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INCREASE OF SPEED ON DELHI-HOWRAH ROUTE FEASIBILITY STUDY

PROGRESS REPORT No. 1 (Vol. 1)

(a) TRACK TOLERANCES FOR HIGH SPEED TRACK
(b) DESIGN CRITERIA FOR CURVES FOR HIGH SPEED TRACK

CIVIL AND MECHANICAL ENGINEERING REPORT No. C & M.1

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INCREASE OF SPEED ON THE DELHI-HOWRAH ROUTE
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(B) DESIGN CRITERIA FOR CURVES FOR HIGH SPEED TRACK

1. Introduction

1.1 In October, 1967, the Railway Board issued orders that a feasibility study should be conducted on increase of speeds on the Delhi-Howrah route (reference DO letter No. 67/WSC/TK/5 dated 16.10.1967 from ME to DG/RDSO, with copies to the GMs Eastern and Northern Railways—copy at Annexure I). The study has been in progress from the end of October, 1967. Annexure II contains extracts from RDSO's note No. DDG/Misc/II dated 2nd February, 1968, giving details of the terms of reference, scope, procedure adopted etc., for the study and general observations regarding the work.

1.2 This report is in two volumes. Volume I deals with the question of limiting values in track defects, for track over which higher speed operation is to be permitted and also discusses the suitability of existing curves for higher speed operation and permissibility of higher cant deficiency for the operation of WDM_4 locomotive and ICF all coil coaching stock at a maximum speed of 120 kmph. Volume II deals with performance of the WDM_4 locomotive and the ICF all coil type bogie, on the Delhi-Howrah section; particularly as assessed by oscillation trials on 5 test sections on this route.

2. Resume of the work already done by the RDSO on high speeds : The work done so far on high speeds includes an assessment of the earlier research and investigations on the strength and structure of the track, strength of fish-plated rail joints, effect of speed on track stresses, criteria for judging 'vehicle performance' on the track, rating and performance of the WDM_4 locomotives, brakes and braking distances, signalling systems and working rules, level crossings, increase of speed on curves, strength of bridges and maintenance of track. As a part of the feasibility study, data was collected regarding the track structure between Delhi and Howrah and regarding the WDM_4 locomotives and ICF all coil coaching stock, to be considered in the first instance for higher speed operation. Preliminary studies were conducted on the track maintenance standards and the behaviour of WDM_4 loco and ICF all coil coaching stock on the Delhi-Howrah section. Preliminary studies were also conducted as regards the relationship between vehicle behaviour and track defects. Thereafter, detailed studies were conducted on the relationship between track defects and the behaviour of the WDM_4 locomotive and ICF all coil coaching stock. These studies included fully instrumented oscillation trials on five test sections, on track 'as found' i. e. before any improvements in maintenance had been attempted. The studies were conducted on vehicles in 'new condition' and in 'worn out condition' and with loaded andempty ICF coaches. On the basis of the studies conducted, tentative limits for track defects were arrived at and communicated to the Northern and Eastern Railways. The two railways have undertaken most of the work necessary for the rectification of these defects, and to bring the track maintenance within the tentative standards so specified. Discussions were held with the Track Maintenance Engineers of the Northern, Eastern and other railways, regarding the suggested track tolerances. Oscillation trials have also been conducted on the up and Down lines between Delhi and Howrah on the track which has been improved in maintenance standards. The data obtained from various oscillation trials, track recordings and ground measurements of track have been analysed. The studies undertaken so far have indicated that it is possible to permit a higher speed of the order of 120/125 kmph, over most of the length of the Delhi-Howrah route, for nominated passenger trains, consisting of ICF all coil coaching stock hauled by WDM_4 locomotives, without incurring any large scale additional expenditure on track or rolling stock.

3. Programme for further work on the Delhi-Howrah route: Further work with reference to the Delhi-Howrah route is aimed at achieving the following results

(i) Obtaining necessary official clearances and sanctions for general operation of WDM_4 locomotives and ICF all coil coaching stock at a speed of 120/125 kmph, on track which is maintained to the requisite standards.

(ii) Obtaining the requisite official sanctions for suitable modifications to the criteria, at present prescribed in the Way and Works Manual, for deciding on speeds to be permitted over curves.

(iii) Arranging the operation of a service train (without passengers) between Delhi and Howrah at a sanctioned speed of 120/125 kmph (subject to local, temporary and permanent restrictions). The trains would operate once or twice a week, to the same path as would be followed later by the regular fast express train. These service runs are to commence in April, 1968 and continue through the rainy season. These service runs would help in monitoring and assessing the behaviour of the track and vehicles over a length of time, in training up the operating personnel and bringing up any difficulties which may arise in the regular operation at higher speeds, of passenger carrying trains in the future.

(iv) Assisting the Northern and Eastern Railways in laying down suitable procedures, for the maintenance of the track to the requisite standards, for higher speed operation and obtaining an assessment of the cost involved.

(v) Assisting the Northern and Eastern Railways in establishing suitable methods for the inspection of track and for control of maintenance standards, suitable for higher speed operation.

(vi) Assisting the Northern and Eastern Railways in establishing satisfactory inspection and maintenance procedures for the vehicles to be used in the higher speed trains, and for ensuring that uniformly satisfactory standards of maintenance are available for such vehicles.

4. Object of the present report: The present report has been prepared incorporating the technical data which would help in dealing with items (i) & (ii) of para 3 and in particular

(i) The extent and magnitude of track defects, which could be permitted in track, over which general operation of WDM_4 locos and ICF all coil coaches could be sanctioned at a speed of 120/125 kmph and also over which these two vehicles may be permitted at speeds up to 136 kmph for purposes of trials.

(ii) To indicate the modifications necessary in the provisions with regard to curves, as existing at present in the Way & Works Manual and showing that these modifications are acceptable.

5. Field investigations: The data presented in this report is mostly based on a study of the behaviour of the WDM_4 locomotive and ICF all coil coach, on five test sections on the Delhi-Howrah route. Oscillation trials were conducted on these five test sections using fully instrumented vehicles at speeds rising from 100 kmph to 136 kmph. The geometrical characteristics of the track on which the oscillation trials were conducted, were recorded; by using the track recording car and also by ground measurements. The data so obtained have been analysed.

6. Test sections: Four of the test sections were on the Allahabad Division and consisted of track which is straight or with mild curves. The fifth test section which was on the Dhanbad Division had curves ranging from 1.36° to 2.5° in curvature (theoretical) and also a reverse curve from 2.33° to 1.7°. Details regarding the test sections as well as the geometrical characteristics of the track on these test sections are incorporated in Annexure VI.

