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Sr. Professional Course (Bridge & General)

PROJECT REPORT
ON

DESIGN LOADS FOR BRIDGES ON HIGH SPEED ROUTES OF 250-350 KMPH

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1.0 INTRODUCTION

High Speed train operations are catching world wide attention from last 30-40 years since Japan introduced high speed train services way back in early 60's. The development of these new lines has been done over a period of more than forty years, between the middle of the 1950s and the current decade. During this period the design criteria have been modified as experience has been gained with the different aspects of high speed running.

There are four objectives (i) To reduce the travel time between activity centers, (ii) faster bulk movement, (iii) environment friendly system and (iv) To compete with air lines in terms of travel time, safety & comforts of passengers. In Indian Scenario, the high speed was reckoned with introduction of Rajdhani Express way back in 1967-68 and then later days introduction of Shatabdi express. The high speed is termed as any speed higher than roughly 120 Kmph. Recently the talk is going on to introduce the high train services on some sections of Indian Railways for example, Mumbai to Ahmedabad without specifying the speed. This talk has already started lot of heat and discussions regarding viability of this project.

Internationally the term 'High speed' is used if the following characteristics are fulfilled:

- Separately constructed lines with defined standard of high speed.
- Vehicles for high speed traffic
- Maximum speed of at least 200 km per hour and generally more than 250 km per hour.

The construction of new high speed railway lines is currently being undertaken in a large number of countries, in particular on the continent of Europe. There are now more than 2 900 km open for commercial service in Europe (and more than 2 000 km under construction) as well as almost 2 200 km in Japan.

Figure 1 shows the increase of maximum speeds in experimental test runs and in commercial service during the last few decades. Figure 2 gives the total number of kilometres of test runs done by SNCF, in the range of speeds between 400 and 515 km/h.

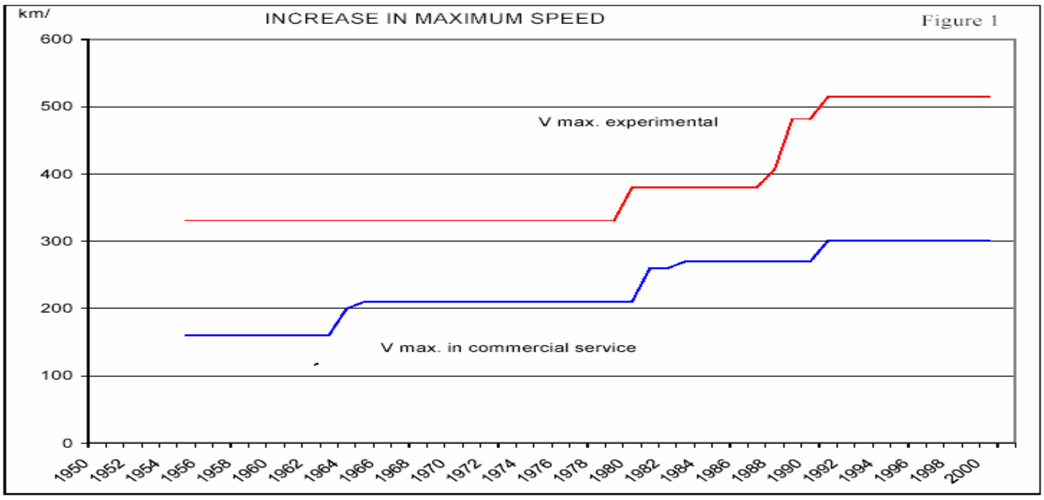


Fig. 1 Maximum speed in test runs and commercial speeds

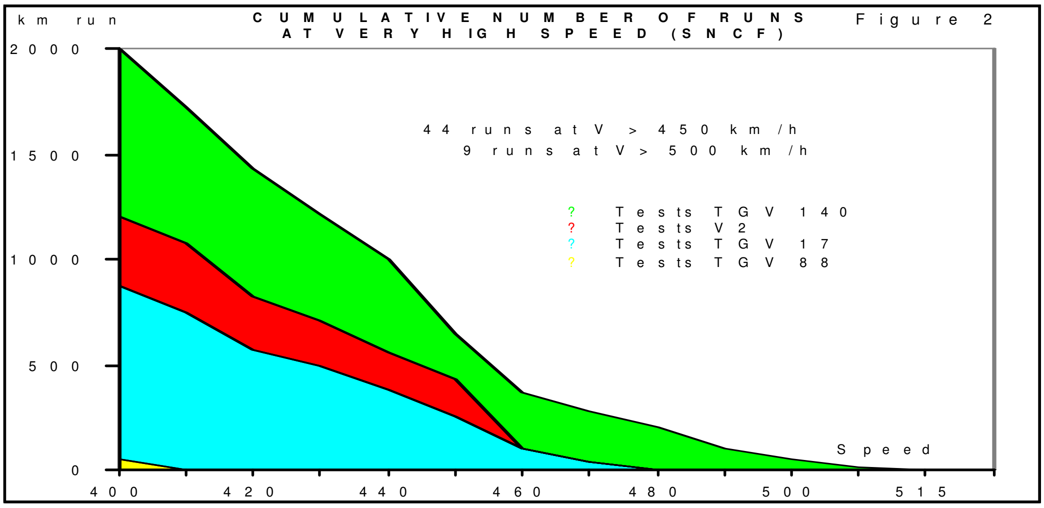


Fig. 2 Cumulative number of runs at very high speed

From the point of view of commercial operation, the experience available is situated in the range from 250 to 300 km/h. However, some lines have been type tested for speeds of more than 300 km/h (up to 320 km/h).

