

BALLAST SPECIFICATION

FOR

HIGH AXLE LOAD (32.5 T)

AND

HIGH SPEED (≥ 250 KMPH)



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HIGH SPEED (\geq 250 KMPH)

PROJECT BY

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SYNOPSIS

*Indian Railway is the largest railway system in the world under a single management having 63000 route km, handling 14 million passengers per day and 1.8 MT freight per day. Till recently, there was complete monopoly of the railway organization for movement of freight and passenger traffic. But, due to development and strengthening of road network and availability of better and improved road vehicles, the roadways are not only offering stiff competition to the railways but are also snatching away traffic from the railways. This, coupled with **increasing transportation requirement** arising out of accelerated growth of the Indian Economy, has forced Indian Railways to reorient itself and gear up for the challenges offered by the present scenario. The Indian Railway needs to convert this challenge into an opportunity and devise various means to meet the demand. As considerable growth in freight movement is expected, it has become inescapable for Indian Railway to go for freight trains with higher axle loads. An attempt is being made, through this paper to study and evaluate the implications of Higher Axle Load (32.5 tonnes) and High Speed (≥ 250 kmph.) on track ballast and sub-ballast and suggest the specifications/requirements of the same.*

1. **INTRODUCTION:**

Indian economy is on the threshold of high annual growth rate of about 8 to 10%. This will result into a growth of about 10 to 12% in the transport sector. This means that the transport capacity needs to be doubled every 7 to 8 years. Highways and Railways are expected to cater to the projected growth in transport sector. Railways, being efficient in energy consumption as well as land use should gear up to carry most of the additional traffic generated.

On IR, the growth of both passengers as well as freight traffic has been phenomenal since independence. However, there has not been much increase in the network on IR, resulting into congestion of all main routes. Indian Railway has embarked upon ambitious modernization plan to improve the carrying capacity of the existing network besides construction of dedicated Freight Corridors. In order to achieve the objective of carrying more freight & passenger traffic, designing the infrastructure for higher axle loads and higher speeds is inevitable. It was in this context that recently, axle load was increased from 20.32 tonnes to 22.82 tonnes on some identified routes. We are on the way to increased axle load to 25 tonnes. We have already achieved a speed of 150 kmph on New Delhi-Agra route and are aiming for further increased speed of 160 kmph. All these were achieved/are being targeted to be achieved without much alteration/improvement to the existing infrastructure other than resorting to better monitoring and discipline. But, these measures can help only in the short run. In the long run there is need to have infrastructure designed/upgraded to run freight trains with an axle load of 32.5 tonnes and passenger trains at a speed of more than 250kmph to meet the future demand commensurate to all-round growth. This will require improvement in locomotives, rolling stock, track structure, bridges, signaling, OHE, etc.

2. OPTIONS AVAILABLE:

To achieve the above objectives of running freight trains with 32.5 tonnes axle load and passenger trains at a speed of more than 250 kmph we have a choice to go either for ballasted track or ballast less track. Each has its own advantages and disadvantages. Some of them are discussed in subsequent paras.

3. COMPARISON OF BALLASTED TRACK AND BALLASTLESS TRACK:

S.N.	DESCRIPTION	BALLASTED TRACK	BALLASTLESS TRACK
1	Maintenance Input.	Frequent maintenance for geometry.	No frequent maintenance for geometry.
2	Cost comparison.	Relatively low construction costs but higher life cycle cost.	Relatively high construction cost but lower life cycle cost.
3	Elasticity.	High elasticity due to ballast.	Elasticity is achieved through use of rubber pads and other artificial materials.
4	Riding Comfort.	Good riding comfort at speeds up to 250 – 280 kmph.	Excellent riding comfort even at speeds greater than 250 kmph.
5	Life expectation.	Poor Life expectation.	Good Life expectation.
6	Stability.	Over time, the track tends to “float”, in both longitudinal and lateral directions, as a result of non-linear, irreversible behaviour of the materials.	No such problem.