7. Test vehicles : On all the five test sections, oscillation trials were conducted on WDM_4 locomotive and an ICF all coil coach in 'new condition.' On one of the test sections on the Allahabad Division and on the test section in the Dhanbad Division, tests were also conducted utilising a locomotive with worn tread condition and with worn clearances as would develop under service conditions. Oscillation trials were repeated on one of the test sections on the Allahabad Division and on the test section on the Dhanbad Division using an ICF all coil coach selected from the workshop, where it had been nominated for POH. Tests were also repeated for the coaching vehicle, under loaded conditions.

Details regarding the vehicles utilised for the oscillation trials, on the five test sections, are given in Annexure VII of Volume II of this report.

8. Instrumentation of the vehicles

8.1 Instrumentation of the vehicles in connection with the oscillation trials on the five test sections, was the same as is usually done for oscillation trials conducted for the purpose of judging the stability and speed potential of vehicles in connection with arriving at recommendations for permissible speeds.

8.2 The WDM_4 locomotive was instrumented for recording the following :

(i) Primary spring deflections
(ii) Secondary spring deflections
(iii) Vertical accelerations in the cab
(iv) Lateral accelerations in the cab
(v) Bogie rotation for the leading bogie
(vi) Bolster swing for the leading bogie
(vii) Lateral forces at the axle level

8.3 The ICF coach was instrumented for recording the following

(i) Primary spring deflections
(ii) Secondary spring deflections
(iii) Vertical accelerations over the trailing bogie
(iv) Lateral accelerations over the trailing bogie
(v) Bolster swing of the trailing bogie
(vi) Bogie rotation of the trailing bogie

9. Analysis of test data

9.1 The data available for the analysis was those obtained from the instrumentation in the locomotive and ICF coach and also data regarding the physical dimensions of the track obtained from the track recording charts and by measurements on the ground.

9.2 The data from the oscillation charts were fully analysed as would be done in the case of oscillation trials undertaken in the normal course for judging the stability and speed potential for vehicles. Charts and tables obtained from this analysis for test sections 1 to 5, together with a discussion on the results, are given in volume II of this Report'.

9.3 The data obtained from the oscillation charts of the test runs, in the five test sections, were also analysed concurrently with the data regarding the physical dimensions and geometry of the track, over which the oscillation trials were conducted. Copies of charts and graphs which were obtained as a result of this analysis are included as Annexures III and IV. Annexure III incorporates the data for the test sections 1 to 4 and Annexure IV that of test section 5.

9.4 The analysis as indicated in para 9.3 above, has been done with a view to establishing the following

(i) The extent and magnitude of track defects, which could be permitted in the track, over which general operation of WDM_4 locomotives and ICF all coil coaches could be sanctioned, at a speed of 120/125 kmph and also over which these two vehicles may be permitted at speeds up to 136 kmph for purposes of trials.

(ii) To indicate the extent to which modifications may be made in the present provisions as regards maximum cant deficiency, cant gradient, and rate of change of cant and cant gradient while considering higher speed over curves.

9.4.1 As regards track defects, the following items have been considered

(i) Unevenness of rail table (rail joint depressions)
(ii) Alignment (of each rail separately)
(iii) Gauge
(iv) Cross level
(v) Twist

The effort has been to determine the extent to which these types of defects affected the behaviour of the two vehicles viz. the WDM_4 locomotive and ICF all coil coach with specific reference to the following

(i) Safety from the point of view of derailment
(ii) Satisfactoriness from the point of view of 'general riding comfort'

9.5 As indicated in para 5.4 of Annexure II (Note No. DDG/Misc./II dated 2.2.68), the stability and safety of a vehicle on the track is judged primarily from considerations of vertical wheel load variations as occurring concurrently with lateral forces. In the case of both locomotives and coaches, vertical wheel load variations are measured. In the case of locomotives, lateral forces are also usually measured at the axle box level. In the case of coaching stock, it is not usual to measure lateral forces but lateral accelerations are measured. The safety and stability of vehicles is also judged by an assessment of maximum instantaneous values of accelerations both vertical and lateral to which it is subjected during the course of the run.

9.5.1 As regards satisfactoriness from the point of view of 'general riding comfort', the yard-stick adopted is the ride index. Ride indices are calculated for both the vertical and lateral directions. The preferred and limiting values of ride indices, accepted in India, are indicated in para 5.4 of Annexure II.

9.5.2 When judging the speed potential of the vehicle, it is usually ensured that the lateral loads and accelerations, when considered in conjunction with the vertical load variations are always within the limits specified. As regards instantaneous values of vertical and lateral accelerations, a few isolated cases of some what higher values could be tolerated. It is further to be noted that the recommended values for the ride indices, for locomotives and coaching stock, are fixed from the comfort point of view and they could be exceeded to an appreciable extent when viewed from the point of view of safety and stability.

9.5.3 In the case of a curve, where the cant provided is for the equilibrium conditions at a particular, speed there will be no residual lateral acceleration on a vehicle, passing over the curve at that speed. The residual acceleration at a higher speed is the function of the cant deficiency. The lateral accelerations on account of track irregularities are super-imposed, on the steady lateral accelerations, on account of the cant deficiency. On a curve, the cant deficiency and the limits of track imperfections have to be so regulated that the total lateral accelerations are within acceptable limits. Lateral forces are also exerted by the vehicle, on account of cant deficiency. The sum of the lateral forces arising out of track irregularities and the steady lateral forces on account of cant deficiency, should also be within acceptable limits. Cant deficiency also results in 'on loading' of the outer wheels and 'off loading' of the inner wheels. These effects when added to 'off loadings' and 'on loadings' arising out of track defects should remain within acceptable values from the point of view of stability and safety. Though, large steady lateral accelerations on account of cant deficiency, on a uniform curve, do not cause discomfort, any rapid change of the lateral acceleration is uncomfortable, 1 ft per sec/sec. is considered a satisfactory limit for the rate of change of lateral acceleration. The length of the transition should be sufficient to ensure that the rate of change of lateral acceleration remains within this limit. The cant gradient should be such that when local track defects are super-imposed on it, the twist in the track does not exceed permissible limits. In arriving at acceptable values for cant deficiency, transition lengths, cant gradient and track defects on curves, these aspects had to be kept in view.

9.6 The data as indicated in para 9.3 above has been analysed separately, first taking the case of the four test sections where the track was straight or on mild curves and second, taking the case of last test section where the test length included curves of varying curvatures.

