Comparison of Ballast and Ballastless Tracks

Master Thesis

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Submitted by

Nina AVRAMOVIC

At Institute for Railway Engineering and Transport Economy

Mentor. O.Univ.-Prof. Dipl.-Ing. Dr. Tech. Klaus Rießberger

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Mojoj majci Slavki,

hvala za podrsku, razumijevanje, vedrinu i ljubav koji su me uvijek pratili mojim putem

Declaration of authenticity

Herby is affirmed that this work was written independently and without outside help, using only the listed sources and none others.

I assure, that this master thesis has not been submitted in Austria or abroad in any form.

Graz, April 2010 Nina Avramovic

Acknowledgment

I want to thank all loving people in my life that have supported and followed me on my way of becoming a master of civil engineering.

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My mother Slavka and sister Ivana, thank you for listening to me, being so supportive and always having a word of encouragement.

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Abstract

In these modern times the railway shows potential to be a serious competition to even airlines. If properly built and maintained railway can be a mean of transport and achieve the speed of 300 km/h and more. How to succeed in this intention the author of this thesis is going to try to explain in following chapters.

The author of this master thesis has for a goal to elaborate advantages and disadvantages of both of most common types of railway: ballasted and ballastless track. Also all of the other important influences and factors such as demands on the material and track, production, lifespan, economics and ecological aspects are to be considered and compared.

Other alternative railway systems, such as frame-sleeper system, are to be shown and described.

Kurzfassung

In heutiger Zeit zeigt die Eisenbahn Potenzial um mit sehr hoher Geschwindigkeit befahren zu sein und somit stellt sie Konkurrenz sogar zu Flugzeugtransport.

In diesem Sinne, hat Autor dieser Arbeit den Ziel dieser Magisterarbeit mit dem Thema: Vergleich von dem Schotteroberbau und Fester Fahrbahn zu schreiben.

Alle Einflussfaktoren einer Eisenbahn wie Herstellung, Instandhaltung, Lebensdauer, Wirtschaftlichkeit und Umweltaspekte werden bei beiden Systemen berücksichtigt und verglichen.

Andere alternative Lösungen für den Eisenbahnoberbau werden vorgestellt und kurz beschrieben.

Content:

Inhalt

1. Historical development of the track

There is an assumption that the railway has existed already in ancient times i.e. 600 B.C. However, there are no remains or written proof of that. As much is known that there was supposedly a track way in limestone between Diolkos[1] across Isthmus of Corinth, measuring between 6 and 8.5 km. It was operated by slaves.

Thereafter the railway was rarely mentioned until 14th century.

"Railways began reappearing in Europe after the Dark Ages. The earliest known record of a railway in Europe from this period is a stained-glass window in the Minster of Freiburg in Breisgau dating from around 1350.

In 1515, Cardinal Matthäus Lang wrote a description of the Reisszug, a funicular railway at the Hohensalzburg Castle in Austria. The line originally used wooden rails and a hemp haulage rope, and was operated by human or animal power, through a tread wheel. The line still exists, albeit in updated form, and is probably the oldest railway still to operate."[2]

At the end of the 16th century, small industrial trains with wooden rails were used to transport ores from mines such as the so called "hunts" in Germany. This type of transport was brought to England by German miners and was in use "by miners working in Mines Royal"[3].

Picture 1: Horse drawn railway in 19th century [4]

[1] Lewis, M. J. T. "Railways in the Greek and Roman World"
[2] According to Wikipedia
[3] Source: http://en.wikipedia.org/wiki/Timeline_of_railway_history
[4] Source: http://www.ckrumlov.info/docs/en/region_histor_doprav.xml

“Early rails were used on horse drawn wagonways, initially using strap-iron rails, which consisted of thin strips of iron strapped onto wooden rails[5]. These rails were too fragile to carry heavy loads, but because the initial construction cost was less, this method was sometimes used to quickly build an inexpensive rail line. Strap rails sometimes separated from the wooden base and speared into the floor of the carriages above, creating what was referred to as a "snake head." However, the long-term expense involved in frequent maintenance outweighed any savings”[6].

At first there were two types of rails: the L-shaped rail with flat wheels developed by Benjamin Outram and flanged wheels on lightly curved rail, an invention of William Jessop in 1789. The second solution spread due to its superiority and better characteristics in curved parts of railway.

In the 19th century initially wooden or stone rails with subsoil of ashes, chalk and clay were first replaced by cast iron rails, but hot rolling iron allowed the brittle, and thus often uneven, cast iron rails to be replaced by wrought iron in 1805. These were succeeded by steel rails made in 1857[7] by Robert Forester Mushet and stone track ballast.

The end of the 18th century, 1794[8] to be precise, also brought the innovation of steam engine which led to an innovation of new steam engine for a locomotive. This steam engine was innovation of Scottish scientist James Watt. In the same year his employee William Murdoch developed the steam locomotive based on the principals of steam engine and James Watt´s work.

After Watt´s and Murdoch´s work, many scientists occupied themselves with the work of evolving steam engine and locomotive. Some of them were John Fitch (USA), Richard Trevithick (UK), Mathew Murray (UK), etc. The most important for the popularization of railroad and introducing the railway as a means of public transport is George Stephenson. He was the first one to develop flanged wheels and use railroad both for transport of general public and of goods. During this time there was development of stronger, more powerful locomotive engines and light, fast, passenger engines that were used for person transportation.

The first railroad route to be used in England was Liverpool-Manchester, with 56 km in length. As the people of England came to understand the breakthrough that railway could bring them, the next step was to build bigger, better railway. It was the Grand Junction Railway in 1837, connecting Liverpool, Manchester and Birmingham.

[5] Bianculli, Anthony J., “Trains and Technology: The American Railroad in the Nineteenth Century”, University of Delaware Press, 2002
[6] http://en.wikipedia.org/wiki/Rail_profile, accessed March 1st 2010
[7] Source: Marshall, John (1979) “The Guiness Book of Rail Facts & Feats”
[8] Source: Gordon, W. J. (1910) “Our Home Railways, Volume One”

Soon enough railways became essential to the swift movement of goods and labor that was needed for industrialization. At some point the canals had the same importance as the railway, but quickly they were given a secondary role due to the fact that the railroad was able to reach places canals could not.

In the 1840s the railroad expanded not only in England but also in Russia, USA and continental Europe and since then the progress of railways has been unstoppable.[9]

[9] Source: http://en.wikipedia.org/wiki/Timeline_of_railway_history

2. Characteristics of ballast

2.1. Production of ballast

What is track ballast?

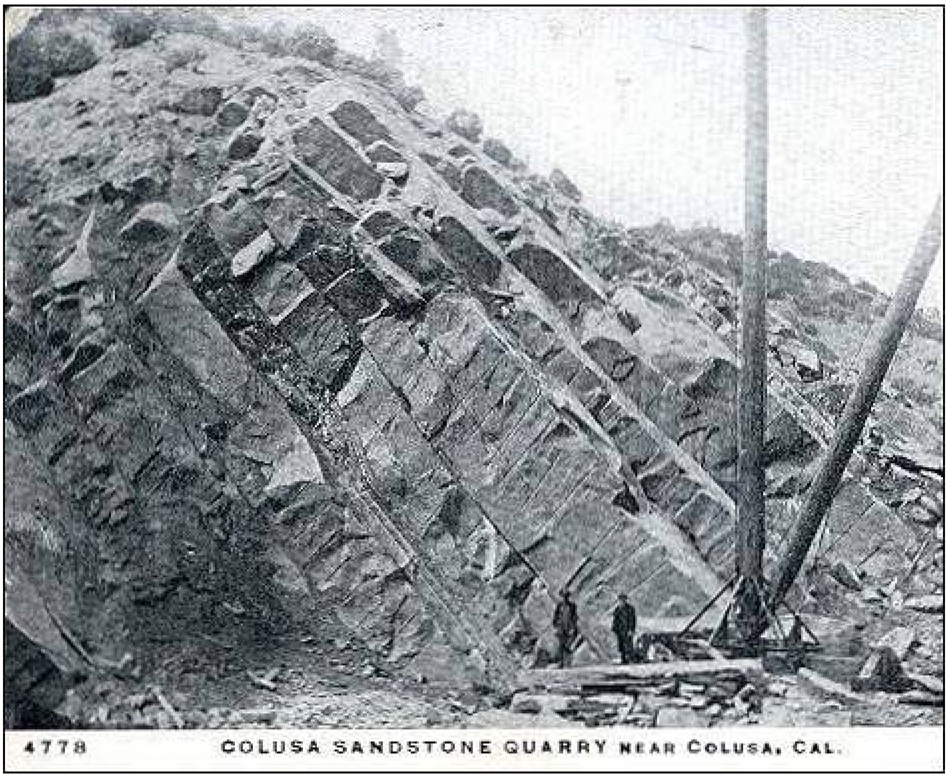
The term "ballast" comes from a nautical term for the stones used to stabilize a ship.

Track ballast is a part of the track in which the sleepers are embedded together with the rails. It should distribute loads from contact points into an area, big enough to allow subgrade to withstand. It is also important that it's resistant to weather influences, strong enough and able to be used as drainage for the water.

The production of the track ballast happens in quarries, by refracting big stone blocks with explosive. Two track ballast granulation classes can be distinguished: [10]

Ballast class I: from 31.2 to 63.0 mm (is generally in use in European railroads)

Ballast class II: from 16.0 to 31.5 mm (is generally in use in the areas that need to be walkable such as train stations or shunting areas).



Picture 2: stone quarry[11]

[10] HOLZEFIND, J. "Zur Prognostizierbarkeit des Qualitätsverhaltens von Gleisen"
[11] http://quarriesandbeyond.org/states/ca/images/ca_books/ca_report_xiv/ca-report_xiv_pg195.jpg

It depends on quality of the material if it will be used for rail road or some other purpose.

The obtained stone blocks are transported by dump trucks to the collecting duct where they are broken for the period of time until a needed fraction is reached. After the breaking process is done, the rocks are sifted until they are divided in several granulation groups.

Ballast is once again transported, first by dump trucks and then by conveyor belt to the sifting unit, where it is going to be stored in 5 m height until it is sold to the suppliers (that are not automatically also the customers).

When loading the track ballast in wagons and trucks additional sifting is required where once again the exact granulation of ballast is confirmed. The not allowed quantity of too small granulation is excluded and forwarded to be used for another purpose.

Complication during loading the dumper truck is that the ballast is tossed once again where it crushes due to the free fall of vast amount and weight of material.

By the standard of European Union good quality track ballast is made of crushed natural rock with particles anywhere from 22,4 mm and 63 mm in diameter, in accordance with the respective grading curves.

A high proportion of particles finer than this will reduce its drainage properties, and a high proportion of larger particles result in the load on the ties being distributed improperly.

Soft materials such as limestone are not particularly suitable, as they tend to degrade under load when wet, causing deterioration of the grading curve.

Granite, although expensive, is one of the best materials in this regard.[12] Granites are solid, relatively coarse crystalline, magmatic deep-seated (plutonic) rocks which are rich in quartz and feldspath, but also contain dark minerals such as mica. Important to say, although granite comes in several colors such as yellow, red, blue or gray, yellow granite tends to be technically poorer than the grey. In yellow granite the feldspath has been partly transformed to clay minerals which are linked to reduction of the strength properties. [13]

[12] http://www.absoluteastronomy.com/topics/Track_ballast
[13] Klotzinger, E. „Track ballast: Requirements and stress“

“Furthermore from isolated occurrences or ultramafit seams, more or less strongly serpentinised dunite, peridodite and bronzite are mined. The mined raw material is described as hard, tough, grainy and resistant to abrasion.”[14]

Some of the also preferred types of stones are basalt, quartzite, diabase and other stones from granulate family. Some of them appear in grey, red, white or pink color. Due to the color of the stone the railroads in USA often got nicknames, i.g.”Pink lady” in Midwest and “salt and pepper” because of the mix of black and white track ballast.

[14] Klotzinger, E. „Track ballast: Requirements and stress“

2.2. Demands on ballast

Track can be described as the “floating” structure. If the rails, fasteners and sleepers are properly calculated and installed then is the track ballast the weakest member of the rail road. Hence if track ballast is to function properly it needs to fulfill material and granulometric requirements. This part of rail needs to be optimized so that weight caused by traffic is as much as possible evenly passed on from the rail, sleeper trough ballast on to the subsoil.

The strength of the ballast bed and drainage of the ground are significant factors for the functioning of the track ballast. Due to the vibrations and stress caused by traffic, the ballast suffers great static and dynamic stress. As the result of vertical force pressure and tension are produced and need to be passed on the subsoil trough the track ballast.

Theoretical knowledge of these demands on the construction shows the complexity of the bond between rail, track ballast and subsoil[15].

In this sense it is very important to have the best track ballast with highest quality and ability to carry out all of the needed requirements. Further, more specific and detailed characteristics of ballast will be elaborated below.

As mentioned track ballast is mostly coarser grained igneous and metamorphic stone. The material is required to be hard, durable stone, angular in shape with all dimensions almost equal and free of dust.[16]

These conditions are going to be elaborated further, so it is understandable why the track ballast needs to fulfill all of them.

If the stone is too soft it crushes due to the vibrations and the vast weight of the train and as a consequence it loses its capability to drain the water and to transmit the forces through its structure. Furthermore it leads to a development of the suitable ground for the growth of vegetation, which in this case is undesirable.

Angular stones are preferable to naturally rounded ones, as these interlock with each other, inhibiting track movement.

In almost every European (e.g. EN 13450) and USA regulation it is mentioned that the ballast needs to be free of dust, plants, materials that are harmful to the health and other foreign matter.

[15] KLOTZINGER, E. “Track ballast: Requirements and stress“
[16] Smith, M.R.; Collis, L. “Aggregates”

Track ballast is mostly coarser grained igneous and metamorphic stone. It has to:

- be produced in certified quarries,

- have certain density within specified limit determined by EU standards (EN 13450)

- be resistant to weathering (tested by boiling the ballast in saline solution)

- have a minimum compressive strength e.g. in Germany 180 N/mm²

- be resistant to destruction and attrition (L.A. Test according to EN 13450)

- be clean of the clay and marl particles

- have a water absorption smaller than 0, 5% of the total weight

- have a grading curve that satisfies the demands (22, 4 mm granulation has to be under 2% of total weight)

Some of the most important other demands that ballast needs to satisfy are (according to the dissertation of DI Jochen Holzefeind "Zur Prognostizierbarkeit des Qualitätsverhaltens von Gleisen"):[17]

<u>Physical attributes:</u>

- Volume density
- Resistance to weather conditions
- Resistance to shape alteration

Physical attributes directly influence the shape of the track. If ballast does not satisfy required demands it could lead to deformation of the track (e.g. when too soft, ballast tends to disintegrate into smaller granulations which leads to instable track).

<u>Mechanical attributes:</u>

- Shock resistance (SR value)
- Resistance to degradation of aggregate by abrasion (by L.A. value)
- Micro-Deval of fine aggregate (MD value, wet test)

Mechanical attributes play a great role in quality and life span of the ballast. It is them who determine if the ballast is good enough to be considered for high speed, low

[17] HOLZEFIND, J. "Zur Prognostizierbarkeit des Qualitätsverhaltens von Gleisen", Dissertation at TU Graz,2009

speed or none of the above railways. In short they describe if the ballast is “durable” to stand all the stresses it is going to be exposed to.

Chemical attributes

Chemical attributes determine ballasts chemical balance when exposed to weather, water, stress, different railroad materials (steel, wood, etc.). If the ballast has unsuitable chemical composition it may lead to development of corrosion on the track or other unwanted consequences.

Geometrical attributes:

- The proportion of granulate
- Fine granulate
- Finest granulate
- Granulate shape
- Granulate length

Geometrical attributes need to be perfected so that track can function at its highest potential. There are exactly prescribed grading curves, that show how much of every granulation track ballast is allowed to contain. If rules are not applied and ballast is mixed unsuitably the track can lose its bearing capacity to a high extent.

2.3. Lifespan of the classic railway

The durability of track ballast is expected to be around 40 years, while it is 60 years by ballastless track. The annual maintenance costs are approximated to be 15.000 DM (ca.7.500 Euros) per kilometer. [18]

Picture 3: Ballast throughout the years[19]

However there is no precise and certain way to determine how long the lifespan of the ballast is going to be. It depends on petrography, quality of rock, maintenance, type of railroad and stress applied to it, weather conditions, etc.

Further some of the causes and consequences of the track damage, and their influence on the lifespan of the track will be explained in detail. (According to Bernhard Lichtberger "Track Compendium", Plasser & Theurer)

2.3.1 Causes of the track deterioration

- Bad sub-soil, i.e. disadvantageous soil type
- High static and dynamic ground stress
- Insufficient compaction of the soil or loss of soil volume
- Deficient drainage in case of rain or rail flooding
- High groundwater
- Filling of the cracks, caused by drought, with rain water, and storing of the water in track bed
- Dissatisfying load capacity of the rail for the current load condition
- Too small sleepers with insufficient spacing
- Environmental influences such as rain, wind and erosion

[18] http://de.wikipedia.org/wiki/Feste_Fahrbahn
[19] Wenety, R. "Railway ballast and its maintenance"

These various causes can lead to following damage:

- wandering of the loose sub-soil, such as sand, trough track bed to the sleeper, caused by ground vibrations

- by not cohesive or poorly cohesive ground cracks are developing due to growing looseness of the sub-soil and soil caused by dynamic pressure

- silty ground combined with wet weather causes wave corrugation of the ground and rising of the mud all way to the ballast surface. Further it leads to sinking of the ballast under the sleepers, gathering of the water and building of the water splash from the ballast bed. Hence the track position is highly unstable, when wet and soon after drying stable again, but in a distorted grounding

- In cohesive ground holes under the sleepers and arching of the ballast between track and shoulder area are developed

- Freezing in winter and dew damage in spring are caused in cohesive ground

- Damage due to wind, that blows sand into the track and in strongly cohesive ground during dry periods

The damage in the track grounds develops in dependence with the traffic load

2.3.2 Consequences of the track deterioration:

More often rail renewal is needed, causing low-speed points, needed track positioning, and in low-cohesive ground concrete sleepers are overloaded and tend to crack. Also ground settlement develops and causes rail overload, quick rail wear and shortening of the rail lifespan.

In clay or loam grounds ballast “pockets” may occur in the sub-soil, where rain water tends to collect. The water sinks down to very deep areas and applies pressure to the track bed, which consequently leads to the breaking of the track bed.

Picture 4: White spot due to ballast overloading

2.3.4 Influence of the different parameters on track quality[20]

- Ballast

Two main influences on deterioration of the ballast are quality of ballast (where it was produced) and the grading curve.

The examination of the ballast was performed according to the EN 13450 standard and on all of the 3 classes of ballast. Grading curve 1 had a very good testing result, where the grading curve 3 was not very satisfying. Grading curve 2 behaved similar to grading curve 1. Concerning types of the rock the granite was graded much better than the porphyrite.