7	Lateral resistance.	Limited non-compensated lateral acceleration in curves, due to the limited lateral resistance offered by the ballast.	High lateral resistance to the track which allows future increase in speeds in combination with tilting coach technology.
8	Noise.	Relatively High noise.	Relatively low noise and vibration nuisance.
9	Churning up of Ballast.	Ballast can be churned up at high speeds, causing serious damage to rails and wheels.	No such damage to rails and wheels.
10	Permeability.	Reduced permeability due to contamination, grinding-down of the ballast and transfer of fine particles from the sub grade.	High impermeability.
11	Construction cost of Bridges/Tunnels/etc.	Ballast is relatively heavy, leading to an increase in the costs of building bridges and viaducts if they are to carry a continuous ballasted track.	Less cost of construction of bridges and viaducts due to lower dead weight of the ballast-less track.
12	Construction Depth.	Depth of Ballasted track is relatively high, and this has direct consequences for tunnel diameters and for access points.	Reduced height.
13	Availability of Material.	Limited availability of suitable ballast material.	No problem of material.

14	Accessibility to road vehicles.	Track is not accessible to road vehicles.	The track can be accessible to road vehicles
15	Dust pollution.	Release of dust from the ballast into the environment thus causing environmental pollution.	Less environment pollution.
16	Suitability on the basis of requirement of maintenance input.	Less suitable due to limited availability of traffic block in the present scenario of high traffic growth.	Highly suitable in the present and future scenario due to very less maintenance requirement.

4. **BALLASTED TRACK:**

Considering extended experience and capital investment constraints, it is proposed to adopt ballasted track for running freight trains with axle loads of 32.5 tonnes and passenger trains at a speed of 250 – 280 kmph.

A typical railway track consists of superstructure (rails, fastenings and sleepers) and sub-structure (ballast, sub-ballast and formation including sub-grade). The function of the ballast is to transfer the load from the super structure to the sub grade. Performance of the track system depends on the effectiveness of the ballast in providing drainage, stability, flexibility, uniform support to the super structure and distribution of the track loading to the sub grade and facilitating maintenance.

Increase in axle loads, traffic density and speed increase the rate of settlement of the track. And to keep this within permissible limits, stresses in sub grade should be reduced suitably to ensure stability of track parameters. There are two modes to achieve this- either by strengthening the track superstructure or by strengthening the track sub structure. Studies world wide have shown that strengthening of track super structure does not help much in reducing sub grade stresses and, therefore, its rate of settlement. Numerical analysis using finite element modeling carried in RDSO, Lucknow in collaboration with IIT/Kanpur have shown that sub grade stresses reduce marginally (4 to 6%) with the increase in rail section or sleeper density. But the stresses reduce drastically with the depth of construction, i.e. total depth of ballast and sub-ballast.

5. PROPERTIES OF TRACK BALLAST:

- 5.1.** The ballast should be clean and graded crushed stone aggregate with hard, dense, angular particle structure providing sharp corners and cubical fragments with a minimum of flat and elongated pieces. These qualities will provide for proper drainage of the ballast section. The angular property will provide interlocking qualities which will grip the sleeper firmly to prevent movement. Excess flat and elongated particles could restrict proper consolidation of the ballast section.
- 5.2.** The ballast must have high wear and abrasive qualities to withstand the impact of traffic loads without excessive degradation. Excessive abrasion loss of an aggregate will result in reduction of particle size, fouling of the ballast section, reduction of drainage and loss of supporting strength of the ballast section.
- 5.3.** The ballast particles should have high internal shearing strength to have high stability.

- 5.4. The ballast material should possess sufficient unit weight to provide a stable ballast section and in turn provide support and alignment stability to the track structure.
- 5.5. The ballast should provide high resistance to temperature changes, chemical attack, exhibit a high electrical resistance and low absorption properties.
- 5.6. Ballast material should be free from cementing properties. Deterioration of the ballast particles should not induce cementing together of the degraded particles.
- 5.7. The ballast material should have less absorption of water as excessive absorption can result in rapid deterioration during alternate wetting and drying cycles.
- 5.8. The ballast gradation should be such that it allows development of necessary compressive strength, meet density requirements of the ballast section, uniform support, elasticity and provide necessary void space to allow proper runoff of ground water. It should reduce deformation of the ballast section from repeated track loadings.

6. **FACTORS INFLUENCING DESIGN OF BALLAST AND SUB BALLAST:**

6.1. **Total Static and Dynamic Loads Coming on the Track:**

The design of the ballast and sub-ballast should be such that they are able to successfully transmit all the loads coming on the track superstructure to the sub grade without any failure of the sub grade.