A. STRAIGHT SECTIONS—TEST SECTIONS 1 TO 4

9.7 *Unevenness*

9.7.1 As indicated earlier, the most important consideration as regards stability and safety, is the relative values of the vertical load and the lateral load. Vertical load variations are measured as 'off loadings' and 'on loadings' as indicated by the primary spring deflections and are mainly caused by unevenness in the track. As regards vertical accelerations also, the main contributory factor is the unevenness in the track. The charts at Figs. III-1 to III-5 in Annexure III give the relationship between measured unevenness on the track and

(a) Primary spring deflection/off loading, of locomotive
(b) Primary spring deflection/on loading, of locomotive
(c) Primary spring deflection/on and off loading of ICF coach
(d) Vertical acceleration of locomotive
(e) Vertical acceleration of ICF coach

These graphs show a certain extent of scatter, on account of the fact that the spring deflections and accelerations caused by the vertical unevenness are super-imposed on the effects of the natural vertical oscillations of the vehicle and also the effect of other movements such as rolling and pitching of the vehicle. In spite of this scatter, it is possible to judge to a great amount of correctness, the vertical behaviour of the vehicle, arising out of the unevenness in the track together with other contributory factors which are normal features of track and vehicle. The charts referred to above, are for the maximum test speeds and indicate the worst conditions as regards the vertical behaviour of the vehicles. At all the lower test speeds, the behaviour was more favourable. The maximum recorded values of spring deflections for both 'off loading' and 'on loading', as well as the vertical accelerations for the locomotive and the coach could be read from the charts. It is also possible to draw border lines enclosing practically all the points in each of the graphs. These border lines can be used to determine maximum possible spring deflections (off loading and on loading) which may result from given conditions of unevenness in the track occurring concurrently with other track and vehicle features.

9.7.2 The maximum values of spring deflections resulting in 'off loadings' for the locomotive, as obtained by drawing the border lines in the chart at Fig. No.

III-1 of Annexure III, are indicated in the table below. The corresponding 'off loading' in tonnes has also been calculated from the spring deflection characteristics and shown in the table.

Unevenness (mm)	*Spring deflection (mm)*	*off loading (tonnes)*
6	15	1.7
10	20	2.2
15	26	2.9

It is seen that an unevenness of the order of 15 mm can be expected to result in an 'off loading' of only 2.9 tonnes i.e. about 37.7 per cent of the nominal sprung load.

9.7.3 The chart at Fig. III-2 of Annexure III, gives the relationship between unevenness in the track and the primary spring deflections, resulting in 'on loading' of the locomotive. It is noticed that this graph is similar to the one for 'off loading' and the conclusions are the same.

9.7.4 A similar study of the spring deflections has been made in the case of the ICF coach and the chart at Fig. III-3 shows that the effect of unevenness in the track on 'on loading' and 'off loading' is comparable and the following are the maximum values which could be expected :

Unevenness (mm)	*Spring deflection (mm)*	*Off loading/On loading (tonnes)*
6	15	0.8
10	20	1.0
15	25	1.3

It is seen that unevenness of the order of 15 mm can result in maximum on loading/off-loading of about 29% of the nominal wheel load of the coach.

9.7.5 The maximum values of vertical accelerations of the locomotive and the coach which could result from unevenness in the track, have been obtained by drawing boundary lines in the charts at Figs. III-4 and III-5 of Annexure III. The values are given in the table below :

Maximum vertical acceleration

Unevenness (mm)	*ICF coach*	*WDM_4 loco*
6	0.11 g	0.20 g
10	0.13 g	0.24 g
15	0.17 g	0.29 g

It is seen that for the locomotive the maximum vertical accelerations which can result from an unevenness of the order of 15 mm is 0.29 g ; which is well within the permissible maximum values of 0.35 g and also within the preferred value of 0.30 g. As regards the ICF coach, the maximum vertical accelerations which can result from an unevenness of 15 mm are very well within the limiting and preferred values respectively of 0.35 g and 0.30 g.

9.7.6 In the charts at Fig. III-6 and III-7 of Annexure III the calculated ride indices have been plotted against correspoding peak values of vertical accelerations recorded in the different test sections, in the case of the WDM_4 locomotive and ICF coach respectively. From the two graphs, the maximum values have been obtained by drawing the boundary lines. In the case of the locomotive, it is seen that with the maximum acceleration being restricted to 0.29 g, the vertical ride index does not exceed 3.95 as against an acceptable limiting value of 4 for the vertical ride index. In the case of an ICF coach, maximum vertical accelerations upto 0.22 g could be permitted for keeping the ride index value within the preferred figure of 3.25. In the case of the acceptable limiting ride index figure of 3.50, the maximum vertical acceleration could be even higher. As against this, an unevenness up to 15 mm results in maximum vertical accelerations of the order of 0.17 g only. It has to be emphasised that the above analysis is only of a limited application. The Ride Index values are a function of not only the peak values of acceleration but also of the distribution of values and the frequency of occurrence etc. It is not implied that ride index values would remain satisfactory if a number of rail joint depressions were of the order of 15 mm. It can, however, be stated that the general riding comfort in terms of Ride Indices would remain satisfactory if the value of 15 mm is reached at a few isolated locations.

9.7.7 From a study of the data discussed above, it is noticed that the WDM_4 locomotive and ICF all coil coach are capable of tolerating fairly high values of unevenness in the track. Unevenness of the order of even 15 mm is found not to affect either the stability or the safety of the vehicle. As regards riding comfort, it is preferable to keep the values of unevenness in the range below 10 mm but a few isolated peaks of 15 mm could be tolerated. It is, however, undesirable to permit large values of unevenness in the track since this may result in the over-stressing of rail joints, with consequent possibility of rail-end failures. In well maintained track in foreign countries, on which speeds of the order of 140/160 kmph are permitted, an effort is made to keep the unevenness about 5/6 mm ; repacking of the track is taken up when unevenness values reach 8/10 mm. In India also, it should be the aim to bring up the maintenance standard of joints as quickly as possible, to the same extent. Since, however this would take time, it is considered that for BG track, over which a speed of 120/125 kmph is to be permitted for general operation of the WDM_4 loco and ICF coach, the unevenness should be in the range below 10 mm. A few isolated spots with values up to 15 mm could, however, be tolerated. The unevenness measurements are under the loaded condition of the track.

9.7.8 As indicated earlier, the data and discussions in the above paragraph refer to the four test sections, where the track is either on straight alignment or with only mild curves.

9.8 *Alignment defects—straight track*

9.8.1 The lateral forces and lateral accelerations in the vehicle, are the result of the cumulative effect of various track defects, one of the most important of which is that in the alignment. The alignment defects over the whole length of the four test sections were recorded by ground measurements of the versines, on the 'floating track'. The behaviour of the vehicle, in terms of lateral forces and lateral accelerations, which occur at various speeds, are recorded in the oscillograph charts. From these data, the charts at Figs. III-8 to III-10 of annexure III, have been prepared to bring out the relationship between alignment defects and—

(a) Lateral force as measured at the axle box level in the WDM_4 locomotive.

(b) Lateral accelerations as measured in the WDM_4 locomotive.

