ELIMINATING SPEED CONSTRAINTS ALONG KADUNA-ZARIA RAILWAY LINK

BY

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October, 1996

CERTIFICATION

This research project entitled Eliminating Speed Constraints along Kaduna-Zaria Railway Link by Laziz Wahab AMADU meets the regulation governing the award of the degree of M.Sc. Transportation Engineering, Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DECLARATION

I hereby declare that this thesis has been prepared by me and that it is a record of my own research work. It has not been presented in any previous publication for a higher degree. All quotations are indicated and the sources of information are appropriately acknowledged by means of references.

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October,1996

DEDICATION

Dedicated to my mother, wife and children, and particularly to my late father, Alh. Abdulaziz Amadu.

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All praises belong to Allah, the most Merciful and Compassionate; for making it possible to undertake this course. I would like to thank first of all my major supervisor, Professor O. Adebisi(currently the Deputy Vice-Chancellor(Academics) of Ahmadu Bello University), for providing technical guidance, counsel and advice and for his continued encouragement throughout the project writing. I also appreciate his attention in reviewing the project.

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ABSTRACT

At the moment, the Railway system in Nigeria is generally unreliable and inefficient. For instance, the journey time on Kaduna to Zaria rail link of 84 km takes 2 hours 15 minutes compared to 45 minutes by road. The problem is due largely to line related infrastructures and geometrical limitations of the route. Specific instances of speed restrictions are identified, analysed and redesigned as appropriate. A short term plan which is not capital intensive is formulated to increase speed on the line to a maximum of 110 km/h.

From data collected on operational characteristics with respect to existing system and design guidelines from standard texts coupled with direct observations through site surveys and experiment, the following factors were examined:-

-Stress on both tangent and curved track due to static and dynamic loads.

-Cant deficiency, superelevation and length of transition for curves

-Curve realignment and easement of curves.

Data analysis, showed that all curves having curvature higher than 3 degree and which constitute 13 percent length of the section, cannot permit speed higher than 100 km/h even when the track structure was confirmed okay for 100 km/h. Rail section wormout on the rail head beyond 10 percent does not permit speed higher than 90 km/h. Track turnout is another hinderance to speed with permissible speed of 60 km/h only. Suitable designs and proposals that effectively eliminate the identified constraints are given.

Specific recommendations to achieve the set objectives were fashioned out in a coordinated perspective planning by considering 15 years long term plan, phased out in a three short term plan of 5 years each. Under each phase, a set of tasks to be performed such as :- safety installation improvement at level crossing and good riding quality, Signalling/Interlocking improvement. Track layout and structural improvement- by completely realigning sharp curves having total length of 10.12 km, rolling stock and traffic movement improvement; are judiciously implemented.

If the recommendations of this research are undertaken, the Railway will spend only about ten million, nine hundred and twenty-six thousand and thirty-six naira (N 10,926,036:00) for the execution, and the savings likely to acrue is ten million three hundred and forty-six thousand six hundred and ninety-eight naira, eighty kobo(N 10, 346,698:80) per annum.

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LIST OF SYMBOLS AND ABBREVIATIONS

A : Cross-section area of one rail (cm^2)

a : Sleeper spacing

a_f: Acceleration rate of train in $m/sec.^2$

a_L : Permissible Lateral acceleration m/sec^2

b : Half wheel gauge in mm

b_1 : Width of rail bottom flange in cm

b_{11}: Sleeper bearing width

b_f : Deceleration rate of train in m/sec^2

BYO : Code letter Birin Yero Station

C : Equilibrium cant in mm

C_1 : Existing cant in mm

C_l : Bogie axle spacing

C_p : Prescribed or proposed cant at site in mm

C_{pa}: Average proposed cant

C_{max}: Maximum permissible cant

C_T: Train traffic capacity in train per day

C_x: Wheel dimension in cm

D: Cant defficiency in mm

D_a: Arrival punctuality in min.

DB: Code letter for Dumbi Station

D_d: Departure punctuality of train in min.

D_i: Distance covered in m

D_s: Sleeper spring constant

D^o: Degree of curvature

d': Heel divergence of turnout in m

D_{max}: Maximum permissible cant defficiency

E: Excess cant in mm

E_p: Proposed excess cant in mm

E_{max}: Maximum permissible excess cant in mm

E_{mo}: Modulus of elascticity of rail in kg/cm^2

f: Rail stress in kg/cm^2

f_a: Allowable limit of rail stress in kg/cm^2

f_b: Ballast stress in kg/cm^2

f_k: Frequency of oscillation in cycle/sec(Hz)

f_{ma}: Maximum lateral buckling misalignment in cm

freq: Frequency of occurance in No.

g: Acceleration due to gravity in m/sec^2

G: Dynamic gauge of track in m

G_t: Gauge of track in m

h: Minimum depth of ballast in cm

h_r: Rail height in mm

Δhr: Head wear of rail in mm

HP: Horse power rating of locomotive

I: Moment of inertia of rail in cm^4

I_y, I_x: Moment of inertia of rail in y and x axes respectively in cm^4

I_d: Dynamic factor (effect) of moving train on track

IP: Intersection point

K: Wheel base coefficient

KDJ: Code letter for Kaduna Junction Station

KDN: Code letter for Kaduna North Station

l: Length of sleeper in cm

l_{cir}: Length of circular arc in m

l_{max}: Maximum length between stations in km

L: Length of the link in km

L_s: Transition length in m

L_T: Total length of curvature in m

L_w: Total weight of locomotive in tonnes

M: Bending moment

M_{max}: Maximum bending moment

m_u: Lateral unsprung vehicle mass in tonnes

n: Number of axle

n_1: Number of station in the link

N: Number of crossing

N_1: Gradient

NTR: New turnout revised

P: Axle load

P_k: static wheel load

P_E, P_w: Effective wheel load, dynamic wheel load

Q: Instantaneous wheel load

Q_s: Resistance to lateral displacement of sleepers

R: Radius of curve in m

r_1: Wheel radius

RBS: Revised British Standard for rail specification

r_{tup}, r_{tdown}: Running time for up and down trains in min

RUR: Code letter for Farin Ruwa Station

S: Shirt of horizontal curve in m

S*: Constant for computing impact force of wheel on track

SL: Switch length of turnout in m

S_{tup},S_{tdown} Stopping time for up and down trains in min.