Looking ahead, it is necessary to report that the present situation will change for certain routes and for certain types of service. On the European level, it is foreseeable that this will be checked, for the first time with the specification of the new TGV Mediterranean lines (it has been decided to operate a section of some 60 kilometres of this line at 320 km/h) and the Madrid - Barcelona line.

In the second of these, over a distance of 625 km (approximately) and for a journey time that the train timing studies have put between 2 ¼ hours and 2 1/2 hours (direct services), the average commercial speed will be between 250 and 278 km/h.

In view of the speed restrictions which are imposed at the approaches to large towns, a running speed in excess of 300 km/h seems to be essential. 320 km/h and if necessary 350 km/h will, therefore, be the reference level for this new railway line.

Essential prerequisite for High Speed corridor is to have control on the degradation of track geometry so as to keep various tolerances well within the specified limits. Degradation of track geometry is a function of Track Design, Axle-Load, Speed, Sub-Grade characteristics. Improvement of sub-grade in poor ground areas and bridges is recognized as one of the most significant factor.

This paper describes the considerations of **loads for design of bridges** in high speed routes of 250-350 Kmph.

2.0 NEED FOR HIGHER SPEED

Transport is the back bone of any nation. Among the available transportation systems, Railway is the bulk, cheaper, less pollution, environment friendly system and hence most of the population use it. Therefore, for faster transportation, lesser pollution and compete with airways there is very much need for increase of speed.

The growing demand of transport is one of the salient features of the developing economy. In developing countries like India, Railways attract major share of growing traffic, as it offers the cheaper transport. Indian Railway is life line of our nation. In India where rapid growth of economy with GDP growth rate more than 8%, Indian Railway trade surplus more than Rs.20,000 crore, Urban population growth. (expected population in 2012 – 368 million or 30.4%), high disposal income of working class, Cost effective & efficient mode of transportation for about 600 km distance, environmental friendly as energy requirement is more than half per thousand commuters transportation, socio-technological advancement and multinational competitive atmosphere are taking place, IR also needs to develop its network and quality of service and that to in a competitive atmosphere. Quality is directly linked with the quality of service to the customer in terms of physical comfort and time saving. The growth of traffic on Indian Railway has been manifold. A quantum increase is expected in the passenger and freight traffic in Indian Railways in the next few years. Integrated Railway Modernization Plan (2005-10) has been made which has objective to enhance capacity, improve rail-port connectivity, higher axle load wagons to carry bulk material and development of dedicated freight corridors. IR also plans to develop a world class high speed dedicated passenger corridor fit for 250-300 kmph trains. Ahmedabad-Mumbai has been identified for feasibility studies as a part of separate project. Indian Railways have to; therefore, embark upon a path of modernization and expansion in a big way.

3.0 DIEEFRENT MODES FOR INTRODUCTION OF HIGH SPEED

High-speed trains currently function under two discrete technologies:

- Improvement of conventional rail systems.
- Exclusive high-speed corridors.
- Combinations of the above two systems.

3.1 Improvement of conventional rail system

The first type uses existing conventional rail systems and its great velocity is primarily the fact of considerable improvements in locomotive performance and train design. England (London-Edinburgh), Sweden (Stockholm-Gothenburg), Italy (Rome-Florence and Rome-Milan) and the United States (Boston-Washington) are examples in this type of technology. Trains can reach peak speeds of approximately 200 km/h in most cases and up to 250 km/h in Italy. The principal drawback for use of this system, however, is that it must share existing lines with regular freight services.

3.1.1 Advantages

The main advantage of improving conventional rail system is lower cost and much less time required in introducing a high-speed train. The cost of constructing a dedicated new high-speed line may be prohibitively high for a developing nation.

3.1.2 Problems running on existing lines

(i) High speed trains and heavy freight trains have different demands on track standards concerning horizontal alignment, cant, gradients and vertical curves. The primary problem with the existing railways is that they can have tight curves. The centrifugal forces on an object going round a bend are the function of the square of velocity, i.e. if you double the speed, you quadruple centrifugal forces, if you triple the speed you increase centrifugal forces by nine folds. Therefore, even what might appear mild curves provide problems at speed. Increasing radius of curve and widening track spacing entail huge cost and sometimes may not be feasible as well.

(ii) Other key problem is that running on existing railway; the new fast trains have to be scheduled in around the conventional trains. This can be a tricky thing, especially on a busy network; fast trains can easily become stuck behind slow running ones, resulting in delays. If the timing of fast trains is ensured, it greatly affects line capacity of the section.