(c) Lateral acceleration as measured in the ICF coach.

The charts relate to the maximum speeds achieved during the test runs as the most unfavourable behaviour of the vehicles was observed at the higher speeds. These charts show certain extent of scatter, on account of the fact that the lateral force and acceleration observed are on account of the cumulative effect of the magnitude of alignment defects and the shape and wave length of the irregularity together with other defects such as in cross level, twist, gauge etc. occurring at or near the same location. In spite of this scatter, it is possible to judge to a great amount of correctness, the lateral behaviour of the locomotive arising out of alignment defects in the track, together with other contributory factors which are a normal feature of track and vehicle. The maximum recorded values of lateral forces and accelerations for the locomotive and lateral accelerations for ICF coach, could be read off from the charts. It is also possible to draw border lines enclosing practically all the points in each of the graphs. These border lines can be used to determine maximum possible lateral loads/accelerations which may result from given conditions of alignment defects in the track, occurring concurrently with other track and vehicle features.

9.8.2 As regards the lateral forces in the locomotive, the values incorporated in the chart are those obtained from axle No. 4, since the lateral forces recorded in axle No. 6 were always lower. The maximum values of lateral forces, in the locomotive, as obtained by drawing the border lines in the chart at Fig. III-8 are indicated in the table below

Alignment (versine) (mm)	*Lateral forces (tonnes)*
5	2.5
10	3.7

The values of lateral forces given in the chart as well as in the table above are the peak values. The magnitude of the forces would be lesser, if only forces extending over a minimum length of 2 metres, were considered. From the point of view of instability (derailments) occurring by track distortion, the force of 3.7 tonnes recorded is very much lower than the permissible limiting value of 9.5 tonnes, for the WDM_4 locomotive, which has an axle load of 18.8 tonnes. As regards safety against derailment by wheel mounting, the instantaneous values of Hy/Q have been worked out and are given in the relevant charts and tables of Volume 2. It will be seen that in all the test sections, and for all speeds the maximum values of Hy/Q recorded are very well within the limiting value of one. It is seen that the lateral forces, as measured in the WDM_4 locomotive do not constitute a governing consideration in limiting the extent of alignment defects in straight track.

9.8.3 The maximum values of lateral accelerations in the WDM_4 locomotive, resulting from alignment defects, as obtained by drawing the border lines in the chart at Fig: No. III-9 of Annexure III, are indicated in the table below. The most frequent lateral accelerations for a particular magnitude of alignment defect, is also indicated in the table.

Alignment (versine) (mm)	*Maximum lateral acceleration (g)*	*Most frequent lateral acceleration (g)*
5	0.24	0.18
10	0.33	0.26

It is seen that for an alignment defect of 10 mm, the maximum lateral acceleration is within the limiting value of 0.35 g, though above the preferred value of 0.30 g. For an alignment defect of 5 mm, the maximum value of lateral acceleration is 0.24 g. In Fig, III-11 of Annexure III, the values of lateral ride indices for the WDM_4 locomotive have been plotted against the highest lateral accelerations recorded in the corresponding kilometres. The enveloping line for these points gives an indication of the highest values which ride indices may reach for various values of maximum accelerations recorded in a kilometre. It has, however, to be noted that this graph is only of limited application since it represents only the distribution of values, frequency of occurrence etc. of accelerations as found on the Delhi-Howrah route. However, the probability of these ride indices being exceeded is small since on a well maintained track the distribution of alignment defects in the range up to 5 mm is not likely to be appreciably different from that observed on the Delhi-Howrah route. From the data presented above, it will be seen that as regards lateral ride indices values, alignment defects in the range up to 5 mm would be tolerated by the locomotive without difficulty. As regards local peak values of accelerations, alignment defects of the order of 10 mm could be permitted. In fact, on straight and mildly curved track, the limiting values for local lateral accelerations are not likely to be reached even with some what larger alignment defects. But it is felt that from the practical point of view, it is neither necessary nor desirable to permit local alignment defects of a magnitude larger than 10 mm. The alignment defects of 5 mm and 10 mm, mentioned above, are versines, measured on a chord of length 7.5 metres.

9.8.4 The maximum values of lateral acceleration in the ICF coach, resulting from alignment defects, as obtained by drawing the border lines in the chart at Fig. III-10 of Annexure III are indicated in the table below. The most frequent values of lateral accelerations are also indicated.

Alignment (versine) (mm)	*Maximum lateral acceleration (g)*	*Most frequent values of lateral acceleration (g)*
5	0.14	0.09
10	0.20	0.15

It is seen that alignment defects of the order of 10 mm result in only very low values of lateral accelerations ; very well within the preferred value of 0.3 g and limiting value of 0.35 g, at the test speeds of 130/136 kmph. The graph at Fig. III-12 of Annexure III has been plotted showing the relationship between maximum lateral accelerations and corresponding values of lateral ride indices, for the ICF coach, as observed on the Delhi-Howrah route. From a study of the data, as indicated above, on the same basis as discussed under Para 9.8.3 above, it can be stated that from the point of view of local behaviour as well as lateral ride indices, on straight and mildly curved track, the ICF coach would tolerate alignment defects within the range up to 5 mm and also a few localised defects of the order to 10 mm. As regards local acceleration peaks, even somewhat larger defects in alignment would be tolerated by the coach. However, from the practical point of view, local defects larger than 10 mm are not considered desirable. The values of 5 mm and 10 mm mentioned above are versines, measured on a chord length of 7.5 metres.

9.8.5 From the discussions above, it would be seen that in the case of straight and mildly curved track over which the WDM4 locomotives and ICF all coil coaching stock is to be permitted for general operation at speeds of 120/125 kmph, and for test speeds of the order of 136 kmph, it would be satisfactory if the alignment defects are kept within the range up to 5 mm. Isolated local defects of the order of 10 mm could also be tolerated.

9.9 *Cross level and twist—Straight track*

9.9.1 As regards track on the straight or on mild curves, it is generally accepted that a uniform departure (defect) in the cross level (within practical limit) does not have any adverse effects as regards stability, safety and riding comfort. The behaviour of the vehicle on the track is, however, affected by the rate of change of cross level i. e. 'twist'. The detailed studies undertaken and under discussion in this report did not include a study of the effect of a uniform defect in cross level in the track ; except in the case of curves where the question of cant and cant deficiency has been dealt with. The service tolerances in cross levels, permitted by various railways of the world are discussed in the reports of the IRCA and UIC/ORE. A study of these reports shows that there are considerable differences in the practices adopted by various railways even though the operating speeds are comparable. In the case of straight track, the French, Austrian and Italian railways permit a cross level variation of ± 10 mm while the Belgian and Netherlands railways go up to ± 20 mm. The tolerance limits for curved track are also of the same order. While it would be desirable to maintain cross level differences to as low values as possible, in the case of high speed track, no useful purpose may be served by attempting to specify any particular values, as tolerances specially applicable for higher speed track. The engineers of the zonal railways also confirm that such tolerance limits would not be of any special advantage to them in judging the speed potential of their track. It would be their aim to maintain the sections nominated for high speed operation, to as close tolerances as possible, as regards cross levels and such tolerances would be superior to those normally available in the case of lower speeds.