S_s: Sleepers stress in kg/cm^2

SYt: Code letter for Sayi Station

t_1, t_2: Time of train acceleration and decceleration in min.

T: Time loss by train in a station

T_T: Total time loss by train in stations throughout the link

T_{sc}: Sectional timing of train in the link

T_a: Actual train arrival time

T_d: Departure time of train

T_s: Scheduled arrival time

T_L: Total tangent length in m

TP: Tangent point

U: Track modulus in kg/cm^2

V: Velocity in km/h

V ': Velocity in m/sec

V_i: Earthwork volume

V_{max}: Maximum speed in km/h

V_s: Safe speed on transition curve in km/h

V'_s: Safe speed on untransition curve in km/h

V_v: Versine of horizontal curve in mm

W_n: Work done by locomotive in horse power rating

W_r: Rail weight in kg/m

W_Z: Ride index

WSN: Code letter for Wusano Station

Y: Impact force from wheel on rail in KN

y_i,y_{iL}: Depression of rail under wheel load in mm

Z_a: Moment of resistance of wornout rail in cm^3

Z_i: Moment of resistance of new rail in cm^3

ZRX: Code letter for Zaria Station

α:	Speed coefficient
α_c:	Angle of crossing
α':	Wheel effective conicity
α_1:	Impact angle in radian/m
σ:	Standard deviation of time
θ_S:	Switch angle
t:	Mean time in hr
λ:	Constant dependent on track parameter in cm^{-1}
ϕ_1:	Angle of transition curve
β_1, β:	Coefficient of depression under load
μ:	Coefficient of friction.

CHAPTER ONE

INTRODUCTION

1.1 PREAMBLE

The entire Nigerian Railway network consists of 3,505 route kilometres and about 808 km sidings. It is classified into main lines and branch lines and variously laid with rail sections of 22.32 kg/m, 27.28kg/m, 29.76 kg/m (60BS), 35.40kg/m (70A) and 39.68kg/m (80 RBS). This particular study is focussed on the Kaduna - Zaria link.

Kaduna to Zaria rail link, is on the main line and consists of 70A rails laid on twin block concrete sleepers. The length of the section is 84 route kilometres.The section is a single line track with gauge 1067mm wide. The track runs on long welded rails with joints at 0.78km and with an average gradient of 0.78 percent. The maximum grade is up to 1.25 percent as shown in Appendix A. The section is made up of 18.86km (23 percent) curved-track with 4.30km of the curves having radius greater than 870m (flat curves) and 14.56km of the curves less than 870m radii (sharp curves).

At the moment, average speeds for both passenger and freight trains are very low while long delays frequently occur. These factors result in long travel times and disruption of train time-tables, thus making train journeys unreliable. Existing permissible maximum speed is 65km/h but average running speed in the section is 40km/h for goods trains and 55km/h for passenger trains as in Fig. A.3 Appendix A.

1.2 DETERMINING FACTORS OF EFFICIENT RAILWAY SYSTEM

An efficient railway system should carry more traffic at high speed while it attains a maximum line capacity. In attaining the maximum capacity of the section,two components of time such as,

a) time between stations (T_1); and

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b) time for operational safety requirement and loading, (T_2) should be minimized.

Minimizing first time component (T_1) relates to maximizing speed and minimizing the second time component (T_2) relates to operational research by way of improvements as shown in Fig. 1.1

In relative terms, T_1 constitutes about 95 percent of total travel time and this research work is focussed largely on this component of travel time.

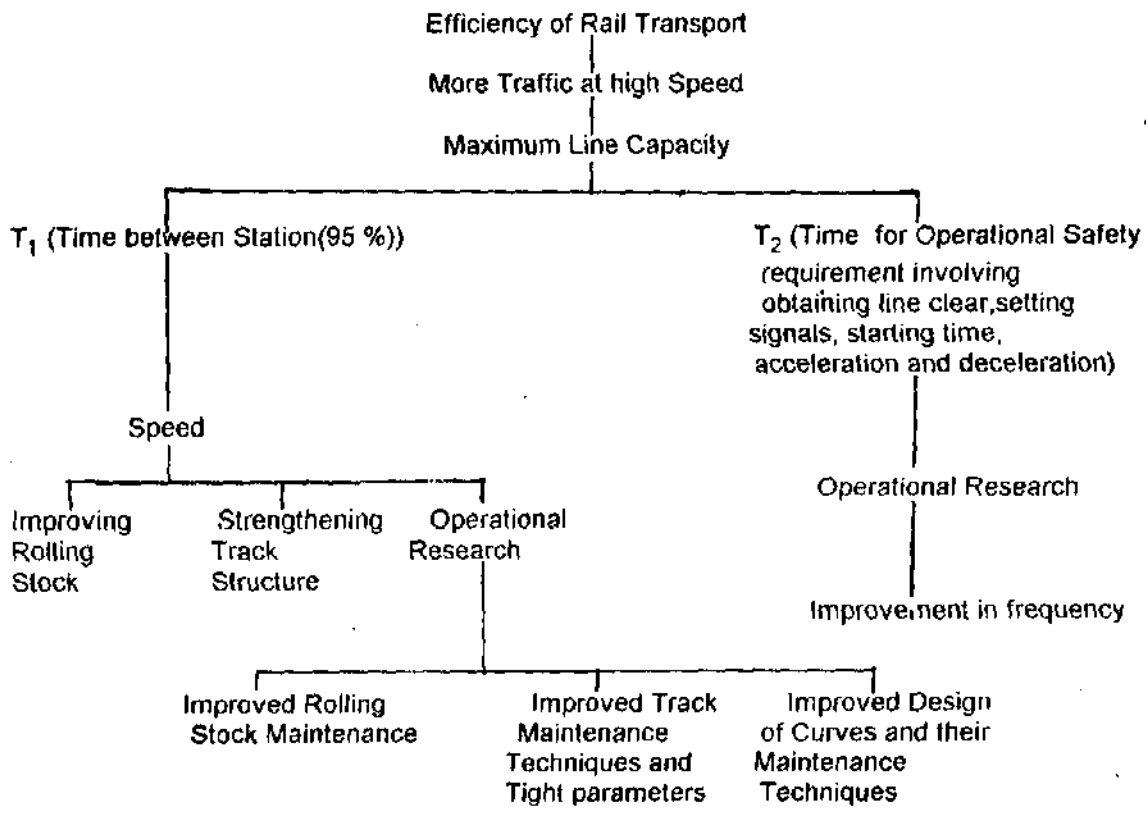


Fig. 1.1: Determinants of an Efficient Railway

1.3 THE PROBLEMS OF THE STUDIED RAILWAY TRACK

1.3.1 Historical Background:

The first rail line in Nigeria was built between 1898 and 1909 to link the seaport of Lagos with Ibadan and Jebba. The rail-line from Jebba to Kaduna and Kano was constructed with the opening of the bridge at Jebba in 1915. Further expansions took the network to what is shown in Fig.H.1 Appendix H