To understand the effect of the increase in axle load, traffic density etc. on track performance, it is necessary to understand the mechanism by which settlement occurs. A part of track settlement is attributed to ballast breakdown, its orientation and lateral creep. But most of the settlement is due to vertical settlement of the underlying sub grade. With increase in axle loads, stresses induced into sub grade increases proportionately which lead to increase in rate of settlement of sub grade. Though with increase in traffic density, stresses in sub grade do not increase but rate of settlement increases due to increased frequency of load application.

6.2. Speed of the Trains:

The speed of the trains affects the Dynamic Augment which in turn alters the magnitude of the load coming on the track. It has been observed that the stresses do not increase with speed but higher speeds call for better maintenance standards (tolerances). With increase in speed, though dynamic augment 'DA' increases a little, but, increase is compensated due to adoption of higher maintenance standards. Studies by ORE have shown that 'DA' increases a little with speed up to critical speed and thereafter it decreases or remains constant but **it is very much sensitive to track leveling defects**. Thus, increase in speed may increase the rate of settlement for which permissible stresses in sub grade should be reduced suitably to keep maintenance within acceptable level.

6.3. Resilience/Elasticity/Flexibility of Track Structure for Good Running Behaviour:

Running of trains causes vibrations which are transmitted to the track through rail-wheel interaction. These vibrations influence the performance of the various track components. The ballast and sub-ballast should be such that it absorbs the vibrations and transfers minimum disturbance to the sub grade.

6.4. Drainage:

The ballast should be able to drain the track system as drainage is the first and prime consideration in the track maintenance and performance of a ballast material. A wet ballast section reduces the shearing strength of the assembly of ballast particles and dirty, moist ballast sections will support the growth of vegetation which reduces the drainage capability of the ballast material. Drainage is the most important factor in contractive and expansive sub grade soil conditions which are prone to cause pumping conditions in the track section.

6.5. Durability:

The material should be such that it does not create fines that may fill the voids between the particles thereby inhibiting drainage. Further, excessive abrasion loss of an aggregate will result in reduction in particle size, fouling of the ballast section and loss of supporting strength of ballast section.

6.6. Cementing Properties:

Some of the powdery fines of carbonate materials have a tendency to cement together and clogging action could occur. Further, cementing reduces resiliency and provides undesirable distribution of track loads and in most instances results in permanent track deformations. Cementing also interferes with track maintenance. So, a ballast material should be free of cementing properties.

6.7. Stability:

To provide track stability, the ballast must perform several well defined functions. The ballast must sustain and transmit static and dynamic loads in three directions (transverse, vertical and longitudinal) and distribute these loads uniformly over the sub grade.

6.8. The ballast and sub ballast material should be such that it should be possible to get well compacted ballast and sub ballast section to provide a stable and uniform areas for the distribution of the track loads throughout the ballast section.

6.9. Uniform support to the super structure and distribution of track load to the sub grade.

6.10. Ease in maintainability of the track parameters like, alignment, cross level and grade. It should allow retention of the track parameters.

- 6.11.** The sub-ballast must be sufficiently impervious to divert most of the water falling into the track to the side drains to prevent saturation of the sub grade which could weaken/soften the sub grade and contribute to failure under load.
- 6.12.** The sub-ballast material should be such that it serves as a buffer or filter to prevent sub grade material from penetrating the sub-ballast section while at the same time permitting escape of capillary water or seepage of water, to prevent accumulation of water below the sub-ballast.
- 6.13.** The sub-ballast particles should be so graded that sub-ballast particles do not penetrate into the sub grade and at the same time does not allow penetration of ballast particles into the sub ballast zone.
- 6.14.** Ballast should have resistance against Ballast Pick Up phenomena.
- 6.15.** It has been observed that at high speeds, the track ballast has a tendency to lift up/fly from the bed and thus hit the under frame of the rolling stock and even the nearby structures. Besides other factors, lifting of ballast is believed to be influenced by-
- the under pressure just behind the front or the rear of the train,
 - vibrations due to train passage that reduce the friction among the rocks and make them lift easier.
- Lifting of ballast can be reduced to some extent by using larger size of ballast and keeping the ballast level low as compared to the sleeper top.