9.9.2 Most of the railways of the world operating high speed traffic (140/160 kmph) specify service tolerance limits for 'twist'. The best range of tolerances achieved is 1 mm/metre in general and up to 2 mm/metre at isolated locations. It is, however, noted that these limits are exceeded considerably by many of the foreign railways even for their high speed track. For such track, the service tolerance for 'twist' permitted by the French Railways is a total of 3.5 mm/metre on transitions. The extent of tolerance permitted in 'twist' on the British Railways could be understood from a study of the practices followed by them, in the computer analysis of maintenance requirements, by the Matissa Track Recording Trolley and the Naptune system. During track recording, at locations where the 'twist' exceeds 1 in 240, red paint is dropped indicating that the defect is very bad and has to be attended to immediately. At locations where the 'twist' exceeds 1 in 300, yellow paint is dropped on the track, indicating that the defect has to be attended to as soon as possible. Considering that the above tolerances are for speeds appreciably higher than 120 kmph and for the standard gauge, it would be well within safe limits, if corresponding values are accepted for BG track on which a speed of 120/125 kmph is to be permitted for general operation. On this basis, it is proposed that on track other than on transitions, the defect on account of 'twist' should not generally exceed 2 mm/metre. At isolated locations, the defect may go up to 3.5 mm/metre. The usual practice in the various railways of the world, is to measure the twist on a base of 3 or 3.5 metres. It is proposed that the measurement of twist for the BG track should be on a base of 3.5 metres. The twist measurements are required to be made on the loaded track.

9.10 *Gauge variations*

9.10.1 It is generally accepted that a uniformly tight or slack gauge, (within practical limits) does not have any adverse effect as regards stability, safety and riding comfort. The outer limits for slack and tight gauge are already prescribed in the Way & Works Manual.

9.10.2 The rate of change of gauge, if excessive, can affect the riding of vehicles, on the track, but the extent of such variations as existing on the track on the Delhi—Howrah section did not affect to any appreciable extent the behaviour of the WDM_4 locomotive and ICF coaches which were tested. It is further to be noted that the local variations in gauge are reflected as variations in the alignment. The effect of alignment variations has already been discussed in the earlier paragraphs. Since the question of gauge variation is not covered by the data collected during the investigations and discussed in this report, the data as available from technical literature was consulted to ascertain the practices in other countries. It was noted that while all countries have specifications regarding maximum slack and tight gauges for track and some countries have limits to be reached in sleeper to sleeper variation of gauge while track is newly laid or freshly overhauled, only a few countries have service tolerances for the rate of change of gauge. Under the circumstances, it is considered that no specific tolerance for gauge variations need be prescribed, at the present stage, for BG track over which speed of the order of 120/125 kmph is to be permitted. As regards the outer limits for slack and tight gauge, the present provisions of the Way & Works Manual would suffice.

9.11 *Points and Crossings*: As could be seen from Annexure VI., test Sections 1 to 4 included station yards, and the straight track over points and crossings. It is found that the behaviour of the two vehicles over points and crossings was comparable to that on through track and the limits of defects as regards alignment, unevenness, cross level, twist and gauge variation could be the same over points and crossings as in the case of through track. It is, however, obvious that the maintenance of these tolerances over points and crossings requires special effort.

B. CURVED SECTION—TEST SECTION NO. 5

9.12 The primary consideration being that the increase of speeds proposed, should be achieved without any large scale additional expenditure, it is necessary that such increase of speeds should be only to the extent as would be possible without involving any large scale realignment of curves. This would mean that existing curvatures and transition lengths would have to be retained and the possibility of increasing the permissible speeds on the curves should be investigated on the basis that a somewhat better and more uniform standard of maintenance could be achieved for curves and transitions on high speed track. The analysis of the data, in the case of curves, as obtained from test section five, was made with a view to determining

(a) The extent of cant deficiency which could be permitted for the operation of the WDM_4 locomotive and ICF all coil coach at higher speeds

(b) The speeds which could be permitted on transitions to the present standard, i.e., with a cant gradient of 1 in 720

(c) The limiting values for track defects which could be permitted on the curves and the transitions

9.13 The details of the track on test section No. 5 are given in Annexure II The test section, from km 329 to 335 on the Up line, included 4 curves with radii varying from 700 to 1400 metres. Curve No. 1 ($1\frac{1}{2}°$) was at some distance from curve No. 2 ($2\frac{1}{2}°$), curve No. 3 ($2\frac{1}{4}°$) was closely followed by curve No. 4 with reverse curvature of $1\frac{3}{4}°$ The curvatures, mentioned above, are the nominal curvatures. For the purpose of the tests, the actual versine were measured at site on the 'floating track' and the average curvatures of the uniform stretches, have been used in the analysis.

9.14 The oscillation trials were conducted with a great amount of care and control, since apart from the curvatures, the track was also on gradients, with a vertical curve within the test section, Test runs were commenced at 100 kmph and the speed was increased in steps, up to 136 kmph. A few runs were taken also at a somewhat higher speed. The instrumentation of the vehicle and the data collected regarding the track, were the same as for the tests on the straight track.

9.15 As indicated in para 9.5 above, the safety, stability and the general 'riding comfort of the vehicles were judged by assessing the vertical load variations, lateral forces, vertical accelerations and lateral accelerations, as measured in the vehicles. On curved track of a given curvature, the cant deficiency depends on the speed. As a result of the cant deficiency, there is spring deflection, leading to on-loading on the outer rail and off-loading on the inner rail. Similarly, there are lateral forces on the outer rail and also steady lateral accelerations in the vehicle. These changes in the vertical loadings, and lateral forces and lateral accelerations exist even on a uniformly curved track without any local defects. The load variation.

lateral forces and lateral accelerations on account of local track defects are superimposed on those induced by the cant deficiency. The first step in the analysis was to determine the extent of load variations, lateral forces and lateral accelerations in the two vehicles, resulting from various magnitudes of cant deficiency. The cant deficiency was calculated over each stretch of curved track having a uniform curvature, and using the measured curvature and cant and the speed at which the run was made. The on-loading and off-loading of the wheels was assessed from the observed spring deflections. The lateral forces and lateral accelerations were read off from the oscillograph charts, being the steady shift of the traces in the oscillograph chart. Charts were then prepared, to indicate the relationship between the following

