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Subgrades of Wrocław tram tracks

Abstract: In the article the reasons of large diversification in constructional solutions for tram track subgrade were determined. The definition of tram track subgrade was proposed. Obligatory rules of tram track subgrade design were analysed. A review and comparison of constructional solutions for tram track subbgrade used in Wrocław during last 25 years were made. In summary, positives and negatives of transformations were presented and the necessity of revision of obligatory rules was proposed.

Keywords: Tram track; Subgrade

Introduction

In the case of infrastructure, the design issues of classic rail lines as well as construction and maintenance of subgrade are well recognized in our country. Statements about the subgrade appear in "railway" regulations [3]. Moreover, PKP has its own multi-page instructions (formerly D-4, currently Id-3) dedicated exclusively to the issues about subgrade. In the case of infrastructure of tram routes, the situation is radically different. Guidelines for "tram" [5] and tram "acceptance control" norm [1] contain only brief provisions on embankments, dredging, drainage and filter layers. As a result, Polish cities with tram networks have developed their own, sometimes different, improved and proven construction and technological solutions in this area.

Another reason for the high degree of differentiation of tram tracks subgrades is the lack of common solutions. In contrast to railway where classic tracks are usually used (i.e. rails on the transverse sleepers and ballast) being largely unified solutions, in trams great popularity gained non-ballast solutions with a wide range of various structures offered by a number of companies. It is not without significance because the tram tracks are often embedded in the roadway, and thus have a structure more similar to the solutions used in roads, and not in the railways.

Another reason for the differences in the substructure solutions for tram tracks are great changes that have occurred over the last several years. In the previous economic system was sometimes used solutions characterized by low levels of durability and reliability, which was in the interests of companies engaged in construction. They have thus been able to to maintain a consistently high level of demand for their services. Now thanks to the demands of guarantees such practices are not already seen. The increase of environmental awareness makes that generally on the occasion of investments such as the construction or modernization of transport routes, it seeks to reduce vibration and noise generated by vehicles to the environment.

It should be also mentioned the phenomenon of tram renaissance in the world, resulting modern solutions in our country used so far only abroad. These reasons caused the construction of tram subgrades over the last few years, a subject to constant modifications.

The definition of "subgrade tram track"

The mentioned in the previous section scarcity in provisions in the form of regulations as well as the diversity of solutions result in the lack of definition about "subgrade tram track". This article assumes that this term determines the structural layers and elements below the surface of the track, that is:

- under a layer of ballast surrounding sleepers - in the case of classic tracks,
- under a layer of concrete base - in the case of slab track.

Guidelines for the design and construction

According to the "tram" guidelines [5] in section 4.2 of part two (dedicated to the design of the tracks) it is recommended the design of the filter layer of sand with a thickness of at least 10 cm, the inclination from 2% to 3%, and drainage connected to the sewage system or if the tracks run through areas without sanitation - to drainage ditches and wells absorbent, all in the case of impermeable surface (coefficient of filtration of less than 10 m/day). In sections 2.4 and 2.5 of part three (dedicated to the construction of the tracks) are given geometric tolerances for track trough, filter layer and drainage, is determined compaction index of the substrate (soil at the bottom of the trough) - at least 0.95 maximum density. In the issue of construction of embankments and drifts is given a reference to the already withdrawn PN-68 / B-06050 (Earthworks Building. The requirements for the implementation and acceptance tests).

In the "receiving" tram norm [1] are given formulation, sometimes more clarified:

- - in the case of the filter layer it was mentioned about coarse sand according to PN-B-11112: 1996 (Mineral aggregates. Aggregates broken for roads) or PN-B-11113: 1996 (Mineral aggregates. Natural aggregates for road paving. Sand) - now withdrawn and replaced by BS EN 13043: 2004 (Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas);
- in the case of density indicator - it is to be determined with the normal method according to PN-B-04481: 1988 (Land Building. Tests of soil samples) - now withdrawn.
-

"Zero Option" - that is, the surface on the substrate

The cheapest, but also the least sustainable way of construction and modernization of tram tracks is application of surface directly on the substrate surface, or laying ballast (in the classical tracks) or concrete base (in the slab track) at the bottom of the trough trench. For obvious reasons, such solution was popular in the 'pioneering era "- just after the Second World War, when it was built to extend the existing tram routes: to Pafawag (1948), Leśnica (1949), Oporów, Klecina and Park Południowy (1950).