7. STRESSES ON BALLAST BED:

Ballast bed and formation are conceived as a two-layer system for the purpose of computation of stresses. Vertical forces on the ballast bed due to wheel loads will be considered as the determining stresses for the load bearing capacity of the layer system. Over loading of ballast bed due to increased axle loads causes rapid deterioration of the quality of the track when heavy axle load trains are introduced. The compressive stresses that the sleepers exert on the ballast bed are considered evenly distributed for the purpose of calculation. It means that the material from which the sleeper is made plays no role. The maximum stress between the sleeper and the ballast bed under the wheel load 'P' is expressed based on Zimmermann's theory and by applying a Dynamic Amplification Factor due the speed of the Rolling stock as per Eisenmann's model.

$$\begin{aligned}\sigma_{sb} &= \{ DA * Pa/2 * (U/4EI)^{1/4} \} / Asb \\ &= F_{max} / Asb\end{aligned}$$

where,

P = Effective Wheel Load (T)

a = Sleeper Spacing (cm.)

U = Modulus of Elasticity of Rail Support or Track Modulus
(Kg/cm/cm)

E = Modulus of Elasticity of Rail Steel (Kg/sq. cm.)

I = Moment of Inertia of Rail Section (cm⁴)

Asb = Contact area between sleeper and ballast bed for half
sleeper (sq. mm.)

DA = Dynamic Augment Factor.

52 Kg and 60 kg sleepers differ only in respect of the distances between inserts so as to accommodate higher rail section and in all

other respects, they are identical. Hence, there would be no difference in ballast stresses due to the use of either sleeper and the half sleeper contact area works out to 336,875 sq. mm. Stresses on the ballast bed due to the force on sleeper, computed for 52Kg and 60 Kg rail sections and different sleeper spacing were worked based on the above formula and it was seen that the stress on the ballast bed due to running of 32.5 tonnes axle load at a speed of 100 kmph. was much lower than the permissible value of 0.5 N/Sq. mm. for sleeper spacing ranging from 65 cm. to 43 cm.

8. RECENT DEVELOPMENTS IN SUB-BALLAST:

In order to ensure that there is no influx of water into the sub grade, which can lead to softening of sub grade in combination with vibration, we can use conventional granular sub-ballast of required qualities as per established practice. But, as per recent developments and current trend, Bituminous Ballast as Sub-Ballast is being widely used throughout the world.

8.1. Bituminous Ballast:

Bituminous ballast consists of mixture of aggregate and bitumen. The mineral aggregate varies from very fine dust (filler) to a maximum particle size, which is usually around 40 mm. By varying the composition of the mixture, the ratio of the various constituents and the particle size distribution of the aggregate, the properties of the eventual mixture can be adapted to suit the specific requirements of the construction. Depending on the mix composition and the quality of the constituent bitumen and aggregates, the bituminous ballast mixture may be either stiff and of

high stability and almost impermeable. The use of special additives or of polymer-modified bitumen offers the possibilities of complying with specific requirements (heavy duty, lower temperatures, and noise/vibration reduction) for the mixture or the construction.

The production of bituminous ballast mixes takes place in either mobile or static mixing plants where, in a continuous or batch process, the mineral aggregate is dried and heated and where the hot bituminous binder is added to the required aggregate composition. Production takes place at temperatures of 130 – 190° C. After production the hot bituminous ballast mix is transported to the site in insulated trucks. On site, application takes place using pavers that place and partially compact the material in the required thickness and width, following which final compaction is achieved using rollers. Immediately after the last passage of the compaction roller the bituminous ballast is ready for use.

A bituminous ballast construction may consist of one or more separate layers of possibly different composition. Depending on the design the various layers each perform a specific role in the construction.

The properties of bitumen offer good opportunities to apply this type of material in railway track construction. This has been proven in various applications, both for heavy loaded tracks and for high-speed tracks. The use of bituminous ballast (10-20 cm.) in railway construction provides a positive contribution to the bearing capacity of the structure. It improves both the stability and the durability of the structure, which contributes to the reduction in the need for maintenance. In addition, the use of bituminous ballast also helps to reduce vibration and noise. The use of bituminous ballast may reduce the total construction height of the superstructure, which is of importance in the case of tunnels and bridges.

