Dublin Light Rail

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SYNOPSIS

The Dublin Light Rail system, designed by Sinclair Knight Merz in Melbourne, included an elevated section that followed the route of a former rail line and involved reconstruction of a number of rail bridges. The original line was constructed in 1854 and closed in 1959. One section of the line had been constructed on a 5m high embankment retained by masonry gravity retaining walls along each side of the embankment. The bridges crossed roads and a canal that intersected the line. The previous bridges would have been wrought iron with a ballasted track, and the replacement bridges are steel with a reinforced concrete deck and direct fixation of the rails to a track slab on the bridge deck.

The considerations that influenced the design task for the bridges included:

- The re-use of existing gravity stone abutments
- The re-use of existing gravity stone retaining walls along each side of the embankment
- The approval process administered by the authority set up to manage the contract
- The substantial increases in under-bridge clearance, by comparison with that which existed with the former bridges
- Preservation of the character of these historically significant structures

This paper discusses how these constraints were handled and the structural solutions arrived at. It also includes a brief reference to other significant structures constructed as part of the project.

1 INTRODUCTION

The Luas (Irish for speed) Light Rail project brings a new light rail system to metropolitan Dublin.

The new lines and associated infrastructure are being constructed as part of a design-and-construct contract. Sinclair Knight Merz was appointed, by the construction contractor, as principal designer for the track, civil, structural, and building components of the project. The construction contractor is a joint venture between MVM Rail and Ballast Nedham International.
The currently proposed network is shown below as fig 1 and includes the following:

- Line A from Tallaght in the south west to the city centre: This line will run for 14km from the city centre, through the north inner-city to Tallaght in the south west. Of this section, 7km is on-street and the balance is on dedicated alignments and reservations.
- Line B from Sandyford in the south east to St. Stephens Green in the city. It is 9km long and follows the route of a former heavy rail line. A portion of this line is being designed not only for light rail but also for possible future conversion to metro operation. Within this section there are six (6) underbridges that have been designed by SKM.

- Line C provides a short link from the city centre to Connolly station and the provincial bus terminal Busarus on the east side of the city centre.