Unfortunately, such solution was also realized much later, even after the transition period, in the case of repair of:

- track between loops "Grabiszyńska- cemetery" and "Oporów" (1995),
- road crossing the tracks to the square Orląt Lwowskich (1995).

"Only the sand" single-layer substructure without draining

After a somewhat chaotic "pioneer" period, there has been a stabilization time, the period of "building a socialist economy" reaching the 70s of the previous century. Almost all construction projects and modernization of tram tracks in Wroclaw at the end of this period were worked out "ex officio" one of the Wroclaw office projects - Biproskim. In these designs, both in the ballast (in the conventional tracks) and the concrete substructure (in the

slab tracks) appeared only the sand layer having a thickness of 10 cm arranged horizontally at the bottom of the trough trench without drops and no transverse drainage. The technical descriptions (almost like a mantra) were repeated a record "because the ground under the tracks is a permeable ground, drain is not expected" [2]. Exemplary realizations of this solution are:

- the avenue Hallera from the street Powstańców Śl. to the street Beyzyma (1993),
- the street Bałtycka (1993),
- the street Piłsudskiego from the square Legionów to the street Świdnicka (1994),
- loop Leśnica (1996).

In several other projects it clarified that the layer of the subgrade has to be coarse sand:

- the street Legnicka / the street Niedźwiedzia (1994),
- the street Jagiełły / the street Dmowskiego (1995),
- the avenue Hallera to the street Beyzyma from the street Grabiszyńska (1997-98), (Fig. 1).

1. The solution of "just sand," under the classic unbuilt tracks (the avenue Hallera, 1997)

In the project of modernization of tracks in the street Powstańców Śl. from the street Świdnicka to hotel Wroclaw (1996) realized by the other project office, the term compacted sand appears. The described solutions can be found in:

- the street Kwidzyńska - built tracks at transverse crossings (1999-2000),
- the street Skargi (2001),
- the street Sienkiewicza and Grunwaldzka (2006-08),

in the case where the thickness was increased to 15 cm and it was used cement-stabilized sand R_{28} with 1,5 to 2,5 MPa – in the first case, and 1,5 MPa – in two latter.

As a reference to the described solution can be constructions used quite recently:

- in 2014 at the street Krupnicza, where natural aggregates stabilized with cement with R_m = 2,5 MPa and the thickness of 30 cm was used under the concrete subgrade of tram tracks,
- in 2016 at the rebuild crossing at the street Dyrekcyjna and Borowska, where the aggregate of cement stabilized with R_m = 2.5 MPa with the thickness of 25 cm was used under the concrete subgrade of tram tracks (the junction node) or twice with 15 cm (in the street Dyrekcyjna).

"Sandwich" - more than one layer, yet still without draining

In 1995, during the reconstruction of the street Ruska and Mikołaja, under the concrete subgrade of tram tracks it was used subtrack consisting of several layers:

- broken stone 31,5/63 with the thickness of 15 cm,
- sand (abscission layer) – twice with 15 cm,
- stabilization of the existing subgrade in the depth of 15 cm.

It is true that in the project appeared a note that the last 30 cm from the bottom of the structure should be used only in the case of bad ground conditions, but in fact this solution included the whole of modernized tracks. The layers were arranged in inclination to 2.75% without, however, drainage for water collection from the lowest point.

In 1997, during the reconstruction of the street Świdnicka on the section from the street Pilsudskiego to the street Podwale, under the concrete substructure of built tram tracks it was used horizontally:

- crushed aggregate with the thickness of 30 cm,
- sand (a filtering layer) having the thickness of 20 cm.

In 1998-99 during the reconstruction of the street Pilsudskiego (from the street Świdnicka) and the street Małachowskiego, under the concrete substructure of built tram tracks it was used horizontally:

- substructure with the thickness of 10 cm,
- crushed stone 32/65 with the thickness of 20 cm,
- medium-grain sand with the thickness of 15 cm.