8.2. Bituminous Ballast as Sub Ballast Layer:

The rail ballast absorbs the train weight and distributes it from the rails to the sub grade, thereby avoiding any deformation. The railroad can thus keep its geometrical features. The rapid decay of the railroad level which occurs with traditional ballast construction is mainly due to the unsatisfactory "fatigue behaviour" of the ballast; this is mostly due to embankment settling. By interposing a special semi-rigid layer (the so-called "sub-ballast") in the area between the ballast and the embankment, the behaviour of the overall structure is greatly improved. The sub-ballast is normally laid on a highly compacted embankment layer.

The sub-ballast functions are:

- to create a working platform on which subsequent work operations, such as ballast and rail laying, are more easily undertaken;
- to assist in distributing the loads transmitted by passing trains;
- to protect the embankment body from the seepage of rain-water and from seasonal thermal extremes (frost and thaw cycles);
- to eliminate contamination of the ballast from fine material migrating up from the foundation;
- to distribute the concentrated pressures and eliminate any "rupture" of the embankment.

A railway structure with sub-ballast works almost exclusively on compression and, therefore, differs from a traditional structure. This consequently eliminates fatigue cracking. Especially on high-speed

tracks maintaining levels and profile is of high importance. This can be achieved by increasing the stiffness of the structure. A higher stiffness has as a consequence of better load distribution to the ballast and sub ballast material. This will prevent an early deterioration of the rail geometric. In this case the use of bituminous ballast in a sub-ballast layer can offer the solution.

8.3. Application of Bituminous Ballast in Railway Construction:

The application of bituminous ballast as a sub-ballast layer will contribute to the following aspects:

8.3.1. Bearing Capacity:

The application of a monolithic layer (0.1 – 0.2 m) of bituminous ballast, as a sub-ballast layer will increase the stiffness of the total structure. The fact that a bituminous ballast layer is also capable of withstanding tensile forces gives an extra positive contribution to this effect.

8.3.2. Geotechnical Stability:

The relatively high stiffness of the bituminous ballast sub-ballast layer will make a positive contribution to the compaction of the layers on top of the bituminous ballast layer. This improves the total stability. So the bituminous ballast mix as sub-ballast contributes to keeping the railroad geometry unaltered.

8.3.3. Resistance to Vertical Deformation:

The relatively high stiffness of the bituminous ballast layer compared to granular material will lead to less permanent vertical deformation by trainloads. The vertical loading conditions and the relatively short loading time are relatively small, so there will be no permanent deformation in the bituminous ballast layer.

8.3.4. Drainage:

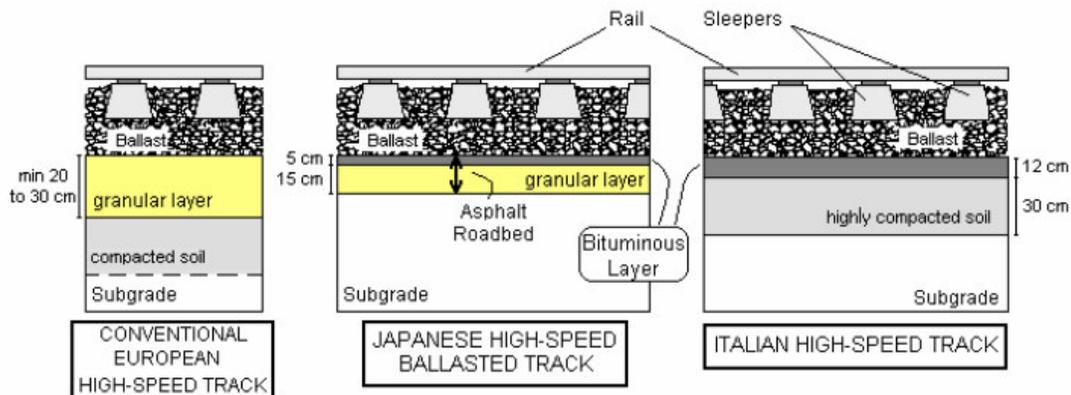
When a layer of dense bituminous concrete is used as a sub-ballast layer, optimal drainage of the total structure will be realized. The impermeable bituminous ballast as sub-ballast layer can prevent possible contamination of the sub-structure by vertical hydraulic transport of mud and fines.

