



CETRA²⁰¹²

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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CETRA²⁰¹²
2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

TITLE

Road and Rail Infrastructure II, Proceedings of the Conference CETRA 2012

EDITED BY

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ISBN

978-953-6272-50-1

PUBLISHED BY

Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE

minimum d.o.o.
Katarina Zlatec · Matej Korlaet

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600

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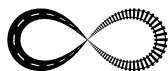
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LIGHT RAIL TRACK STRUCTURE COMPARATIVE ANALYSIS

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Abstract

In the paper the review of the light rail track structure for that kind of public passenger transport from the accessible literature and authors's engineering experience is carried out. For that purpose the light rail track structure are classified into structures on discrete supports, either on sleepers in ballast bed or on slab, and structures continuously supported. For all of them the examples are presented. In that way, the systematization of main existing track structure types of light rail system is performed.

On the basis of those data, the comparative analysis of the light rail track structures, in respect to the technical, economic, operating and ecology requirements with the respect to the several criteria, is carried out. From that analysis the resent conclusions are derived.

Keywords: light rail system, public transport, track structure, slab track, comparative analysis.

1 Introduction

Light rail system ('Light rail' or 'Light Rail Transit' – LRT) is a particular class of urban public passenger railway that utilizes less massive equipment and infrastructure with modern light vehicles of great capacity. The term was adopted as a conscious break from the obsolescent image of trams and sometimes used largely for political reasons in order to obtain the financial support. It is usually the upgraded tram system or reused old railway netlines [1].

Light rail traffic is an integral part of the public transportation systems in many central city areas. The proximity to the neighboring buildings, the environmental protection from vibration and noise and the necessity to share the route with motor traffic are the main factors for track design and construction.

Depending on the route, light rail line may be built atgrade, on elevated structure or in tunnel. Light rail has an average speed of 25 to 35 km/h in urban areas or even higher at exclusive tracks. Track geometry must has the ability to handle sharp curves and steep gradients, making it possible for the light rail vehicle to be integrated in the existing city infrastructure. The minimum horizontal radius is depending of the construction of the chosen vehicle, which is commonly long and articulated one. For vertical curvature also the vehicle construction is decisive for the minimum curve. The demanding comfort for the passengers throught maximum acceleration, depending of the speed of the vehicle, should be taken into account designing the track. The capacity of light rail is higher as is the maximum speed, for which the more free track, or better more exclusive track, with optimum structure is needed [2], [3].

2 Classification of the light rail track structure with the examples

The track superstructure consists of the track grid itself (rails, rail fastenings and sleepers) and the track bed made up of ballast or bonded bearing layers (concrete, bituminous materials or something similar). Underneath these layers are under ballast mats, protective layer, anti-frost layer, which some regulations classify as part of the substructure. The light rail track, besides the primary well known requirements, must fulfil the following [4]:

- Operational safety that demands exact track arrangement during construction and maintenance;
- Ease of access for road vehicle, where applicable;
- Electrical conductivity and insulating properties;
- Avoidance of stray current and corrosion of metallic elements;
- Noise abatement and vibrations attenuating;
- Resistance to the chemical action presented in urban areas.

The types of track structure used on light rail systems vary, depending on urban and routing requirements and the local environment. The track can be open track, covered track and mixed systems (partially covered).

The types of the light rail track structure according to the way of rail supporting are those with: discrete supports, and continuously supported.

Track with discrete rail supporting according the kind of rail base can be on the:

- sleepers in the ballast (ballasted track structures), and
- solid (concrete or asphalt) bed (ballastless, slab track structures), with or without the sleepers.

2.1 Light rail track structure with discrete rail supports

2.1.1 Light rail track structure with sleepers in the ballast

Although the traditional ballasted type of railway track structures can be used where the light rail is separated from the road traffic, the main drawback of that classical railway structure is the high cost related to its inspection and maintenance.