In 1999, during the reconstruction of the street Nowy Świat, under the concrete substructure of built tram tracks it was used:

- filtering layer of gravel sand with the thickness of 15 cm,
- reinforcing layer of soil with the thickness of 35 cm.

As in the case the street Ruska and Mikołaja, these layers are made with a drop-section (here just 2%), but without providing the receiving water from the lowest points. Almost similar solution was repeated in 2002-03 during the reconstruction of the street Wyszynskiego, with the only difference that the thickness of the soil layer was reduced to 25 cm. Going back to 1999 - during the reconstruction of the street Kołłątaja on the length of the segment with good soil conditions, the concrete substructure of built tram tracks it was used horizontally:

- key aggregate with the thickness of 20 cm,
- gravel sand with the thickness of 15 cm.

In 1999-2000, the modernization of the loop Kowale, under the ballast of tram tracks with the classic structure it was uses horizontally:

- key aggregate 5/25 kl.II gat.1 with the thickness of only about 5 cm (clinch layer),
- coarse sand with the thickness of 20 cm.

"Sandwich" as before, but with drainage

In the years 1994 to 1995, during the reconstruction of the street Grabiszyńska section from the square Srebrnego to Guard Brigade, under the concrete substructure of built tram tracks it was used subtrack with drainage, consisting of layers:

- gravel sand with the thickness of 10 cm,
- crushed stone 32/65 with the thickness of 20 cm,
- medium-grain sand with the thickness of 15 cm, with the slope of the bottom 4% to the axis the tracks, where a drain was placed with the diameter of 100 mm, inside the crushed stone 32/65.

A similar solution was used in 1998 during the modernization of the tram line along the street Lotnicza between the trading house "Astra" and the street Metalowców (Fig .2).

2. Solution of "sandwich" type with drainage under the classic unbuilt tracks (the street Lotnicza, 1998)

In the years 2010 - 12, during the construction of sections of the "tram plus" line on Kozanów and to the stadium EURO 2012, under the substructure of tram tracks in the form of reinforced concrete it was used:

- key aggregate 4/31,5 with concrete (a stabilizing layer) having the thickness of only 6 cm,
- key aggregate 4/31,5 with the thickness from 17.5 to 32.5 cm, the inclination of the bottom 4% or 5.3% to the axis of the tracks, wherein a drain was provided in the form of perforated pipe having the diameter of 100 mm, inside gravel and below it the following layers were laid:
    - sand with the thickness of 5 cm - in the case of the substrate that does not need reinforcement,
    - chemical stabilization of the substrate to the depth of 15 or 30 cm - in places with insufficient bearing capacity.

In the realized project it was stated that according to the declaration of the executor the following values of the secondary modulus will be obtained:

- 180 MPa – in the key aggregate layer,
- 120 MPa - on the sand layer or stabilized substrate.

"Sandwich" with geosynthetics, with or without drainage

In 1996, during the reconstruction of the street Powstańców Śl. from hotel Wroclaw to The avenue Hallera, under broken stone ballast of tram tracks with the classic construction it was uses:

- the gravel layer with the thickness of 25 cm and the slope of the bottom 4% to the axis of the tracks, where a drain with diameter of 150 mm was placed inside the gravel,

- geofibric,
- stabilization of the existing substructure with the old broken stone to the depth of 20 cm.