(iii) Safety is also a paramount consideration. Although since initial construction many years ago, the track will have been replaced many times, the foundation of the railways are same which means after heavy rains for example the track may sag slightly and loose some alignment, only a real problem at speed.

(iv) Maintenance of track for high-speed trains will require track geometry to be maintained within very tight limits. On mixed traffic routes, both high-speed passenger trains and heavy axle load freight trains operate on the same track and these heavy axle loads can be up to 25T. This poses problem for the Civil engineer in that these heavy axle loads can accelerate the deterioration of the track.

3.2 Exclusive high-speed corridors

The second category of high-speed trains runs on its own exclusive and independent corridors. Such systems are presently in operation in France, Spain, Germany, Japan, South Korea etc.

3.2.1 Relative merits of dedicated high-speed railways

There are two main drawbacks of building high-speed railway lines, construction costs and environmental impact. Construction costs of civil and electrical infrastructures are very high in comparison to improving existing tracks and the income received may, usually, not be enough to pay off a high-speed railway line. Environmental impact comes in through cutting down grown up trees/re-landscaping for the railways, and creating a brand new transport corridor. However where possible this can be reduced, for example in France the section of high speed line from Lille to Paris was built so that it ran right along side a 6 lane motorway. This means a new transport corridor isn't created so environmental disruption is at a minimum.

Dedicated high-speed rail is only really applicable if it cannot be achieved by conventional railway. Although existing track can be safely run up to 250km/h, existing track may have a number of speed restrictions because of curves. High-speed lines may also be looked at if railways are in saturation and no extra services can be timetabled in. Sometimes when existing railways were built they were constructed a bit at a time and a haphazard network arose. This means train lines often don't go in a roughly straight line between distant locations, often because they go to other towns in between. Building a new line gives the option of building a direct straight line between cities giving a shorter running distance again reducing journey time. However with the advent of tilting mechanisms, which allow curves on existing railways to be negotiated with up to 30% more speed, it puts a knife in the case to build.

4. SALIENT FEATURES OF A HIGH SPEED CORRIDOR:

The salient features of the high-speed track /bridges are as follow:

(i) The new corridor will be of double electrified lines for high-speed passenger traffic with a speed of 250 kmph-350 kmph.

(ii) The trains shall be hauled by two electric locomotives with 18 nos. air-conditioned coaches.

(iii) There will be grade separation on the new corridor i.e. there will be **no surface level crossings** and complete line shall be fence to avoid interference of local people and cattle's. The minimum height of the embankment shall be 3m.

(iv) The maximum grade shall be 1 in 200 and minimum radius of curvature is proposed to be 4000 m.

(v) The track structure shall be 60 Kg CWR on PRC Sleepers with sleeper density of 1720 per Km and ballast cushion of 300 mm or more. The fastenings are proposed to be of double elastic type and turnouts are proposed to have movable nose or ballastless track with slab track structure wherein the rails are supported at discrete points or embedded track structure.

(vi) Rail joint should be eliminated or minimized including over the bridges.

(vii) Measures should be taken for good riding comfort while moving over approaches into the bridge and vice-versa.

(viii) Trolley refuge to be provided at lesser distance wherever required.

(ix) The signaling system shall have cab signaling. Automatic train control, solid state Interlocking device, Centralized traffic control and non-insulated track circuits. The telecommunication shall be with latest technology consisting of Optic fibre system, train radio control and tele-printer and faximile arrangement.

(x) For electrification, the power supply system will have auto transformer system of 2x25 kV with OHE system of maximum span of 60 m and current carrying capacity of 920 Amperes.

5.0 PARAMETERS FOR HIGH-SPEED CORRIDOR

5.1 Geometrical parameters of the line

The main factors governing the standards required for the geometry of a high-speed railway is for the comfort of passengers.

5.1.1 Curves

Gentle curves are generally adopted on high-speed track. Gentle curves become necessary in view of restriction on maximum values of cant deficiency and cant excess along with maximum speed of operation. The minimum radius of curvature for the high-speed lines on developed HSR networks generally varies from 4000 m to 7000 m for standard gauge. Table 1 shows values, effect of speed on the selection of the geometric parameters of curves as adopted on SNCF.

Table 1 Geometric parameters of curves

Parameter	Speed (km/h)		
	270	**300**	**350**
Radius (m)			
Recommended	3846	4545	7143
Normal	3226	4000	6250
Exceptional	3125	4000	5556
Max Cant (mm)			
Normal	180	180	180
Exceptional	180	180	180
Cant deficiency (mm)			
Normal	100	85	65
Exceptional	130	100	85
Cant excess (mm)			
Normal	100	110	--
Exceptional	100	110	--
Variation of Cant deficiency (mm/s)			
Normal	30	30	30
Exceptional	50	50	50

Recommended and minimum horizontal curve radius as a function of speed as per Swedish Standard is presented in Table 2.

Table 2 Recommended and minimum horizontal curve radius on Swedish Rail

	Speed (km/h)					
	200	**250**	**280**	**300**	**330**	**350**
Recommended (m)	3200	5000	6300	7200	8700	9800
Minimum (m)	1888	2959	3700	4248	5140	5782

In reality, however, it is often difficult to meet these recommendations. On several newly built lines compromises have been made due to economic and other reasons such as locations near important bridges, stations etc. Such locations may require suitable speed restrictions.