(a) Cant deficiency and off-loading (at spring level) for WDM_4 locomotive

(b) Cant deficiency and on-loading (at spring level) for WDM_4 locomotive

(c) Cant deficiency and off-loading (at spring level) for ICF coach

(d) Cant deficiency and on-loading (at spring level) for ICF coach

(e) Cant deficiency and lateral force (at axle level) for the WDM_4 locomotive

(i) On curves with radii in the range of 700 to 800 m

(ii) On curves having radii in the range of 900 to 1400 m

(f) Cant deficiency and lateral acceleration in the WDM_4 locomotive

(g) Cant deficiency and lateral acceleration in the ICF coach

These charts are incorporated in Annexure IV. It is seen that, except in the case of lateral forces, it was possible to cover the data from all the curves, in a single graph, for each parameter. In the flatter curves, the lateral forces were not being recorded in axle No. 6, whereas in the sharper curves it was shared by axle 4 and 6. Under the circumstances, curves of different radii had to be covered by separate charts, in dealing with question of lateral forces.

9.15.1 Apart from giving the observed data, as mentioned above, certain of the graphs of Annexure IV incorporate theoretically calculated values such as the following

(a) On-loading and off-loading at the rail level in the case of the WDM_4 locomotive and ICF coach

(b) Theoretical lateral accelerations

In the theoretical calculations for on loading, off-loading and accelerations, the shift in the centre of gravity of the vehicle on account of the bolster swing, and the tilt on account of the primary and secondary spring deflections etc. have been taken into account. The method of calculation is indicated in Annexure V.

The charts at Figs. IV-1 and IV-2 of Annexure IV, give the relationship between off-loading and on-loading of the wheels and the cant deficiency for WDM_4 locomotive. The observed values of off-loading and on-loading as assessed from the spring deflections and the theoretical values calculated for the spring level and the rail level are incorporated in the graphs. It is seen that at the spring level, the calculated values for both off-loading, and on-loading, are comparable to the observed values confirming the accuracy of the records and the method of calculations. On the same basis, it could be presumed that the calculated values for off-loading and on-loading at rail level are dependable.

9.16 From the charts mentioned above, the following values are reproduced indicating off-loading and on-loading at spring level and rail level for the WDM_4 locomotive.

Cant deficiency (mm)	Calculated value (tonnes) of off-loading at		Calculated values (tonnes) of on-loading at	
	Spring level	Rail level	Spring level	Rail level
100	0.51	1.10	0.58	1.19
125	0.64	1.35	0.72	1.45
150	0.74	1.58	0.85	1.71

The off-loading for a cant deficiency of even 150 mm are only 1.58 tonnes and 0.74 tonnes at rail level and spring level respectively. The values are appreciably smaller for a cant deficiency of 100 mm. The values of 'off-loading' and 'on-loading' referred to above are only the 'steady' values on account of the cant deficiency.

9.17 From similar charts at Figs. IV-3 to IV-4 of Annexure IV, for the ICF coach, the following values are reproduced

Cant deficiency (mm)	Calculated values (tonnes) of off-loading at		Calculated values (tonnes) of on-loading at	
	Spring level	Rail level	Spring level	Rail level
100	0.35	0.53	0.39	0.57
125	0.43	0.65	0.48	0.72
150	0.50	0.77	0.56	0.86

It is seen that the off-loading and on-loading on account of cant deficiency is small for a cant deficiency of even 150 mm.

9.18 From the charts at Figs. IV-5 and IV-6 of Annexure IV, the values of lateral forces, as measured at axle box level of the WDM_4 locomotive, have been extracted and given in the table below

Cant deficiency (mm)	Observed values of lateral forces (tonnes)			
	Curve No. 1 and 4 radius 900 to 1400m		Curve Nos. 2 and 3, radius 700 to 800m	
	Axle 4	Axle 6	Axle 4	Axle 6
100	1.08	0.00	0.50	0.46
125	1.28	0.00	0.65	0.57
150	1.48	0.00	0.79	0.68

It is seen that the lateral forces on account of cant deficiency are comparatively small. It is interesting to note that the lateral forces are somewhat larger in the flat curves No. 1 and 4 as against the sharp curves No. 2 and 3. The reason for this is that on the flat curve, no lateral forces were recorded on axle No. 6, the lateral force carried by axle No. 4 being correspondingly more. In the sharper curves, the lateral forces are shared by the two axles.

9.19 From the charts at Fig. IV-7 of Annexure IV, the lateral accelerations, on account of cant deficiency, in the WDM_4 locomotive are extracted in the table below

Cant deficiency (mm)	*Lateral acceleration (calculated) (g)*
100	0.072
125	0.088
150	0.105

Similar data, regarding the ICF coach, are extracted below from the chart at Figure IV-8.

Cant deficiency (mm)	*Lateral acceleration (calculated) (g)*
100	0.069
125	0.085
150	0.101

Charts at Figs. IV-7 and IV-8 of Annexure IV for lateral accelerations, give both observed and calculated values. Since these values are very close, the calculated values have been incorporated in the above tables. The values for the locomotive and the coach are practically the same and the magnitude of accelerations for a cant deficiency of 100 mm are small, when compared to the permissible limiting figures of 0.3/0.35 g, for local peak acceleration values.

9.20 ***Cant Deficiency :*** From the data presented above, it would be observed that a cant deficiency of the order of 100 mm does not result in any large values of wheel off-loading and on-loading, lateral forces or lateral accelerations. This was expected since a cant deficiency of 130 mm for standard gauge is an accepted practice in foreign countries on their high speed lines (140/160 kmph). The extent of cant deficiency to be permitted in India, for an operating speed of 120/125 kmph, is to depend on the standards which could be achieved in the maintenance of the track on curves. Considering the practical difficulties in achieving a uniformly very high standard of track maintenance for higher speed operation, it is recommended that the maximum permissible cant deficiency for higher speed operation be fixed at 100 mm.

9.21 ***Limiting values for track defects on curves***

9.21.1 The effect, on the behaviour of the WDM_4 locomotive and ICF all coil coach, of various types of defects on straight track, has been discussed in para 9.7 to 9.10 of this report, and the limiting values for unevenness, alignment defects and twist have been indicated, for track on which higher speed operation of these vehicles is to be permitted. A similar analysis has been made for curved track. This analysis is based on the oscillation trials undertaken on test section No. 5. The geometrical characteristics of the track in test section No. 5, have been obtained from the track recording charts and also from ground measurements. The unevenness values are those obtained under loaded conditions, the versine, cross level and gauge readings are on the floating track'. The variations in versines are those observed from the average versine of the stretch of track under consideration. Similarly, the cross level variation is the departure from the average super-elevation of the stretch of track.