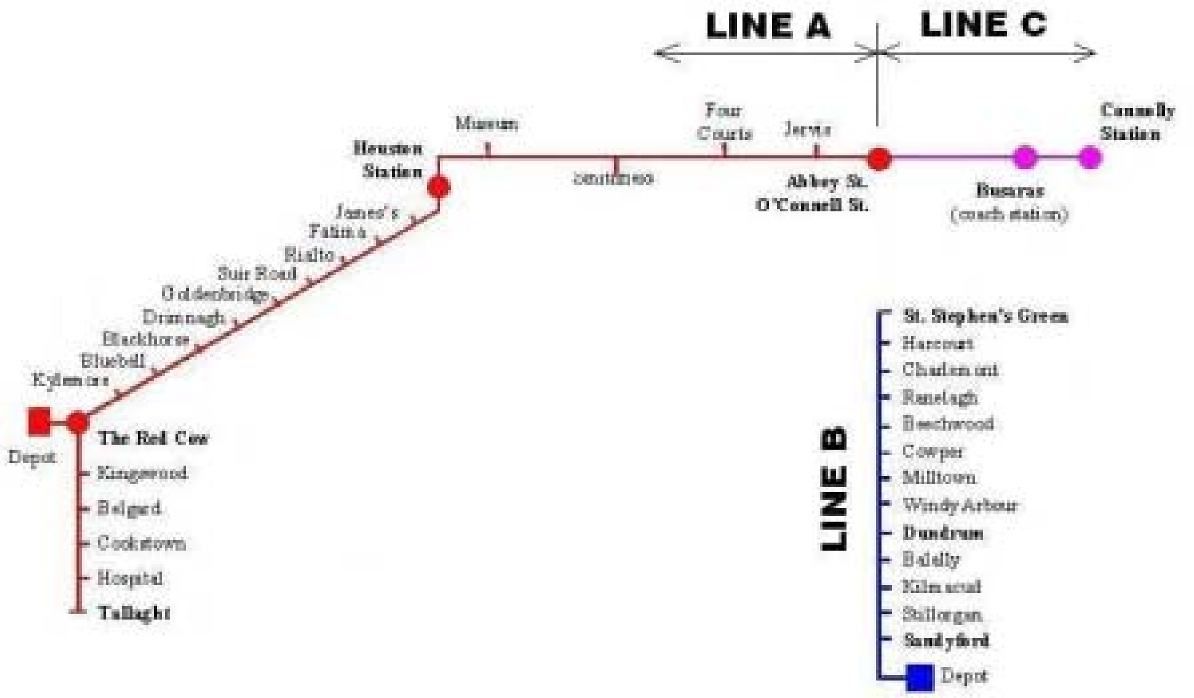

Figure 1 : Proposed Routes for Dublin Light Rail

3 UNDERBRIDGES

3.1 Introduction

The underbridges on Line B presented a particular challenge with this project.

The old Harcourt Street Line carried heavy rail mainline rail from its opening in 1854 to its closure in 1959. When the line was closed the superstructure of the bridges was removed. With the introduction of the light rapid transit system this line will be reopened. The section of line running over these bridges was originally constructed on a 5m high embankment and extends for a length of approximately 1km. The old superstructures were removed because the clearances under the bridges, although suitable for horse drawn vehicles, were unsuitable for today's road vehicles.

Economic and historical pressures to retain and reuse the existing abutments and the retaining walls along each side of the embankment were a major influence on the concept for the bridges and the detailing used to increase the height of the embankments and the retaining walls.

The new light rail system provides two tracks with a 700mm wide emergency walkway on each side of the bridges and the embankment.

3.2 Bridge Superstructure

There are five (5) bridges crossing roads within the length of the old Harcourt Line embankment:

- Northbrook Road
- Dartmouth Road
- Charleston Road
- Ranelagh Road
- A single bridge crossing Charlemont Place, the Grand Canal and Grand Parade, referred to as Charlemont Bridge

Critical to the design of these bridges is the minimisation of construction depth. The required minimum clearance of the bridge soffit above the road level is 5.1m.

The first four are single span bridges and the third is a three span continuous bridge. At the southern limit of the Harcourt Street embankment, the line threads its way between the Hilton Hotel and an office building. The light rail line is supported on a suspended concrete structure over the entrance driveway to the hotel car park.

A similar concept was adopted for each of the five bridges referred to above. A typical superstructure cross-section is shown as fig 2 and an elevation on a typical bridge is shown as fig 3. The superstructure is a steel box girder through structure. It comprises a pair of steel box beams along each side supporting cross girders at 3m centres. The concrete deck is cast by first laying reinforced concrete planks between adjacent cross girders to act as a soffit form. These planks act compositely with the in-situ concrete in service. The box girders are supported on pot bearings. Movement joints are provided at each end of the bridge. In some instances the bridge is supported on the pre-existing foundations, suitably strengthened, and in others new foundations are being provided.