-Drainage

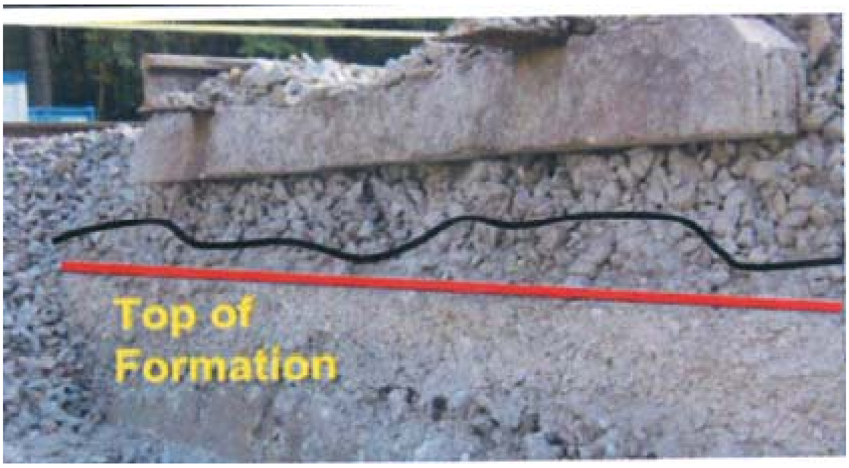
In some cases when drainage is bad it can cause bad track geometry and clogging of the noise barriers and in other case the small beside-dam is built (possibly from the left-over material of the previously used track-cleaning machine). Both of these cases showed an important influence on the track quality and confirmed an old railway thinking that a good drainage is a foundation stone to sufficient railway durability.

2.3.5 Contamination of the ballast- assessment of the pollution degree[21]

Causes of the ballast pollution are:

- A higher percentage of the fine grain after the ballast installation
- Deposit of the small grains from the air
- Deposit from the rail traffic (e.g. coal, ores, etc.)
- Grains rising from the sub-soil
- Vegetation left-overs
- Abrasion due to tamping

[20] According to Bernhard Lichtberger "Track Compendium"
[21] Researched by Britisch Rail, now Network Rail



Picture 5: Cross section of the fines building up from the bottom

The chemical composition can also be influenced by abrasion between rails and train (milled ferritic material), electricity supplier's components or chemical influences from the surroundings

2.3.6 Influence of the Earthworks on the quality of the track

Most of the railway cuttings, embankments and formations on the ground level were made in the second half of the nineteenth century using comparatively limited technical analysis. The loading from traffic was relatively small, but since those times it has increased considerably.

Over the years, the track structure has been strengthened to match this increase, but the earthworks have been hardly altered in most cases, and the formation and earthworks rarely match present-day needs from a geometrical and geotechnical point of view. Enhancement of the strength of these earthworks is necessary to cope with increased- and increasing- loadings. The processes necessary to ensure availability, proof of carrying capacity and proof of usability bring up a numerous geometrical and geotechnical issues that are shown in the table 1.[22]

Table 2 shows us some of the possible methods to improve and strengthen the subgrade and in the way solve the problems mentioned in table 1.

[22] Weissman, U.; Lieberenz, K. "TrackFormation and Earthworks- Geotechnical Problems and Solutions in Route Upgrade Works", RTR, Special 2007

Problem Group	Characteristics
Geotechnical Problems	- Soft and organic materials in subgrade - Inadequate bearing capacity of subgrade - Unsuitable and non-homogenous material used as abutment backfill - Inadequate consolidation of made ground - Inadequate stability of abutments and cuttings under heavy traffic loading - Necessity for widening of the embankments and cuttings with increased impact on existing ground
Geometrical Problems	- Inadequate width of trackbed and consequent loss of correct profile - Lack of space for drainage - Inadequacy of slope gradient of cuttings and embankments - Avoidance of encroachment onto adjacent land
Construction Problems	- Ensuring safety of personnel on the track under engineering occupation, and of the operational track in the case of two routes - Necessity of a safety buffer strip between the operational track and the worksite
Ecological Problems	- Intrusion into the natural environment and disturbance of the ecological balance - Disturbance of natural hydro-geological conditions and ground water condition - Vegetation growth on embankment and cutting slopes - Significance of roads and footpaths, fields and housing in the vicinity of the worksite
Operational Problems	- Effect on trains on operational tracks from the track under engineering occupation - Impact on the track geometry from long-term consolidation of the subgrade, especially from secondary consolidation

Table 1: Problems in Enhancing the Capacity of Subgrades and Earthworks[23]

[23] Weissman, U.; Lieberenz, K. “TrackFormation and Earthworks- Geotechnical Problems and Solutions in Route Upgrade Works”, RTR, Special 2007

Validation of Fitness-for-Purpose and Carrying Capacity		
Increasing Bearing Capacity of Subgrade	Reduction of the Forces from Traffic	Monitoring
Strengthening at Foundation or Subgrade Level, such as: - Formation Replacement - Formation Strengthening - Piled Foundations	Intelligent Track Form as: - Elastic Elements - Massive Construction	- Observation methods - Monitoring - Detailed Inspection
Strength Enhancement at Track Level: - Geoplastics reinforcement - Fixed Track Systems		
Combination of the Concepts		

Table 2: Strength Enhancement Methods[24]

[24] Weissman, U.; Lieberenz, K. "TrackFormation and Earthworks- Geotechnical Problems and Solutions in Route Upgrade Works", RTR, Special 2007

2.3.7 Life expectancy of track components on high-load main tracks in Europe

The following table is going to show the life expectancy of the track, track members and needed renewals according to renewal period.

Tamping	40-70 million ton	4-5 years
Grinding	20-30 million ton	1-3 years
Ballast cleaning	150-300 million ton	12-15 years
Rail renewal	300-1000 million ton	25-30 years
Wood tie renewal	250-600 million ton	20-30 years
Concrete tie renewal	350-700 million ton	30-40 years
Fastening materials	100-500 million ton	10-30 years
Ballast renewal	200-500 million ton	20-30 years
Sub grade rehabilitation	<500 million ton	< 40 years

Table 3: Track members and track maintenance lifespan

On track of the highest category, a work cycle of up to 8 years is the norm, where other track categories are advised to be maintained about every 4 to 5 years, depending on an average load between tamping that should be 50 million ton.

Ballast cleaning is undertaken only in connection with other major treatment (on track with timber sleepers about every 25 years, on track with concrete sleepers about every 30 years).

The service life of rails is usually half the service life of the track system (about 10 years): the limiting factor is not usually that the rail head is fully worn, but the incidence of metallurgical faults in the running surface. Ballast renewal normally takes place in connection with full track relaying (at between 25 and 30 years intervals).

The following chapter 2.4. will elaborate more in to detail some of the most important maintenance processes for elongating the ballast lifespan.

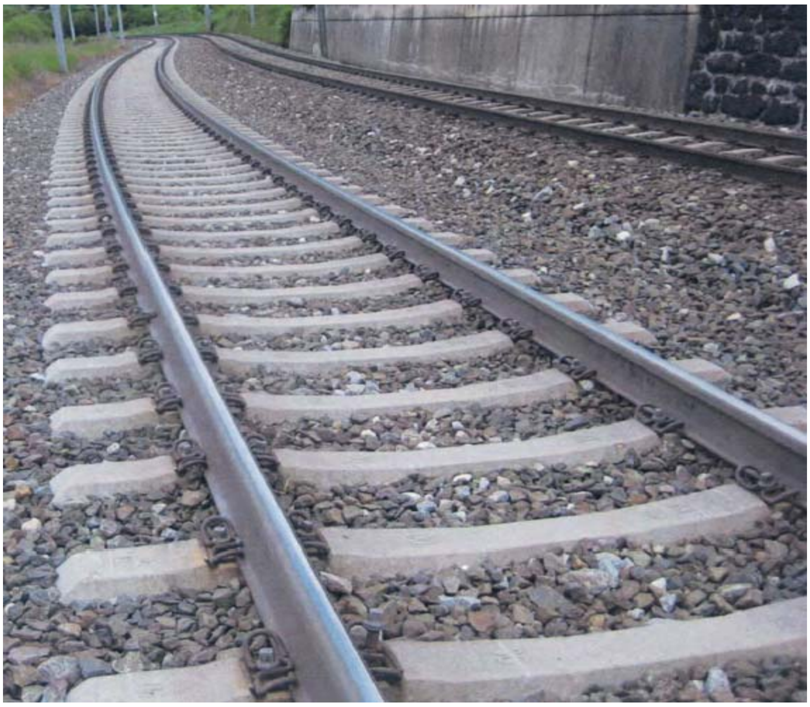
2.3.8 Example:

Depending on rail profile, steel grade, under sleeper pad, type of sleeper, fasteners, etc. the difference in lifespan of the railway can be more than 10 years. E.g. two ÖBB tracks done between Scheifling and Mariahof (Südbahn), track 1 renewed in 1999, with no sleeper soling and not so good steel quality and track 2 renewed in 2001, with sleeper soiling, better steel quality and more elastic rail pad.

The testing of these two tracks showed that

-track number 2:

had a lifespan of 20 years, fasteners had to be re-tightened after 8 years, needed to be grinned every 10 years and had almost no rail pad wear



Picture 6: Track 2

Picture 7: Rail wear

Picture 8: Condition under tie pad

Picture 9: Condition of the rail pads

Picture 10: Ballast condition

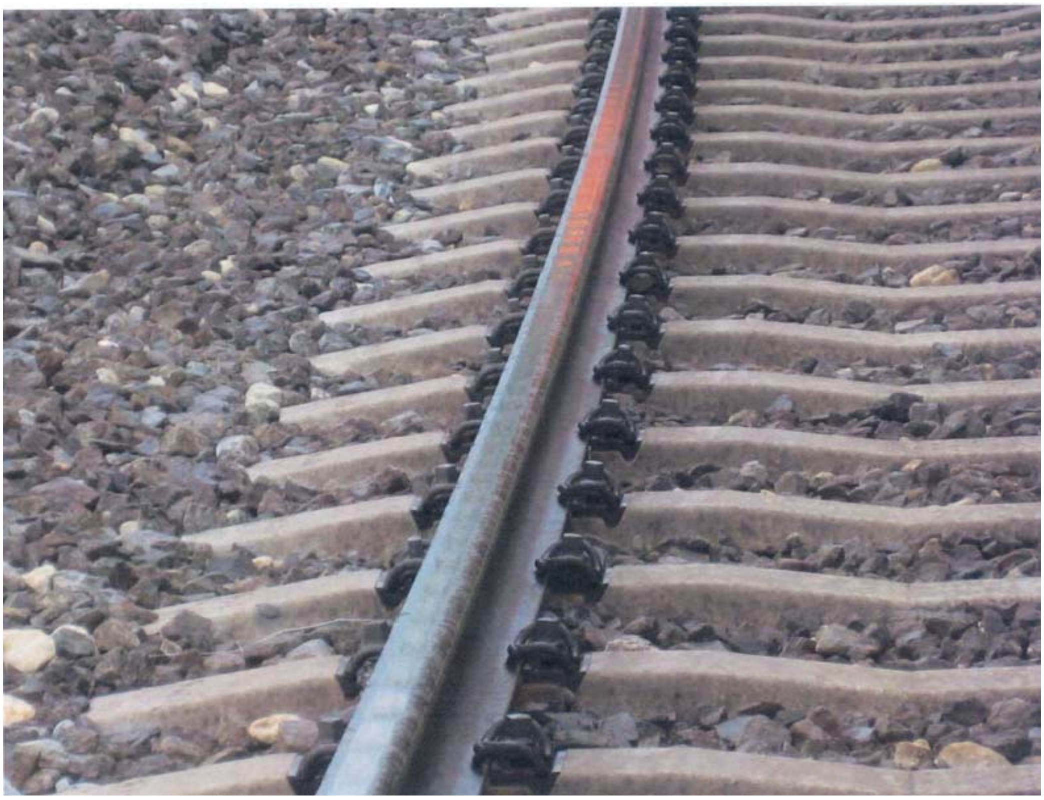
- Where track 1:

Had 6 to 8 years lifespan, sleeper damage, tie cracks due to wave corrugation, needed grinding once a year and replaced rail pad after 8 years[25].

Difference: track 2 had under ties pad, lower rail pad stiffness, higher clamping force and better steel grade)

Picture 11: rail wear

[25] According to research of Florian Auer of ÖBB infrastucture



Picture 12: Wave forming

Picture 13: Tie wear

Picture 14: Rail pad wear

Picture 15: Ballast condition

2.4. Maintenance of the track

"Over the course of time there appears fouling of the ballast bed and irregular settlements due to traffic load and above mentioned influences. The extent of the fouling determines the development of the track quality over time and consequently the cycle required for maintenance work, especially track geometry correction by mechanized tamping, and the necessity of track bed cleaning."[26]

2.4.1 Cyclic Maintenance

"Settlements in the course of operational loading do fluctuate very widely-even under apparently similar conditions. This is due to the random arrangement of the ballast stones under each sleeper. (The sum of the contact surfaces of the ballast stones under the sleeper varies from sleeper to sleeper.) Wavelengths ranging from 3 to 25 m occur in the longitudinal length of the track due to the different settlements. And the settlements crosswise to the track centerline the area of the sleeper support are also not uniform and therefore this results in faults in the cross level and later faults in the alignment. When these faults reach a certain size, it is necessary to perform track geometry correction (tamping)."[27]

Tamping is the process where in case that track bed becomes uneven, it needs to be packed underneath sunken sleepers to level the track out to its initial position. Prior to development and mechanization it was done by manual labor with help of beaters.

Picture 16: Continuous action four-sleeper machine with integrated track stabilization[28]

[26] Klotzinger, E. "Track bed ballast: How the quality develops over time and when to take action"
[27] Klotzinger, E. "Track bed ballast: How the quality develops over time and when to take action"
[28] Wenty, R. "Latest Developments in Track Rehabilitaton and Maintenance", RTR special 2007

In 1930´s the development of the first tamping machines started in Switzerland. It was not until 1950´s that the first hydraulic tamping machine was on the market. The ballast track needs leveling/lifting, lining, tamping, ballast regulating, fine ballast consolidation and track recording. It took years to step by step develop the complex machine that could do all of the above simultaneously.

It was in 1978 when dynamic track stabilizator was developed, and since then has advanced to a current working speed of approximately 2, 4 km/h[29].However, while the tamping helps to renew track geometry it also causes some damage in the ballast itself and causes some questions.

The company Plasser & Theurer as one of the leading companies in railway maintenance machines production offers some of the answers to these questions.

Since the tamping also breaks the ballast (tests have shown that after 20 tampings the limestone grains are 5-10% crushed, where this percentage is 2, 5-5% in granite) the question occurs if the damage caused by tamping is causing the deterioration of the track geometry. Actually fines caused by ballast tamping are just a small percentage of the total ballast fines.

The main cause for ballast fines are running trains, followed by fines from the air, traffic and finally by tamping. Deterioration caused by tamping is 1,8 to 3,9 kilograms per million ton per sleeper (this is approximately 0,17 to o,37% of ballast volume per sleeper), where ballast volume per sleeper is 1050 kilograms. With 30 metric ton axle load tamping cycles have to be about every 50 million tons.

Tamping of the main routes needs to be performed every 4-5 years. Due to crushing of the ballast during transport new ballast can have 3% of the fine granulation. After the cleaning of the ballast the fine granulation percentage is even smaller than by newly delivered ballast.

[29] Ing. Wenty, R. “Machinery for Cost-Effective Track Maintenance”, 1995

2.4.2 General Maintenance (Screening)

When track geometry maintenance becomes frequently necessary due to fouled ballast, maintenance of the ballast by ballast cleaning is the most economical solution.[30]

Picture 17: Mud spot due to deferred maintenance of the ballast

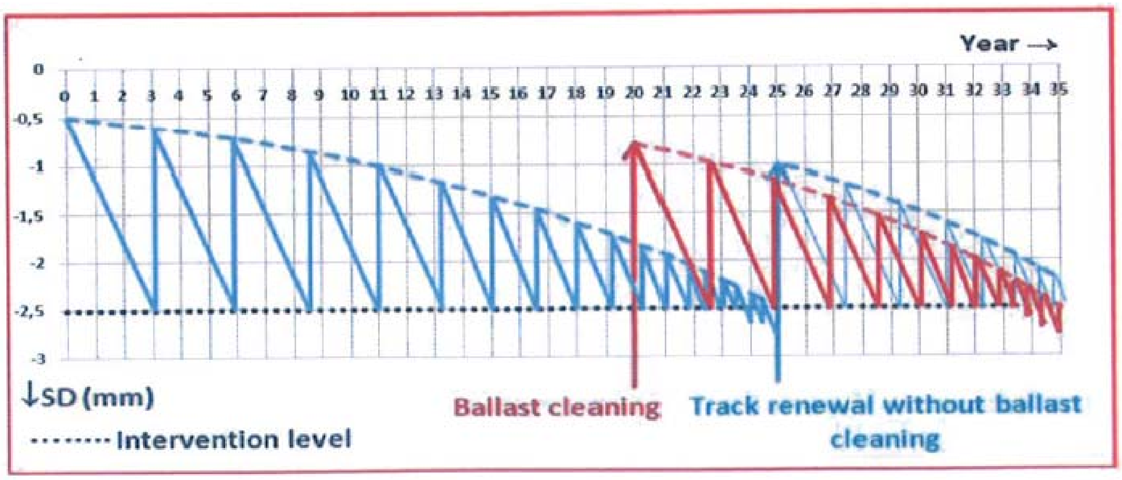
Picture 18: Broken sleeper in fouled ballast

[30] Ing. Wenty, R. "Railway Ballast and its Maintenance", 2009

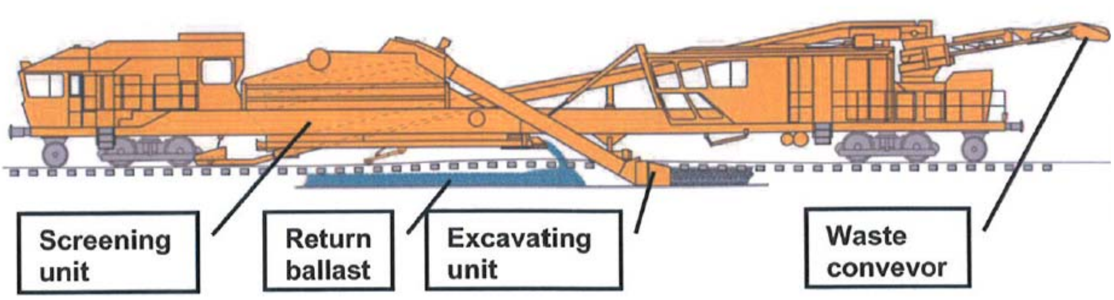
The best way to assess the necessity of the ballast bed cleaning is by taking a ballast sample and in all cases this should include the area underneath the sleepers.

According to UIC [31] research when fouling of the ballast has reached the 30% of total weight, that is when 30% of the screenings go through a 22,4 mm square-meshes screen, the ballast needs to be cleaned. The grain itself has become rounded due to abrasion and rubbing. It causes bigger percentage of the fine grains that sink to the ground and cause loss of the load capacity of the sub-soil.

"Though tamping is a very good art to maintain and improve track quality after approximately 25 years without ballast cleaning, the ballast will wear out and the track can no longer be kept in desired geometrical threshold. If the cleaning is done when tamping cycles become more often (about 10 tamping cycles and approximately 20 years) the track can be restored to a better quality and premature wear of track material can be avoided. An overall service life of 35 years can be expected." [32]



Picture 19: Improvement of maintenance cycles and extension of service life of track by ballast cleaning



Picture 20: Typical layout of ballast cleaning

[31] Union Internationale des Chemins de Fer, Paris
[32] Ing. Wenty, R. "Railway Ballast and its Maintenance", 2009

In Europe ballast cleaning is typically done every 25-30 years. For the high axle loads and resulting increased production of the fines caused by traffic, a much shorter cycle is recommended (estimate of 12 years).

Picture 21: Ballast cleaning machine[33]

Cleaning of the shoulder area is also an option for partial track cleaning if during the transport a lot of material is lost on the shoulders. However it is not a highly effective way to clean the track but it can be very helpful in case when the whole track cannot be cleaned and some time needs to be gained.