Between 1955 and 1963, Nigerian railway recorded high operating results but from 1964 to 1979, the furtunes of Nigerian Railway started to decline and the cost of operations over revenue rose above 100%. In 1979, the system was contracted to the Railway of India Technical and Economic Services (RITES) which ran the system till 1982. During this period, Nigerian Railway enjoyed enormous financial support from government and its overall results were quite good. During the period of 1982 to 1988, attempts were made to formulate an action plan for the revitalization of the system; unfortunately they were inconclusive. From 1989 to date, the focus has been on planning for commercialization of the corporation.

At the moment, the Nigerian Railway is beset by many operational problems which include; poor track alignment and design standards when line was first constructed, stagnation in development of rail network since 1964 coupled with neglect of existing infrastructure in areas of maintenance, dearth of locomotives and rolling stocks, unreliable and malfunctioning locomotives and wagons, inadequate or obsolete telecommunication facilities, reduced or limited line capacity and indiscipline amongst the staff.

1.3.2 Speed Potential: Kaduna - Zaria Link

It is commonly held that the present gauge of 1067mm is not necessarily the major constraint to higher speed of up to 160km/h. Many countries with 1067mm gauge such as Cote de Voire and India have achieved speed of up to 160km/h on that gauge. Conceviably, therefore, Kaduna to Zaria line can achieve average speed of up to 100km/h for passenger trains and 80km/h for goods trains with minimum improvement and modernization of exisiting track and communication system. For higher speeds on the Railway, the standard of maintenance and tolerance would need to be vastly improved.

The Rail link is already laid with long welded rail on concrete sleepers and elastic fastening which could meet the requirement for higher speed. This aspect will be investigated in this work and the permissible maximum speed will be determined.

1.4 GOALS AND OBJECTIVES OF THE STUDY

The primary goal of this study is to prescribe steps to be taken to increase speed and enhance reliability on the existing Kaduna - Zaria Railway link. Towards this end, the following specific objectives are earmarked for the study:

i) To isolate all constraints against the attainment of maximum speed of up to 120km/h and average speed of 95km/h for passenger and 75km/h for freight trains.

ii) To come up with design changes needed to attain (i)

iii) To improve the track structure and geometry and ensure safety and high riding comfort consistent with the speed target in (i)

iv) To identify delays in journey time and counter measures against delays so that average running speed of train will be greater than 100km/h.

1.5 SCOPE OF THE PROJECT

This research work concentrates mainly on the Civil Engineering aspects of the railway system relating to the proposed increase in speed. In this regard the work seeks to:

-Determine whether the track structure, track layout, track geometry, tractive power units (locomotives), rolling stock and signalling systems are capable of facilitating the target speeds of the trains

-Identify constraints on speed

-Make proposals on how to remove the constraints

-Analyse the safety implications of such proposed improvement

The following factors affecting speed and reliability are specifically looked into:

-Turnouts and yards improvement as consistent with the speed targets. Areas of restriction to speed especially curves, track geometry, etc.

-Aspect of operation relating to the requirement of the objectives of study especially those relating to improve travel time are looked into.

1.6 CONSTRAINTS TO THE RESEARCH

At the moment, it is difficult to study the effects of lateral and vertical accelerations at various speeds. This is simply because Nigerian Railway has not yet set up an experimental track that could facilitate such observations. Such a track should be with suitable gauge, isolated from the existing main line track and should be at least 10km long while incorporating the various track parameters to be tested for, e.g. long welded rail, concrete and steel sleepers on straight and on curve tracks, and various curve radii, etc.

Another constraint is the non-availability of a mobile laboratory incorporated in a coach and equipped with measuring devices such as, strain gauge for measuring lateral and horizontal forces, wheel set equipment on calibration bench for calibration of the axle (at the wheel and on deck of coach or wagon), accelerometer for monitoring acceleration of rolling stock components. The two factors described above are two of the major constraints to the study.

1.7 OUTLINE OF STUDY METHODOLOGY

Both analytical and statistical methods have been utilized. The basic steps are outlined below:

-Analysis of static and dynamic stresses induced on track structure at proposed speed by theoretical methods

-Survey of all existing Railway infrastructure and their adequacy at the speed targets.

-Analysis of the sectional profiles of the permanent way especially alignments and suitability of rail section and sleepers to withstand the induced stress. The depression pegs experiment is used in assessing the track modulus and dynamic effect of train on track.

-The geometrical characteristics of the sections of track are scrutinized very closely on the premises of the adequacy and effectiveness of the tolerance and other relevant parameters regarding track structure, signalling/interlocking, etc. Both by theoretical consideration and actual trial runs of Matisa Trolley Recording Machine along the link.

-Analysis of speed chart from trial runs with reference to existing section profile with a view to appraising speed restrictions at critical sections.

Fuller details of the methodology are given later in the text.

1.8 SIGNIFICANCE OF THE RESEARCH

The real justication of the project is better appreciated by contrasting with the situation that would result if the project were not implemented. For one, speed of trains would continue to decrease drastically because the effects of speed restrictions would become more severe as the tracks age. Consequently substantial reduction in level of service and considerable loss of revenue would result and this would cause diversion of more railway traffic to road transport. It is instructive to note that increasing speed of British Intercity Services from the range of 96km/h to 112km/h to the range 112 to 128km/h produced N450 million (10 million pounds) additional revenue [12].