5.1.2 Ruling gradient

Generally steeper gradients can be allowed on high-speed lines in comparison to conventional lines. Very high momentum of trains makes it feasible to negotiate steeper gradients.

French Railways

The maximum gradient allowed on high-speed lines (TGV) is up to $35^{0}/_{00}$. However transition between two different gradients is always provided by a circular transition curve whose radius is more than 12,000 m.

Japanese Railways

The maximum gradient may attain $15^{0}/_{00}$ as long as the average over a distance of 12 km does not exceed $12^{0}/_{00}$. Between two successive gradients, a circular transition curve is always provided.

5.1.3 Vertical curves

The practice on some of the high-speed railway networks is as follows:

French Railways

The desirable value of radius of vertical curve has been prescribed as 10,000m.

German Railways

Desirable radius of vertical curve in meter is calculated as $0.4V^2$, where V is maximum speed in km/h. The minimum value of radius of vertical curve is prescribed as 20V+550.

Japanese Railways

Vertical curve of radius 10,000 m for straight and horizontal curve up to 3,500 m radius and 15,000 m for horizontal curves steeper than 3500 m has been specified as desirable.

5.1.4 Spacing of tracks

Wide spacing between the lines is important for high-speed track because when two trains pass each other, the speed difference can be as much as 600 Km/h. If two trains are too close together, there is burst of air pressure when they first pass and then a drop of pressure between the carriages. Although this is not enough to push the trains off the track, repeated stress on the windows may cause fatigue, which result in breakage of window glasses. However, wider spacing between tracks has economic implications. Studies show that an increase of 30 cm in the width of the sub-grade would involve an increase in cost of the civil engineering works by 1%.

Minimum distance between track centres adopted by some of the high-speed networks using standard gauge are given in Table 3 below.

Table 3 Minimum distance between tracks

Country	Minimum distance between tracks (m)		
	250 Km/h	**300 Km/h**	**350 Km/h**
France	4.2	4.2	4.5
Germany	4.5	4.5	4.5
Italy	4.5	5.0	5.0
Spain	4.3	4.3	4.7

Indian Railways have recommended to adopt spacing of 5.35 m between tracks of broad gauge for new construction projects, which is sufficient for speeds up to 300 km/h.

5.2 Track bed

Track bed for high-speed lines is much deeper than conventional railways. It is necessary that embankments are unyielding and stable. Suitably graded granular material with minimum of fines is generally used in construction of high-speed embankments. Usually a layer of concrete or tarmac is put down and then the sub-ballast and ballast is put on top.

Drainage problems often lead to lowering the strength of the sub-grade and consequential distortion of vertical alignment during rainy season. Any settlement of the sub-grade can be far more damaging to the track geometry than improper quality of ballast. The need for proper design and execution of drainage below the track can not be overemphasized.

5.3 Ballast

Generally the thickness of ballast cushion varies from 30 to 35 cm over high-speed lines. Ballast is laid on a sub-ballast layer of thickness 20 to

30 cm. The characteristics of ballast and sub-ballast on some of the high-speed networks are given in Table 4.

Table 4 Characteristics of ballast and sub-ballast

Parameters	Country (Speed: Km/h)			
	France	Germany	Japan	Italy
	300/350	300	300	300
Minimum/Maximum size of ballast (mm)	25/50	22/63	30/60	30/60
Minimum thickness of the ballast (Cm)	30	35	30	35
Minimum thickness of sub-ballast	20	30	25	30

5.4 Ballastless track bed

Presently all over the world non-ballasted track concepts are being applied, although still at a moderate volume. The great advantages of such structures can be summarized as follows:

- Reduction of structure height;
- Lower maintenance requirements and hence higher availability;
- Increased service life;
- High lateral track resistance, which allows future speed increases in combination with tilting technology;
- No problems with churning of ballast particles at high-speed.

If the low-maintenance characteristics of slab track on open line are to be retained, great care must be taken to ensure that the sub-grade layers are homogenous and capable of bearing the loads imposed. The slabs may be prefabricated or poured on site. The high level of investment required has prevented widespread use of slab track on open line so far. However, on the basis of life cycle costs a different picture is obtained. The greatest savings will be achieved in tunnels and on bridges. The use of more efficient construction methods, of the type used in the road construction industry could reduce construction costs still further.

5.5 Rails and Sleepers

The quality of rail is not, in principle, affected by the increase in speed above 250 km/h, if the rail to be laid is of the "top of the range" type. Most of the high-speed networks use UIC 60 rails of 900 A grade steel. It is recommended that attention should be paid to the aspects; acceptance, assembly, welding, surface defects, etc. World over, pre-stressed concrete sleepers have been used on high-speed lines. The number of sleeper varies from 1587 to 1666 per km.

5.6 Rail pads, fastening system and stiffness of the track

The stiffness of the track must be limited in order to reduce the vertical dynamic forces between wheels and rails, by the use of rail pads under the rail with appropriate characteristics.