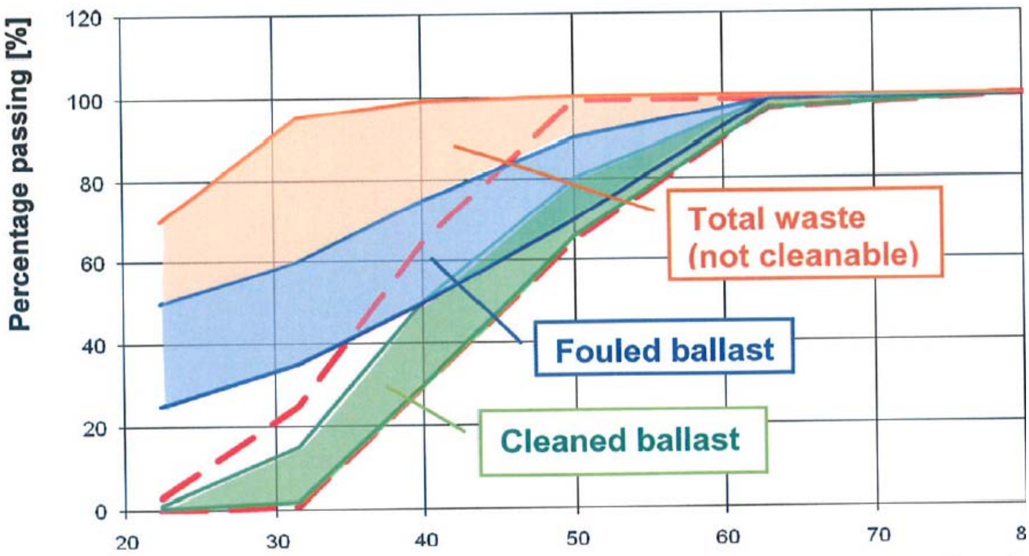
One of the most important characteristics of the ballast is its shearing strength, which represents the force necessary to shear off a body. The bearing strength of the ballast bed depends on the shearing strength. The inner friction angle determines the rise in shearing strength. Its size depends mainly on the irregularity, the grain size, grain shape and grain roughness as well as the density. The greater the friction angle the higher the shearing strength will be. Table 4 shows the importance of the inner friction and the influence of the ballast cleaning on the inner friction angle and rise of the shearing strength.

[33] http://www.ontrackplant.com/photo/76101-2

Description	Proportion of interlocking contact c' [N/cm²]	Inner friction angle Φ[°]	tg Φ
Fouled Ballast	5,2	57,7	1,58
Cleaned Ballast	8,1	63,4	2,0
Round Gravel	4,2	57,4	1,56
Processed Ballast	9,2	65,2	2,16

Table 4: Proportion of interlocking resistance and inner friction angle of various types of ballast material[34]

After ballast cleaning using ballast machines the proportion of the fine particles is around 2,8 % which is less than permissible (3-5%) in new ballast.



Picture 22: Sieve analysis of fouled and cleaned ballast

[34] tested by TU Graz, used by Klotzinger, E. "Track bed ballast: How the quality develops over time and when to take action"

"Another technique is to lift the rails and ties, and to force stones, smaller than the track ballast particles and all of the same size, into the void by compressed air. This has the advantage of not disturbing the well-compacted ballast on the track bed, as tamping is likely to do.

Picture 23: Ballast "stoneblower"[35]

This technique is called **pneumatic ballast injection** (PBI or "stoneblowing"). However, this technique is not as effective with fresh ballast, as the smaller stones tend to move down between the larger pieces of ballast."[36]

Some of other common maintenance jobs include spraying ballast with herbicide to prevent weeds growing through and disrupting the ballast. This is typically done with a special weed killing train.

[35] http://www.freefoto.com/preview/23-26-3
[36] http://en.wikipedia.org/wiki/Track_ballast

2.4.3 Grinding

Rail infrastructure companies all over Europe are paying increased attention to the railhead. Grinding is gaining in popularity, especially as preventive measure to prevent railhead deterioration.

Traditional grinding process is used to counteract the effects of incipient cracks caused by normal rail wear that is to reprofile rail surface to maintain the correct wheel-to-rail contact interface and to remove surface defects such as roughness and corrugation that can lead to rail failure.

It is vital to monitor and measure the rail roughness on the high speed lines. Causes for roughness and corrugation of the rail are total tonnage, types of wheel used and the roughness level of the wheels. On the main lines, short wavelength corrugation is generally within the range of 30 to 100 mm. Increasingly stringent demands are being made of grinding to reduce longitudinal irregularities on the rail to the amplitudes of less than 10 µm.

The direct measuring method is measuring roughness by recording the displacement of a transducer that is moved along the rail. This produces very accurate results but it only measures the roughness on a short section of the track. In the indirect method, vibrations or sound from a train wheel running on the rail are recorded and translated back into roughness levels for that specific rail. This provides measurements for a longer section of the track, but it is more sensitive to disturbance and is likely to be less accurate.

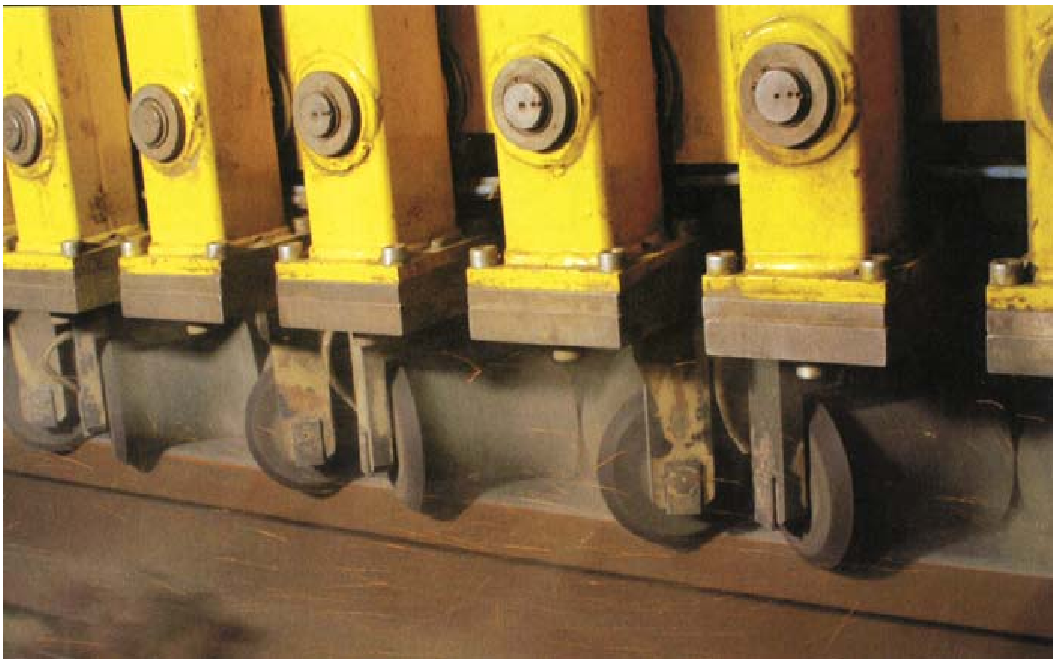
Main line rail grinders almost exclusively use grinding modules which rotate about an axis normal to the rail. The typical rotation speeds are 50 to 60 Hz and grinding speeds are 5 to 10 km/h.

Wavelength ranges [mm]	Limiting amplitudes [mm]
10 to 30	0,01
30 to 100	0,02
100 to 300	0,02
300 to 1000	0,13

Table 5: Limiting amplitudes depending on the wavelength ranges set by European Railways[37]

[37] Grassie, S.L.; Smith, J.D.; Saxon, M. “Measurement of the irregularities underpins grinding criteria”, Railway Gazette International, March1998

Picture 24: Linsinger rail shaper



Picture 25: High-speed grinding[38]

[38] Abbot, J. "Rail grinding and milling become precision arts", ERR, Issue 3 2004

Grinding reduces the roughness of the rail to a certain level and that roughness will decrease further just after grinding until a certain minimum level is achieved. After the minimum roughness level is reached, the rail roughness will increase again until the maximum allowable level is reached and intervention is required. [39]

Advantages of the grinding are:[40]

- Improvement of the rail surface and transverse rail profile

- Reduction of the wear on rail head

- Improvement of the wheel-rail geometry

- Reduction of maintenance costs and life-cycle costs (LCC)

- Reduction of noise level (impact sound and airborne sound emissions)

At this point grinding can be done at high speeds of 80 km/h (such as the one from the company Stahlberg Roensch) without influence on the train time schedule .In the following table performance data of one grinding machine will be shown as an example.

Picture 26: RC 01, Stahlberg Roensch 40 km/ h grinder[41]

[39] Kuijpers, A.; Schaffner, J.C.; Bekooy, M. „Grinding programme combines noise reduction and preventive maintenance“, Railway Gazette International, June 2006
[40] Abbott, J. „Rail grinding and milling become precision arts“, European Railway Review, March 2004
[41] Püschel, A. “Schnelles Schienenschleifen; High Speed Grinding”, Der Eisenbahningenieur Octobar, 2009

2.5 Mechanics and deformation of the ballast

This subchapter has for a purpose to explain the mechanics of the ballast in track and show its disadvantages in high speed track.

Since the tracks and the stone ballast have been made a standard in 19th century they have been able to successfully fulfill the demands on the whole track. In 1970´ties current operating speed in leading railway countries such as Germany or France was already up to 200 km/h. The need and the ambition to rise the operating speed to 250 km/h or even 300 km/h has appeared. Hence the tests and researches were made to find out how the track on the stone ballast interacts and behave in such high speeds. Some of the results and occurring problems are going to be furthermore explained in this sub-chapter.

In 1963 Karl Klugar[42] researched the tensions and stability in ballast. The tests were made on a replica of the track with track bed, sleepers and track. With the help of apress horizontal stress was made in the track. The inner friction angle was tested and showed on various examples that it is only economical up to the value of tg Φ= 0,3. The movement of the track was just 0,3 mm when tg Φ was 0,3 and jumped to a five time as big as 1,6 mm when tg Φ was raised to 0,4. These examples also showed the influence of the origin of the stones, the shape of stone and the compaction. For example first class basalt with a good compaction showed with the same grading curve much better results than ballast of the lower quality, which started to break already by the small stress conditions. Another problem that occurred during these tests is that in reality the ballast between the tracks is not as well compacted as the one under the sleepers, which brings non uniformity into the track. Also as only 5% of the first class material was replaced with lower quality material: the total distortion was approximately two times bigger and plastic shape deformation was as much as five times bigger.

As the track is in use more and more fines are produced and the pressure is being transferred on to the big grains instead from one big grain to another trough the track. The elastic behavior of the ballast track is possible only when the stones are wedged together so that they build a uniform and tense track bed. The increase in the portion of the fines leads to the loss of the tension and uniformity and causes a quick plastic deterioration.[43]

Settlements in the track depend on compaction of the track itself and develop through the grain position rearrangement and grain abrasion. Especially dangerous are different settlements of the sleepers. One thing that could be done to improve resistance to the settlement is to make an initially high quality height profile, since it is the one characteristic that slows the settlement down.

[42] Klugar, K. „Ein Beitrag zur Mechanik des Schotterbettes“, ETR August 1963
[43] Klugar, K. „Über die Verformung des Schotterbettes“, ETR August 1969

Since the track has to have an almost perfect geometry at high speeds: large radius, long transition curves, minimal track elevations and minimal track distance need to be followed. Also at speed as high as 200 km/h tunnels have to have a minimal area of 50 m^2.

At speeds higher than 270 km/h the sleepers are loosened, fluctuations in length and cross section are so big that they become unacceptable. A phenomenon of a “ballast flight” develops. Ballast flight is most probably caused by the combination of mechanic and aerodynamic forces. Ballast particles become airborne during the passage of trains, potentially causing damage to both the railhead and the vehicle. Some researches in Spain have shown that the ballast flight develops only if there is ballast on sleepers. However if ballast is tightly packed in the track and does not wander on to the track, most probably there will be no ballast flight. Also the tolerances in curves and track need to be kept low that they are almost impossible to follow. Allowed tolerances will be shown in table 6 on the next page.

“Sunburn” is a phenomenon that appears by basalt or basalt-related rocks. After being exposed to atmospheric influence these rocks tend to develop grey-white stains, form cracks that degrade mineral structure of the rock and in the end degrades the whole rock. Depending on origin of the rock this can happen within few months from mining. Hence the track ballast rock should be tested according to EN 1367-3 to prove its resistance to “sunburn” development.

On the example of the Tokaido railway in 1970ties with an operating speed of 250 km/h and 70 train pairs per day on the ballast track, it was shown that it needed tamping 4 times per year and annual lining/lifting and correction of the track. All in all it was obvious that greatest weakness of the classic track was the ballast-caused track geometry deterioration and settlement and other solutions and alternatives needed to be developed and researched.

Measuring values	J.N.R. Japanese National Railways Installation	 Maintenance	D.B. Deutsche Bundes-bahn Installation	 Maintenance	S.N.C.F. Socité Nationale des Chemins de Fer Francais Installation	 Maintenance
Mutual altitude	2 mm	5 mm	+/- 2 mm	+/- 5 mm	+/- 3 mm	+/- 5 mm
Twisting	1,5 mm/2,5 mm	3 /2,5 mm +/- 5/2,5 mm			1 % Per 3 m measurement base	1,5 to 2 %
Length altitude	2 mm	5 mm	2 mm/5 mm			
Move ment – straight		+/- 3mm 10m sinew		+/- 2 mm 16 m sinew		
Move ment – curve	2 mm	4mm +/- 3mm 10 m sinew	2 mm 16 m sinew	3 mm	+/- 1 mm 10 m sinew	+/- 3-4 mm
Roughness		+/-7 mm In 10 m				
Gauge width		+5 mm -3 mm		+3 mm and -2 mm in the straight +10 mm in the curve		
Joint Position			Point joints to 2 mm, no perpendicul ar joints			
Welding		+0,2/-0,4 mm				
Sorce:	Matsubara, K. and Yashuhisa Oka		Birmann, F.		Proud´Homme, M.A.	

Table 6: Allowed tolerances in installation and maintenance of the track at 200 km /h in J.N.R., DB and S.N.C.F. in year 1968[44]

[44] Birmann, F. „Geometrie und Konstruktion des Oberbaues von Schnellfahrstrecken“, ETR December 1968

3. Why ballastless track?

After describing the production, demands and maintenance of the ballast some of the solutions for the occurring problems in the ballast track will be explained so that the author can show how it came to an idea a development of the ballastless track.

As some of the most important criteria for the attractiveness of the railway following are stated: speed, availability, comfort, punctuality and service. Speed being the first and often most important factor in the choice of a transport plays a great role in railway as in any service of public transport.

Through the centuries the engineers have tried to develop and improve railway speed, track geometry, material characteristics and travel comfort. For decades the classic ballast track progressed to higher speeds where in the 1970ties the maximum operating speed of 200 km/h was reached. At this point the standard IC-track had UIC 60 rails, B 79 W sleepers and sleeper distance of 60 cm (in Germany) costing about 0,42 to 0,52 million Euros per kilometer. Nonetheless at speeds higher than 250 km/h ballast vibrated two times as much as by speed of 160 km/h, and started to show weaknesses.

Weakness of the ballast is that it is especially sensitive to the type of traffic it develops on the track. In the case of mixed traffic (freight and passenger) ballast tends to settle very easily. Since the 1950ties it was tried to enhance the size of the concrete sleeper so that the track would be less sensitive to the settlement. Hence from 2,3 m B 55K the width of the sleeper was gradually expanded to 2,80 m B 75. Bigger width than 2,80 m would cause a need for a new way of track compacting. In the past in England the idea of length sleepers was tried out, but they showed an insufficient structural strength and incapability to sustain the track width. However the advantage of this idea that is the idea of sleepers with bigger bearing area brought to development of the prestressed concrete frame sleepers that offered the advantage of the stronger railway than the ballasted railway, but with lower costs than the ballastless track. This concept will be furthermore elaborated in chapter 9.

Some of the possible improvement measurement for track elasticity is an insertion of the elastic baseplate pad and changing the replacement of the usual W fasteners with highly elastic Loarv 300 fasteners to provide the track with elasticity and in that way reduce the ballast pressure. Similar to this an elastic underpad should be installed in case of rigid bridge underconstruction.

Picture 27: Prestressed concrete sleeper with elastic pad as seen on fro top and the bottom

Previous experience shows that for high-speed ballasted track the dynamic factor for static wheel force is 1, 8; where it is only 1, 5 for the ballastless track regardless of the traveling speed.

At these speeds a great disadvantage of traditional track structures was the heavy demand for maintenance, particularly surfacing (tamping) and lining to restore the desired track geometry and smoothness of vehicle running. Weakness of the sub grade and drainage deficiencies also leads to heavy maintenance costs. The thought was that this could be overcome by using ballastless track. In its simplest form this consists of a continuous slab of concrete (like a highway structure) with the rails supported directly on its upper surface (using a resilient pad).[45]

There are a number of proprietary systems variations include continuous in situ placing of a reinforced concrete slab, or alternatively the use of pre-cast pre-stressed concrete units lay on a base layer. Many permutations of design have been put forward and all of these will be furthermore elaborated in chapter 5.

However ballastless track is very expensive in first cost and in the case of existing railroads requires closure of the route for a somewhat long period. Its whole life cost can be lower because of the great reduction in maintenance requirement. Ballastless track is usually considered for new very high speed or very high loading routes, tunnels and bridges, or for localized replacement in the case of exceptional maintenance difficulties. At early stages of development the tested ballastless solutions were 2-3 times more expensive than the ballast track, where the track fasteners were up to 6 times as expensive as the ones for ballast track.

At first ballastless track was built in tunnels and on the bridges so that the track height could be kept low.[46] In this way the track height was reduced to 20 -35 cm, long support spans on viaducts were enabled and heavy maintenance was no longer necessary.

[45] http://en.wikipedia.org/wiki/Rail_tracks, accessed March 8th 2010
[46] Birmann, F. „Schwellen- und bettungsloser Oberbau“, ETR August 1969

Although the ballastless track offered a good solution for a railway with low maintenance a significant problem was the question of the future-needed maintenance technique.

All of these factors and influences can be differently understood and interpreted. Where one advocate the conventional ballast track and interpret its operational deformation as an advance explaining how ballasts loose structure provides better conditions for track maintenance, others claim that that same loose structure causes deterioration of the track geometry and lack of stability needed for high-speed tracks. It is certain that ballast provides some advantages. The ballast can be recycled, which in modern times is a valuable characteristic. There is only so much material and environmental pollution allowed. In speeds of 250 km/h and 300 km/h ballast track can bear a 225 kN and 170 kN of wheel load respectively and still be economical and technically operative. So as shown it is not only the speed but also the load and type of transport (freight, passenger, etc) applied to the track that determines the lifespan and deterioration of the ballast track. S.N.C.F. and its high-speed railway TGV proved that it is possible to have a high-speed ballast track, however with frequent maintenance, tamping, preventive controlling of track geometry, high quality drainage and if needed the improvement of the sub-soil. [47]

Another "example for the adaptation of ballasted track to the requirements of high-speed rail traffic is a very heavy ballasted superstructure installed in certain sections along the high-speed line from Hanover to Berlin. This track features use of the B 75 prestressed concrete sleeper, 2,80 m long, with the highly elastic Vossloh 300 rail fastening, as also known in work with ballastless track. The static spring stiffness of the support point is 27 kN/mm. In addition, the thickness of the ballast bed was increased to 40 cm, in order to create sufficient room for the fine rock particle produced by train operations and maintenance work. Experience gained on this line to date have confirmed the effectiveness of this solution: the stability of the track geometry from Hanover to Berlin is outstanding."[48].