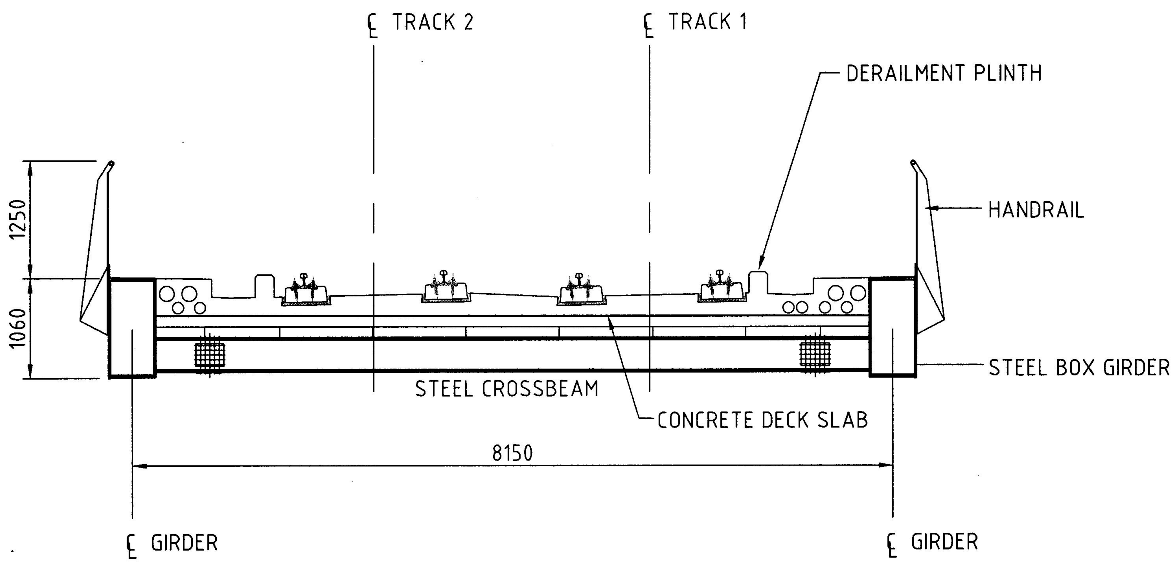

Figure 2 : Cross Section of Typical Bridge

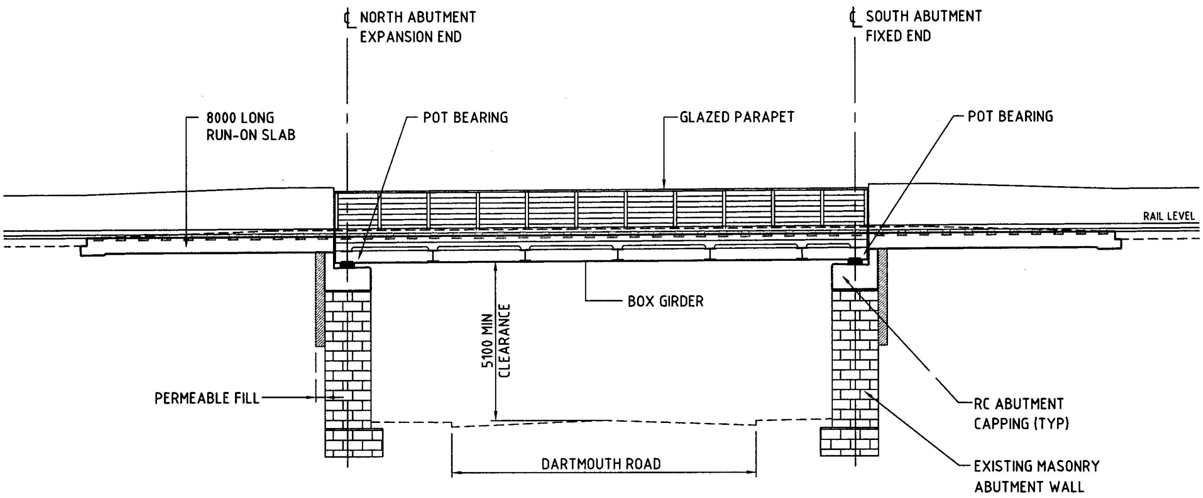

Figure 3 : Elevation on Typical Bridge

The four single span rail underbridges have span lengths ranging from 12m to 25m and a skew ranging from zero to 45°. The three span bridge over Grand Canal is 56m long and it is on a 300m radius horizontal curve.

An evaluation has been undertaken of the capacity of the superstructure and bearings to withstand the loads due to road vehicle impact in accordance with BD 60/94.

Although the existing embankments have been there for around 150 years, a run-on slab is to be provided for the transition between each end of the bridge and the embankment.