9.21.2 The results of the analysis are incorporated in the charts at Figs. IV-9 to IV-15 of Annexure IV. The charts indicate the relationship between the following

(a) Unevenness and primary spring deflection, in the WDM_4 locomotive

(b) Unevenness and primary spring deflection, in the ICF coach

(c) Unevenness and vertical accelerations, in the WDM_4 locomotive

(d) Unevenness and vertical accelerations, in the ICF coach

(e) Alignment and lateral forces (at axle level), in the WDM_4 locomotive

(f) Alignment and lateral accelerations, in the WDM_4 locomotive

(g) Alignment and lateral accelerations, in the ICF coach

9.21.3 Since the data analysed is only that relating to one test section, the number of points in the above charts are not as large as in the charts relating to the straight track. For a comparative study of the above charts, relating to the curved track, with the charts at Figs. III-1 to III-5 and Figs. III-8 to III-10, giving similar relationship for straight track, enveloping lines from the chart for the straight track have been reproduced, in the corresponding charts for curved track. In the study of the data presented in the charts at Figs. IV-9 to IV-15, it is to be noted that the vertical load variations, lateral forces, vertical accelerations and lateral accelerations, arising out of local track defects, on curves, have to be super-imposed on the corresponding vehicle parameters, resulting from cant deficiency.

9.21.4 A study of the charts at Figs. IV-9 to IV-15, shows that for the larger magnitudes to track defects, the observed values of vehicle disturbance, due to local track defects, are generally well within the enveloping lines reproduced from the corresponding charts for straight track. For the small values of track defects, the observed vehicle disturbances are at times found to be more than those covered by the boundary lines. This would appear to be due to the vehicle, being more sensitive to a combination of track defects on curves, than when it meets similar circumstances on straight track. A local variation of unevenness, or cross level, result in a local change in cant deficiency giving rise to corresponding increase in lateral forces and lateral accelerations. Similarly, alignment defects can give rise to an increase in spring deflections and corresponding vertical disturbances in the vehilce. A study of the oscillation charts, however, indicate that as regards vertical and lateral behaviour, the two vehicles are less lively on curves, than on straight and mildly curved track. This may perhaps be due to the fact that on the sharper curves the vehicle has a tendency to hug the outer rail. As a result of the study of the data mentioned above, it was considered that for purposes of arriving at limiting values of track defects it will be satisfactory if it is presumed that the vehicle disturbances, due to local defects on curves, would be comparable to those occurring on straight track, on account of local defects of correponding magnitudes. The analysis has been done on the basis that wheel off-loading, accelerations etc. occurring on account of local defects on curves, when added to the steady values occurring on account of cant deficiency, should be within the limits prescribed for the criteria of stability and riding comfort.

9.21.5 The analysis of the data collected from test section No. 5, on the lines indicated above, shows that the limiting values for track defects on curves could be the same as those for straight track, except in the case of alignment defects. The tables in paras 9.16 to 9.19 of this report, give the maximum values of off-loading, lateral forces and lateral accelerations for the WDM_4 locomotives, and the maximum values of off-loadings and lateral accelerations, in the case of the ICF coach, for various cant deficiencies. The concurrent study of the values given in the above tables, with those obtained from the charts at Figs. IV-9 to IV-15, shows that the unevenness of the order of 15 mm on curved track could be tolerated by the two vehicles without exceeding permissible limits, for wheel off-loading and vertical accelerations, when this occurs with the cant deficiencies of 100 mm. Even when the cant deficiency is of the order of 150 mm, the values of wheel off-loading and vertical accelerations may not be exceeded. The lateral forces recorded on the curve have, under all conditions and speeds been well within permissible limits and did not become a governing consideration in arriving at permissible limits for alignment defects. In the case of the WDM_4 locomotive, it is found that a local alignment defect in the curve of about 10 mm, may result in lateral accelerations exceeding the value of 0.35 g, if the cant deficiency is 100 mm. With a cant deficiency of 100 mm and alignment defect of ± 7 mm the lateral accelerations in the locomotive would be within the permissible values of 0.35 g. As regards the ICF coach, the lateral accelerations are of a much lower order and local alignment defects of 10 mm would be tolerated by the coach, even with a cant deficiency higher than 100 mm. An alignment defect of 10 mm occurring with a cant deficiency of 150 mm is likely to result in a lateral acceleration within 0.35 g, in the case of the ICF coach. It has, however, been indicated, in para 9.20 above, that for higher speed track on the BG a cant deficiency larger than 100 mm is not at present proposed.

9.21.6 Based on the discussions in the preceding paragraphs, it is considered that local defects in alignment on curves may not exceed ± 7 mm, when measured on a chord of 7.5 metres. The total variation in versine from chord to chord, should not however exceed 10 mm. In the case of unevenness, it is considered that the limits as prescribed for straight track are satisfactory for curved track also. Special efforts have to be made for improvement of the joints, so as to utilise the temporary relaxed limits of 10 mm and 15 mm for unevenness, only for as short a period as possible. As regards other parameters such as cross level, twist and gauge, the considerations governing the tolerances, in the case of curved track, would be the same as discussed earlier in the case of straight track. It is felt that as regards cross levels and gauge no special tolerances need be prescribed for Broad Gauge track, on which speed of 120/125 kmph is to be permitted. As regards twist the limits of 2 mm per metre for general application and 3.5 mm per metre for isolated location would be applicable in the case of curves also.

9.22 *Transition lengths*

9.22.1 In arriving at transition lengths for curves, an important consideration is that of comfort of passengers, as the vehicle passes over the transition. A vehicle passing over a curve is subject to a lateral acceleration on account of the cant deficiency. The steady lateral acceleration experienced on the uniform curve is not a cause of discomfort, as long as the values of the accelerations are within practical limits. Any rapid changes in the lateral accelerations, however, cause discomfort. The length of the transition has to be sufficiently large to obtain a satisfactorily low rate of change of lateral acceleration from the curved track on to the tangents. A rate of change of lateral acceleration, of the order of 1 ft per $secs^2$/sec, is considered entirely satisfactory from the point of view of comfort. This limit will result in a rate of change of cant deficiency of 52.2 mm/sec. On high speed track (140/160 kmph) in foreign countries, values up to 60 mm/sec are currently adopted, for standard gauge, for the rate of change of cant deficiency. 55 mm/sec for rate of change of cant deficiency, is considered a suitable value for adopting in India, for track over which higher speeds (120/160 kmph) are to be permitted. This would be entirely satisfactory from the point of view of comfort since our gauge is wider than the Standard Gauge of the European countries. During the test runs on test section No. 5, rate of change of cant deficiencies of the order of 90 mm/sec had been achieved without any appreciable discomfort.