What often is stated as a disadvantage of the ballast track is nowadays not so complicated and expensive as it was a couple of decades ago. The track maintenance technology has progressed and developed so much that maintenance can be performed within hours, at relatively high speed and at reasonable costs (annual track maintenance costs are 17% of total costs[49])

However the ballast track also has its disadvantages. One of the disadvantages was the mean variation of the wheel load, where this variation was as low as 8% in the ballastless track.

[47] Gerlach, A.; Köhler, M.; Beckedahl, H.; Hothan, J. „Zur Eignung des Schotteroberbaues für die Neubaustrecken der Deutschen Bundesbahn"
[48] Bachmann, H.; Lay, E.; Huesmann, H. „Requirementes met by Advanced Railway Track Systems: Maintenance and Cost Effectiveness", RTR Special, 2007
[49] As concluded by A.O.Prof. Dr. Tech. Peter Veit

Another ecological problem that occurs nowadays in ballast track is the chemical prevention of the plant growth. Use of herbicides is forbidden and thermal plant treatment is difficult, expensive and time consuming. After a certain period of time the ballast becomes so polluted, either due to herbicides or the vegetation, that a more often track cleaning is needed, which causes a growth in track maintenance costs.

There are also supporters of the idea of the ballastless track that find that its almost perfect geometry and low maintenance of the ballastless track justify initially high costs. They also state other numerous advantages such as a possible use of eddy current brake, a possibility to follow states high-way alignment and in that way reduce noise level (that in this case would be only up to 3 dB higher than the one caused by high-way) and most importantly ballastless tracks long lifespan.

At this point ballastless track has been in use for about 40 years so it cannot be said with certainty if its lifespan will truly be 60years.

The advantages and disadvantages of the both systems will be listed below for a better overview.

Advantages of ballast track:

- Low initial costs- highly economical
- Easy technical adjustment and maintenance
- Since decades in use and proven to function
- Low noise emission

Disadvantages of the ballast track are:

- “floating” track position in loose ballast
- Needs regular Maintenance
- Growing ballast pressure by rigid subsoil
- Growing vibrating at high speeds
- Chemical plant removal needed

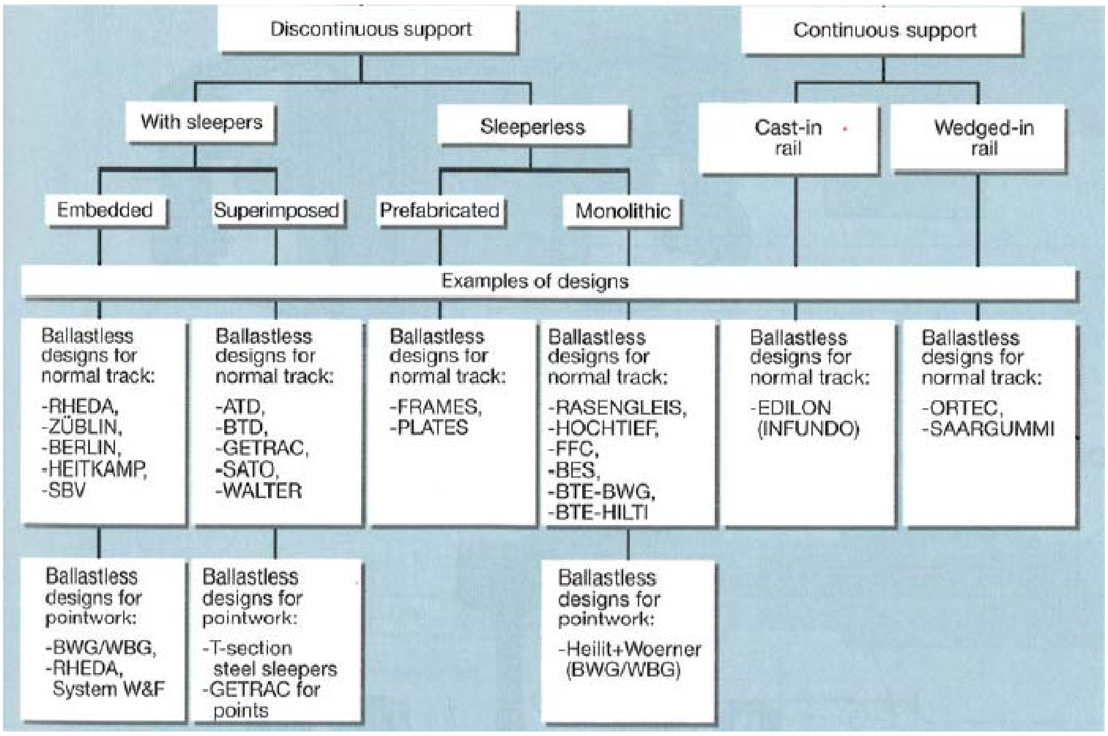
Advantages of ballastless track:

- Low maintenance
- Low built-in height
- Big security redundancy
- small alignment parameter possible
- use of eddy-current break possible
- no ballast whirl
- open for emergency car and trucks traffic
- no herbicide plant deduction necessary

Disadvantages of the ballastless track are:

- High initial costs
- Higher maintenance effort needed
- Needs additional absorption coating
- Difficulties at easily settled grounds
- Difficulties in need of renewal or maintenance

Important to mention is also the development of the frame sleepers- an alternative solution that combines both of these systems. It offers a lower price than by ballastless track but higher stability and lower maintenance need than the ballasted track. This system offers numerous possibilities and while the two main currents debate about ballast and ballastless track, the frame sleepers could become a silent winner and solution to the problems to both systems. Therefore the frame sleepers will be furthermore elaborated in chapter 9.



Picture 28: The various layers of the different types of ballastless track[50]

[50] Darr, E. "Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison", RTR March/April 2000

4. Development of ballastless track

“In the wheel-rail system, rolling stock and the track continuously interact. The characteristics of the track essentially determine the quality and the productivity of the overall system. For all rolling stock, the track must enable safe traffic operations within the context defined track-geometry and maintenance conditions. The most recent decades have witnessed significant increase in operational speeds for freight and passenger trains, up to more than 300 km/h- with further increase being planned. In addition, axle loads of 22, 5 tones have become routine for freight trains in Europe, in Germany already up to 25 tons on a number of line sections. In other countries-including the USA, Canada and Australia- axle loads far above 30 tones are regularly experienced in operations. In addition to the increase in these parameters, the number of trains themselves has significantly risen. In Japan, high-speed lines are used by up to 300 trains per direction and per day. Intervals of less than 3 minutes between commuter trains in metropolis areas are no longer a rarity. That led to ballastless track, such as shown in picture xx, to become the norm for lines serving high-speed traffic”[51]

Picture 29: The new rail line between Nuremberg and Ingolstadt in Germany

Hence demands placed on a high performance railway infrastructure increased and ballasted track needed an alternative solution. Also due to a numerous research and tests made with ballast track in high-speed railway the conclusion was made that ballast track, highly sensitive to frequency, could be replaced by a heavier track with a bigger contact area between track and sleepers that is subsoil. Though ballast could be fastened to the track using securing cap and using a heavier track and the deterioration of the track position could be influenced in that way, it could not be eliminated in any other way than trough an implementing of the ballastless track.

[51] Bachmann, H.; Lay, E.; Huesmann, H. „Requirementes met by Advanced Railway Track Systems: Maintenance and Cost Effectiveness“, RTR Special, 2007

The first experiments with the ballastless track were made in USA already in 1909. Those experiments were made with both concrete and bituminous subsoil. Further development in this area was made in 1949 in UdSSR with the main goal of creating the track that could bear up to 100 million ton per year. Czech Republic developed a ballastless track with concrete plates on a 15 to 20 cm thick sand layer. Their conclusion was that if this new type of the track construction had a solid connection and transfer of forces with the subsoil it could be a perfect solution for high-speed railway with low maintenance and renewal costs.

Japan began with the experiments in 1924. In 1942 a alternative rail with wooden blocks in concrete bed were built in tunnels and in 1960 a 13,7 km long Hokuriko tunnel was built in this way, with satisfying results. A concrete blocks on a concrete base was a variation of the ballastless track that was built in Tahakara way. The installation work took 10 times as long as the installation of the ballast tracks so it was only performed in tunnels with stabile subsoil. General conclusion in Japan was that this type of railway needed lowering of the costs, shorter installation time and a possibility of the correction of positioning irregularity to be built in larger scale and be competitive to ballast track.

In the end of 1959ties and beginning of 1960ties the idea of ballastless track was widely developed and was being brought into realization. As already mentioned in chapter 3 at first ballastless track was built in tunnels and on the bridges so that the track height could be kept low.[52] In this way the track height was reduced to 20 -35 cm, long support spans on viaducts were enabled and heavy maintenance was no longer necessary.

In 1970ties Japan decides to switch the Tokaido line connecting Osaka and Tokio from the ballasted to ballastless system, since the maintenance work became so extensive that it was no longer economical.

In 1986 the ballastless tracks were being built in Japan (1000 km two track concrete railroad). In 1984 due to the growing demands Germany decides to try to build other types of track as well. Until that point the maximum operating speed was 200 km/h, but has been raised to 250 km/h.

Recently Korea is building 200 km of ballastless track, China 1150 km and Taiwan about 500 km on the bridges, which shows the growth in popularity of ballastless track in Asia.

Since then Germany has produced little less than 1000 km of ballastless track and continues to produce it more and more. With 16 various types approved, 5 of them in use and another 11 in testing phase, 3 different construction systems Germany remains Europe´s biggest ballastless track producer.

[52] Birmann, F. „Schwellen- und bettungsloser Oberbau“, ETR August 1969

Ballastless track is to be recommended in the following cases:[53]

- In tunnels longer than 500 m since the maintenance work causes a lot of dust and lower visibility. Also a lower system thickness offers a lower breakthrough profile in the tunnel and therefore lowers costs

- At longer downward sections before the railway stations the ballastless track could be inevitable, because an Eddy current brake may have to be set in use, which would cause problems by ballasted track, due to the heat caused by putting the brakes on

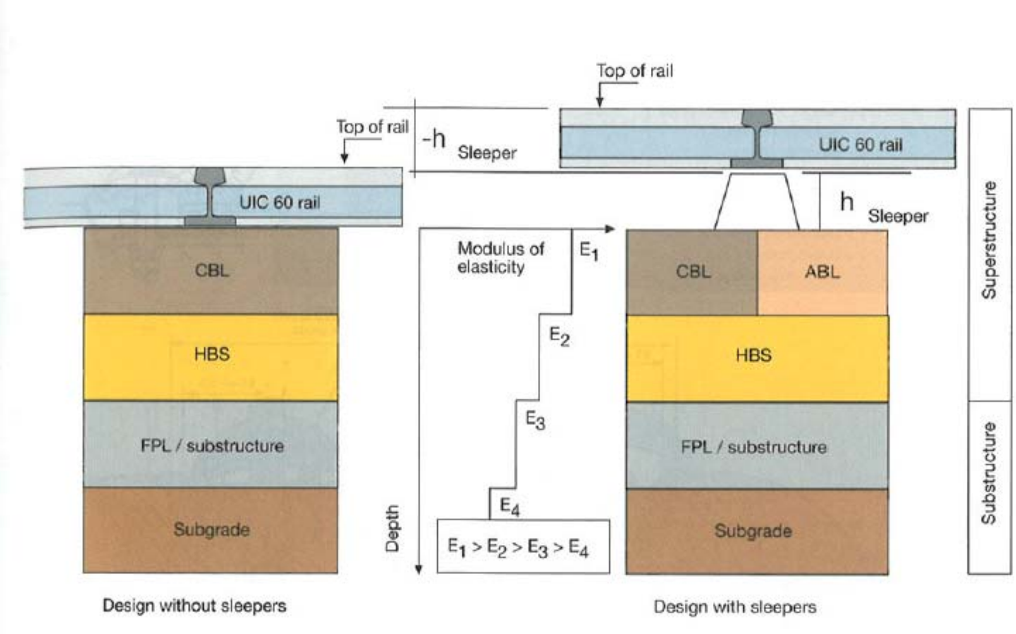
- In curves where allowed alignment is up to 25% higher than at ballasted track, which offers possibility of a higher speeds, smaller radiuses, etc.

- In case of firm, rock subsoil

[53] Oberweiler, G. „Die Feste Fahrbahn- eine Kritische Zwischenbilanz nach 30 Jahren Forschung, Entwicklung und Erfahrung“, ETR, January / February 2002

4.1. Demands on the Ballastless Track

"Ballastless track" is mounted on a material that provides more durable track-bed stability than ballast-typically concrete or asphalt. Now wheel-rail systems must have a certain degree of elasticity in their track, and the ballast itself can normally provide more or less all the elasticity that is needed. For ballastless track, elastic pads are inserted in the support assembly that holds the rails in place. These pads have an elasticity range of 22,5 +/- 2,5 kN/mm under a static axle load of 200 kN or 20 tons respectively. This helps each support to share the load exerted on its neighbors and reduces the dynamic forces. Ideally, ballastless track ought to be constructed on terrain with zero subsidence or, at the very least, minimal subsidence. As a general rule, that is the case for tunnels and bridges. Ballastless track constructed on earthworks needs to have frost-free, minimum-subsidence base underneath it. This means stiffness declining with depth through several layers in order as shown in picture 31.[54]



Picture 30: Various layers of ballasted and ballastless track[55]

[54] Darr, E. "Ballastless track: Design, Types, Track Stability, Maintenance and System Comparison", RTR March/ April 2000

[55] Darr, E. "Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison", RTR March/April 2000

Elastic underpads also offer a possibility of track alignment correction, when needed. A height correction of 30 mm, 26 mm upwards and 4 mm downward, is possible, and a side correction of 5 mm. Allowed correction is 10 mm in height and 1 mm to the side.

As already mentioned firstly ballastless tracks in Europe appeared in 1970ties. To be precise in 1972 the Technical University in Munich replaced ballast with concrete track base. One time the exact track height and transversal alignment was created by inserting a wooden wedge which 30 years after the installation is still intact. First ballastless systems such as Rheda were monolithic, but proved to be very difficult when it came to additionally correcting the track position, and track renewal was virtually impossible. This fact led to development of new systems so called superposed system that had separated layers of track, which allowed easier maintenance and eventual renewal.

After working on concrete systems, the asphalt was also used at ATD system that offered precise installation up to +/- 2 mm in height positioning.

Even though bridges and tunnels offer settlement-free subsoil special precaution is needed at bridges, because the bridges have a special elastic, mobile structure that allows the bridge to tolerate temperature change. Therefore ballastless track needs special optimization and modification for the transition section from bridge to conventional subsoil Substructure needs to be specially compacted with inserted slow disks and ballastless track runs another 50 m after the bridge end where it then switches to ballasted track. Also at transitions from ballastless to ballasted track the stress on the ballast is vast which leads to instability in ballast track bed. To avoid track geometry deterioration, ballast can be glued together or additional rails can be installed to take the stress of the ballast.

An important factor that needs to be considered by ballastless track is space for the installation of the signaling and electrical devices. This is easy installed in ballasted track but can cause problems in ballastless track. That means that signaling and electrical line planning needs to be done, even before ballastless track is being laid and built.[56]

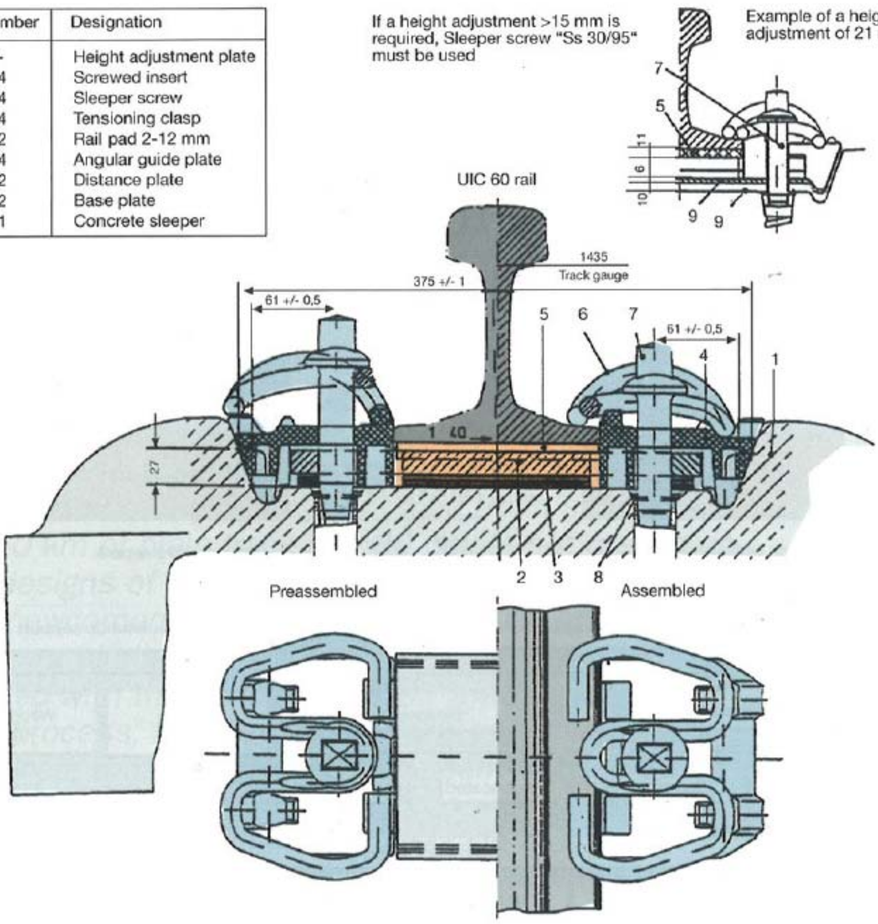
[56] Darr, E.; Fiebig, W. “Stand der Entwicklung und des Einbaus der Festen Fahrbahn”, ZET+DEV Glas.Annale, April 1996

4. 2 Construction

The initial construction of the ballastless track was monolithic and so compact that bigger track position correction was hard and track renewal almost impossible. That led to development of new types of ballastless track which had superposed structure and offered more flexible, maintainable solution.

When it comes to fastening usually used fasteners are type “300” (shown in picture 31) that offer possibility of additional positioning and alignment. Another advantage of the ballastless track is a usage of other types of trains such as ICE 3 that is highly resistant to wear and tear and has eddy-current break rail, possible to use without problems since ballastless track is not sensitive to temperature changes. In this case rails can also be welded at lower temperatures, which lead to smaller openings in the rail in case of damage.