The traditional ballasted track is with the lower edge of the sleepers usually rests on a base of 25 to 30 cm of compacted ballast. The improvement can be made by incorporation of elastic elements by building in the under ballast mats and the sleeper pads, in combination with other measures, such as frame sleepers or concrete trough. Under ballast mats reduce the dynamic forces by adding the damping to the system and isolate it from structure-born noise (figure 1. left) [5]. Elastic sleeper pads are suited for vibration mitigation, avoid gauge widening and lower the track stiffness (figure 1. right).



Figure 1 Additional building in the under ballast mats and the sleeper pads

2.1.2 Light rail track structure on solid base

Especially, where the light rail share the same space with the road traffic the track design tends towards the track without ballast. The main advantage of the ballastless track is low maintenance effort and high availability.

Characteristic feature of ballastless or so-called slab track structure is the supporting of the rails on treated layers (concrete or asphalt) by specified resilient supports to reach a sufficient and uniform load distribution and the permanent fixation of track geometry. In that way, the required elasticity of the track is guaranteed solely by the support point elasticity and, at the same time, the base course structure (a frost protection layer, a hydraulically bonded layer and a final concrete or asphalt layer) is characterised by a rigidity increases from the bottom up. So, the minimum deformation modulus for these layers are: on the track formation $E_{V_2} \geq 45(60) \text{ MN/m}^2$, and on the frost protection layer $E_{V_2} \geq 100(120) \text{ MN/m}^2$. Such slab track solutions require very high laying precision in the position and height with level accuracy of $\pm 2 \text{ mm}$ and the permanent constancy of the structure even. The width of the concrete or asphalt base layer amounts to 3,20 m (180–300 mm thick), while the width of the hydraulically bonded layer amounts to 3,80 m (300 mm thick) [6].

The rail fastening systems are either direct without ribbed plates (f. e. system 300 Vossloh) or indirect with ribbed plates (f. e. system 336 Vossloh). Height correction amounting to 20 mm and lateral correction of only 4 mm are possible [7].

A few typical systems for light rail track construction of slab system will be explained below.

Rheda City consists of bi-block sleepers connected by lattice girders embedded in cast-in-place concrete after fine alignment and height adjustment of the track panel by using spindles (Figures 2.). Special rail seats (type Ortec) can be employed for added vibration protection (variant Berlin NBS). The track covering can be provided in several asphalt layers, concrete, paving blocks, or with humus substrate in the case of so-called green track (variant Rheda City Berlin or NBS-G) [6].

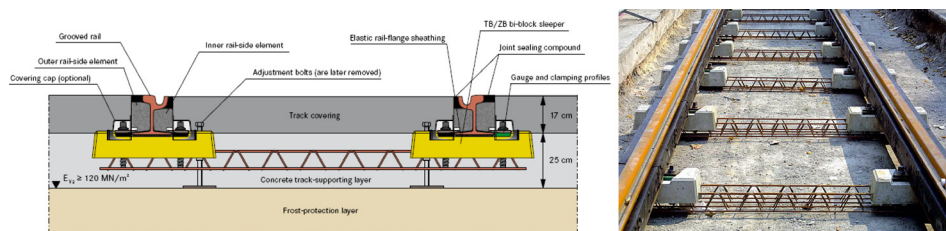


Figure 2 Rheda City

ATD design consists of several asphalt layers with longitudinal plinth in the middle against transverse forces. The bi-block sleepers are laid directly onto the asphalt layers (Figure 3.). Because of asphalt's visco-elastic properties these track have the slight plastic adaptability. The material is moreover reusable and the system allows exchange of sleepers in case of damage by derailments [6].

