special foundations have been developed with bolted connections for the mast bases. By using ferrules on the bolts their length can be increased and the foundations made up between the original foundation level and the raised structure masts.

The foundation for these structures has been designed on a gravity basis and the mast seatings have been installed at heights up to 5 ft. 0 ins. above rail level to allow for additional tipping of ashes on the embankment clear of the actual structural steelwork. To limit the toe pressure, it was necessary to install the main slab of the foundation under the outside track.

9 Foundations

Foundations for structures supporting the overhead equipment are of two types, i.e. side bearing or gravity type.

9.1 *Design of Side-bearing Foundations*

Cylindrical or rectangular-sided foundations are used in side-bearing for structures on which the overhead equipment is supported but not terminated. They are designed to take the maximum across-track bending moment due to the radial pull of the wires plus vertical loading from structures and ice-loaded equipment.

There are several empirical formulae in common use for calculating the stability of such foundations. The one adopted is based on the following assumptions:—

(1) The centre of overturning of the foundation is at a point two-thirds of the foundation below ground level.

(2) The stress diagram from ground level to centre of over-turning is bounded by a parabola.

(3) The stress diagram from centre of over-turning to base of foundation is bounded by a straight line.

(4) The permissible ground pressure varies directly as the depth.

From the above assumptions the size of the foundations is determined from the expression $M = \frac{20}{243} D^3 LK$ ft. lbs.

Where D = depth of foundation in feet
L = length or diameter of foundation in feet
K = the assumed pressure in the ground in lbs/ft.^{2} per foot of depth.
M = applied moment in feet taken about the underside of the foundation.

For good ground conditions the value of 'K' is taken as 1,000. For inferior ground conditions, but where the earth is capable of remaining stable a 'K' value of 500 is taken.

Cylindrical foundations are installed in bored holes of 2 ft. 0 ins., 2 ft. 9 ins., 3 ft. 0 ins. or 3 ft. 6 ins. diameter of depths varying from 5 ft. 0 ins. to 12 ft. 0 ins., and are capable of resisting overturning moments up to 210,000 ft. lbs.

9.2 *Gravity Type Foundations*
Gravity type foundations are used for supporting structures where ground conditions are not suitable for side bearing. The normal type of foundation is a rectangular block and slab designed for bearing pressures of 560, 1,000 or 2,500 lbs. per square foot on the underside of the slab, depending on the local conditions.

When foundations are subject to uplift, a frustrum of earth at 30° to the vertical is assumed in reasonably good ground in addition to the weight of concrete as resisting the load on the foundation. In bad ground the assistance from the frustrum of earth is neglected. Reinforcement is provided in these foundations to relieve the concrete of any undue tensile stresses.

A concrete mix of 4:2:1 is normally used for all foundations.

9.3 *Special Foundations for Embankments liable to slip*
Structures and foundations have been designed to allow a major bank slip under one foundation without detriment to the structure, and to permit the reinstatement of the structure to its normal position without delay. These are described and illustrated in Paper 8.

9.4 *Foundations for Peat Sub-Soil*
To cope with ground where the sub-soil is composed of peat, hollow foundations are used, the foundations being installed in the resistant ground overlying the peat. The resistance to overturning is provided by a safe value of friction of 1,000 lbs. per square foot, established after a series of tests.

The bored foundations are 3 ft. 6 ins. diameter with a 6 ins. or 9 ins. reinforced wall.

A sulphate resistant cement is used in the vibrated concrete.

10 Conclusion
It has been necessary to omit descriptions of many structures of special interest as, for example, the span of 170 ft. outside the new Manchester Piccadilly station, one end of which is supported on the roof of the new signal box.

At terminal stations special efforts are made to incorporate the supports and terminations of the equipment into the station steelwork. At the new Piccadilly Station, Manchester, the equipment is supported from the roof trusses and terminated on the new forecourt steelwork. Structure masts are incorporated with Platform Awning Columns wherever possible.

Where underbridges are being reconstructed, the support of structure masts are provided for on the new bridge girders. Examples of this can be seen in the vicinity of Manchester.