As far as ballasted high-speed lines are concerned (according to the Technical Specifications for Interoperability (STI)), the dynamic rigidity of the rail pads under the rail must not exceed 600 MN/m.

Similarly, the total dynamic stiffness of slab track systems must not exceed 150 MN/m.

Rail pads are generally formed of rubber or elastomer elements and one of their main characteristic is the vertical stiffness. It is especially critical on bridges, tunnels and slab track.

5.7 Tunnel and Bridges

The cost of construction of tunnels and bridges are much higher as compared to cutting and embankment construction. There has been tendency to avoid tunnels and bridges to reduce the cost of construction. If the curvature and gradient used to avoid tunnels and bridges are not suitable for permitting the desired speed, their construction becomes inescapable.

At high speeds, airwaves are generated inside the tunnels, which can be detrimental to the health of passenger. To mitigate this health hazard, following alternatives may be adopted.

- Increased cross-sectional area of the tunnel
- Avoiding double line tunnels
- Operating only air sealed coaches
- Provision of pressure release shafts

A combination of alternatives may be used depending on the requirement. In case of bridges, approaches receive sudden impact loading due to a change in the vertical stiffness between the bridge deck and approach embankment leading to frequent settlement of the approach bank. This may create large acceleration at high speed. Proper design of approach bank is necessary. Possible solutions include; provision of an approach slab; and providing tapering stone fill to simulate gradual rise in approach stiffness.

5.8 Level crossing / grade separation

Normally level crossing is not suitable for higher speed train operation and hence for road transport either road over bridges or road under bridges need to be planned. However, in unavoidable circumstances, level crossings must be interlocked with the signals. Sophisticated arrangement of interlocking the signals of train with that of road transport with help of video camera is used on JNR.

5.9 Fencing

On high-speed lines, trespassing is very risky. Even the train may suffer accident and consequences of accidents can be alarming. Thus, the entire high-speed track is generally provided with fencing. In any case, areas prone to trespassing have to be provided with fencing on high-speed routes.

5.10 Environment

The aspect of the environment most affected by the increase in speed is the subject of noise. In fact, the nature of the noise changes with the speed, such that as the speed increases, the predominant noise, which is that of motor up to 120 km/h, becomes the track noise 160 km/h, then the pantograph and aerodynamic noises above 250/300 km/h.

In principle it is reasonable to suppose that the more the speed increases the more noise problems will be created. As a result measures should be taken to protect against noise (screens, mounds of earth, etc.), as well as possible modifications of the route or the creation of artificial tunnels or covered sections, modifications of the maintenance (grinding) and, of course, modifications to the rolling stock.

6. TRACK GEOMETRY MONITORING FOR HIGH-SPEED LINES

Track geometry is described by track profile, cross level, alignment and gauge. As a vehicle travels, it responds to track geometry variations and irregularity. Since the natural frequency of carriages designed for high-speed is low, generally less than 1 Hz, long wavelength anomalies provide dynamic input to the high-speed passenger vehicles and can excite car body modes at high speeds. At speeds of 250 km/h and above, track irregularity up to 80 m wavelength would be important.

The present day chord length of 9.6 m and 7.2 m for measurement of top and alignment respectively are grossly inadequate in correctly assessing the track irregularity for high-speed operation. Transfer function of these chords is presented in Figure 3.

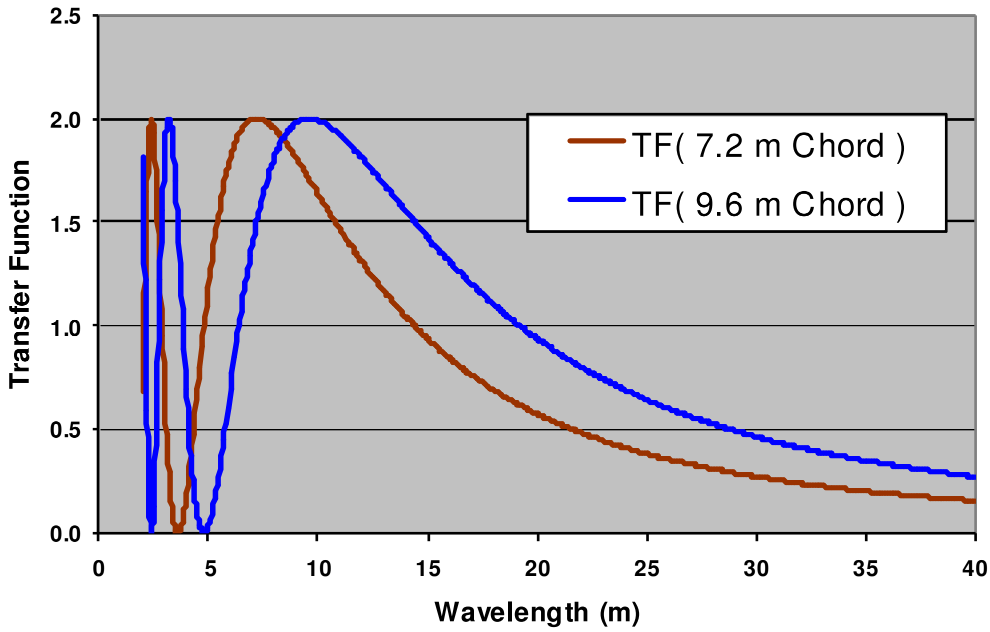


Fig 3 Transfer function of 7.2m and 9.6m chords

To control longer wavelengths, most foreign high-speed railroads either use a 30 or 40 m chord or inertial principle of measurements. These longer chord lengths allow measurement of anomalies with wavelengths up to 90 m. A 40 m chord was adopted by Japanese Railways after increased speed on Tokaido line. JR research and testing indicates a strong correlation between car body motion at high speed and track geometry limits based on 40 m mid chord offset.