Thus, the significance of this research derives from the improved efficiency that will acrue in the areas of travel time reduction, technology advancement, enhanced competition with other modes and better split of traffic load among modes. The improvement of train reliability on the Kaduna - Zaria link especially will be of significance in terms of economy and social activities. It will also bring about the following:

-Improved margin of safety at high speed

-Improved speeds of passenger and freight services

-Ensure elimination of speed restrictions at critical sections with attendant increase in the capacity, reduced turnround of rolling stock and enhanced operating efficiency.

-Reduced delay to passenger trains and delivery of goods.

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW OF PREVIOUS SPEED ENHANCEMENT EFFORT

Increase in speed on Railways has assumed a major importance throughout the world. Speed of up to 250km/h had already been attained by Japanese National Railways. The thrust of speed enhancement efforts on railway is to make the mode more competitive than the air mode for distances of less than 500km, in terms of door-to-door travel times. The work done by some countries of the world with respect to speed increase is reviewed in this chapter.

2.2 PREVIOUS EFFORTS IN THE SOVIET UNION

Research to increase speed of trains on existing Railway system for Soviet Railways was undertaken by setting up a special programme to upgrade a number of lines to run trains at speeds of 160km/h. After extensive analyses, Sotnikov [43] suggested the following as being necessary to achieve high speeds:

-Use of 65kg/m rails to be laid on concrete sleepers with 25mm deep rail seat and spring type fasternings as well as shock absorbing rail pads.

-Turnout design should be such that it ensures trouble-free operation at temperature ranges between +40°C and -40°C. Where excessive heat pose problems, roofing of turnout areas was recommended.

-Track formation where local material used as filling is stablized by using cementing additives and consolidation materials to reinforce the upper layer of the formation (geotextile fabrics and foils, foam plastics as well as other materials were recommended).

-Planting of forest strips along the line to protect track against drifting snow.

-Use of high speed power locomotive of dual electric voltage operated on 24KV AC and 3KV D.C. lines and having a rated capacity of 8,000 to 10,000 KW. The locomotives

were recommended to be placed on both ends of the train and to be synchronously remote controlled.

-The bogies of high speed coaches to be equipped with independent damping of vertical and horizontal oscillation.

-Connection of coaches to be through a rigid type of automatic coupling with pressure sealed-off intercoaches passes.

-Use of good catenary suspension system for electric locomotive

-Use of automatic block signalling and automatic locomotive cab-signalling. The headways between trains going each direction could be as low as 6 minutes.

2.3 PREVIOUS EFFORTS IN BRITAIN

The British Railway operated speeds as high as 160km/h before 1976. In 1976, the upper speed limit was extended to 200km/h. Heard [19], highlighted the factors responsible for the problems being experienced at high and very high speeds running on British Rail. He reviewed all aspects of high speed operation on British rail track and suggested the following:

-Provision of an earlier warning signal to drivers of high speed trains when approaching speed restrictions or diverging junctions. He considered use of Automatic warning system adequate, provided a reaction time of 7seconds is incorporated in the design. Additionally, he also recommended two yellow flashing lights spaced at about 275m apart and flashing at a rate of 60 per minute and steady yellow at the junction is illuminated.

-Elimination of level crossing by providing overhead bridges to replace the crossings.

-Enhanced methods of checking the integrity of rails by way of frequent and ultrasonic testing of rails.

-Use of swing-nose crossing to reduce hammer-blows at crossing.

-Use of radio communication to provide fail safe data links between signalling centres and trains. This method enables information to be passed to any train requiring it within 2 to 2.5 seconds.

In his own assessment, Emerson [12] concluded that; "Improved timing and speed are possible on route of easy curvature which have been maintained in accordance with a proper classification system, with moderate expense on slewing and with only small amendments to prevent rules relating to speed, curvature and cant.

On routes having sharper curvatures and with more physical obstructions to slewing, improved timing and speeds are possible if the rules relating to speed, curvature and cant are applied using values based on modern track testing procedure, subject to safeguards involving the design of vehicles and the wear and maintenance of track under high speeds. Limits of tolerance should be laid down for all track parameters"

2.4 PREVIOUS EFFORTS ON THE FRENCH RAILWAY (SNCF)

French Railway lines have been able to achieve high speed of 380 km/h. Montagne [30] wrote on Five year's experience with French high speed track achievements and future prospects, and highlighted the technological characteristics required for the design of a line specially intended for passenger traffic of maximum permissible speed in the range 260 - 300 km/h as:

-Gradient profile with 14,000m minimum radius for vertical curves at sag (the most usual radius being at least 16,000 m)

-Adequately good curve profile with maximum superelevation of 180 mm and cant deficiency of 100mm.

-Design axle load on track limited to 16.5 tons

-Suspension system with non-suspended masses having low centre of graviity.

It is instructive to note that the track structure of SNCF Railway have the following characteristics:

-Minimum ballast depth of 30cm

-Heavy rail section of 60kg/m

-Twin-block concrete sleeper with two 84cm blocks and with "Nabla" elastic fasternings having 9mm grooved pad with high resistance.

-Some switch diamond turnout designed for speed of 160 - 220km/h

-High level maintenance and regular inspection of track by, regular checks on foot, tours of inspection in inspection cab or rail car and by use of accelerometer recordings, ultrasonic inspection of rails, recordings of track geometry using the Mauzin recording coaches.

-The formation is designed to distribute uniformly the stiffness characteristics of the track by using different types of substrata.

Montagne [30] enumerated the load characteristics resulting from measurements taken both on board vehicles and on the track of SNCF Railway and concluded that for:

-The lateral resistance, under 160KN axle loads, of track laid on twin-block concrete is 135 KN for stabilised track and 90KN for a non-stabilized track.

-The maximum lateral loads measured on the track, and evaluated at 99.85 percent, are limited to 26KN but during high-speed test, lateral load measurement was restricted to 40KN at 350km/h. Thus, a fairly reasonable margin of safety is incorporated in the design and operations.

-Vertical loads for the track components is such that 87 percent of the deformation energy of the rail is concentrated at frequencies below 35Hz as is 91 percent of the sleeper reaction loads. In case of the sleeper acceleration, the percentage is only 11 percent. The weakness of the high frequency stressing of track components is as a result of high degree of flexibility between rail and sleepers.

Also Prud' hamme[36] gave problems of high speed tracks as that of dynamics which he classified as:

-Problem of stability

-Problems of vertical and transverse forces induced by the layout and track defects,

-Problem relating to the quality of track geometry such as definition of a minimum level controlling this level

-Maintenance or restoration of a certain degree of quality.