9.22.2 The Way and Works Manual permits a maximum value of 165 mm for cant on curves and it is not proposed to make any change in it for speeds up to 120/125 kmph. The limiting value of cant gradient at present prescribed in the

'Way & Works Manual' is 1 in 720. For a cant gradient of 1 in 720 and a speed of 120 kmph, the rate of change of cant is 46.2 mm/sec. This value being well within the recommended value of 55 mm/sec, a cant gradient of 1 in 720 could be permitted for a sanctioned speed of 120 kmph. The cant gradient recommended by foreign railways for higher speed operation (140/160 kmph) varies from 1 in 1000 to 1 in 1200. Lower values down to 1 in 500 are permitted in special cases. The cant gradient of 1 in 720, proposed for a speed of 120 kmph, would be generally in line with the practices followed by other railways.

9.23 *Limits of track defects on transitions :* One item of track tolerance, requiring special consideration in the case of transitions, is that relating to twist. The cant gradient of 1 in 720, at present permitted by the Indian Railways Way and Works Manual, corresponds to a twist of 1.4 mm/metre. In foreign countries, for high speed track (140/160 kmph) the maximum twist permitted on transitions is of the order of 3.5 mm per metre, including local defects. On Broad Gauge track, for speed upto 120/125 kmph, a somewhat larger limiting value could perhaps be considered. It is, however, felt that it would be preferable to keep the limiting value of twist on transitions to 3.5 mm per metre for B.G. track, on which speeds of 120/125 kmph is to be permitted. In this case, it is necessary that the extent of local defect as regards twist on transitions be limited to 2.1 mm/metre. This limiting tolerance of 2.1 mm per metre, would apply for isolated locations on the transition. The general maintenance standard of the transition should be such thet the local defects on account of twist are within 1 mm/metre. The measurement of twist as indicated above is to be taken on loaded track, on a base of 3.5 metres.

10. Behaviour of new and worn out vehicles

10.1 The oscillation trials, on test sections 1 to 5 were conducted with WDM_4 locomotive and ICF all coil coach, in 'new condition' as well as in 'worn out condition'. The details regarding the comparative behaviour of the vehicles in these two conditions are incorporated in Volume II of this report. From these details, it would be observed that the differences in vehicle behaviour are so small as to permit both 'new' and 'worn out' vehicles to operate on track to the tolerances indicated earlier. The trials with ICF coach included both on empty vehicles and on loaded vehicles. The comparative data, for the vehicles in the two conditions, is incorporated in Volume II of this report. It is seen that the vehicle behaviour is practically the same under the two conditions and no reassessment of the tolerances is required on this basis.

10.2 The five test sections over which the oscillation trials were conducted, had not been specially prepared for these trials. They were selected on the basis that they included track defects of various magnitudes. A detailed study of the behaviour of these vehicles on these five test sections is incorporated in Volume II of this report. This study confirms the satisfactoriness of the tolerances indicated in this volume and also the suitability of the proposals as regards cant deficiency and length of transitions.

11. Observations

11.1 The analysis of the data obtained from the oscillation trials on the first four test sections, where the track was either on the straight or on mild curves, has given sufficient basic information for stipulating limiting values for track defects as regards unevenness and alignment, on such track. As regards twist, the tolerances have been based on a consideration of International Practices for high speed track. It is considered that no special tolerances need be prescribed as regards cross levels and gauge, for B.G. track on which speed of the order of 120/125 kmph is to be permitted.

11.2 The analysis of the data from test section No. 5, gives the basic information necessary for indicating that an increase in cant deficiency to 100 mm is permissible, for track meant for higher speed operation, which is maintained to specified tolerances. It is further observed that the cant gradient of 1 in 720, at present prescribed in the Way & Works Manual, is suitable for general operation at moderately higher speeds, of the order of 120/125, kmph, subject to tolerances in twist being kept within specified limits. A rate of change of cant deficiency of 55 mm/sec. could be adopted for high speed track.

11.3 The tolerances and parameters for curves indicated above would also apply for track on which trials may be conducted at speeds up to 136 kmph.

11.4 The investigations so far undertaken on the Delhi-Howrah route are with the WDM_4 locomotive and ICF all coil coaching stock and the above observations would, for the present, apply only to these two vehicles. The question of track tolerances for other vehicles have to be investigated separately.

11.5 The investigations undertaken with the WDM_4 locomotive and ICF all coil coaching stock, in 'worn out' condition show that the specified track tolerances and curve parameters would apply, both to new as well as to 'worn out' vehicles. In the case of the ICF coach, the observations in the previous paragraphs, would apply to vehicles in loaded and empty condition.

12. Recommendations

12.1 On the basis of the data discussed above, it is recommended that the following limits are prescribed for the guidance of the Engineering officials in deciding on the suitabilty, of the standard of maintenance of the track, for general operation of the WDM4 locomotive and the ICF all coil coaching stock at a sanctioned speed of 120 kmph, and at test speeds up to 136 kmph.

(i) *Alignment defects* (versine measured on a chord of 7.5 metres)*

(a) *On straight track*—5 mm; values of 10 mm could be tolerated at a few isolated spots.

(b) *On curves*—± 5 mm over the average versine. Values up to ± 7 mm could be tolerated at a few isolated spots.

Total change of versine from chord to chord should not exceed 10 mm.

(ii) *Cross Level Defects* :—No special tolerance limits. As regards cross levels, the track should be maintained, to standards generally superior to that at present available on main line track on which unrestricted speeds are permitted.

(iii) *Twist***

(a) On straight and curve track, other than on transitions—2 mm/metre, except that at isolated locations, this may go up to 3.5 mm/metre.

(b) On transitions of curves—Local defects should not exceed 1 mm/metres, except that at isolated locations this may go up to 2.1 mm per metre.

(iv) ****Unevenness rail joint depressions*,—6 mm in general and 10 mm for isolated locations.

(v) *Gauge variations*—No special specifications. The maximum limits for tight and slack gauge should be as indicated in the Indian Railways Way and Works Manual.

12.2 It is recommended that for curves, on track which is maintained to the tolerances indicated above for higher speed operation, a cant deficiency up to 100 mm may be permitted. On such track, a speed of 120 kmph may be permitted for general operation of WDM_4 locomotives and ICF all coil coaching stock provided the cant gradient does not exceed 1 in 720 and the rate of change of cant and cant deficiency does not exceed 55 mm/sec.

*The versine measurements may be either on the 'floating track' or on 'loaded track'.

**Twist measurements are to be made on the loaded track, on a base of 3.5 metres.

***The unevenness is to be measured on loaded track, on a base of 3.5 metres. As an immediate beginning for the introduction of higher speeds, these limits may be relaxed up to 10 mm in general and 15 mm for isolated locations. For curves, these relaxations should be availed of for as short a period as possible.