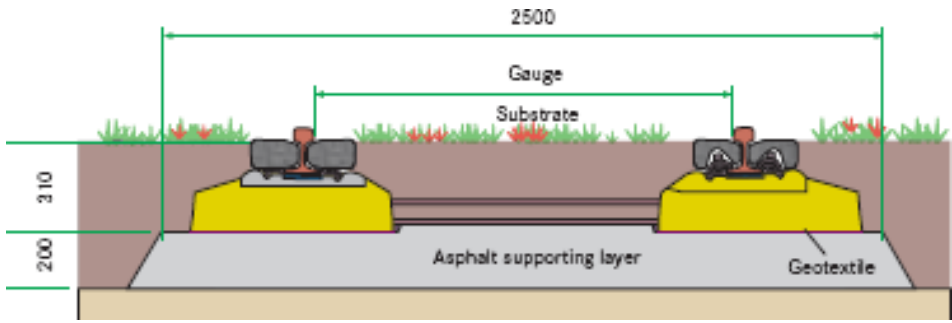


Figure 3 ATD system

BÖGL system consists of prefabricated slabs with pre-assembled rails on the hydraulically bonded base, which are spindled to the required height (Figure 4.). The slabs are coupled with turnbuckles and the joints between them and the base layer are filled with bitumen-cement mortar through openings in the slab [6].

INPLACE track design is characterized by track panel with precast rail chairs set in cast-in-place longitudinal concrete beams or slabs by 'top-down method' (Figure 5.) [6]. Mass-spring systems (or so-called 'floating slabs') are completely separated from the substructure and the sides by using elastic intermediate elements. They are used in applications where the isolation and comfort demands are very high. Decisive parameter for noise and vibration absorption is the natural frequency (eigen-frequency) of the whole selected system (between 15 and 23 Hz for light system and between 7 and 12 Hz for heavy system). Over recent decades, a wide range of mass-spring systems have been developed. There are systems that use continuously reinforced in-situ concrete or prefabricated prestressed concrete components, their combination, with or without a ballast bed. There are three different types of such systems: full surface layer, linear support and discrete bearings (Figure 6.) [8],[9].

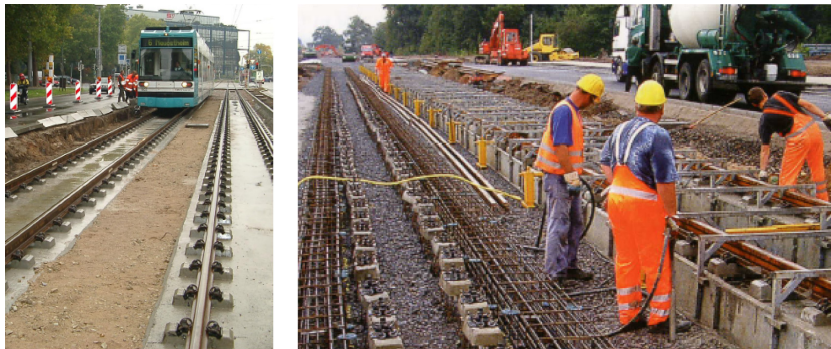


Figure 4 INPLACE system

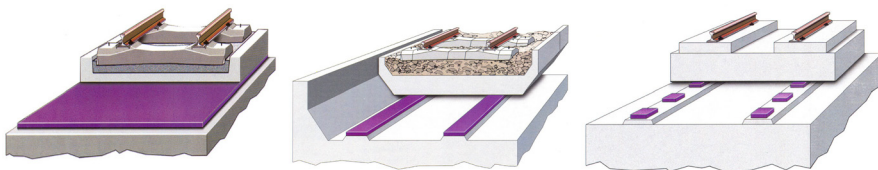


Figure 5 'Mass-spring' systems

2.2 Light rail track structure with continuous rail supports

The advantages of the elastic continuous supported rails are the absence of dynamic forces due to secondary bending between discrete rail supports, reduction of noise emission, increase in the life span of the rails and further reduction of the maintenance. Track structures with continuously supported rails are always slab tracks.

INFUNDO/EDILON system (Figure 7.) is made of continuous concrete slab by using slipform paver, prefabricated or semi-prefabricated. It contains the grooves for rails laid on elastic strips and embedded in compound. Semi-prefabricated solution provides a high accuracy of execution and concrete quality in the areas of the rail fixation system [10], [11].