2.5 PREVIOUS EFFORTS ON THE ITALIAN (FS) RAILWAYS

Rolling stock for high speed trains was assessed by Cardini[6] who found that use of rolling stock with tilting bodies is advantageous for speed higher than 250km/h. The Italian Railway utilizes mostly the tilting bodies rolling stock of the "Pendolino" series. The characteristics of such rolling stock are:

-Its bogies have improved elastic characteristics of the suspension, and of the connections between axle boxes and bogie frames, positioning of the anti-yaw dampers outside the frame, and progressive elastic buffers to restrict the transverse displacements between body and bogie.

-Braking is by a conventional electro-pneumatic braking system whose control valve actuates the electric braking system on five levels. The braking system has an automatic speed regulation system.

2.6 PREVIOUS EFFORTS ON THE POLISH RAILWAY (PKP)

Polish Railway started modernising her network in 1977 in order to introduce higher speeds on a phased basis (120km/h - 140km/h - 160km/h and over). Semrau [40] gave the policy of Polish State Railways for the modernization of the entire system as:

-Superstructure consolidation in order to handle heavier trains (22.5 ton axle load).

-Development of electrification because of its greater cost effectiveness

-Modernization of several other installations

-General introduction of automatic block signalling.

Semrau [40] also gave factors for attaining high speed as:

-Line layout with large curve radii

-Design standards of the superstructure

-Track maintenance levels

-Reliability of the signalling system

The following specific guidelines were suggested:

-Heavy track profile using 60kg/m rails

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-Conventional type continuous welded rails and sleeper spacing of 1733 prestressed concrete sleepers per kilometre.

-Use of elastic spring fastening,

-High level of track maintenance based on highly mechanised track inspection and renewal operations using high performance modern machines, specialised especially in track realignment.

-Automatic control and evaluation of superstructure defects, by means of two track cars with inborne microprocessors (type EM120) having a provision for real-time analysis and print-out of track evaluation indices.

-Development of high-calibre supervisory and management staff in key jobs, linked with work monitoring control and organizations and use of high speed locomotives with maximum speed of 160km/h.

2.7 PREVIOUS EFFORTS ON THE INDIAN RAILWAYS

Indian Railways have been able to achieve speed of 120km/h on their metre gauge track and the maximum permissible speed on broad gauge track has been increased to 130km/h on trunk routes since November, 1971. Measures taken to improve the track for further high speeds of 160km/h were enumerated by Gupta [17] as:

-Structural requirements of track component at high speed operation by using 60kg/m and 52kg/m rails and using elastic fastenings which can withstand the high frequency vibrations and shocks of high speed trains without affecting the track structure.

-Use of welded rails by welding of three rails together in the first stage and 5 rails panel in the second stage.

-Use of concrete sleepers and sleeper spacing of 1,667 sleepers per kilometre.

-Ballast cushion should not be less than 25 cm for long welded track with ballast shoulder width of 35cm on straight and 50cm on curves.

-Suitable subgrade, stabilizing the formation if found defective

-Turnout should have long curves and switches, either switch and crossing to be curved to the same radius as the lead curve or transition curve should be provided between the toe of the switch and the nose of the crossings and higher cant defficiency should be provided on turnout curves.

-High level maintenance, prompt track renewals, fixed and strict adherence to track tolerances.

2.8 PREVIOUS EFFORTS ON THE PAKISTANI RAILWAYS

Pakistani Railways have long attained a speed of 160km/h on their trunk route and there are plans to increase the speed further. Ahmad [3] wrote that during mid 50s, the Pakistan Railways chose to speed up its train operation for passenger as well as freight by increase of direct speed from 96km/h to 120km/h for passenger express and 55km/h to 75km/h in case of goods trains. Necessary steps were taken to replace, renew and strengthen the existing infrastructure in respect of Track structure, Bridges, Rolling stock structure/Traction, Signalling and Telecommunication structure/systems, to achieve the targetted higher speed.

Mian [27] enumerated the major works done to achieve the speed target by rationalising the existing operations which was to involve modest investment as:

-Improvement of automatic vacuum brake system

-Improvement of existing suspension system of coaches and wagons

-Improvement in signalling by providing distance warner

-Improvement of layout of tracks by providing transitions.

Ahmed [3] summarized Pakistan Railways action plan on speed increase as:

-Introduction of heavier and more robust track structure comprising 49.6kg/m welded rail up to one kilometre length duly supported on prestressed concrete sleepers with higher sleeper density and with high value of ballast cushion.

-Mechanical signalling was progressively replaced with all relay interlocking using colour light signals.

-Autoblock was introduced to replace the age-old absolute block system

-Rolling stock with braking distance of 900 metre for speed of 120km/h on a 1,200 grade was introduced.

-Maximum trailing load on flat was determined to be 800 tonnes at 80 percent load factor corresponding to 7th notch position.

-Effective braking system using 50 percent composite brake shoe/blocks and 50 percent cast iron block shoes was introduced.

2.9 PREVIOUS EFFORTS ON THE JAPANESE NATIONAL RAILWAYS (JNR)

Observations on the experiences of the High speed track on JNR by Srinivasan [44], can be summarized as:

-On track with joints, the vertical oscillatory acceleration of the rails increased with speed, it varied from 90 to 280g (where g = acceleration due to gravity) over a speed range of 60 - 130km/h. Vibration of sleepers and ballast increased when a gap existed at the fishing (junction) surfaces of the rail. Strengthening of a joint was achieved by reduction of the expansion gap; wear of fish-plates due to loosened bolts and relative shifting of the rails are not desirable.

-On long welded rail, the vibratory acceleration varied but little with the speed and remained below 120g up to a speed of 150km/h.

-Acceleration of the rails decreased as the weight of the rail increased.

-The acceleration of ballast increased with reduction of clean ballast cushion as in a hard bed. The vibratory acceleration communicated to the ballast ranged from 0.3 to 0.6g.

-The pressure of the sleeper on the ballast and that between rail and sleeper was confirmed to the ranges 0.20 to 0.25kg/cm^2 and 1.8 to 3kg/cm^2 respectively, irrespective of the speed.

-Contrary to expectation, the rates of acceleration and frequency of vibration remained almost the same regardless of the type of rolling stock, and whether it was loaded or empty.