3.3 Bridge Foundations

To satisfy the requirement for increased vertical clearance under the bridge, the new superstructure and hence the level of the embankment at each end of the bridge must be around 1m higher than that of the original construction. Both the existing abutments and retaining walls along the sides of the embankment are gravity structures. The increase in embankment level results in increased lateral soil pressures on the abutment, as well as the retaining walls. To accommodate these increased pressures the existing abutments are strengthened by means of a cast in-situ reinforced concrete capping with a horizontal restraint back into the retaining wall along each side of the embankment behind the abutment. In addition, an 8m long approach slab is adopted to prevent lateral earth pressure forces on the back of the abutment due to live load surcharge on the embankment.

Little is known of the details of the existing abutments. They were inspected in detail prior to commencement of design and found in most cases to be in excellent condition demonstrating that during their previous service the abutments performed satisfactorily. The basis of the design of the abutments and retaining wall modifications is that the new condition is to be no worse than that which existed when the bridges were previously in service. Some additional geotechnical investigation and site measurements were undertaken to provide an understanding of the dimensions of the abutment and the soil conditions and to provide the parameters used for the comparisons. Where doubts existed, a range of parameters was considered.

The specification required the application of large longitudinal braking and traction loads. These are significant loadings for the evaluation of the stability of the abutment supporting the fixed bearings. It is also important to note that previous satisfactory performance of the bridge abutments does not necessarily provide conclusive proof that the abutments can carry these longitudinal loads as it may not have necessarily have arisen with the previous service.

The most important consideration in the approach to the re-use of the existing foundations is the proven performance of the abutment in the past as demonstrated by its present condition and a recognition that an earth retaining structure can be expected to show signs of movement well before it reaches a state of collapse. Accordingly, the calculation of pressures is primarily to confirm that the new works do not result in a more adverse condition.

4 EMBANKMENT RETAINING WALLS

As with the existing abutments, the old limestone gravity retaining walls along each side of the embankments were in excellent condition.

The increase in the level of the embankments will result in higher lateral earth pressure forces on the retaining walls along each side of the embankment.

The design solution involves in-situ concrete being placed on the shelf on top of the wall and dowelled into the existing stonework. It also includes removal of part of the existing fill material and placement of a cement-bound aggregate fill material to make up the level of the underside of the trackbed.

To establish the load carrying capacity of existing walls and abutments by theoretical means would have been difficult. Such a calculation requires knowledge of the shape of the wall along its full length and the material properties immediately beneath the foundation. Short of demolishing the wall, it is not possible to confidently determine the foundation capacity enhancement or degradation that might have been effected during construction. Satisfactory performance over a long period provides a considerably more reliable measure of the adequacy of the wall to continue performing its function than attempts at theoretical computation of performance. Furthermore, given that previous performance is the only reliable measure, the preferred course is not to require any more of the existing wall than this proven capacity.

Other measures included:

- Localised areas of the top of the wall where stones are missing or damaged are being reinstated with either stone or mass concrete faced with stone
- Cast in-situ capping is being constructed along the top of the wall to bring it to the required level
- Precast concrete panels are attached to the cast in situ concrete capping
- The upper section of the earth embankment fill will be replaced with stabilised fill material in the form of cement treated crushed rock and selected fill material
- The depth of fill replacement will be such that the soil bearing pressures under the wall in-service are no greater than those which existed when the wall was previously in service.

5 OTHER STRUCTURES

Other bridges included:

- Kilmacud Pedestrian Bridge – a 12.5m span structure comprising precast pretensioned concrete girders and a composite in-situ concrete deck.
- Kilmacud Cable Bridge – a 22m span steel arch supporting a 110kV high voltage cable.
- Goldenbridge Pedestrian Bridge and Drimnagh Pedestrian Bridge – two architect-designed bridges crossing the Grand Canal and providing access to adjacent stops.