The object throughout has been to achieve the maximum economy of material consistent with maintaining a stock of structures to keep pace with the programme and a low overall cost. In assessing the cost, both the initial cost and the cost of maintenance have been taken into account as mentioned in Paper 6 where particulars are given of the galvanising technique standardised for all steelwork. Increasing care has been taken over the question of appearance and close co-operation has been maintained with consultants appointed by the Commission's Design Panel. The effects will become increasingly apparent as newer designs are erected. Earlier designs were, to some extent, prejudiced by the necessity of stockpiling steel to ensure maintenance of production during a period of steel shortage that occurred early in the Design programme.

Many alternative constructions were considered before the decisions as to type reported above were taken. So far it has not been possible to establish a case for the use of concrete structures in any form although some masts of prestressed concrete installed on the D.C. 1,500V electrification to Southend in 1952 give a good account of themselves. This matter is always under review as circumstances change. Recently more use has been made of tubular structures and both supporting and terminating structures fabricated from tubular members are being used in fairly large numbers on the Chelmsford – Colchester electrification now in hand.

In common with every other aspect of the electrification, further changes may be anticipated as new knowledge is applied to the subject.

SUMMARY

This Paper, after defining the design parameters and the methods used, gives details of the first of the standard and then of special structures. The normal standard mast for the hinged cantilevers used on double track sections is of the broad flange beam type. A new type of angle/welded rod structure for use on multiple track up to spans of 75 ft. is described and illustrated. This is substantially lighter and more pleasing in appearance than its predecessors.

The circumstances in which structures with lattice booms are used are then described and particulars given of terminal and mid-point anchor structures. Particulars are given of structures to deal with the specially difficult ground at Sandbach near Crewe where underground pumping of brine causes excessive settlement of the main line track and reference is made to other special types of construction.

The Paper concludes with particulars of the basis used for foundation designs under normal and special conditions and with a statement of the overall objective and of the approach adopted in regard to appearance problems and to alternative methods of construction.

RÉSUMÉ

Cet exposé, après avoir défini les paramètres de construction et les méthodes utilisées, donne des détails d'abord des supports unifiés, et puis des supports spéciaux. Le support unifié normal pour les consoles articulées, utilisé sur les sections de voie double, est une poutrelle à larges ailes. Un nouveau type de support à verges soudés aux angles pour être employé sur voies multiples avec portées atteignant 75 ft. est décrit et illustré. Ceci est substantiellement plus léger et plus attrayant dans son apparence que ses prédécesseurs.

On décrit les circonstances dans lesquelles des supports avec poutres en treillis sont utilisés et on donne les détails des supports pour ancrages terminaux et ancrages aux milieux de fils. On donne aussi les particularités des supports prévus pour le terrain spécialement défavorable à Sandbach près de Crewe, où l'extraction de sel par pompage souterrain des eaux salées cause un abaissement excessif de la voie principale. Quelques indications sont données sur d'autres types spéciaux de construction.

L'exposé conclut en citant les particularités des bases utilisées pour les projets et constructions de fondations sous des conditions normales et des conditions spéciales. On indique aussi les objectifs d'ensemble et les voies adoptées au sujet des problèmes d'apparence et des méthodes alternatives de construction.

ZUSAMMENFASSUNG

Nach einer Erläuterung der in die Entwürfe eingehenden Kenngrössen und der benutzten Methoden gibt der Bericht Einzelheiten über Regel- und Sonderausführungen. Als normaler Regelmast für angelenkte Ausleger und zweigleisige Strecken dient ein Breitflanschträger. Eine neue Ausführungsform eines durch angeschweisste Stäbe verstärkten Trägers aus Winkeleisen für mehrgleisige Strecken mit Spannweiten bis zu 75 Fuss wird beschrieben und abgebildet. Sie ist wesentlich leichter und sieht gefälliger aus als ihre Vorgänger.

Weiter werden die Bedingungen beschrieben, unter denen Stützpunkte mit Fachwerkträgern benutzt werden; Einzelheiten betreffend End – und Mitten – Ankerstützpunkte werden gegeben. Im Einzelnen beschrieben werden die Stützpunktausführungen für die besonders schwierigen Bodenverhältnisse nahe Sandbach bei Crewe, wo Pumpförderung von Salzlake zu starken Senkungen der Gleise der Hauptstrecke führt; andere Sonderkonstruktionen werden erwähnt.