-Widening of track gauge in 1:8.5 turnout by 3mm and 6mm did not help in reducing the lateral forces but on the contrary, there was a slight rise in the lateral forces.

During tests at high speeds, it was discovered that for ordinary track the pressure, depression, displacement and stress were practically independent of train speed. The wheel with a flat spot about 40mm long on the tread produced rail stress, displacement and pressure twice as large as a regular wheel for speed up to 50km/h, no increment was observed at high speed.

It was, therefore concluded that, having direct influence on deformation of rail and wheel contact surfaces, the surface finish near the welded rail joint should be made with greatest care. The stress at points of change of rail section (expansion joint) as wheel transverse on rail was small enough and did not tend to increase with the speed.

2.10 PREVIOUS EFFORT ON THE NIGERIAN RAILWAY

The Nigerian Railway management on its own effort to improve existing railway system, have earmarked track curvature greater than 3 degree for elimination. Though not much has been done due to its poor finance, survey work on some of such curves have been done. On the part of Government, the idea of New standard gauge track has been conceived and necessary survey work has been done but the project has been put in abeyance on account of poor funding.

This research work seeks to establish a linkage between effort made by other countries on their Railway system as in the literature review and appropriate action plan that achieve similar result in Nigeria but such a contemplated improvement should be within available resources.

CHAPTER THREE

THEORETICAL BACKGROUND

3.1 PREAMBLE

Speed increase in rail systems is dependent largely on layout of track. Other influencing factors are loads, deformations and stresses in track components which are mainly the parasitic moment (pitching, rolling, bouncing, etc) of the vehicle on the track.

This chapter highlights influences of design and technology on the attainment of the target speed. Clearly, for now, increase in speed is to be achieved by utilizing the existing infrastructure with modernisation and improvement in the standard of maintenance practices.

3.2 INFLUENCE OF PERMANENT WAY ON SPEED

Permanent way consists of rails, sleepers, fastenings, and the ballast which are laid on a well prepared formation to form a railway path. In rail systems the aspects of permanent way that affect speed include track layout and track structure.

3.2.1 Track Layout

The specific aspects of track layout that affect speed include curve characteristics, track geometry and switch-cum-crossing assembly. Among these factors, the most important in deciding maximum rail speed is the curve, because of centrifugal force which creates lateral force between the wheel flange and the outer rail. The force is capable of causing skidding or overturning of the vehicle and often constitutes a severe constraint on safe operating speed on an existing track.

3.2.1.1 Curve Characteristics

Several limiting conditions are imposed on train operating speed on account of the track's curve characteristics. These are briefly reviewed as follows:

-Overturning due to centrifugal force, for which velocity likely to cause overturning [29] is:

$$V_o = \sqrt{((RG_1)/2H)} \qquad (1)$$

where, V_o = velocity at which overturning may occur

R = radius of the curve

H = height of centre of gravity above rail top of the vehicle and it is related to cant C in Fig. 3.. 1

G_1 = constant representing distance between rail centre (gauge of track)

The overturning limit of speed when $H/G_1 = 1$ is given by

$$V = 0.71 \sqrt{R} \qquad (2)$$

where , R = radius,in m.

-Passenger comfort is also affected during acceleration and deceleration. On this account, the comfort limit is the permissible lateral acceleration which is specified [27] as:

$$a_L = 0.1g \qquad (3)$$

where, a_L = permissible lateral acceleration in cm/sec.^{2}.

g = acceleration due to gravity

Modern rapid transit trains are often specified with a maximum braking rate [27] of 1.0 m/sec^2 or 100cm/sec^2 (= 0.1g) and the acceleration rate may also have this value in the lower part of the speed. From comfort consideration, speed limit is [29] given by:

$$V = 11.3 \sqrt{(} R(C+D)/G) \qquad (4)$$

where V = maximum compatible speed in km/h

G = dynamic gauge in mm = G_1 + 63mm

and;

C = the Cant of rail or superelevation is the elevation difference between the inner rail and the outer gauge rail along a curve as shown in Fig. 3.1, and is introduced to counteract the effect of centrifugal force. The equation for calculation of equilibrium cant required to balance centrifugal force at a speed V, is given [27] as,

$$C = (GV^2)/(0.127R) \qquad (5)$$

the cant, C is in (mm) and permissible maximum cant,

$C_{max} < 0.1G_1$

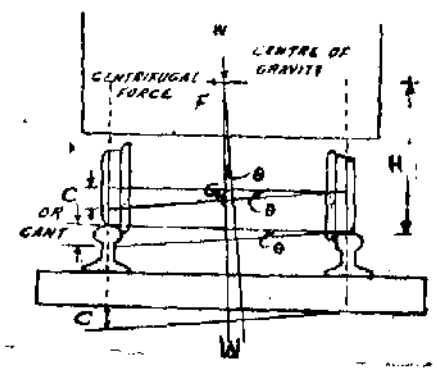


Fig. 3.1: Illustration of Cant on Elevated Track on Curve.

-D = Cant deficiency is defined as the amount by which the existing cant is less than required to attain equilibrium at particular speed. This is inevitable since traffic moves at varying speeds. The suitable value of cant deficiency is given [27] as:

$$D = ((GV^2_{max}) / (0.127R)) - C_p \qquad (6)$$

where, D = cant deficiency in (mm)

C_p = prescribed maximum cant that can be attained at site keeping in view fast trains (in mm)

i.e. $C_p = (C_{max} + C_{min}) / 2$

C_{max} = cant for fastest train

$C_{min.}$ = cant for slowest train

The cant deficiency should be within limits and an excess cant when consideration is given to trains moving at slower speed than design speed should also be specified as:

$$E = C_p - C_{max} \qquad (7)$$

where E = excess cant in mm, also

$$E_{max} = (4/5) \times D_{max} \qquad (8)$$

E_{max}= maximum excess cant permissible.

A graphical illustration of permissible speeds implied by equation (2) and (3) is given in

Fig. 3.2 wherein (H/G) has been taken as 1. It is evident from the figure that passenger comfort has greater constraint on speed than centrifugal force in almost all instances.