The Indian Railways Track Recording Cars are capable of measurement of track irregularity on any selectable chord, since the measurement is based on inertial principles. However, standards for judgments of irregularities on these high chords will have to be worked out.

7.0 DESIGN LOADS FOR BRIDGES IN HIGH SPEED ROUTE

7.1 With respect to normal speed, the bridges are subjected to more impact affect, vibration which may lead to resonance, riding comfort, thermal forces for LWR/CWR track, affect due to change in track modulus for travel from approach into the bridges & vice versa.

For the bridges in high speed route, following forces to be considered as per IRS Bridge Rules except Dynamic effect, forces due to CWR/LWR track:-

i. Dead load
ii. Live load
iii. Forces due to curvature or eccentricity of track
iv. Temperature effect
v. Frictional resistance of expansion bearings
vi. Longitudinal force
vii. Racking force
viii. Forces on parapets
ix. Wind pressure effect
x. Forces and effects due to earthquake
xi. Erection forces and effects
xii. Derailment loads
xiii. Load due to Plasser's Quick Relay System (PQRS)

- **IMPACT**

The provision in IRS Bridge Rules for Coefficient of Dynamic Augment (CDA) is applicable for speed upto 125Kmph/160 Kmph for broad gauge goods train/passenger train respectively. The formula can not be adopted for high speed. It requires to be revised.

CDA depends upon the speed of train and irregularity of tracks. In absence of Indian code, UIC code maybe adopted.

ORE D 23 Committee concluded that the ratio of maximum stress due to a train crossing at speed to the max stress due to the same train crossing very slowly (the dynamic effect) is usually a function of the parameter **K =v/(2Lf).** This function is intended to give safe estimates for all except the unusual cases. Later work has modified this function and added a component intend to include the effect of typical dipped joints.

For a simply supported beam the static influence line for stress may be calculated if span and section modulus is known. For most cases therefore the only bridge parameter leaded to calculate the stress history are span(L), first mode natural frequency(f) and section modulus (W).

Natural frequencies

The limits of the natural frequencies are given in **UIC leaflet 776-1R**.

$$f_{max} = \left(\frac{438.80}{L}\right)^{0.748072}$$

&

$$f_{min} = \frac{80}{L} \quad \text{when } L \le 20\text{ m}$$

Or

$$f_{min} = \left(\frac{207.80}{L}\right)^{0.592217} \quad \text{when } 20 \le L \le 100\text{ m}$$

Dynamic increment (φ)

UIC leaflet 776-1R gives a value for dynamic increment (φ) which is made of two components. The *first component* d*ynamic increment due to speed (φ')* which applies to perfect track is based on the work of ORE D 23 Committee.

φ' $= K/(1-K+K^4)$ Where $K = v/(2Lf)$

v : velocity in m/s

L : span in m

f : frequency in Hz

The *second component dynamic increment due to track irregularities (φ")* applies to a dip in the track.