Part no.	Number	Designation
9	-	Height adjustment plate
8	4	Screwed insert
7	4	Sleeper screw
6	4	Tensioning clasp
5	2	Rail pad 2-12 mm
4	4	Angular guide plate
3	2	Distance plate
2	2	Base plate
1	1	Concrete sleeper



Picture 31: The „300- Vossloh“ fastener[57]

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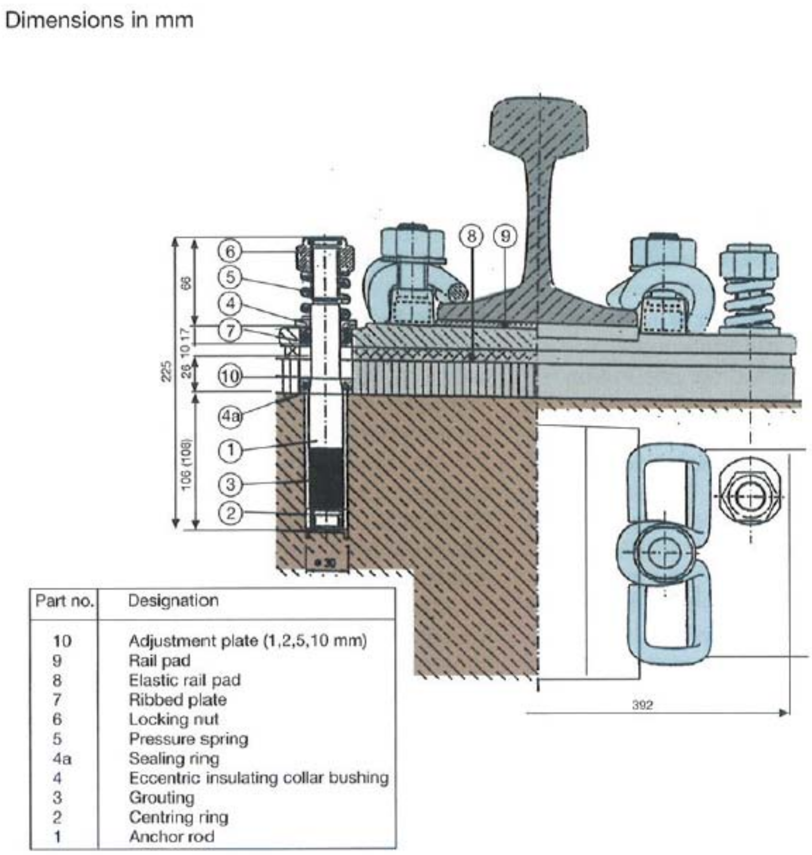
[57] Darr, E. “Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000



Part no.	Designation
10	Adjustment plate (1,2,5,10 mm)
9	Rail pad
8	Elastic rail pad
7	Ribbed plate
6	Locking nut
5	Pressure spring
4a	Sealing ring
4	Eccentric insulating collar bushing
3	Grouting
2	Centring ring
1	Anchor rod

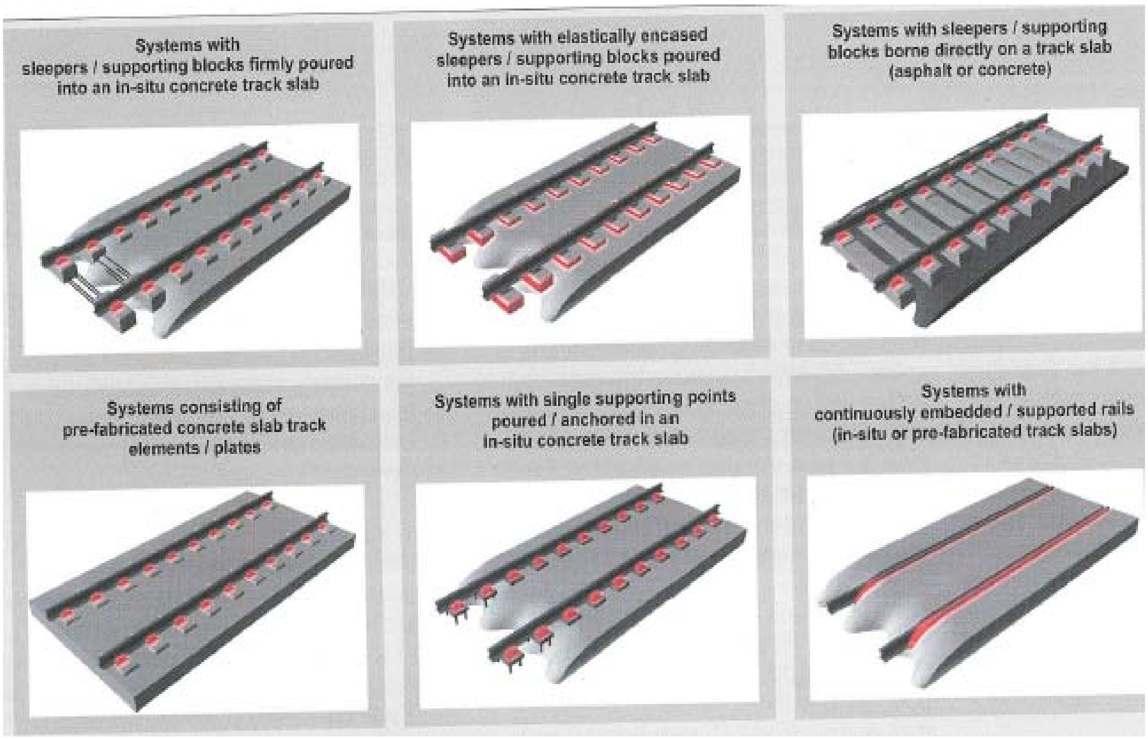
Picture 32: „336-Hilti“fastener[58]

Ballastless track allows more favorable longitudinal and especially transversal track elevation which offers the possibility of track alignment with radii down to 1000 m, following the highway routes.

The most frequently asked question is what type of slab track is the best. There is not ultimately best system, but there is the best system for given circumstances. In the variety of the systems the ones with pre-cast slabs or with sleepers fixed in in-situ concrete, or using individual rail support have prevailed. Other types have been used in much reduced volumes, or completely abandoned. The causes of this are not so much the functionality of the structure of the respective track type, but the speed, price and the quality of the execution. Many design types that have seemed to offer so much promise from their basic concept, lost ground because of poor construction quality and the resulting maintenance costs. In addition, there is still plenty of opportunity for error at the installation stage of the “established” systems, and this can easily negate the hoped-for goal of zero maintenance, undermining at the same time planned beneficial cost projections.[59]

[58] Darr, E. “Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000
[59] Schilder, R.; Diedrich, D. “Installation Quality of Slab Track-A decisive Factor for Maintenance”, RTR, Special 2007

Important factor for a ballastless track is a type of the subsoil. The importance and the role of subsoil have been explained in subchapter 2.3.6 for classic ballasted track, and since they are the same for ballastless track they will be no further explained.



Picture 33: Six ballastless types of structure[60]

Six of the most important ballastless systems will be mentioned here and explained in detail in the chapter 5.

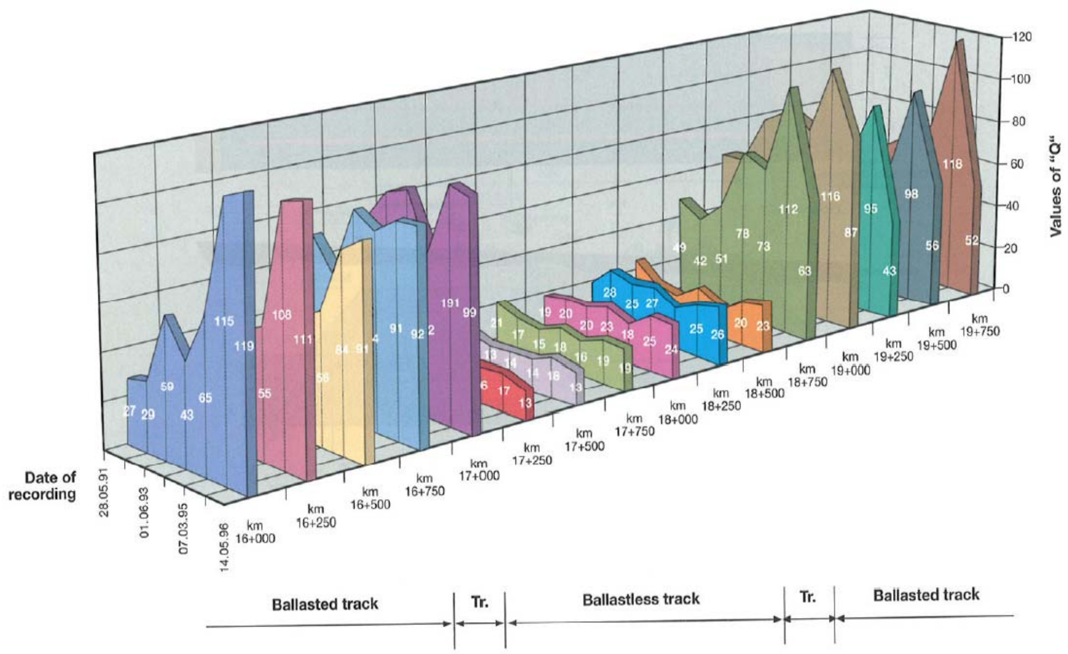
1. Systems with sleepers/supporting blocks firmly poured into an in-situ concrete track slab
2. Systems with elastically encased sleepers/supporting block poured into an in-situ concrete slab track
3. Systems with sleepers/supporting blocks borne directly on a track slab (asphalt or concrete)
4. Systems consisting of pre-fabricated concrete slab track elements/plates
5. Systems with single supporting points poured/anchored in an in-situ concrete track slab
6. Systems with continuously embedded/ supported rail (in-situ or pre-fabricated track slabs)

[60] Schilder, R.; Diedrich, D. “Installation Quality of Slab Track-A decisive Factor for Maintenance”, RTR, Special 2007

4.3. Maintenance and lifespan of the railway

While the German Railway (Deutsche Bahn) claims that ballastless track maintenance need only as 10% of ballast track maintenance, in north Japan in colder areas this percentage was up to 60% of the ballasted track maintenance. The reason for that is that the molten mortar sublayer was not resistant to freezing and needed over 100 km of renewal and replacement. Similar experience was also made in Karlsfeld, Germany or Friaul, Italy.[61]

“Impressive evidence of track-bed stability of ballastless track and the instability of ballasted track can be seen in the graphic representation of a computed track-alignment quality coefficient called “Q”. “Q” is derived from the geometric records of track alignment measured over many years by a self-propelled track measuring vehicle, working over sections of a ballastless track and the adjacent section of the ballasted track. The parameters that are used to establish “Q” are: longitudinal elevation, transverse elevation, direction and buckling. The higher the value of “Q”, the worse the alignment of the track bed is.



Picture 34: Alignment of ballastless track and adjacent sections of ballasted track [62]

[61] Oberweiler, G. „Die Feste Fahrbahn- eine Kritische Zwischenbilanz nach 30 Jahren Forschung, Entwicklung und Erfahrung“, ETR, January / February 2002

[62] Darr, E. “Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

Over the full five years for which such records were produced, the sections of ballastless track maintained the same high level of quality of track alignment. Over the same period, the sections of ballasted track deteriorated so far that the value of “Q” climbed to 100, which is regarded as the maximum acceptable limit. Sometimes it even exceeded 100.”[63]

Ballastless track needs as well as ballasted regular grinding of the rails and occasional changing of the elastic underpads.

The critical track load for ballastless track is 300 million ton. Lifespan of the ballast track with wooden sleepers is 25 years for sleepers, ballast and track. Ballasted track with concrete sleepers has 25 years for track and 40 years lifespan for the sleepers, and for the ballastless track it was up to 60 or 70 years, where 2 to 3 rail changing was needed.

However the predicted lifespan of 60 to 70 years for ballastless track cannot be confirmed or denied, since it has been just about 40 years since the implementation of ballastless track.

[63] Darr, E. „ Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

5. Types of Ballastless Track

All the various slab track systems can be divided in 3 main groups:

Monolithic systems- such as Rheda, Berlin, Züblin, Heitkampf, Holzmann, BES and Hochtief

Superposed systems- such as ATD, BTD, Walter, FFYS, GETRAC and others

Other systems

Though 16 types of ballastless track, 5 in use and 11 still in testing phase, have been developed some of them such as Rheda have been much more set in use compared to other systems. The total length of some of the most important systems (stand 1997) will be listed below:

- "Rheda" in 26 sections, total of 37 184 m
- "Züblin" in 4 sections, total of 17 329 m
- "ATD" in 4 sections, total of 17 338 m
- "Berlin" in 4 sections, total of 13 335 m
- "FFYS" in 5 sections, total of 32 300 m
- "Walter" in 2 sections, total of 9 400 m
- "BTD V1" in 1 section, total of 370 m
- "BTD V2" in 1 section, total of 120 m

Stated constructions and some developed and built after 1997 will be furthermore explained. With the exception of Rheda system, which was the product of DB, University Munich and construction companies, others are protected, private patents.

Some of them will be elaborated, and others, less used, just shown in picture to demonstrate the differences.

System Rheda

It is the “Rheda” model and its various further developments that are to be found most frequently in Deutsche Bahn´s tracks. It was made in Germany in Munich, by Technical University Munich, Prof. Eisenmann in cooperation with DB in 1972, year that could be marked as a birth year of the ballastless track, at least in Germany.

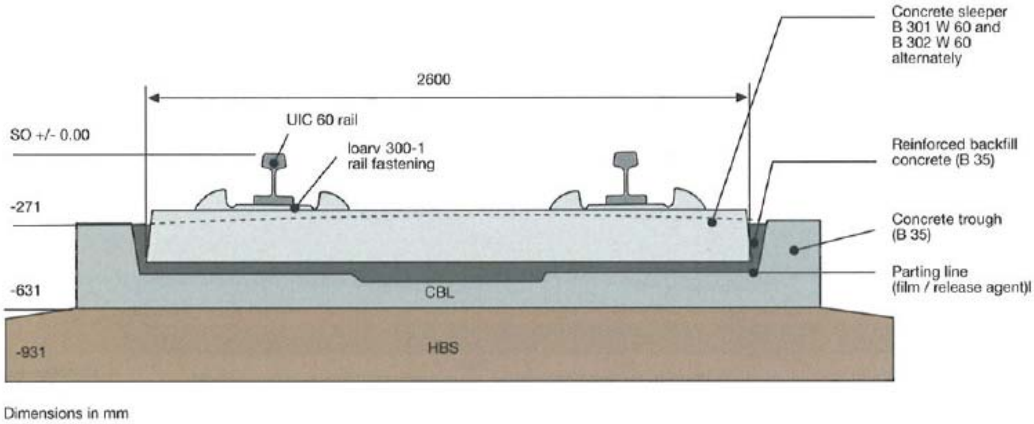
As already mentioned Rheda is a monolithic system. The concrete trough is first built and afterwards the rails are mounted and positioned on this concrete trough and molded with ca. 5 cm filling concrete. To overcome the looseness of the rail in concrete, steel reinforcement is placed in transversal and length direction. Rheda is made of 2,60 m long mono-block concrete sleepers, causing the total width of the system of 3,20 m.[64]

Since 1972 the Rheda type has been most used ballastless system in Germany and a lot of variations of Rheda system have occur. Some of those are Rheda-Sengeberg or Rheda 2000.

“The Rheda.Sengeberg system derives from the original method and consists of a concrete trough, made by means of sliding formwork, and a reinforced concrete slab placed into it. Integrated into the track slab are the prestressed concrete sleepers providing the rail seating. Specialized equipment was developed and employed for the rationalization of the concreting procedures, in particular a sensor-controlled apparatus for the largely automatic placing of the in-situ concrete of the track slab.”[65]

Picture 35: System Rheda

[64] Darr, E.; Fiebig, W. „Entwicklungstendenzen der Festen Fahrbahn“, ZET+DEV Glas.Ann, June 1998
[65] Hilliges, D.; Bittner, W. „Feste Fahrbahn/ Bauart Rheda-Sengeberg“, ETR, March 1990



Picture 36: System Rheda[66]

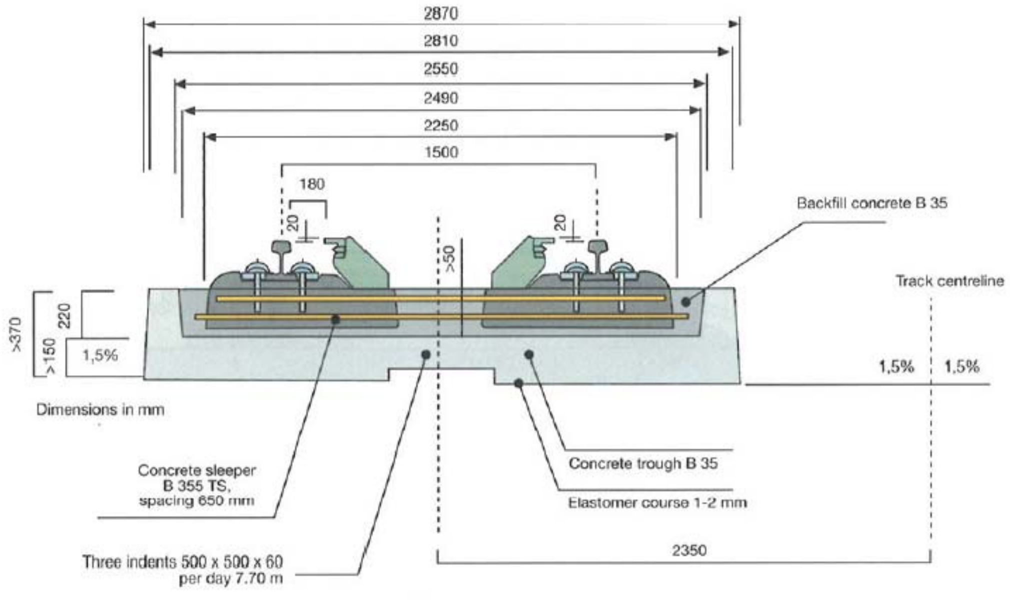
"Rheda 2000 was approved in July 2000 and the technical quality of this system is optimized by dispensing with the trough. The linking of the base plate reinforcement with the braced-girder dual-block sleepers, working together with the base plate concrete, meets the requirements set."[67]

Picture 37: Installation of the RHEDA 2000 ballastless track system[68]

[66] Darr, E. „ Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison", RTR March/April 2000
[67] Bachmann, H. "Rheda 2000- Erfahrungen aus Einbau und Verarbeitung"
[68] Freudenstein, S.; Silbermann, T. „Renewal of the Brandleite tunnel with GETRAC Ballastless Track System on Asphalt", RTR Special 2007

System Berlin

System Berlin, also called Rheda-Berlin opposite of Rheda has bi-block 2,25 long sleepers, and through that the track width can be reduced to 2,80 meters. The length reinforcement is not positioned beside of the track, but is instead it connects two sleeper blocks transversally.



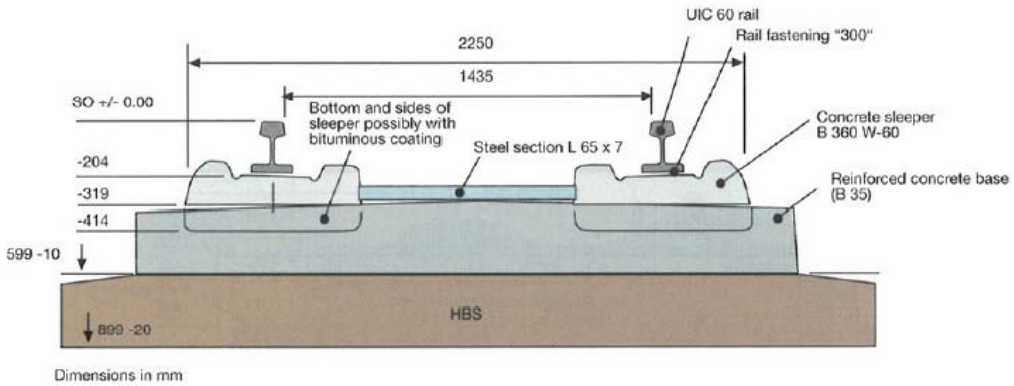
Picture 38: System Berlin

The positioning of the system is done by regulatory framework positioned under the rail itself. System Berlin has been used in Berlin subway in total length of 13 335 m.[69]

[69] Darr, E.; Fiebig, W. „Entwicklungstendenzen der Festen Fahrbahn“, ZET+DEV Glas.Ann, June 1998

Züblin

Opposite of Rheda system, Züblin system has concrete sleepers that are not molded but they are jolted instead. This system was developed and tested in 1977 in Munich in Nordring, and further set in use in 1991 on a Mannheim- Stuttgart line in a Markstein tunnel. The construction is similar to Rheda, but instead to position the concrete under and between the positioned rails, in Züblin the sleepers are to be installed in-situ concrete track slab. Hence the concrete consistence is to be chosen so that the sleepers do not move, because of their weight, after being installed.