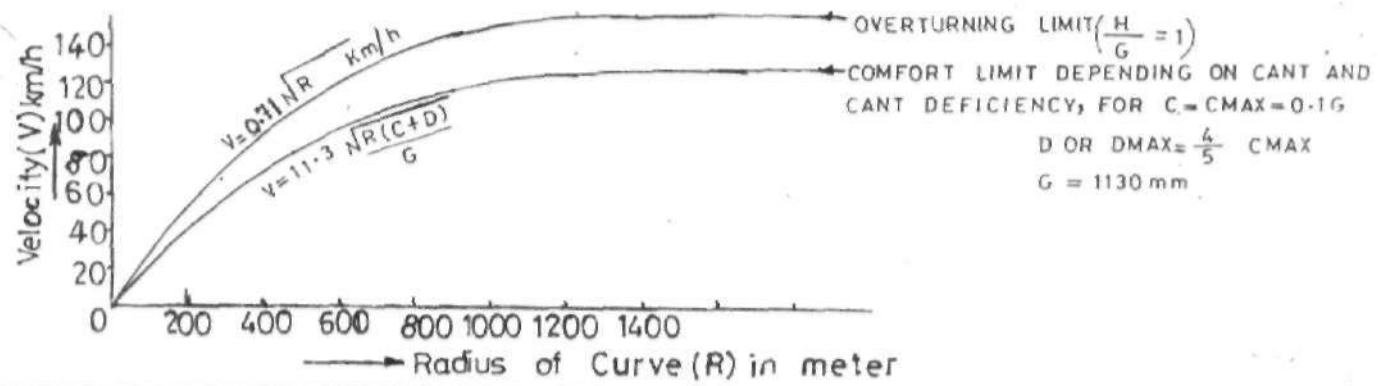


Fig. 3.2 Speed Limits on Curve Track.

-The maximum permissible velocity in km/h = V_{max}, is the highest speed permissible on a curve and its transitions when radius, cant, cant deficiency are all taken into consideration V_{max} has been shown [27] to be:

$V_{max} = 0.27 \sqrt{(R(C+D))}$; for transitioned curve or $0.27\sqrt{(R(C_1+D))}$; for untransitioned curve (9)

where, C_1 = cant at 7.2m from the tangent point of the untransition circular curve.

Actually, V_{max} in equation (9) represents a limit value and for safe operation, it can hardly be used. Rather, train operators have defined safe speed on curves, which is the speed at which a train will move on the curve. This safe speed as given in [29] is;

$V_{safe} = 4.4 \sqrt{(R-70)}$; for transitioned curve or $3.52\sqrt{(R-70)}$; for untransitioned curve (10)

where, V_{safe} = safe speed on curve in km/h.

3.2.1.2 Adequacy of Curve at Target Speed

When assessing the suitability of an existing curvature to accomodate a desirable speed, use is made of the following property of curved track.

-Degree of curve (D^o), is the angle subtended at the centre by a cord of 30.5 metre length and it is represented [8] by;

$$D^o = \frac{1746.48}{R} \text{ in degrees}$$

Or $$R = \frac{1746.48}{D^o} \quad (11)$$

-Transition and Transition Length (L_s)

Transition curve is introduced between the curved portion and the tangent. The length, L_s, of such a transition has been shown [38] to be;

$$L_s = V^3 / R\alpha_a \quad (12)$$

where α_a = rate of change of radial acceleration in m/s^3

For comfort limit, Shortt[38] gave the value of rate of change of radial acceleration, α_a= $0.3m/s^3$ above which side throw of track is noticed. When V is measured in m/s and α_a in m/s^3 and R in metres, then

$$L_s = 0.0715V^3 / R \quad (13)$$

This length of transition is used when designing a new curve or when total relocation of existing curve has been decided. However, for maintenance or slight realignment of existing curve, the desirable length of transition (L_s) is worked out from any of the following formular adopting the maximum value if site conditions permit [29]:-

$$L_s = \text{Max}\ (0.0062\ CV,\ 0.0062DV,\ 0.40C) \text{ in metre} \quad (14)$$

This is based on the rate of gain of superelevation and of deficiency equal 45mm/sec and maximum superelevation gradient of 1:6.17V in mm or 1:720.

-Shift:

For providing transition, the circular curve requires shifting inward from the original alignment as shown in Fig. 3.3 The amount of shifting of the circular curve is given [38] by:

$$S = L_s^{\,2} / 24\,R \qquad (15)$$

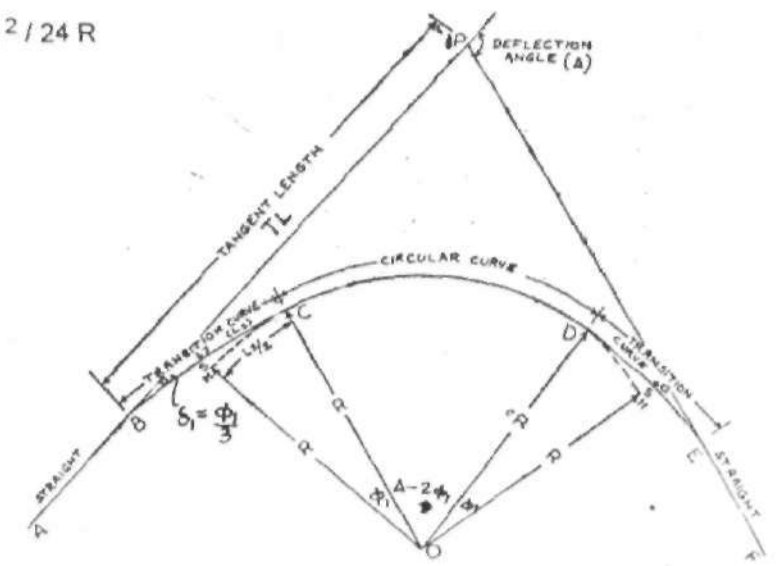


Fig. 3.3 Elements of Circular Curve with Transition

-Deflection angle, δ_1, needed to locate a point on the transition with 10m chord length and l_x(m) from TS is given [38] as,

$$\delta_1 = (1800 / \pi R L_s)\, l_x^{\,2} \text{ in minutes} \qquad (16)$$

$$\text{Length of circular arc, } L_{cir} = (\pi R/180)\,(\Delta - 2\phi_1) \qquad (17)$$

where, ϕ_1 = Angle of transition curve in radians

$$\text{Total tangent length (TL)} = (R + S)\tan(\Delta/2) + L_S / 2 \qquad (18)$$

-Minimum Radius of Curvature (R), allowed especially in a long welded rail (LWR) section should be in accordance to the formular [29], given as:

$$R = 1000/\left((1012Q_s/A.\Delta t) - (A.\Delta t.f_{ma}/13.92I_y)\right) \qquad (19)$$

where, R = Minimum radius of curvature in metre

Δt = Temperature surge above the LWR fixing temperature or maximum possible temperature minus minimum temperature

Q_s = Resistance to lateral displacement of sleepers, 5kg/cm for concrete sleeper and

7 kg/cm for steel sleepers.

f_{ma} = misalignment = 2.5cm (maximum lateral buckling misalignment)

I_y = moment of inertia of rails related to vertical axis in cm^4

A = Cross sectional area of one rail (cm^2).