Milltown Viaduct

In addition to the stone abutments and retaining walls, there was also a large stone arch bridge by which the Dublin and South-eastern Railway was carried across the Dodder valley. It is the most conspicuous feature in modern Milltown and comprises nine arches.

The works under the contract included the cleaning, repair and structural assessment of the bridge. The top surface of the arch was sealed prior to constructing the track across the bridge. It has a total length of 100m and a maximum height above the Dodder river in the valley below of 14m. The arch bridge was found to be in excellent condition and capable of carrying the light rail vehicle loadings. The art of refurbishing these old stone structures is developed to a high degree in Ireland. One interesting technique is the formwork systems that have been developed to enable concrete finishes that closely resemble the old stonework.

Kilmacud Cutting

A major challenge that arose during the course of the work was the construction of the track through an existing cutting with a depth of 4m to 8m. Virtually no investigation of the side slopes of the cutting had been conducted prior to the award of the contract. Detailed site investigation was undertaken and it was noted that there were areas where minor slope failures had occurred and that for the most part the material in the slopes was low strength glacial till. Further site investigation and analysis was undertaken. For much of the cutting, it was not possible to show, based on the results from site investigation and slope stability analysis that the slopes had the normally accepted margins of safety against failure. One unknown that was clearly a significant influence on the stability of the existing slopes was the effect of vegetation and binding the material in the slopes and preventing failure. A variety of measures for retaining systems and slope treatments was adopted, including:

- Cantilever retaining walls
- Gabions
- Regrading the slopes to improve the factor of safety
- Seeded biomat with geogrid mesh
- Geogrid mesh secured by soil pins
- For steep rock slopes, removal of loose blocks or securing them with rock dowels and applying rock fall netting. Where netting is not provided, a catch fence is provided in front of rock outcrops.
- Shotcrete facing structure with tie anchors into rock or soil in the cutting bank. Limited use was made of this solution because of the potential for problems with way leave agreements.

6 DESIGN STANDARDS

The bridges were designed in accordance with BS5400. Included as Appendix A is a sketch showing the loadings adopted for the LRV. The live load impact coefficient adopted was 1.5. Fatigue analysis of several of the box girder connections was an important aspect of the design. Load spectra for the assessment of fatigue life were based on the performance requirements for the LRV operations and predictions regarding the number of people travelling at peak and off-peak periods. A longitudinal braking load of 550kN along with a traction loading on the adjacent track of 230kN was adopted.

The standards for construction are those of the Irish NRA Specification for Roadworks.

The detailing of items such as derailment containment were governed by Railway Safety Principles and Guidance – Part 2, Section A – Guidance on Infrastructure, produced by the HSE HM Railway Inspectorate.

7 TRACK FORM ACROSS BRIDGES

In general, traditional track was adopted across the bridge structures and along the top of the embankment. This comprised rails supported on Edilon blocks (ref fig 4). The Edilon block was supported on a trackbed that was isolated from the structural deck of the bridge by a waterproofing membrane. To permit thermal and other movements of the bridge deck, the fixings on the bridge were generally designed to permit the rails to slide across the top of the Edilon block by using low toe load fixings. Wherever possible, expansion joints in the rails were avoided.