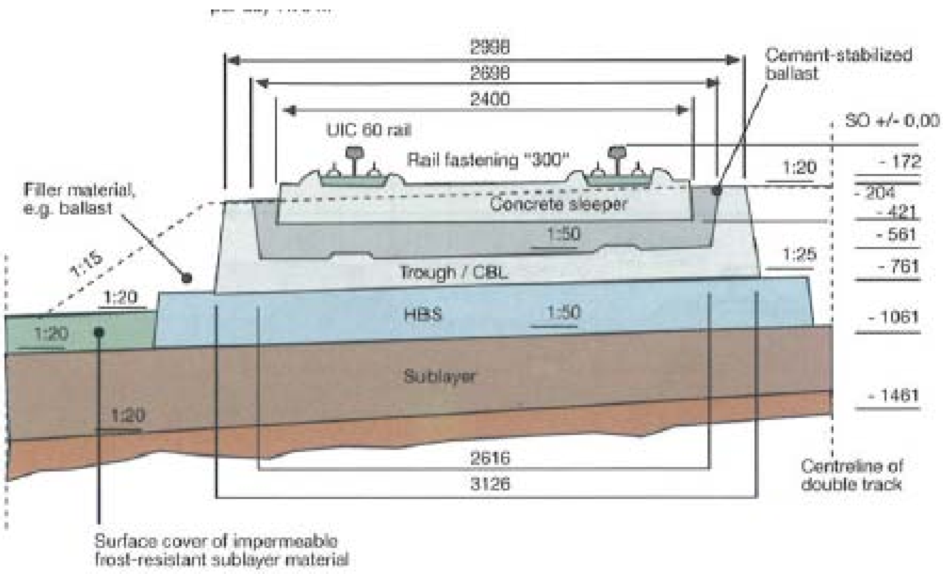


Picture 39: System Züblin

Picture 40: Track built in Züblin system

System Heitkamp

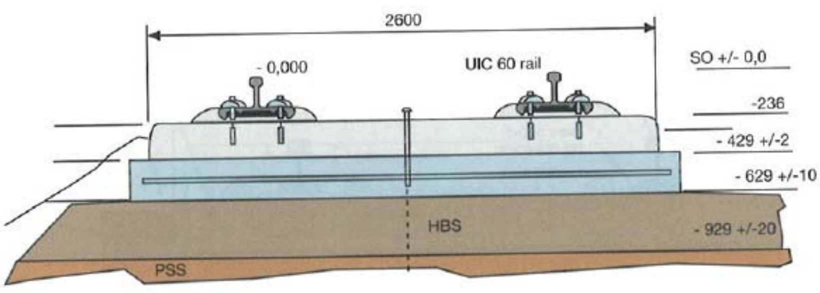
The system Heitkamp is a very similar to Rheda, but has a few changes, such as the type of concrete and positioning of the track, that are done differently.



Picture 41: System Heitkamp

System BTD

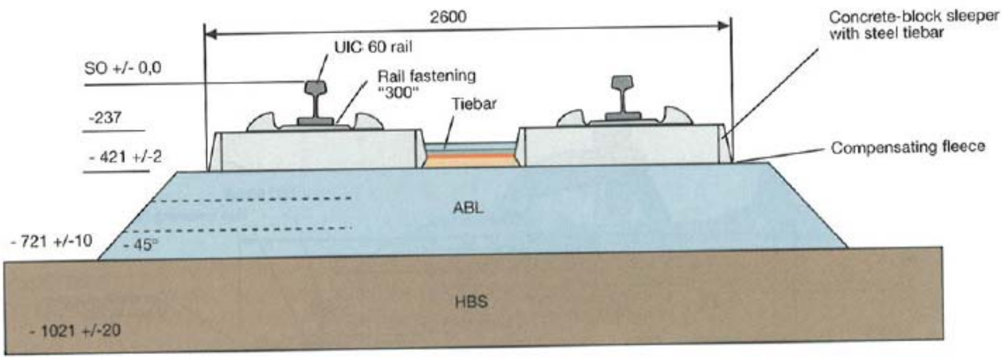
This system is one of the rare superposed systems done in concrete. System is built with a hole in the middle, where a bolt will be installed, connecting the sleeper with the concrete slab.



Picture 42: System BTD

System ATD

Pre-condition for this system is a precisely positioned asphalt boned layer, ABL. It can be built in mono or bi-block sleeper. A transversal mounting is connected to the sleepers an provides the track with horizontal stability.



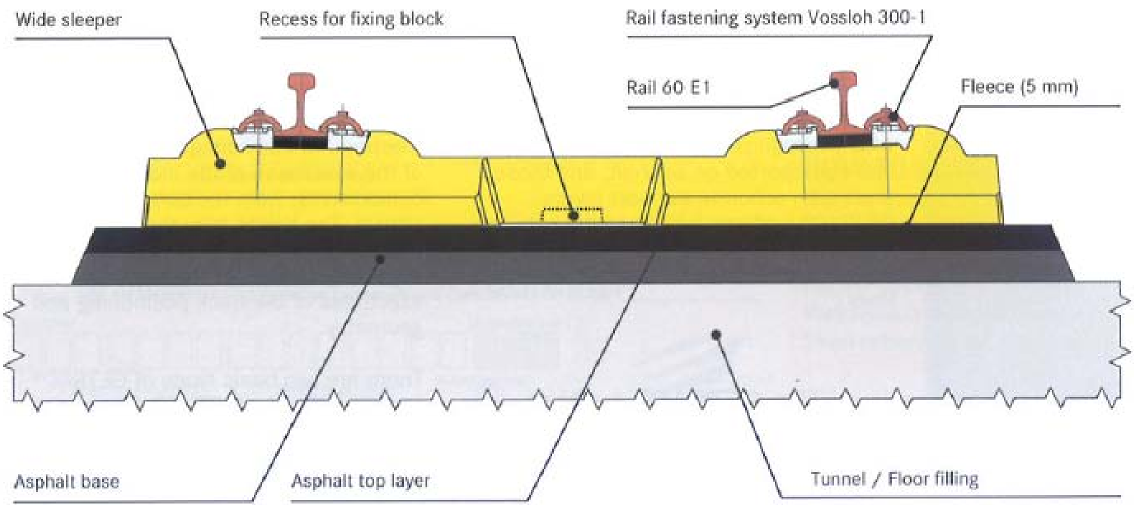
Picture 43: System ATD

GETRAC

"The system GETRAC is a ballastless track system of a slab track type consisting of an asphalt supporting layer on which the track panels directly rest. The sleepers are elastically connected to the asphalt layer by special high-strength concrete anchor blocks, which transfer the lateral and longitudinal forces from the track panel to the asphalt." There are a few GETRAC systems such as GETRAC A1, with classic 2, 60 meter sleepers, and GETRAC A3, with narrow 2, 40 meter sleepers that finds use especially in narrow tunnels.

Picture 44: The finished GETRAC A3 ballastless track system[70]

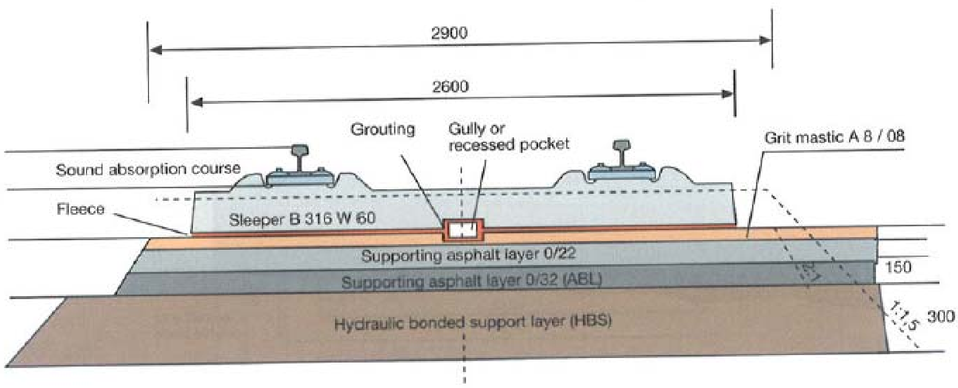
[70] Freudenstein, S.; Silbermann, T. „Renewal of the Brandleite tunnel with GETRAC Ballastless Track System on Asphalt", RTR Special 2007



Picture 45: Cross section of the GETRAC ballastless track system in tunnel[71]

GETRAC A1 was first built in 1994 on a high-speed line Hanover-Berlin on radii smaller than 600 m and with a 3,6 kilometer length. This was the first time that the hydraulic bonded separating layer was left out, through the raising the asphalt layer height. GETRAC system use mostly Ioarv 300-1 and Vossloh fasteners and offer a lot of advantages such as availability of the track right after the installation, accuracy of the track position and elevation, and use of techniques and machines used in road construction.

In 2004 the German Federal Bureau of Railways, EBA granted its approval for use of GETRAC system without speed limitations.

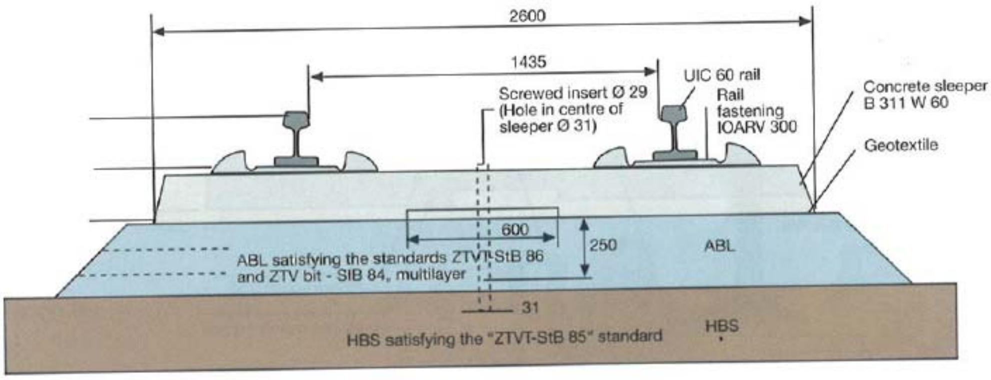


Picture 46: System GETRAC

[71] Freudenstein, S.; Silbermann, T. „Renewal of the Brandleite tunnel with GETRAC Ballastless Track System on Asphalt", RTR Special 2007

System Walter

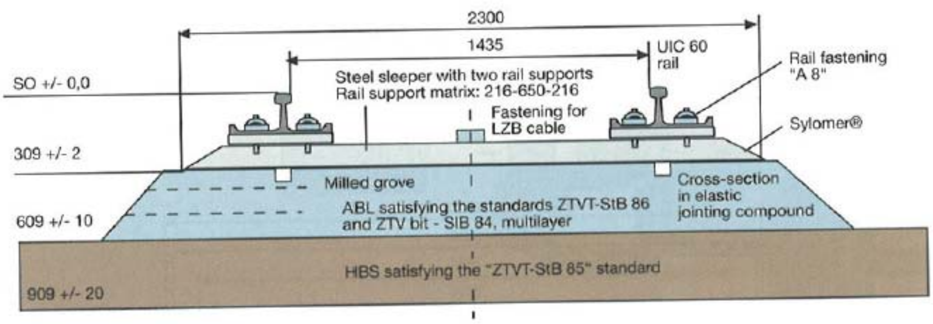
This is a system with an asphalt base, using the same construction as a BTD system, for connection between sleeper and track slab.



Picture 47: System Walter

System SATO

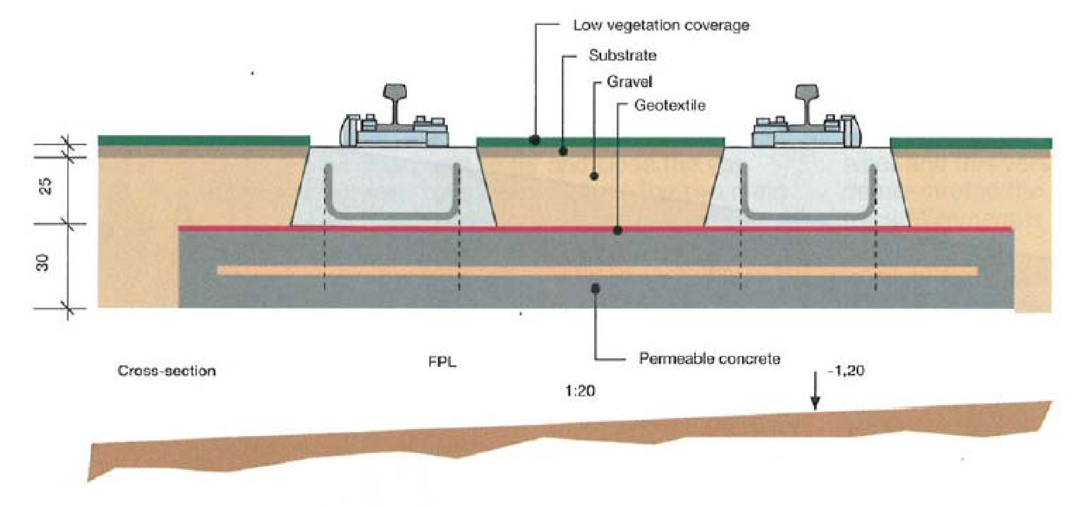
Four layers of asphalt are installed on a hydraulic bonded separating layer. Every other sleeper is connected with the concrete slab through an elastic rabbet. Correction of the track position is possible with the help of A 8 fateners.



Picture 48: System SATO

System Rasengleis

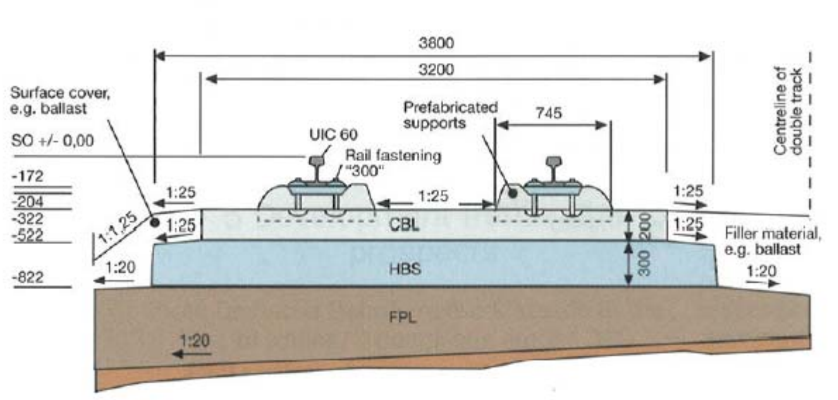
Instead of hydraulic bonded support layer, HBS, a drain concrete is built-in in the subsoil. As a support for the rails, there are two concrete length beams, connected to drain concrete. To provide transversal support a steel reinforcement is installed in drain concrete, in a 1 m distance. The fasteners used are type “336”, and provide a possibility for position correcting. Between length concrete beams the gravel is inserted serving as a suitable groundwork for the planted grass. In this way “Rasengleis” represents a ecologically friendly slab track.



Picture 49: System Rasengleis

System Hochtief

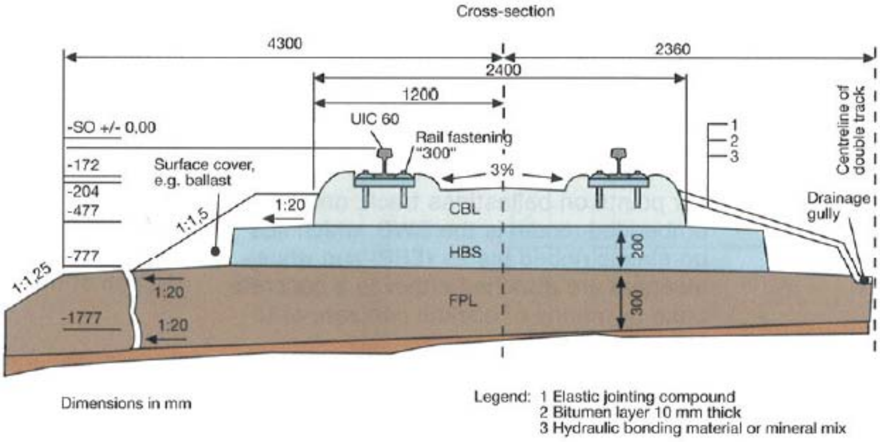
System Hochtief consist of 20 cm thick concrete slab with centered reinforcement, providing the resistance to building of the cracks. After installing the concrete, reinforced slab, the fasteners, usually type “300” are installed and adjusted to achieve the wanted track position.



Picture 50: System Hochtief

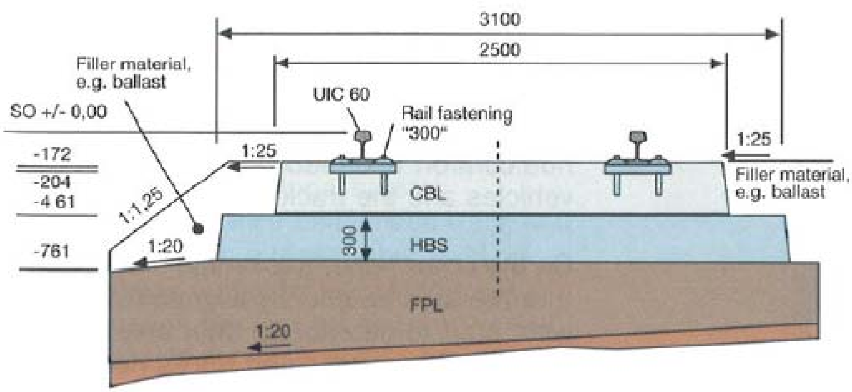
System FFC

System FFC is constructed as an infinite monolithic sleeper. Base is a hydraulic bonded separating layer, on which comes the concrete slab, with “300” fasteners, serving the possibility of position adjustment.