Der Bericht schliesst mit Angaben über die Grundlagen, auf die sich der Entwurf von Fundamenten unter normalen und besonderen Bedingungen stützt und mit einer Erklärung betreffend die allgemeine Zielsetzung und die Einstellung zu den Problemen des Aussehens der Bauwerke und zu abweichenden Konstruktionsmethoden.

RESÚMEN

Este informe define los parámetros del diseño, y describe los metodos empleados, dando en seguida unos detalles de las primeras estructuras normales y entonces de las estructuras especiales. La torre normal ordinariamente empleada para brazos articulados, que se hallan en las secciones de línea en doble vía, es de tipo construido de vigas de alas anchas. Hay tambien una descripcíon con ilustraciones de un tipo nuevo de pórtico construido de escuadras y varas soldadas, para su utilización sobre vías multiples, de vano hasta 23 metros. Este tipo es mucho mas ligero y de aspecto mas agradable que aquellos empleados anteriormente.

Se halla luego una descripción de las circunstancias en que se emplean pórticos con traviesas de celosía; hay también detalles que se refieren á las estructuras terminales y del punto medio de anclaje. Se describen las estructuras utilizadas para los terrenos de suma irregularidad en las cercanías de Sandbach, próximo á Crewe, donde existen salinas subterráneas. La extracción de la salmuera por bombas hace dificultades debido al hundimiento excesivo de la vía principal. Hay referencias, además, á otros tipos especiales de construccíon.

El informe se concluye con unos detalles de la base empleada para los planes de cimientos en condicciones normales y especiales; se halla, también, una exposición del objetivo en general, y la actitud en cuanto á los problemas del aspecto y de los métodos alternativos de construcción.