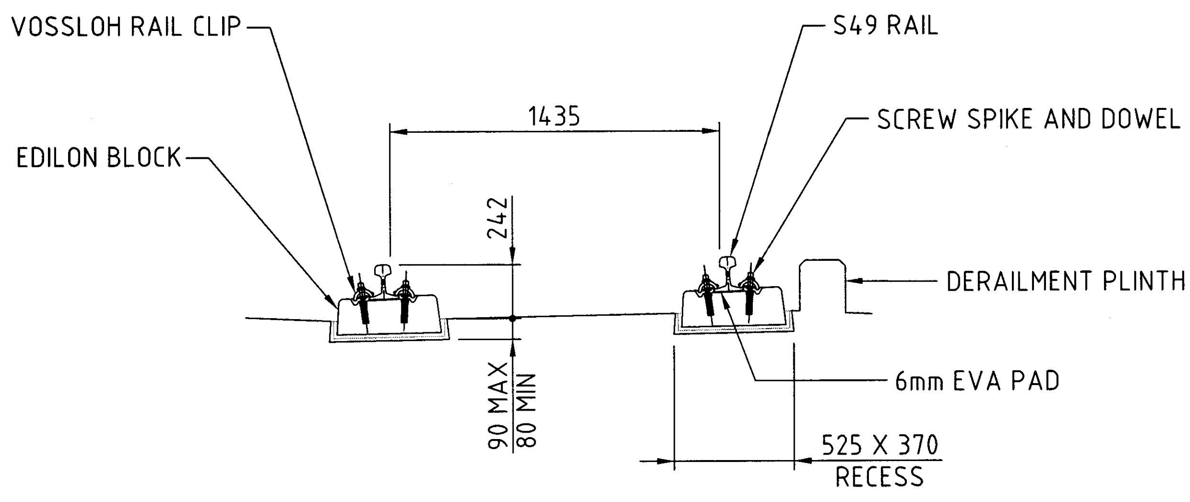

Figure 4 : Traditional Track

For the two larger bridges at Charlemont and Ranelagh, there was a tram stop on the bridge. In these instances, the rail was encased in rubber embedded in the concrete trackbed. It was therefore not possible to permit the rail to move relative to the trackbed, which required the use of rail expansion joints at the expansion end of the bridge.

7.1 Stray Currents

The LRV is electrically powered. The power is delivered through an overhead conductor system and returns through the rails. The need to control stray currents was a major consideration in the detailing of the bridges. The following lists features of the design arising from these considerations:

- The trackbed is isolated from the structural deck by means of a waterproofing membrane
- There is a stray current collection system within the trackbed comprising electrically connected longitudinal and transverse reinforcement. Electrical continuity of the stray current mat across the expansion joints is provided by means of a flexible cable bonded to the stray current mat within the trackbed abutting each side of the joint.
- The parapets along each side of the bridge are made electrically continuous. They are bonded to the closest rail and they are electrically isolated from the superstructure steelwork. A voltage limiting device (VLD) is provided between the parapet railing and the rail to which it is electrically connected. The pits for the VLD are beyond the ends of the bridge.
- The reinforcement within the deck is connected to an electrical drainage system off the bridge
- Reinforcement in support structures is isolated from that in the superstructure
- There is no electrical contact between the running rails and metal parts of the bridge
- The bridge superstructure is isolated from the substructure by the use of rubber supports.

7.2 Noise and Vibration

The Light Rail is being constructed through a 1000 year old city. At some locations the trams are running only metres away from residential buildings. Noise and Vibration was a major consideration in the design.

The noise from bridges is a combination of directly radiated noise from the wheel and rail and re-radiated noise from the bridge structure. Once the vibrations have entered the bridge structures and the adjacent embankment structures it is very difficult to stop them being radiated to adjacent facilities and as noise. Innovative specialist low height noise barriers and vibration isolation matting have been designed to bring the impact of noise and vibration to less than the stringent contract performance limits [1].

7.3 Ducting

Management of a timely definition of the ducting requirements for communications and electrical cabling presented a particular challenge. A typical section on the line includes up to 12 No 160mm diameter ducts on each side of the line. Limitations on the space available on the bridge superstructure dictated that the number of ducts be kept to a minimum. However, a typical bridge still includes a total of up to 9 No 160mm diameter and 13 No 120mm diameter ducts. Two of the bridges were on stops, which required that an additional 10 No 120mm diameter secondary ducts be provided for cabling to lighting, advertising drums, emergency telephones and ticket validators.