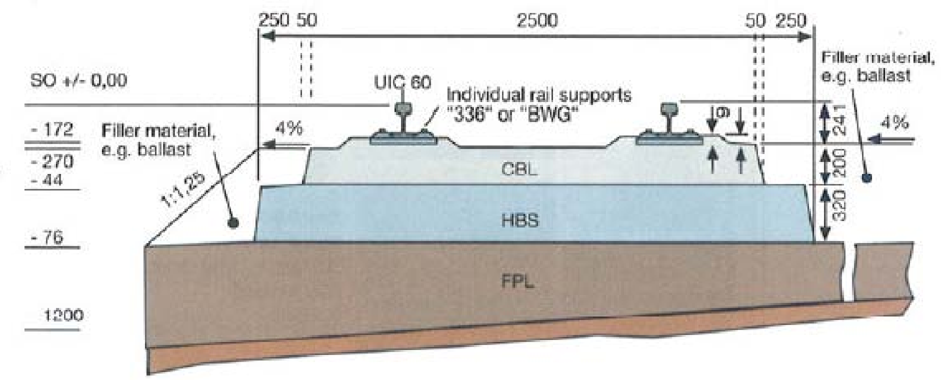
Picture 51: System FFC

System BES



Picture 52: System BES

BTE



Picture 53: System BTE

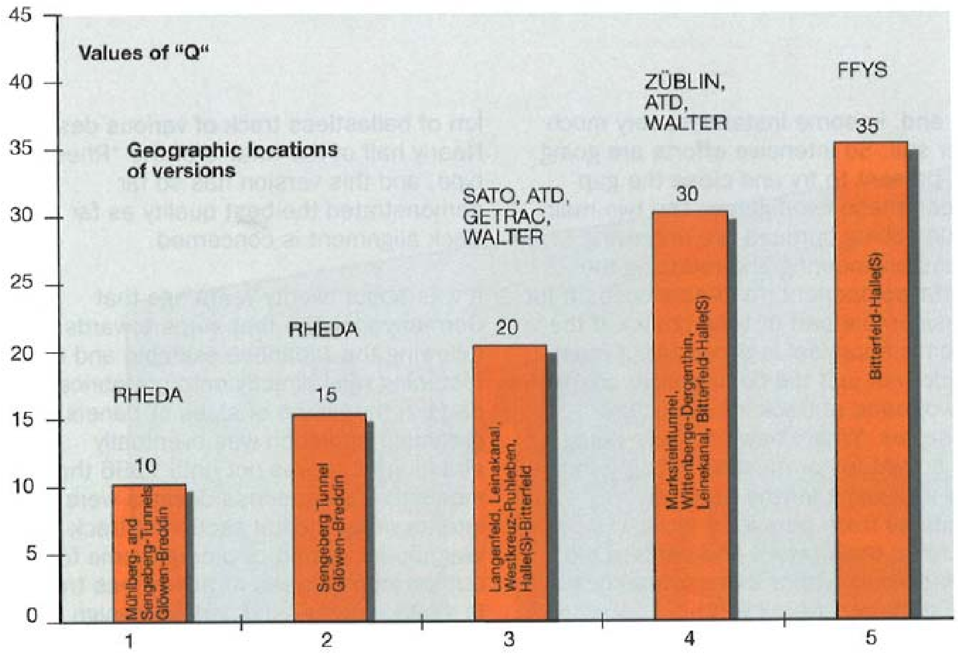
System Bögl

The Boegl permanent railway consists of 20 cm thick and 6,45 m long transverse, prestressed prefabricated slabs of steel fiber concrete B 55, which is produced in continually high quality at electronically controlled production facilities to be true to size. The slabs are coupled lengthwise with turnbuckles and underfilled following adjustment with bitumen cement mortar. The system is universally applicable for excavation work, in tunnels and on structures, integrated in testing segments in strait lengths, arcs and transition arcs.[72]

Picture 54: Bögl ballastless track in China[73]

[72] Holzinger, H.; Schreiner, U. "Feste Fahrbahn Bögl- ein universelles System", ETR, March 2001
[73] http://www.max-boegl.de/boeglnet/web/show.jsp?nodeId=1000494&lang=en, accessed March 19th, 2010

As already mentioned in 4.3 an alignment quality coefficient “Q” showed, also the quality of the track after some operational years. Following diagram has for a purpose to compare different slab track systems and their quality.



Picture 55: Comparison of the track alignment of the various design of ballastless track

6. Economic comparison of the two types

The diagram showed by Prof. Veitshould be shown to elaborate the costs of the ballast track: (Hauptleis in österreich)

In 100% of track costs 50% is capital depreciation, 33% is operation hindrance and 17% in maintenance.

“The first parameter to be established when making a “business case“ for ballastless track compared with ballasted track is derived from the high maintenance outlay for later. Secondly, however, the final outcome depends on the differences in the costs for original construction of ballastless track and ballasted track, which ought not to exceed a certain amount. This figure has been calculated to be around 30-40% and it is basically arrived at by taking the interest payable on the additional capital necessary to finance ballastless track and comparing it with a reasonable level of maintenance outlay for ballasted track. That situation has not yet been arrived at for the design currently most favored in Germany on account of the long, intensive experience with it, namely “Rheda”. Its initial costs are still 1,5 times that of comparable estimates for ballasted track and, in some instance, very much higher still. Intensive efforts are going on at present to try and close the gap between these two figures. The two main avenues being pursued are improving process engineering and reducing the material component (materials account for a considerable part of total costs). If the economic appraisal is complete, it must consider not just the comparative costs of the two forms of track infrastructure themselves. Where new lines are being built, a third factor must be brought in to make allowance for the fact that ballastless track permits more favorable track layout and permits the line to be built with a lower overall height and narrower overall width."[74]

The decision to built ballastless track is also a question of state railway politics. In some European states the state railway pays for the track, e.g. S.N.C.F in France or RENFE in Spain, and in others the state pays for the railway and the state railway pays for the maintenance, e.g. DB in Germany.

It is clear that in cases where state, for example Germany, pays for the railway the ballastless track is automatically preferred since it offers lower maintenance costs and longer lifespan, which is to be financed by DB. In others such as France or Spain all the factors are considered and ballastless track is principally evaluated as uneconomical.

Of course in case of tunnel or bridge where firm subsoil is firm and settlement- free, thus the subsoil does not require any preparation ballastless track is an obvious favorite since the costs of the superstructure are almost the same for the ballasted and ballastless track. In tunnels due to a great ballast rail underpads are prescribed which leads to higher railway costs, so the ballastless track is in this case the obvious choice.

It was always said that ballasted track is cheaper in initial costs and more expensive in maintenance than ballastless track. However it could never be confirmed, as there are various influences that determine the price, and every track is a case for itself. What can be done is to make a rating system based on Life Cycle Costs- LCC. With the help of this system, that regard various factors it can be said if the ballasted or ballastless track is in economical and technical sense the favorite. LCC system regards superstructure and subsoil costs, quality, availability and economics of the both track systems.

It has been determined that the costs for ballastless track are just about 5-6 % of the total costs of new rail infrastructure. A big difference between the two systems is that ballastless track needs subsoil preparation, to ensure resistance to settlement, which leads to higher costs. The ballastless structure itself is not much more expensive than the ballasted one.

Determining the total costs of the system are the number of bridges and tunnels, allowed and planned alignment of the track, allowed elevation and minimal curve

[74] Darr, E. „ Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

radii. To show influence of these parameters line alignment and costs for Stuttgart-Ulm will be calculated and compared by both systems. For the assessment will be used capital method, that says that higher initial costs are more unfavorable than higher later costs, since they do not earn interests. Planning will be calculated as 10% of total costs. Ballastless track is laid in tunnels, for both versions and the rest of the track is ballastless track compared to “UIC 60-B70-W60” or “UIC 60-B75-loarv300-63” ballasted track. Lifespan of ballasted track is assumed to be 40 years, with rail replacement and cleaning and supplementing of the ballast and for ballastless track lifespan of the 60 years with total track renewal is assumed, after 25 million ton of load per track and year. For this line a operational speed of 250 km/h, ballasted track needs track elevation of 130 mm, and a minimal radius of 3 700 m, since the tracks with mixed traffic are highly sensitive to different operational speeds. Ballastless track is planned to operate at 250 km/h as well, with minimal radius of 2 300 m and allowed track superelevation of 170 mm. Under these conditions ballastless track allows more favorable track alignment that is able to follow the state highway at higher speed than ballasted track. Ballasted track needs at allowed alignment higher percentage of tunnels and bridges which increases the costs significantly. However this grading system does not favor ballastless track. In the case of the Offenburg-Basel line with fewer tunnels and bridges and better track alignment, due to good topological and geographical conditions, ballasted track showed lower costs. Some uncertainties regarding costs for maintenance and ballastless track were noticed, but did not influence the total cost much. However the smallest change in track alignment could raise or lower the costs significantly.

An important and often forgotten factor for the costs of ballastless track is the length of the track itself. When longer than 300 km the total costs are 33% lower than by ballastless track shorter than 100 km. Travel comfort, the advantage of the ballastless track, cannot be monetarily estimated.

Finally, ballastless track is to be preferred by high-speed tracks with tighter curve radii that help reduce the number of tunnels and bridges and so reduce the total costs. If the total costs of the ballastless track amount more than 15% of the total ballasted track costs, the ballastless system is not to be recommended.[75]

[75] Huesmann, H.; Lay,E.;Bente, H.; Levkov, I. “Feste Fahrbahn und Schotteroberbau- Entwicklung eines Bewertungsverfahrens für NBS”, ETR March 2004

7. Opinions:

7.1. DB-Deutschland

Since 1965, Deutsche Bundesbahn (and new Deutsche Bahn AG) has accumulated vast experience with the operation and the maintenance of high-speed lines. Initially, these were lines that had been upgraded for 200 km/h. The travel speed was planned to go up to 250 km/h and eventually 300 km/h. These are the reasons that led to replace ballasted track with first experimental section of slab track back in 1972. The chosen location was Rheda station. Experience with this experimental track has been good right up to the present.

Given that the ballasted track on the first lines to be upgraded for 200 km/h had served its purpose well, Deutsche Bundesbahn decided to stick with ballast for its completely new lines, which have now been in service since 1991. After the first five years or so, it was realized that the track resting on its bed of ballast had insufficient elasticity. This had caused destruction of ballast under the concrete sleepers and the appearance of noticeable blemishes in the ballast bed as well as faults in the rails and an increasing noise level inside trains. This made it necessary to remove the stiff rail pads (500 kN/mm) and to replace them with more elastic ones (60 kN/mm). On the bridges matting was inserted under the ballast.

Changes were made in the rules defining the structure of ballasted track to be used on any high-speed sections to be constructed in future. Bigger and heavier sleepers with a larger contact surface were prescribed, softer pads were to be placed under the rails, and the ballast bed was to be thicker (35-39 cm to the lower face of the sleeper instead of 30 cm beforehand).

Over the past 35 years, Deutsche Bahn has forged ahead with the development of slab track and today has more than 50 sections of it in service in various parts of its network, comprised of a number of different models.

Taking Deutsche Bahn´s high-speed network as a whole, the high-speed Hamburg-Berlin and Hanover-Berlin lines already incorporate long sections of ballastless track. The high-speed line between Cologne and Frankfurt, which is only 100% passenger line in Germany, was built with slab track throughout. The Deutsche Bahn´s total length of slab track is little under 1 000 km therefore the biggest ballastless track network in Europe.

7.2 ÖBB Austria

The ballastless track in Austria is built almost exclusively in tunnels. Though it occupies the small percentage of the country´s railway a big importance has been laid on noise reduction. Therefore a project "Quiet Railway" has been developed, and as in Germany, a low-noise ballastless system has been set in use. The company PORR worked together with state railways ÖBB and developed a modified ballastless system with loosely reinforced, precasted plates, Loarv 300 fasteners and a separating layer with modified mortar and a polyurethane foil.

Regarding the noise the results of measuring on this kind of system showed a reduction of the noise of about 3-4 dB compared to ballasted track. The special PORR/ÖBB ballastless track system has been set to use in Tauer tunnel- 4 km, Galgenberg tunnel-12 km, Römberg tunnel and in various different tunnels and bridges.

This comes to show that in Austria the ecological, economical and constructive factor of a railway track are highly considered.

7.3 Schweizerische Bundesbahnen SBB,Schweiz

To establish whether the ballastless track is advantageous for the SBB railways a assessment of the situation was carried out. In this assessment the following factors were considered: investments, type of traffic and maintenance. When built the product stays in the track system for years even decades, so the Life-Cycle Costs (LCC) were also taken into consideration. Except in tunnels where the ballastless track is almost always clearly the best choice, other tracks are to be constructed in usual, well-known ballasted construction.

"The outcome of the investigation carried out by the Swiss Federal railways is that today´s familiar forms of slab track are too inflexible for the conditions prevailing in Switzerland for open-air use on top of earth structures, that there are high latent risks, and that the existing systems are too expensive (measured in terms of life-cycle costs). The life-cycle labor time for laying and maintaining slab track has been found to be significantly higher. These conclusions do not, however, rule out slab track altogether. On a case-by-case basis, the technology may be considered for new or upgraded lines where improving travel times over selected sections could be in the interests or an overriding timetable concept."[76]

[76] Steinegger, R.; Langt, T.P.; Güldenapfel, P.; Ablinger, P. „Systementscheidung Feste Fahrbahn versus Schotteroberbau für die Schweizerishe Bundesbahn", ETR, June 2005

Also a study about advantages and disadvantages of the use of ballastless track in Switzerland was made by TU Graz and showed that the soil in Switzerland is not suitable for the use of ballastless track due to a humidity of the soil.

7.4 Network rail, National Rail and Freightliner& EWS, United Kingdom

UK has very complex safety requirements and does not easily apply new system. Regarding the ballastless system, in 2005 it was only applied where structure gauge clearance issues dictated that it was only viable solution. In addition to common and know disadvantages of the ballastless track (as stated in chapters 3 and 4) the UK also has a disadvantage of a humid soil, that is not compatible and favorable for the ballastless track.

This type of track is used rarely and only as an exception. Some of the examples where ballastless track was built in UK are in Hibel and Prestbury tunnels, a part Kidsgrove line, Ipswich tunnel and the Channel tunnel. Almost every of these constructions were in Rheda system and with Vossloh fasteners. The track in St. Pancras international station is a slab construction, as well, and is built on a slender concrete viaduct. The track system is noise reducing system Pandrol Vanguard.

Obviously UK tends to use ballastless track system in tunnels, viaducts and train station, where its advantages and the security of the system has already been proven.[77]

7.5 J.R Japan

Outside of Europe the ballastless track is rarely in use. An exception to that is Japan and in newer days China and Taiwan. In Japan seven privatized railway companies have already built over 2500 km of ballastless track on Schinkansen lines.

Since Tokaido line in 1960 was built Japan began to build ballastless track, because the high-speed, frequently used lines such as Tokaido demanded often maintenance, when built as ballasted track. However they build ballastless track only when they have firm, rock subsoil and the total percentage of the ballastless track is estimated to be 30-40%. Turnouts, for example are almost always built as classical ballasted track.

[77] Bateman, D. „Non-ballasted track forms in the UK“, RTR, March 2005

Some of the Japan most important lines will be shown in percentage of ballasted and ballastless track:

- Tokaido, 1964: is a 1031 kilometer long ,100 % ballasted track with 47 % of artificial constructions, such as tunnels and bridges
- Sanyo I, 1973: is a 326 kilometers long, 95% ballasted track and 5% ballastless track, with 93 % of artificial constructions, such as tunnels and bridges
- Sanyo II, 1974: is a 782 kilometer long, 32% ballasted and 68% ballastless track, with 86% of artificial constructions such as tunnels and bridges
- Joetsu, 1982: is a 539 kilometer long, 5% ballasted and 95% ballastless line, with 100% of artificial constructions, such as tunnels and bridges
- Tohoku, 1982: is a 931 kilometer long, 10% ballasted line and 90% ballastless line, with 94% of artificial constructions, such as tunnels and bridges
- Ohmiya-Ueno, 1985: is a 54 kilometer long, 100% ballastless line, with 100% of artificial constructions, such as tunnels and bridges

7.6 Other European countries

In other European countries such as France, Spain and Italy, ballastless track is rarely in use. A good example of implementation of ballasted track for high-speed lines is France and its SNCF and TGV lines. In fact world record of 574, 8 km/h in train speed has been set by French TGV on ballasted track. They rarely build ballastless track, except in tunnels or on bridges.

Italy use to build ballastless track, but after a bad experience, such as the one in Friaul, the most of the ballastless track has been de-installed. FS, Italy´s state railway, has also evaluated the ballastless track as too expensive for their conditions.

Spain and its state railway RENFE also tend to build ballasted track as in addition to everything they would have to finance the ballastless track, which they find too expensive. On the Madrid-Barcelona line so called “hanging canals” and a vast lateral movement occurred, and though the ballast has moved, the track stayed in place, which would not be the case with the ballastless track.

8. Ecological aspects

European countries, such as France, Germany and Switzerland, have set the laws already in 1980ties that prescribe re-use and recycling of track material and proper waste disposal, and especially consideration of the ecological aspects that follow the railway, e.g. noise reduction, sustainability of ballast material, recycling and other ecological aspects. Ecological aspects do favor the ballasted system since it offers the possibility of recycling, re-use of the materials and lower noise. Some of these aspects will be furthermore elaborated in following subchapters.

8.1 Recycling of the ballast material

In 1992 at UNO conference for environmental protection in Rio de Janeiro a concept of “sustainable development” was discussed. An expression “sustainable development” comes from forestry and means that satisfying the needs of this generation is not to disturb and endanger possible satisfaction of the needs of the next generations. There are 3 aspects of sustainable development: economy, ecology and society.

Ultimately all guidelines prescribe recycling and re-use of the track ballast. In some parts of the track such as train stations or parking spots for locomotives, the ballast tends to be more damaged then in others. Though such ballast appears in certain section the total percentage of it is not high. There is an efficient way to separate this kind of ballast from the other with the Plasser & Theurer Jumbo VM 170 (picture 56).

Picture 56: Jumbo VM 170 from Plasser & Theurer

There are different types of ballast pollution that need different ways of cleaning procedures such as:

- Mechanical cleaning
- Washing of the ballast
- Biological cleaning
- Chemical treatment
- Thermal treatment

Main factor for the choice of treatment is the economy, which includes the transport, treatment, recovery and disposal of ballast. Most economical solution is the mechanical sieving of the ballast eventually in combination with one of the treatments above.

To show the economical and ecological aspect and value of re-use of ballast some of the ballast consumption in European countries will be stated:

- Germany 4 000 tons/year

- Austria about 500 000 to 700 000 tons/years

- Switzerland with about 595 000 tons/ year

When considered that the price for new ballast is about 10 €/ton it is clear that existing ballast needs to be re-used.

Other costs that need to be considered are those of disposing the ballast on landfills. It costs about 60 € per ton depending on ballast pollution and landfill type. Compared to this costs, the cost of wet treatment and re-use of the ballast including the transport are 30 € per m³ that is per 1, 7 ton. It is clear that it is not only ecologically, but also economically reasonable to re-use the existing ballast.

When it comes to ballast treatment, it can be done by trucks or railway machines. The trucks cause air pollution through carbon dioxide emission and therefore ecological damage. In addition transport costs amount up to 60 % of the total costs. If done on-rail by rail machines, that are highly mechanized and modernized there will be no carbon dioxide pollution, soil damage due to trucks and no track closure. Usually the ballast is lifted and washed by these machines and in this way freed of the fines that cause track deterioration.[78]

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[78] Becker, R.; Vierlinger, P. “Nachhaltiges Wirtschaften durch gleisgebundenes Schotterrecycling“, Eisenbahningenieur June 2006

Picture 57: Washing of the polluted ballast

SNCF one of the biggest railway companies in Europe re-uses the track ballast or sells it to be used for other purposes. SNCF is French state railway and France is known to have mainly ballasted track with 3 500 000 tons of new ballast used per year. They send about 20% of the ballast after washing and cleaning right back into the track and sell the rest to be used in road construction for example. Their measuring show that the ballast that laid for 27 years in the track bed had an LA value of 16 and Micro Deval value of 5,5 after the washing and preparation. Some of the high-speed lines of the class UIC 2 in France were renewed only with re-used ballast and show no deterioration. The future goal in France is to raise the percentage of the re-used ballast from 25% to 50 %.[79]

[79] Josse, F.; Hager, J.L. “Wiederverwendung von Altschotter”, Schienen der Welt, Juli /August 2000

8.2 Noise reduction

The question of noise reduction is active for ballasted track as well as for ballastless track. By ballastless track a common measures of noise reduction are the noise barriers or the elastic soling in the track.

The cause of frequencies by ballasted track is the “empty” space between the sleepers. At 100 km/h a frequency of 46 Hz was measured, and by 250 km/h it was raised up to 116 Hz. At the distance of 2, 5 m from the track, the sound measured at these frequencies was at its peak. It was noticeable that the higher the speed the more peaks appeared. In the case of ballasted track near the buildings with massive construction the noise reduction was possible by installing the elastic underpads. In the case of steel and wooden construction of the buildings the track needed to be constructed as mass-spring system.