8.3.5. Durability:

Because of the confinement of the ballast by the bituminous ballast layer, the ballast layer is strengthened and deterioration of the ballast is reduced. The bituminous ballast as sub-ballast layer increases the foundation modulus, providing a more rigid foundation, with the effect that there is a reduction of tension and shearing stress inside the ballast material, with consequently less fatigue and less degradation and wear of the individual aggregate particles. Because of the low air voids in the mix (1 – 3%) and because the bituminous ballast layer is buried, weather effects (temperature changes, Ultra Violet radiation, oxygen) will not affect the hot mix, so no deterioration (aging) of the bitumen will take place. Even if limited deformation of the sub-soil does take place, this will not affect the bituminous ballast layer because it is capable of withstanding the deformation without losing its integrity because of the visco-elastic properties of bitumen.

8.3.6. Noise and Vibrations:

The mechanical properties of the bituminous ballast layer will lead to a reduction in the vibrations and noise produced by passing trains. The use of modified bitumen (polymer modified bitumen, rubber crumb) can further improve the vibration dampening effect of the sub-ballast.

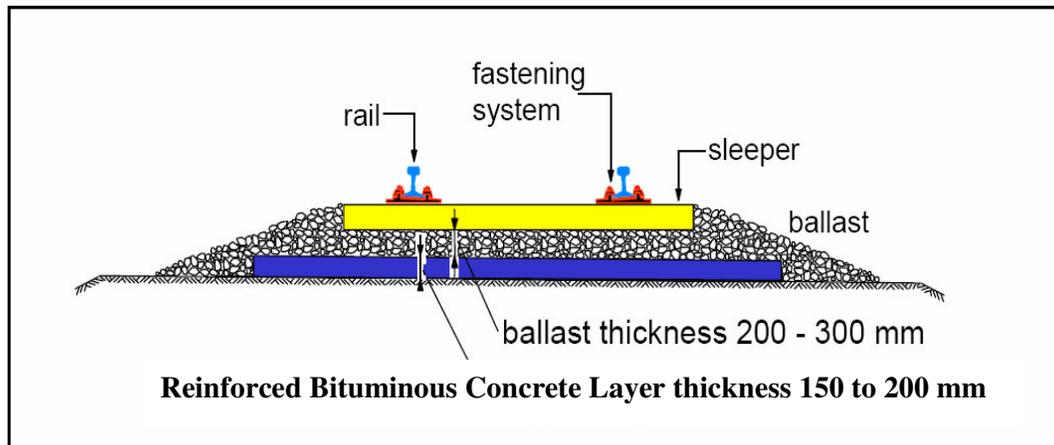


TYPICAL CROSS SECTIONS OF HIGH SPEED TRACKS WITH SUB-BALLAST

8.4. Reinforced Bituminous Concrete Layer:

High speed lines in Japan and Italy are also laid on a waterproof bituminous concrete layer between 5 cm and 8 cm thick to prevent softening of sub grade. In order to efficiently distribute and even reduce sub grade stresses this bituminous concrete layer can be increased to 15 cm or 20 cm. Bituminous concrete layers may offer major advantages in the construction of new track designed for relatively high axle loads and high gross annual tonnage. In addition, the use of reinforcing layers on conventional track designed for passenger services could lead to a significant

reduction in the frequency with which the track geometry has to be maintained. Studies have shown that the stresses at the sub grade level do not depend only on depth of ballast, but depend on total depth of ballast and sub ballast.



8.5. Experiences

8.5.1. Italy

The first experience with asphalt mixes in high-speed railway construction in Italy date from the early 1970s. Hundreds of kilometers have been built in the last 20 years. The results have been very satisfactory and have shown that the application of an asphalt sub-ballast layer contributed to the stability of the rail geometry. In particular, at critical points such as switch points, expansion joints, level crossings and in areas between concrete structures (bridges) and embankments, where dynamic forces are substantial, the asphalt sub-ballast layer introduced a remarkable improvement of the superstructure stability.

Within a few years, more than 1200 km of high speed lines have been equipped with bituminous sub-ballast layer.

8.5.2. Germany

This construction method was used for the first time in Germany around 25 years ago, with an asphalt base course. Since then, seven different systems of the asphalt construction method have become approved by the DB AG. They are the following, in detail:

- SBV Sleepers with bituminous sealing
- FTR Prefabricated frame
- ATD Asphalt base course with a rail web
- SATO Concrete sleeper or Y-steel sleeper with double base
- FFYS Solid railway trackbed with Y-steel sleeper
- Walter System Walterbau
- GETRAC [A] German Track Corporation Asphalt.