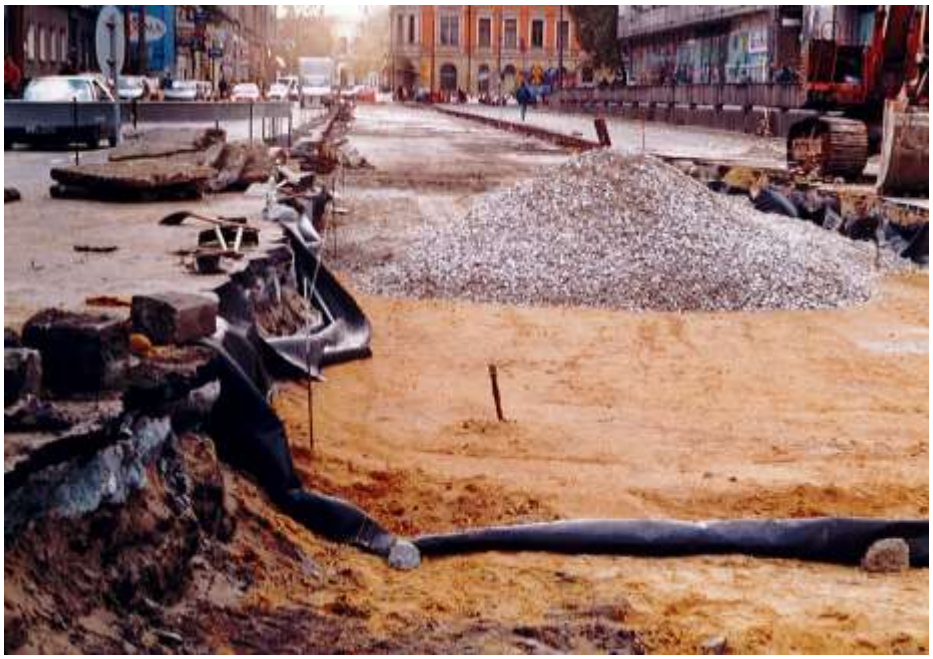
Three years later, in 1999, during the reconstruction of a two-track tram line with the classic design in the street Różyckiego and Paderewskiego, at the bottom of the trench geofibric was also provided, above which only a layer of sand with the thickness of 10 cm was laid. It was a kind of a back to the previously described solution (‘only sand’). Along the street Różyckiego the bottom of the pit was made unusually, i.e. in one-side decline to the drain placed asymmetrically on the north side of the track, while along the street Paderewskiego typically, i.e. in bilateral declines to the drain of the tracks' axis.

Similarly, in 1999, in the case of described in two chapters before, the reconstruction of the street Kołłątaja (Fig. 3), but this time in the section with bad soil conditions, under the concrete substructure of built tram tracks it was used horizontally:

- key aggregate with the thickness of 20 cm, with the secondary modulus E2 (measured at the surface) of 120 MPa,
- gravel sand with the thickness of 15 cm,
- geofibric coated from top and bottom by sand layers with the thickness of 5 cm.

Additionally, in the worst ground conditions (requiring exchange of clayey sands in a plastic state), the geofibric was used:

- sand with various granulation with the thickness of 15 cm,
- lime stabilization of the substrate to the depth of 20 cm.



3. Solution of "sandwich" type with geosynthetics without drainage, under the built track (the street Kołłątaja, 1999)

A very similar solution was applied in 2005 during the modernization of the street Sienkiewicza on the section from the street Ukryta to the street Suchardy also containing the built-tram tracks. The differences consist in that the layer of key aggregate, which had a slightly lesser thickness of 15 cm. Instead of geofabric it was used a geotextile, whereas in the worst-case ground (silts clay in the plastic state) the reinforcing layer of soil CBR > 20% with the thickness of 30 cm was additionally provided at the bottom.

On the other hand, in 2006-07, during the reconstruction the square Powstańców Wlkp., another modification of the described solution was used
in built tracks. The thickness of key aggregate was increased to 20 cm, but it was abandoned completely with gravel sand layer and additional strengthening in the worst ground conditions because they did not occur.
In 1999-2000, during the modernization of the tram line along the street Toruńska and Kwidzyńska (Fig. 4), under the broken stone ballast of tram tracks with the classic design it was used:

- key aggregate layer 5/25 kl. II gat.1 with the thickness of only about 5 cm (clinch layer),
- coarse sand layer with the thickness of 10 cm with 4% inclination of the bottom to the axis between the tracks (asymmetrically - due to the foundations of traction poles), wherein the drain was provided in sand,
- geofibric with continuous fibres having tensile strength ≥ 9,5 kN/m.