Ballastless system shows a malus of 3 to 5 dB compared to ballasted system. In removing this malus either change in the system of the ballastless track needs to be made, or an effective rail grinding can be done as a very good maintenance for the track, but also as a measure of noise reduction.

New noise reducing systems of ballastless track, such as an acoustically innovative ballastless track (AIFF), have been developed, mostly in Germany. The concept of this system is a track panel with damped and resiliently seated sleepers on a support plate, the whole acting as a structure-borne noise absorber. With the results of the simulations and the laboratory and prototype tests, the acoustic effectiveness and the suitability for the test running are shown. However this system also shows deficiencies in the geometrical precision of the concrete plate and needs correction in the track fasteners. Researching the new AIFF system it was noticed that the source of the noise by ballasted track is the wheel and by the ballastless track the source is the rail. [80]

Hence to reduce the noise in the ballastless track the rail needs to have a perfect geometry. Acoustic grinding smoothes out irregularities in the contact surface between the rail and wheel, reducing noise caused by rolling contact. Consequently noise produced is effectively cut off at the source. To mitigate the roiling noise effectively, the roughness of the rail should be reduced at certain wavelengths corresponding to acoustic frequencies that dominate the noise spectrum. Reducing the long wavelengths in rail roughness will reduce the low-frequency noise, whereas reducing the fine roughness will reduce the higher frequencies. With the help of the acoustic grinder HSL-Zuid the rail roughness can be reduced for wavelengths between 10 and 250 mm. Such acoustic grinding was carried out in Holland with great results, on Rheda 2000 NL ballastless track.[81]

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[80] Abbott, J. „Rail grinding and milling become precision arts“, European Railway Review, March 2004
[81] Kuijpers, A.; Schaffner, J.C.; Bekooy, M. „Griniding programme combines noise reduction and preventative maintenance“, Railway Gazette International, June 2006

Acoustic grinding carried out in accordance with prEN ISO 3095 contributes a reduction of the noise of about 3 dB. For high-speed lines, grinding methods that are now being developed and refined will permit a further reduction of noise emissions by 5 dB in the centimetric roughness spectrum and below.

8.3 Other ecological aspects

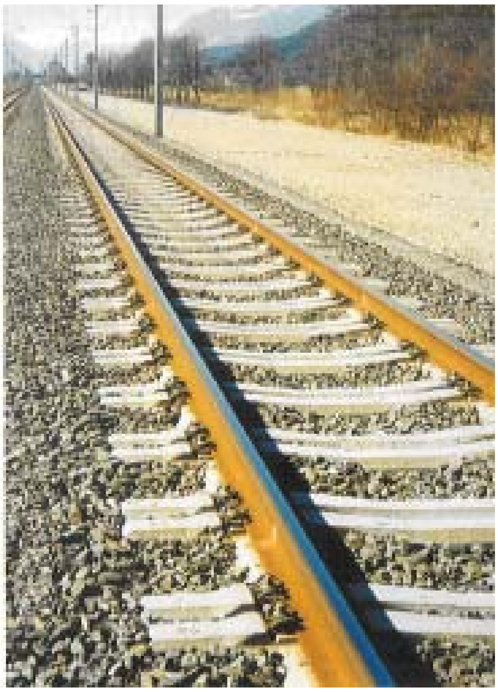
Noise barriers help reduce the noise caused by rolling contact in the track, but can cause worsening in drainage especially in case of improperly dumped waste.

Ecological problem that occurs nowadays in ballasted track is the chemical prevention of the plant growth. Use of herbicides is forbidden and thermal plant treatment is difficult and time consuming. After a certain period of time the ballast becomes so polluted, either due to herbicides or the vegetation, that a more often track cleaning is needed, which causes a growth in track maintenance costs.[82] However the concrete sleepers offer a great solution to avoid the use of herbicides, since the concrete is resistant to plant growth. To prevent the plant growth in the track bed itself, the ballast needs to be maintained and cleaned regularly. If so that the fines will not be developed in the track and in this way the plant growth will be disabled.

[82] Leykauf, G. “Trends bei Oberbausysteme für die Zukunft”, ZEV Rail, August 2000

9. Alternative: Frame Sleepers

Two classical railway solutions ballasted and ballastless track have already been elaborated. As shown both have advantages and disadvantages. Ballasted track is a well known standard solution with satisfying costs but often unsuitable for speeds higher than 250 km/h. Ballastless track has great track geometry and stability, but after its lifespan needs to be totally renewed and has high initial costs. Obviously “transition” solution between these two systems was needed. In Germany wide sleepers were researched, in Japan ladder sleepers, and for a short while “Ear” sleepers were developed in Austria, but quickly dismissed. What came to be the most advanced and most spread solution is the frame sleeper from Austria.



Picture 58: Frame sleeper on the ballast and on a straight line[83]

“Frame sleepers system consists of prestressed concrete elements in a double H-form that is laid side by side on a ballast bed and form a sleepering for a railway track. The through welded rail is supported quasi-continuously and between the elements forms a link that is vertically stiff to thrust and horizontally flexible to bending. The elastically seated sleeper panel spreads the forces in the style of a chain link drive and reduces both the pressure on the ballast and the pressure differences substantially.”[84]

Already in 1970 former USSR made a 550 m long experimental track section with frame sleepers. It had 2418 mm width, length-sleeper of 750 mm and total length of 2460 mm. One element was composed of five of these frame sleepers and weighted

[83] Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005
[84] Rießberger, K. “Das Rhamen-Schwellen-Gleis- ein inovatives Schottergleis”, ETR, March 2000

about 2 tons. An installation was no more complicated than the installation of the classic ballasted track with concrete sleepers. These experiments in USSR showed that the frame sleeper is much more stable than the classical transversal sleeper, and what was especially important low and uniform settlement of the track was to expect.

It was obvious that frame sleepers showed potential and needed to be researched furthermore. This development happened in Austria where a compromise between cross and length sleeper a prestressed concrete frame sleeper B 95 was developed. An almost continuous rail support is provided through a length sleeper member of 40 cm width connected to 2, 60 m long cross sleeper.

This type of sleepers was built in Austria for the first time in 1983 on an 400 m long experimental section on the Vienna Südbahnhof with daily load of 35 000 tons. This first experimental section already showed significantly smaller settlement than the ballasted track on the same section. The next section with frame sleepers in Austria was built in 1999 on two lines, where tamping machine and dynamic track stabilizator have already been set in use. Another testing section was built in July 2000, on Semmering line under extreme conditions with curve radiuses smaller than 200 m. Continuous welding of the rails on lines like this is very difficult. In this case at curves with radius of just 176 m the positioning of the UIC 60 rail was complicated but performed without any significant problems. Measuring showed that after a couple of months in use, vertical settlements were very small, and transversal movement was uniform and about 3 mm to the outer side of the track. [85]

For the required calculation for the frame sleeper an axle load of 25 ton was taken as a standard. As already mentioned a system consists of prestressed concrete profile with H-form with two prestressed wires connecting the frames in curves. There are only two fasteners on each side of the frame sleeper at distance of 2x 375 mm. These four fasteners, connected directly to the frame sleeper, provide a massive stiffening of the structure in the horizontal plane similar to a “Vierendeel beam”. However since the fasteners are rigid they require a softer, more elastic layer in between. Also the frame-sleeper-system needs elasticity which is most commonly provided with soiling of the sleeper itself.

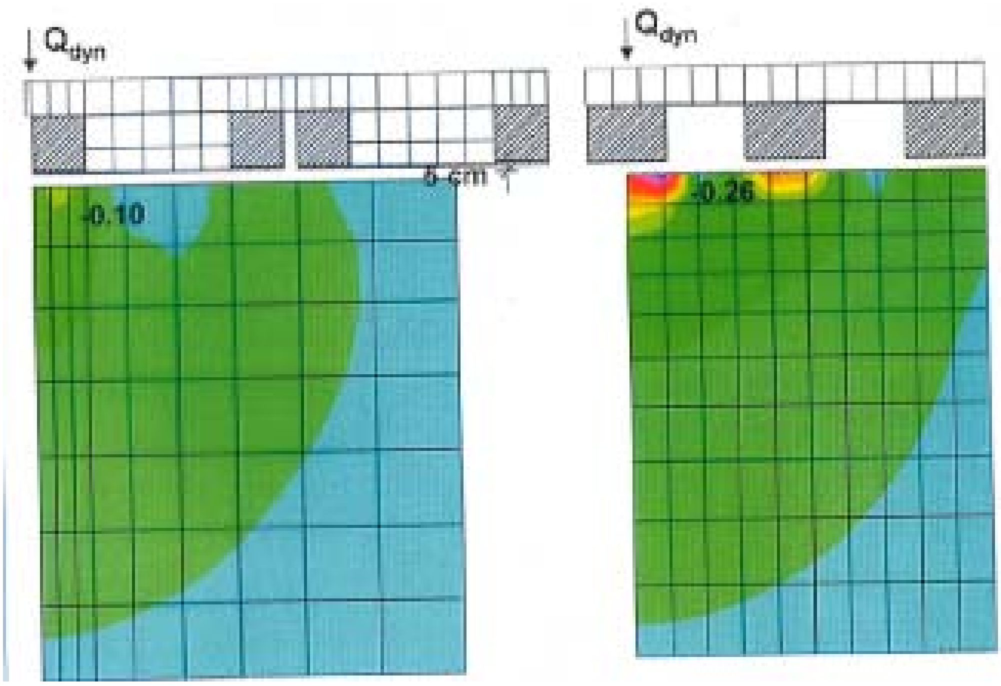
The soiling is made of 12 mm thick polyurethane plates that provide a sufficient contact to the concrete frame sleeper even without gluing them together. Also different soiling-plate thickness offers a variation of other application possibilities and could be modified for the different types of subsoil.

[85] Leykauf, G. “Trends bei Oberbausysteme für die Zukunft”, ZEV Rail, August 2000

Various advantages of the elastic soiling of the frame sleepers are:

- Reduction of the extreme local pressures
- Ensuring the track elasticity independently of ballast
- Equalizing the elasticity of sleepers
- Provides possibility of the lower track bed and leads to possible reduction of the total track costs
- Increase in contact area from maximal 12% without and to 30-36% with elastic soiling

The analysis of the track after the soiling has shown a great reduction of the stress and extortion of the ballast, and more importantly a more even distribution of the stress in the track bed.



Picture 59: Soil pressures in the upper layer of the substructure, left: on frame sleeper track, right: on conventional ballast track[86]

The four fasteners on the sleeper frame are responsible for a good resistance to buckling of the sleeper. This also enables a possible use of eddy current brake on the frame sleeper track. Another big advantage of the frame sleepers is an exact track positioning, resistance to cross movement and a simple handling, as in Japanese "Ladder Track".

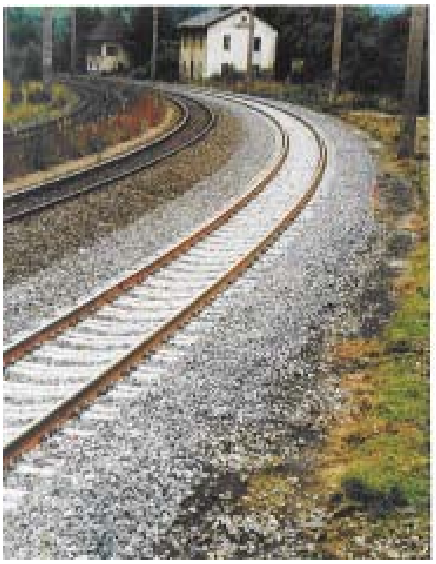
[86] Rießberger, K. „The project „Frame Sleeper Track"", ZEVrail special edition 2005

Frame sleepers need elastic under pads- a 12 mm thick polyurethane layer that is connected to the sleeper through fresh concrete. Through this a higher percentage of the contact area and a better distribution of the stress in the track are expected and a tilting of the sleeper is prohibited. It is important to coordinate the elasticity of the under pad and fastener to avoid secondary vibrations.

The total soil pressure by frame sleeper track is just 50-60% of the total pressure of the classical ballasted track with transversal sleepers, which leads to 8 times lower need for tamping. When it comes to noise, though conventional test trains were used, the frequencies were low and noise reduction was obvious.

Regarding the economics of this system it needs to be said that it has some higher initial costs then the classic ballasted track with transversal sleepers, but they are reduced during the tracks lifespan due to a lower maintenance, which leads to lower total costs of the frame sleeper compared to transversal ones. On an example of the Vienna-Salzburg line the economicalness of the frame-sleeper system is going to be shown. This line has 150 trains per day that travel at 200 km/h on it. An annual costs for a kilometer of transversal-sleeper track is 28 517€, where 60% is capital depreciation, 17% is traffic hindrance and 23% of the costs is maintenance. Annual costs for frame-sleeper system per kilometer would be 21 584 €, with 65% for capital depreciation, 17% for traffic hindrance and 18% for maintenance. As shown maintenance costs for frame sleepers would be 5% lower, this is caused by less frequent maintenance intervals. However maintenance for frame sleepers, though less frequent, demands rail grinding with every tamping in combination.

The financial advantage of the frame sleepers is reduced at lower traffic loads, but very good at high traffic loads and complicated track alignment such as the one at Semmering line. [87]

Picture 60: Frame sleepers in the curve and being installed[88]

[87] Rießberger, K. ´”Festere Fahrbahn auf Schotter”, ETR April 2002

As already mentioned the Semmering line represents extremely complicated line. For it the frame sleepers were adjusted and the original middle, single-layered steel reinforcement was doubled and moved from the middle, after which no problems were obvious in this section. This is also a great advantage of the frame-sleeper system that it can be adjusted to the needs of the specific line.

Though very similar to the transversal-sleeper system, frame-sleeper system is not the same. Hence special tests for the frame sleepers such as “Twist Test” or “Shear Test” were developed.

Summary of the advantages of the frame sleeper is going to be listed down[89]:

- All track geometries (short radii, transition curves and ramps, etc.) can be made
- Good tamping is possible
- An effective embedding in the ballast bed can be achieved using the DGS
- All known techniques of ballast bed cleaning can be applied
- Industrial production can be made in sleeper works including quality control
- This enables complete integration into the existing logistic structures and
- The slightly higher price is compensated by the longer durability of the track geometry which results in far lower life cycle costs (LCC)

Further trials are being set up in Switzerland and in Italy. In USA half frame sleepers are being used by Pacific Union. They were built in September 2009 and already show 6 times as lower need for maintenance, but predicted is that it is going to be as low as 8 times, compared to the ballast track.

Another development of alternative to classic ballasted track with transversal sleepers is RSZ, constructed and patented by Prof. Dr. Tech, Rießberger in Austria. This system has longitudinally positioned concrete blocks under the rails and between the sleepers, which offers better stability of the track and easy maintenance.

All in all developments and great progress are being made in the railway engineering, bringing us to a new, more modern era of the railways.

[88] Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005

[89] Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005

10. Summary

Throughout the world, the concrete sleeper is one of the technologically most mature products for all track and turnout areas of a rail network. Over the years the sleeper industry has optimized concrete mix formulations, production processes, standardization, as well as now extensively developed mechanization of installation and alternation process, especially with regard to maintenance on rail lines. In addition, specialist companies have further developed the product itself in its performance characteristics, especially with respect to load-bearing capabilities and effective accessories-such as elastic pads. Since concrete sleepers require no chemical treatment that could damage the environment, they are ecologically highly significant.

With its proven benefits, the classical ballasted track will, over the long term as well, remain the most extensively used basis for traditional areas of application in rail transport with moderate speeds and loads. Now, as before the concrete sleeper remains undisputed as an excellent solution: not only as a result of characteristics such as flexibility and degree of mechanization during installation and maintenance work- but also because it is by far the superior technology within the context of such work as renovation and upgrading of individual sections of rail line, and construction of provisional sections of track. However performance limits of ballasted track become obvious at speeds above 250 km/h. Fragments of ballast that are whirled through air by passing trains can lead to damages to rolling stock and to running surface of the rail. The track-geometry stability required for the use of eddy-current breaks furthermore makes additional measures necessary, or the implementation of especially difficult track-superstructure solutions. An increase in train speed is accompanied by disproportionately great increases in effective vertical vibration velocities in the ballast and in the substructure. These phenomena accelerate the process of track geometry impairment. To be sure, it is possible here to employ counteractive measures to enhance track-superstructure elasticity: but the consequences are considerably higher costs and increase in the space required for the track. These disadvantages more than outweigh the original cost benefits of ballasted track over ballastless solutions. As a result of these phenomena, the application of ballastless tracks for the new construction of high-speed rail lines over the past 10-15 years has developed from a customized design solution for niche applications (for example, in tunnels, on bridges, or in track sections near train station) to standard, end-to-end technology for superstructure solutions on lines with demanding requirements and high loads.[90]

As such structure it shows many advantages, undisputed track geometry and good behavior at high speeds, as well as promised long lifespan and low maintenance. However, true lifespan and renewal of the ballastless track still remain unknown.

[90] Bachmann, H.; Lay, E.; Huesmann, H. „Requirementes met by Advanced Railway Track Systems: Maintenance and Cost Effectiveness“, RTR Special, 2007

Significant economical and ecological disadvantages occur. Most European countries can and will not afford this type of track. Other do not have geological and geographical conditions needed for ballastless track.

Promising is the development of the frame sleeper system, that offers a great track geometry and stability, such as the ones by ballastless system, but also known and proved maintenance techniques and lower initial costs than the ballastless track.

As shown through this paper, railway has existed throughout the centuries, but the progress made in last 40 years, new systems and ideas being developed, new speed records being set show an increasing importance and potential and a promising, bright, new era of the railways.

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Picture 4-15: research of Florian Auer of ÖBB infrastructure

Picture 16-20: “Continuous action four-sleeper machine with integrated track stabilization”;

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Picture 27:“Prestressed concrete sleeper with elastic pad as seen on fro top and the bottom “;

Picture 28:” The various layers of the different types of ballastless track”; Darr, E. “Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

Picture 29: “The new rail line between Nuremberg and Ingolstadt in Germany”; Bachmann, H.; Lay, E.; Huesmann, H. „Requirementes met by Advanced Railway Track Systems: Maintenance and Cost Effectiveness“, RTR Special, 2007

Picture 30: “Various layers of ballasted and ballastless track”; Darr, E. “Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

Picture 31-32: „The „300- Vossloh“fastener “

„„336-Hilti“fastener“

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Picture 35: “System Rheda”

Picture 36:”System Rheda”; Darr, E. „ Ballastless Track: Design, Types, Track Stability, Maintenance and System Comparison“, RTR March/April 2000

Picture 37: “Installation of the RHEDA 2000 ballastless track system”; Freudenstein, S.; Silbermann, T. „Renewal of the Brandleite tunnel with GETRAC Ballastless Track System on Asphalt“, RTR Special 2007

Picture 38-39: “System Berlin”

“System Züblin”;

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Picture 40: “Track built in Züblin system”;

Picture 41-43: “System Heitkamp”

“System BTD”

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Picture 45: “Cross section of the GETRAC ballastless track system in tunnel”;Freudenstein, S.; Silbermann, T. „Renewal of the Brandleite tunnel with GETRAC Ballastless Track System on Asphalt“, RTR Special 2007

Picture 46-53: “System GETRAC”

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“System SATO”

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Picture 56: “Jumbo VM 170 from Plasser & Theurer”; Plasser& Theurer

Picture 57: “Washing of the polluted ballast”; Plasser&Theurer

Picture 58: “Frame sleeper on the ballast and on a straight line”; Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005

Picture 59: “Soil pressures in the upper layer of the substructure, left: on frame sleeper track, right: on conventional ballast track”; Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005

Picture 60: “Frame sleepers in the curve and being installed”; Rießberger, K. „The project „Frame Sleeper Track““, ZEVrail special edition 2005

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