In addition to the fastening technique, paving at the precise height is extremely important. Although, in the beginning, milling off was still necessary in part to achieve the required height precision, evenness of paving has since been improved to ± 2 mm, with reference to 4 m, through multi-layer paving and laser-supported paving technology. With the above-mentioned systems, several sections have been constructed in Germany to date.

8.6. Depth of Ballast and Conventional Granular Sub ballast:

Almost all leading world railways provide a layer of sub-ballast along with ballast. However, there is wide variation in the practices followed in different countries of the world. The depth of ballast and sub ballast which are in use on the various railways are given below:

S.N.	RAILWAY SYSTEM	DEPTH OF	
		BALLAST (MM)	SUB-BALLAST (MM)
1	Australia	200-300	150
2	England	225-375	Variable
3	France	150-350	Variable
4	UIC	250-550	Variable up to 450
5	Japan	300	200
6	Swedish Railways	240	90
7	USA	300	300

Studies conducted at FAST (Facility for Accelerated Surface Trials, Pueblo USA) have demonstrated that track geometry correction requirement both for alignment and profile variations were least for test sections having ballast depth 300mm and these increased for test sections having ballast depth both lower (150 mm) and higher (450mm) than 300mm.

9. RECOMMENDED SPECIFICATIONS:

S.N.	DESCRIPTION	PROPOSED SPECIFICATION FOR HIGH AXLE LOAD (32.5 T) AND HIGH SPEED (≥ 250 KMPH)	EXISTING SPECIFICATION FOR 22.82 AXLE LOAD AND 150 KMPH SPEED
1	Type of Rock Material	Granite or Basalt	Does not specify the type of rock material.
2	Basic Quality	The ballast should be clean and graded crushed stone aggregate with hard, dense, angular particle structure providing sharp corners and cubical fragments with a minimum of flat and elongated pieces. It should be free from organic impurities and inorganic residues.	Ballast should be hard, durable and as far as possible angular along edges/corners, free from weathered portions of parent rock, organic impurities and inorganic residues.
3	Particle shape	Ballast should be cubical in shape. Individual particles should not be flaky and should not have generally flat faces with not more than two rounded/sub rounded faces.	Ballast should be cubical in shape as far as possible. Individual particles should not be flaky and should have generally flat faces with not more than two rounded/sub rounded faces.

4	Mode of manufacture	Ballast should be Machine crushed only.	Ballast should be Machine crushed.
5	Aggregate Abrasion Value.	25%	30% Maximum. (Relaxable to 35% on technical and/or economic grounds).
6	Aggregate Impact Value.	18%	20% Maximum. (Relaxable to 25% on technical and/or economic grounds).
7	Water Absorption.	0.5% Maximum.	1% Maximum.
8	Size ad Gradation.	Retained on 65 mm sq. mesh sieve - 30%-50%. Retained on 40 mm sq. mesh sieve - 70%-90%. Retained on 20 mm sq. mesh sieve - Not less than 90%.	Retained on 65 mm sq. mesh sieve - 5% maximum. Retained on 40 mm sq. mesh sieve - 40%-60%. Retained on 20 mm sq. mesh sieve - Not less than 98% for Machine Crushed Ballast.
9	Depth of Ballast	300mm	Upto 350mm
10	Depth of sub-ballast of Conventional Granular Particles/ bituminous ballast/ bituminous concrete layer.	150mm	Nil
11	Width of Shoulder Ballast	500 mm on straight 700 mm on curves	350 mm on straight 500 mm on curves.

10. **CONCLUSION:**

Based on the above discussion, it can be concluded that for high axle loads (32.5 T) and high speed (≥ 250 kmph) :

- Ballasted Track on PSC sleepers can be adopted.
- Depth of Ballast of the order of 300 mm. is adequate.
- Higher size of the ballast is preferred.
- Ballast material should be Granite/Basalt only.
- About 150 mm thick Sub-ballast layer preferably of Bituminous ballast is necessary.
- The shoulder ballast may be increased to 500-700 mm.
- The various design parameters should not be decided on the basis of initial cost of laying but on the basis of principles of Life Cycle Costing.

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