4. Solution of "sandwich" type with geosynthetics and drainage, under the classic unbuilt tracks (the street Kwidzyńska 2000)

In 2000, during the reconstruction of the street Grabiszyńska at the square Pereca, under the concrete substructure of built tram tracks it was used:

- key aggregate with the thickness of 20 cm,
- gravel sand with the thickness of 20 cm and the 4% inclination of the bottom to the axis between the tracks, where a drain with the diameter of 100 mm was provided in filter layer,
- geofibric coated at the top and bottom by sand layers with the thickness of 5 cm.

This construction was a modification of the already described solution (the street Kołłątaja - for bad ground conditions) involving the use of downhill of the trough bottom and adding drainage. In 2003, during the reconstruction of two-track tram line at the street Oławska from the square Dominikański to the street Krasinskiego, under the broken stone ballast of tram tracks with the classic design it was used:

- key aggregate 4/31,5 with the thickness of 20 cm,
- gravel sand with the thickness from 15 cm, with the 4% slope of the bottom outside the track, where drains of 100 mm diameter from hard polyethylene were placed inside the key aggregate on the ballast of compacted sand with the thickness of 5 cm,

- needled geofibric polymer with a tensile strength > 46 kN/m.

In 2004, during the modernization of the tram line at the street Osobowicka, in the section under the newly built Millennium bridge, under the ballast of tram tracks with classic design it was used:

- key aggregate 4/31,5 with the thickness from 15 cm to 30 cm, the 4% or 5.1% inclination of the bottom to the space between the track axis (asymmetrically - due to the foundations of traction poles) where the drainage with the diameter of 100 mm of perforated PVC pipes was provided inside the filter layer,
- geofibric coated at the top and bottom by sand layers with the thickness of 5 cm
- in places with insufficient bearing capacity - additional exchange of ground or chemical stabilization to the depth of 30 cm was applied.

A similar solution - in both classic tracks and those with the concrete substructure (on the lateral road crossings) it was used:

- in 2006, during the reconstruction of the tram line at the street Żmigrodzka, but no additional exchange or soil stabilization was applied,
- in 2008, during the reconstruction of the tram line at the street Lotnicza in the section from the street Metalowców to loop Pilczyce, including this loop.

A similar type of solution was also applied in the project for the newly constructed sections of the "tram plus" line in Kozanów and the stadium EURO 2012. The only differences were:

- greater than 5 cm thickness of key aggregate, i.e. from 20 to 35 cm,
- exchange or soil stabilization in one or two layers (15 or 30 cm).

Eventually, it was sent to the implementation a slightly modified variant of the structure (without geofibric), as described in the previous section.

"Sandwich" with unsorted material as a tight layer, with or without drainage

In 2008-09, during the reconstruction of the street Grabiszyńska in the section from the square Srebrny to the church of St. Elizabeth, under the concrete substructure of built tram tracks it was used horizontally:

- broken stone aggregate with continuous grain size 0/63 (i.e. unsorted) with the thickness of 20 cm,
- geotextile,
- ground stabilized by hydraulic binder - twice with 15 cm.

In 2014-15, during the reconstruction of a two-track tram line between loops "Grabiszyńska-cemetery" and "Oporów" (Fig. 5), under the ballast of tram tracks with the classic design it was used:

- layer of unsorted material 0/31.5 with the thickness of 20 cm, the inclination of 3% to the axis between the tracks, where a drain with the diameter of 130 mm of double-walled, corrugated, perforated (the upper half of the cross section) HDPE pipe was placed in the buffer zone of the geofibric, inside gravel 5/10, on the geotextile and sand bed with the thickness of 5 cm,
- separation geotextile with tensile strength of at least 40 kN / m and below it::
    - sand with the thickness of 5 cm - in the case of a substrate not requiring reinforcement (G1),
    - the layer of stabilized soil with the strength of 2.5 MPa and the thickness of 15 cm - in places with insufficient bearing capacity (G3).

Along drainage every 50 m, PVC wells with the diameter of 315 mm were used with hatch, the telescope and the bottom.