7.4 Derailment Containment

Three types of detail were used for derailment containment

- For ballasted track on bridges a check rail was adopted
- For traditional track, where the rail was directly fixed to the trackbed, a continuous plinth was included alongside the rail
- For embedded track, a continuous trench was included alongside the rail. The trench was covered with a frangible lid so that the wheel of a derailed vehicle would drop into the trench to arrest further lateral movement

8 RISK

Risk management is becoming an increasingly visible part of the design process for major projects. For the bridges, risk management was addressed at two levels.

- A risk register was prepared for the complete project using a relational database package. These risks were assessed and risk mitigation measures developed and incorporated
- Each structure was analysed within the context of this risk register and risks specific to that structure were identified and detailed.

9 RAM

Another feature of the contract requirements was the process required for the demonstration of an acceptable level of reliability, availability and maintainability. The Contractor was required to provide evidence of its understanding of this process and competence to comply with it. Additionally, the Contractor was required to provide detail of the methodology to be adopted to ensure compliance with these requirements.

For each structure, a detailed report was prepared that identified key reliability, availability and maintainability issues and how they were being handled. Issues identified included:

- Provision to enable replacement of defective bearings
- Service life of paint system
- Access for inspection of all structural elements

10 CONCLUSION

The reinstatement of a 150 year old rail line within a 1000 year old city involved the reconstruction of a number of old rail bridges. In particular the reinstatement of five bridges along the length of Dublin’s old Harcourt Street embankment presented a particular challenge. The work included raising the level of the existing embankment and the bridges to provide the required under-bridge clearance. A key consideration in the structural design for this work was the capacity of these structures as demonstrated by their condition and the satisfactory performance over many years when the line was previously in service.

An authority (Light Rail Procurement Authority – LRPO) was set up by the Irish government to administer the contract. An observation worth noting is the difficulty authorities in this situation can have with defining and controlling the role they play in ensuring the constructed works satisfy the required performance standards. In particular, careful judgement is required in deciding the level of monitoring, checking and review such an authority should undertake, given that the primary responsibility for the design rests with the contractor and its designers. This issue is assuming an increased significance in Australia with the increasing move towards design-and-construct and BOOT schemes for transport infrastructure.

11 REFERENCES

1. DANIEL L., “Noise and vibration mitigation, Dublin Light Rail” *Conference on Rail Engineering*, June 2004.

APPENDIX A : ROLLING STOCK LOADINGS

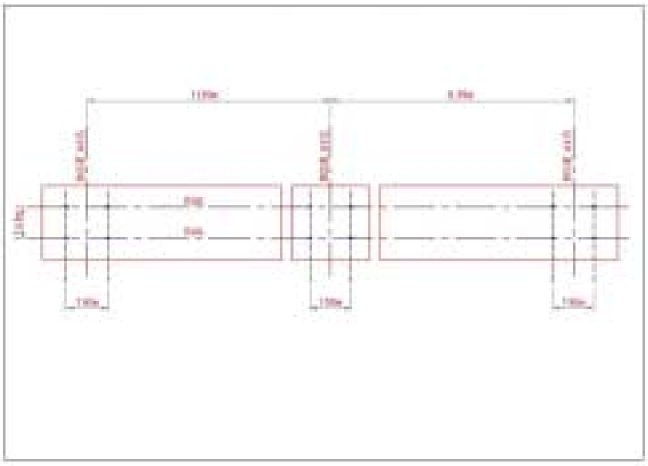

Figure 5 : Horizontal view: 1 bogie = 2 axles = 4 wheels

Loads by Bogie	**1**	**2**	**3**
MLC	199KN	224KN	196KN
ELC	206KN	238KN	205KN

MLC: maximum load condition
ELC: exceptional load condition (accidental situation)

- Dynamic coefficient = 1.5
- Transversal guide force = 35KN/wheel in a curve R = 25m with a speed of 60 km/h
- Longitudinal forces for a double vehicle:

– 400KN is the emergency breaking force in one direction

– 130KN is the acceleration force in the opposite direction