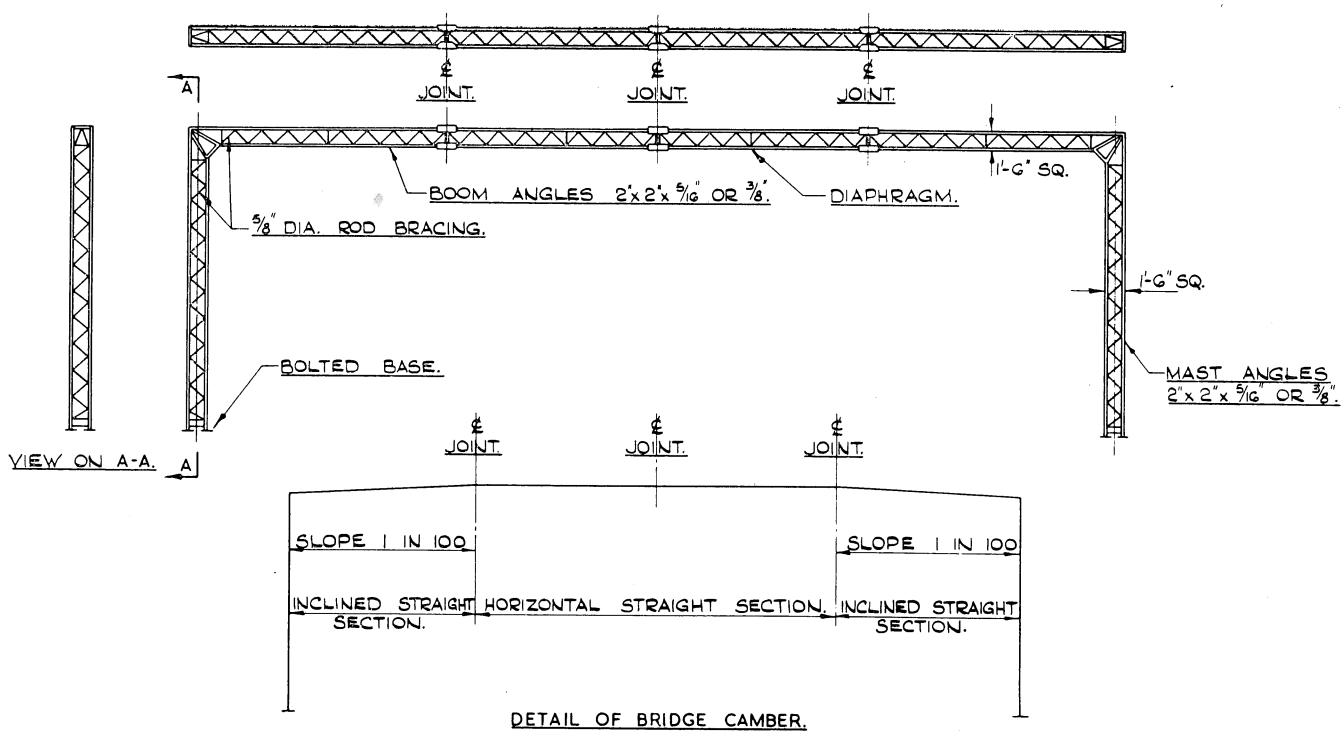

Fig.1 (a) Five track supporting structure (Max. span 75 ft.)

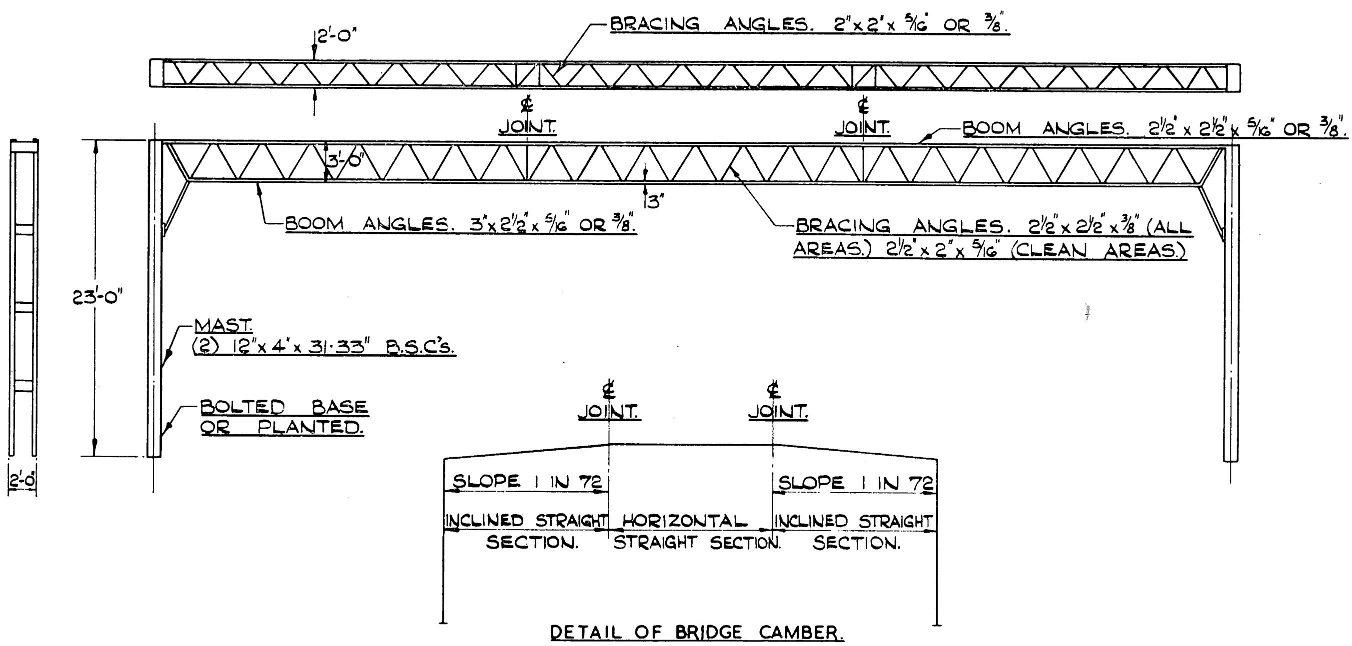

Fig.1 (b) Eight track supporting structure (Max. span 100 ft.)