CDM-Cocon track system consists of H-shaped concrete frames in lengths of 18 m (Figure 8.). On the top of longitudinal sleeper the bistrip for rail is applied. The rail web chambers are glued to the rail to avoid the contact with surrounding concrete or asphalt [10].



Figure 6 INFUNDO/EDILON system

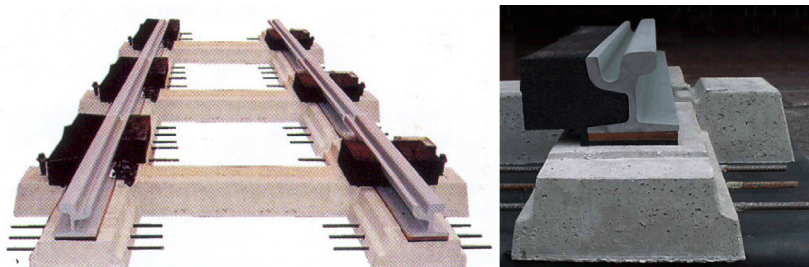


Figure 7 CDM-Cocon track system

3 Comparative analysis of the light rail track structures

The evaluation of the various technical solutions available for the light rail track structure is a difficult task, because of far too of them, which have to be justified by different local condition. The comparative analysis for the several criterion and essentially only two track types: ballasted track and ballastless slab track is going to be carried out. For these two alternatives the qualitative list of the criterions under the four target requirements is presented (Table 1.). In the table 1 the solution with outstanding priority is signed as \bullet and the solution with possible competitiveness but under the additional technical measurements is signed as \oplus [4], [12], [13]. Unevaluated criteria for some option usually means that the certain option is not concurrent even with the additional technical measurements.

According to the present knowledge, the slab track has a building and installation cost level of from around 1,2 (sleeperless design) [14] to even about 2,6 times ballasted track (500 euros pro 1m of track length) with great disipation [15]. From the technical standpoint the similar and less sensitive the track design, the easier is to manufacture and the more reliably high quality can be achieved. To improve manufacturing tolerances and to shorten construction time (building work in urban environment causes traffic disruptions) the semi–precast unit solutions for slab track design are opted especially when building new sections of track.

Table 1 List of requirements and criteria for two options

Requirements	'Criteria	Options	
		Ballast track	Slab track
Minimum investment costs	– Superstructure construction costs	●	
	– Superstructure construction time	●	⊗
	– Superstructure weight (bridges)		●
	– Superstructure height (tunnels)		●
	– Site access conditions for mechanisation	⊗	●1)
	– Building materials delivery conditions	⊗	●2)
	– Susceptibility to substructure quality	●	⊗
Minimum operational and maintenance costs	– Engagement of domestic contractors	●	⊗
	– Durability of track geometry		●
	– Need for subsequent track geometry regulation	⊗	●
	– Maintenance and repair costs		●
	– Possibility of rail reuse and recycling	●	⊗3)
	– Track life–cycle time		●
	– Possibility of track cleaning		●
Minimum environmental impacts	– Integration in the streets	⊗	●4)
	– Integration into traffic infrastructure		●
	– Emission of noise and vibration	●	⊗5)
	– Visuel route integration in urban environment		●
	– Space occupancy of inner sity areas		●
Maximum safety	– Preservation of space entities		●
	– Water contamination and soil degradation		●
	– Track stability at high temperatures		●
	– Accesibility for staff and rescue–vehicles	⊗	●

Notes:

- 1) – Advantage of the track with continuously supported rails
- 2) – Advantage of the track with continuously supported rails
- ⊗3) – Advantage of the track with discrete rails supports
- 4) – Advantage of the track with continuously supported rails
- ⊗5) – Advantage of the track with continuously supported rails

Fully precast units deamed advantageous under specific circumstances. The diversity of design variants can be greatly reduced by standardising the precast units. Choices in favour of special designs should be dictated by local requirements, such as the need for greater protection against vibration or strey currents, or crossing by traffic. The space restrictions in innersity track network often prevent construction work from being mechanised and prolonged the construction time.