5. Solution of "sandwich" type with unsorted material as tight layer and drainage between tracks, under the classic unbuilt tracks (the street Grabiszyńska 2015)

A similar solutions were used in 2015 during the reconstruction of the tram line in Oporów, with the only difference being that in the case of individual tracks drainage were placed in their axis.

Ditches and embankments, gutters drain

Due to the fact that the overwhelming majority of Wroclaw tracks are carried out at existing streets, their substructure run mainly in the dig. However, it is not the classic case of excavation (with ditches and slopes), as the top of rail remains at the ground level. The depth of trough results from the overall height of used construction and ranges from about 60 cm in the case of single-layer solutions ("just sand") up to 120 cm, in the case of multilayer solutions ("sandwich").

Classic ditches with the reduction of vertical levelling of tram tracks below the adjacent terrain are used rarely. Over the past 25 years, the following solutions were used only in:

- 2008, during the reconstruction of the street Lotnicza before the loop Pilczyce (new tram tracks were carried out without collision under the flyover road leading circular motion toward the centre),
- 2011-12, during the construction route "tram plus" in Kozanów between the streets Gwarecka and Nadrzeczna (behind the "white" church).

In the both above cases, due to lack of space in cross section, instead of the conventional trench side, reinforced concrete gutters were used.

Embankments with the elevation of grade line of tram tracks above the adjacent terrain are also used rarely. In the analysed period, such solutions were applied only in a few cases:

- in 1996, during the reconstruction of loop Leśnica (new loop was located partly in another place, in low ground),
- in 2011, during the construction of an integrated interchange "PKP Stadion" along the streets Lotnicza and Kosmonautów (access to railway viaduct was carried out partly in other course),
- in the years 2011-12, during the construction of the new end of route "tram plus" at the street Gwarecka (in the site of allotments in low ground) and the access roads to the new tram bridge over the river Ślęza along the street Pilczycka (change the requirements for the migration of animals - higher gauge).

Protection elements against propagation of vibration

Isolators of vibrations in the tram tracks are mainly present in the surface, although one of its possible forms, i.e. anti-vibrations mats, can be found on the contact surface and substructure. In Wroclaw, this solution was applied:

- in 2005, on a street intersections at the street Sienkiewicza and Wyszynskiego and Sienkiewicza and Piastowska,
- in 2007, on the square Powstańców Wlkp.,
- in 2014, at the street Curie-Skłodowskiej, Krupnicza and Nowowiejska.

Another form of protection against the propagation of vibration is to use reinforced concrete shield elements with the shape of the letter "L" or inverted "T" (in Warsaw, Katowice, Prague) at sides of pavement and subgrade. Unfortunately, Wroclaw has not benefited from such a solution.

Summary

Analysing modifications, which over the past 25 years were subjected construction solutions of tram tracks subgrades in Wroclaw , you may notice the following right trends:

- increasing the number of layers of the railroad bed and consequently lowering the elevation of the bottom of the excavation works,
- resignation from sand for aggregates with larger grains: unsorted material, key aggregate, gravel sand,
- increasing use of drainage (also in built tracks), goesynthetics (filtration, separation, reinforcement), ground stabilization and protection elements against propagation of vibration.

Unfortunately, they can be seen also some errors in the design, such as:

- the use of slopes in bottom layers, but without receiving water,
- filter layers from unsorted material,
- the use of geotextiles (separation) under unsorted material,
- the use of geofibrics (filtration) without a drop and water reception.

Quite troublesome practice is to use in projects and construction various measures of density of the substrate and layers:

- secondary deformation modulus (E_2),
- California index of bearing capacity CBR,
- density index according to the withdrawn standards PN-B-04481:1988,
- groups of bearing capacity (G1 - G4) according to annex 4 of "road" regulation [4].

Another difficulty for both designers and construction and maintenance workers, as well as infrastructure managers is related to old, outdated and inconsistent regulations, guidelines and normative documents.

Raised for many years need to develop new guidelines for design, construction and maintenance of tram tracks should take into account a much broader range of issues about subgrades than it is in the "old" guidelines [3].

Source materials

[1] PN-K-92011: 1998 Torowiska tramwajowe. Wymagania i badania.
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