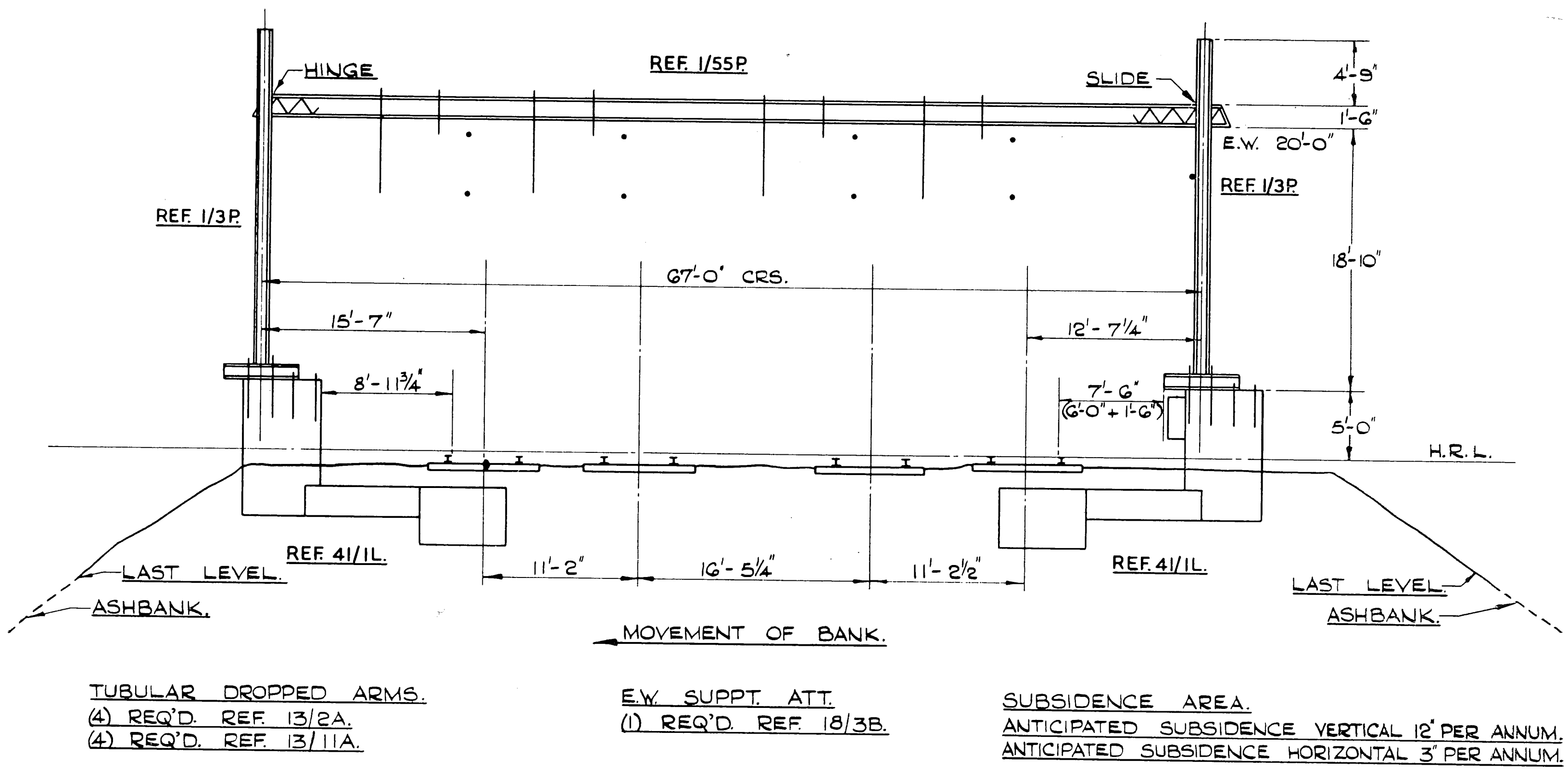

Fig.1 (c) Four track supporting structure for use in subsidence areas

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