In longer tunnels (over 500m) slab track has been accepted as the standard superstructure, because the maintenance work on ballasted track would be difficult and unsafe, the less height (by about 30 cm) means the smaller tunnel cross-section and reduction for the excavation, but in case of accidents it must be accessible for rescue vehicle. As the result, the installation costs for the track and tunnel combined are not higher for solid base track than for ballast track [16]. The main requirement in using slab track design is a settlement free foundation. Problem locations discovered during investigation of the ground must be remedied by suitable geotechnical ground improvement measures to meet the requirements.

The higher production investments costs for slab track are compensated by cost savings in maintenance and additional revenue from the higher availability of the route. The slab track systems require hardly any maintenance. The lasting good track quality up to now, does not only guarantee a minimum of maintenance and improved driving comfort for the citizens, but as well as the highly available track. The durable stable position of the slab track and the track quality has been proven [15]. The maintenance work is restricted to replace the rails when the rail heads have suffered a certain amount of wear and tear, changing of the synthetic rail pad and preventive rail grinding (slower corrugation develop, stop the beginning of headchecks and decrease noise production).

In maintenance costs domain slab track is clearly more advantageous than ballasted track (no sleepers tamping, rail realignment, ballast cleaning and packing, vegetation control with herbicides and so on). The costs of operational impediments by maintenance work that include substitute services, reduced speeds, single track operation, depends of the duration of the required work and all design requiring shorter installation times are clearly advantageous (pre-cast or semi-precast units).

For slab track no precise repair costs is available yet since no major repairs have been required so far, but it may well prove that would cost more than repairs to ballast superstructure. Full renovation of slab track may only be needed in exceptional cases and then be restricted to individual sections of track. In general, the more solid the design, the higher the waste costs in the event of renovation compared with a ballasted track alone.

Track life-cycle time for the slab track is much longer (proposed about 60 years). If profitability factors are taken into account when comparing the technical aspects of the track solution, the costs over the entire lifetime (life-cycle costs, LCCs) of the given system need to be examined in each case. Beyond that, factors that cannot be costed can play as decisive role as those which can be evaluated in monetary terms. On the other hand, exist no sufficient long-term experiences with solid base track in the inner-city areas (about twenty years). From a LCC standpoint, the ballast superstructure is economically superior to slab track. The maintenance and availability benefits of slab track are usually not sufficient to make it economically preferable to the ballast superstructure [14]. There is the opposite opinion that ballastless track is more economic than ballast track because its long-term annual costs are lower [15].

Consequently, as a rule, switching from ballast to slab track on an existing light rail line is not an economically attractive proposition. For slab track to be economically superior, it must be a new line, whereby the other advantages of slab track apply at the same time [14].

Noise and vibration insulation of slab track is achieved by the installation of sound-absorbing components and acoustic barriers, which raise the costs and can make maintenance more difficult. In the densely-developed areas, around light rail lines sensitive to vibration quality protection, raises investments costs, especially when mass-spring systems are required [5]. Better integration into the urban environment shows all types of slab track, especially so-called 'green track' designs, which greatly contribute to the acceptance of new line and therefore enhance their feasibility.

A conventional ballast superstructure remains the preferred solution for all tracks on independent formation. On the other hand, when tracks runs along the streets or are finished as green track, the difficult accessibility and the maintenance and repair problems of ballasted track lead to a preference for slab track.

4 Conclusions

In each individual case, when comparing the investment and life cycle costs and profitability of different types of light rail track structure over their full lifetime as part of the overall consideration of the design solution, a wide amount of factors and requirements needs to be taken into account. The created qualitative list indicates that evaluation of the many involved contributed factors is the only way to arrive the technically and economically balanced result when selecting the track structure design for a given section of light rail line. The final choice depends on the track's location.

The cheapest solution may not always be the best and most cost-effective when all factors are taken into account. Success of choice depends on the combined, greatest possible fulfilment of all these factors and criteria, which is why there can be no unic solution for track structure used for public light rail passenger transport in city.

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