$$\varphi'' = (a/100)\,(56 \exp(-L^2/100) + 50\,(f L/80 - 1) \exp(-L^2/400))$$

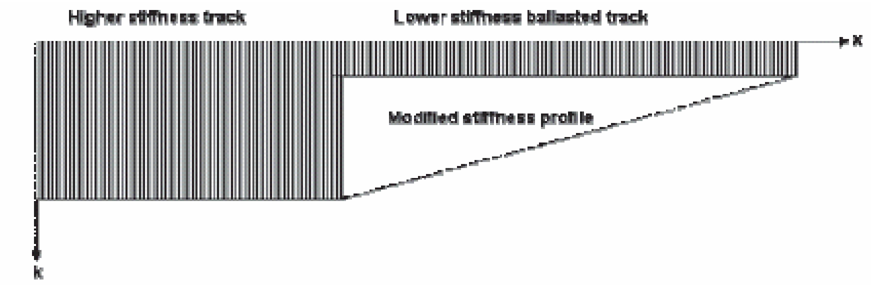
Where **a** = v / 22 ; v≤ 22 m/s

a = 1 ; v> 22 m/s

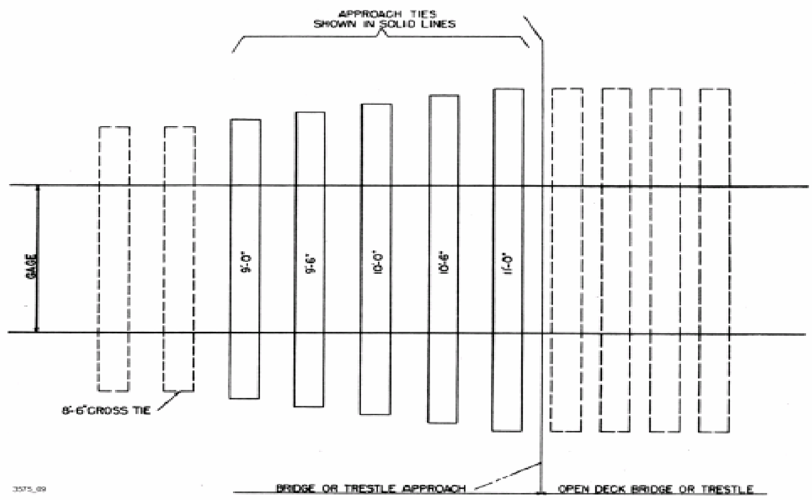
- For normally maintained vehicles and track
  Dynamic increment φ = φ' + φ''
- For especially well maintained vehicles and track
  Dynamic increment φ = φ' + φ''/2

- Riding comfort

In any Railway system, riding comfort is one of the primary goals. There are many causes responsible for riding comfort. In high speed, any minor irregularity in track shall lead to riding discomfort. In case of bridges, approaches receive sudden impact loading due to a change in the vertical stiffness between the bridge deck and approach embankment leading to frequent settlement of the approach bank. This may create large acceleration at high speed. Proper design of approach bank is necessary. Possible solutions include; provision of wider sleepers at approaches (Fig-4-i & ii); an approach slab(Fig-5-i & ii); more rails at approaches and providing tapering stone fill(Fig-6) to simulate gradual rise in approach stiffness.

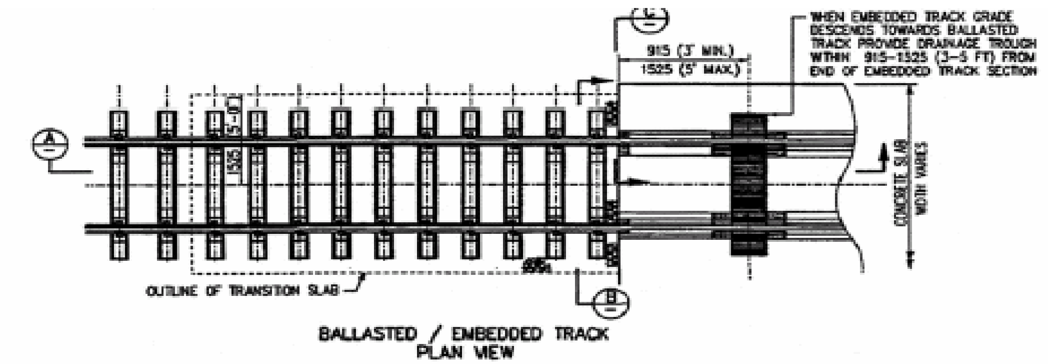


Note: x = distance, k = stiffness



Source: AREMA 2005a.

Fig-4(i) & 4(ii): Wider sleeper at approaches of bridge



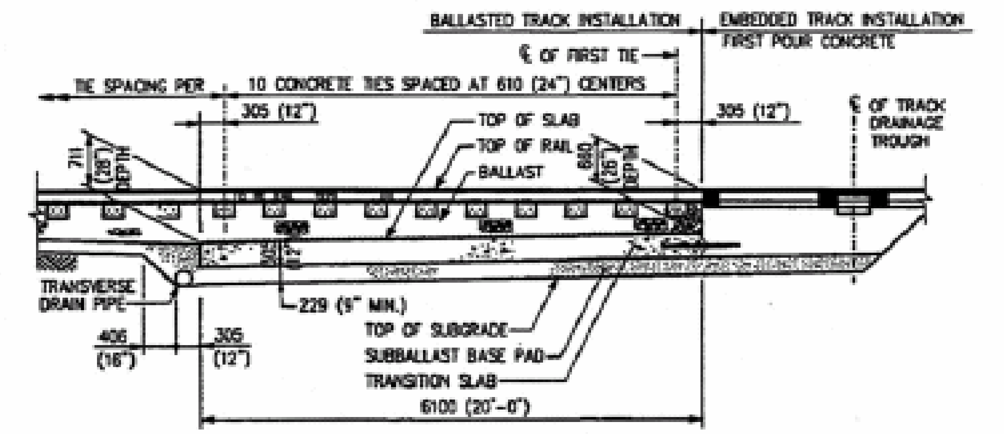


Fig-5(i) & 5(ii): Approach slab

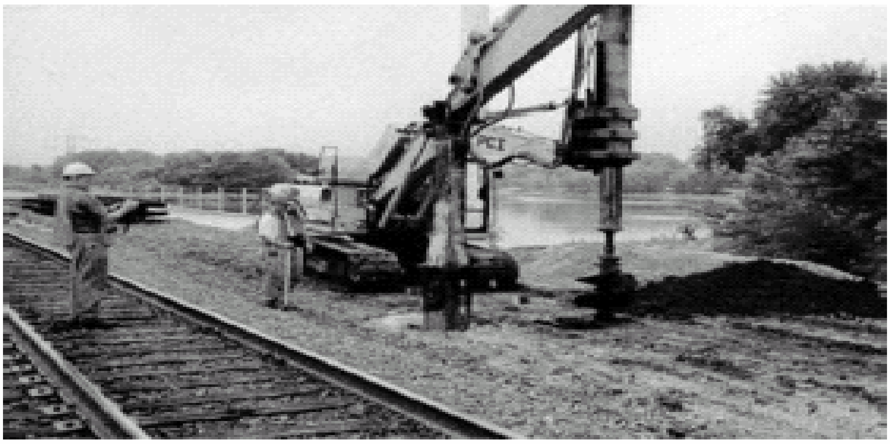


Fig-6: Work for providing stone column

Deflections of superstructure, is other main cause for riding comfort.

The *maximum deflection of a railway bridge is dependent* on

- speed of the train
- span length
- mass, stiffness and damping of the structure
- axle loads of the train

Limit values for deflection (L/f) dependent on span length and speed under **φ x LM UIC 71**.

RESONANCE PHENOMENON

Another problem encountered in high-speed railways is the **vibration** of bridges caused by the moving trains.

The loads induced by a moving train on the bridge are repetitive in nature, as characterized by the sequentially moving wheel loads, implying that certain frequencies of excitation will be imposed on the bridge during the passage of a train.

When trains travel at a higher speed, making it possible for the excitation frequencies to coincide with the vibration frequencies of the bridge, resulting in the so-called **resonance phenomenon**.

Whenever the condition of resonance is reached, the bridge response will be continuously amplified as there are more wheel loads passing the bridge.

The mass ratio of the vehicles to the bridge is generally larger for railways, due to the fact that a train consists of a number of cars in connection and the railway bridge deck is relatively narrow, it carries no more than two tracks in most cases. For this reason, the interaction between the moving vehicles and bridge appears to be much stronger for railways. Finally, concerning the manoeuvrability of the train in motion, the riding comfort or vehicle response is an issue that should be taken into account in the design of high-speed railways.

In case of resonance excessive bridge deck Vibration can cause

- loss of wheel/rail contact,
- destabilisation of the ballast,
- exceeding the stress limits.

Resonance is given, if

$$\mathbf{n_{Bridge} = i \cdot f_{excit}} \qquad i = 1,2,3,4$$

with $\mathbf{f_{excit} = v/L_{vehicle}}$ and the first natural frequency for bending $\mathbf{n_0}$ the critical speeds can be calculated with the formula

$$\mathbf{v_{crit} = \frac{n_0 \cdot L_{vehicle}}{i}} \qquad \mathbf{i = 1,2,3,4}$$

8.0 CONCLUSION

8.1 In addition to then normal speed, the bridges in high speed route are subjected to more impact forces, vibration, susceptible to passenger discomfort and chances of occurrence of resonance.

8.2 In case of bridges, approaches receive sudden impact loading due to a change in the vertical stiffness between the bridge deck and approach embankment leading to frequent settlement of the approach bank. This may create large acceleration at high speed. Proper design of approach bank is necessary. Possible solutions include; provision of an approach slab; wider sleepers at approaches; more rails at approaches and providing tapering stone fill to simulate gradual rise in approach stiffness.

8.3 The choice between ballasted and ballastless track is purely a techno economic decision. World over the trend is to go for ballastless track.

8.4 The shared or dedicated track depends on discipline of operations and techno economic considerations.

8.5 The improvements in existing track also depends on discipline of operations but in view of present system, a new track is preferred.

8.6 For designing a High speed bridges, dynamic simulation softwares become the necessity.

8.7 Suitable design procedures should be developed.

8.8 A High degree of reliability is essential in design, manufacturing and transportation.

8.9 For maintenance innovative methods will have to be planned.

8.10 Suitable high speed and high performance maintenance machines should be used.

8.11 Although not all possible applications of the integrated track/vehicle model could be discussed in this article, it should be obvious that dynamic simulated softwares offers many new possibilities for investigating track performance resulting from load excitation by moving vehicles, operated at both conventional and high speed.

9.0 REFERENCES

9.1 "Statistical distribution of axle loads and stresses in railway bridges" report no. D 128/RP 5/E, Office of the Research and Experiments of the International Union of Railways.

9.2 Design of new lines for speeds of 300 –350 km/h – State of the Art", October 2001, High Speed Department, International Union of Railways

9.3 "Experience with the introduction and operation of high and very high speed lines", Proceedings of the ORE Colloquium, Office of the Research and Experiments of the International Union of Railways

9.4 "Engineering studies in support of the Development of High-Speed Track Geometry Specification", by Magdy El-Sibaie etl, IEEE/ASME Joint Railroad Conference, March 18-20, 1997, Boston, Massachusetts.

9.5 "Track geometry for high speed railways", by Martin Lindahl, Railway Technology, Department of Vehicle Engineering, Royal Institute of Technology, Stockholm.