-Versine or middle ordinate of a chord on to a curve is proportional to the curvature and is the basis of all railway curve alignment, checking and adjustment. For purposes of field measurements and calculation of the versine at the body of the curve, the versine, V_v, is [20] given by:

$$V_v = C_h^2 / 8R \quad \text{.....(20)}$$

where, V_v = Versine in mm

C_h = Chord length in metre usual taken as 20m

R = Radius of curve in metre.

At site, the degree (D^o) of a curvature can be determined after versine survey determination of versine from the formular,

$$D^o = 0.0349V_v \quad \text{.....(21)}$$

-Vertical curve: For preventing vibration due to vertical acceleration, vertical curves should have radius greater than 3,000m. The permissible velocity of a train on a gradient ($1:N_1$) is given [11] as;

$$W_n = 1.6\ V\ \{(5 + 0.003V^2) + 2240/ N_1\} \quad \text{.....(22)}$$

where, W_n= Work done by train on gradient of (1:N_1) in Horsepower

V = Speed in km/hr

N_1= Gradient (e.g. 1:N_1)

Work done is always specified in Horse power for locomotive.

3.2.2 Track structure

The track structure consists of rail section, sleepers or ties, fittings and fastenings, ballast section, formation (sub-ballast) or sub-grade and turnouts. The track right of way is called the permanent way. The section of track showing constituent elements is shown in Fig. 3.4 and Appendix F Drawing No. 3.

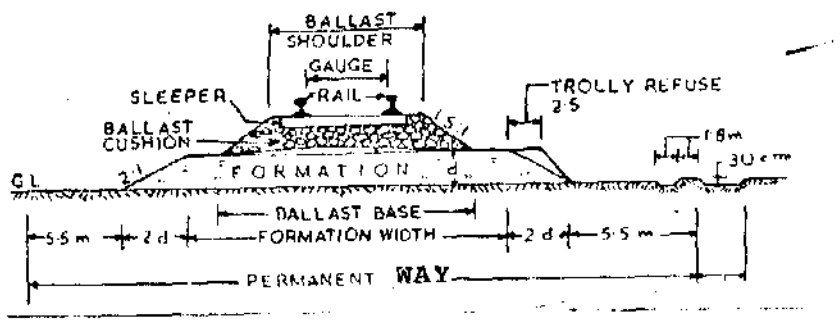


Fig. 3.4 Components of Railway Track.

For the purpose of this project the stresses in track structure are considered important both in the point of view of static and dynamic loads. Though all parts of track structure have bearing on stresses induced on account of dynamic load, those elements playing prominent part are considered as below:

3.2.3 Analysis of Stresses in Track Structure

In assessing track stress, the track system is idealized as having elastic supports equivalent to a continuous elastic foundation to simplify the analysis. Thus, a rail subjected to a wheel load P_w, has deflection ordinates as represented in Fig. 3.5.

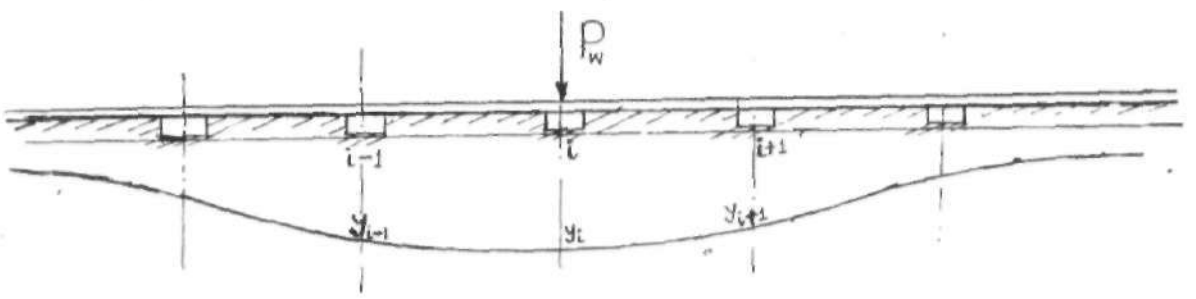


Fig. 3.5: Single-wheel Load Depression for Idealised Rail Track.

Assuming that the spring constant D_s is the same for every sleeper, and from the consideration of equilibrium we have;

$$P_w = D_s \Sigma y_i \qquad (23)$$

where, D_s = Sleeper spring constant

y_i = Deflection at point of wheel load P_w

Introducing another constant called the track or rail modulus, U, then,

$$U = D_s / a = P_w / (a \Sigma y_i) \qquad (24)$$

The rail modulus is an index for measuring the resistance to deformation of rail track. It is the pressure in kg/cm^2 on ballast surface needed to depress the ballast bed (or the rail) 1cm. The modulus can be measured using the depression peg experiment which is described in section 4.3.1.

The maximum bending moment of rail is obtained [42] as:

$$M_{max} = P_{w1}/4\lambda + P_{w2}/4\lambda \left(e^{-\lambda C_1}(Cos\lambda C_1 - Sin\lambda C_1)\right) \quad (25)$$

where, C_1 = Spacing between wheels axle in a bogie in (cm)

λ = Constant in cm^{-1}

$$\lambda = (U/4E_{mo}I)^{0.25} \quad (26)$$

U = Track modulus of track or rail in kg/cm^2

E_{mo}= Young modulus of rail in kg/cm^2

I = Moment of inertia of rail in cm^4.

P_{w1}, P_{w2} are wheel loads (in tonnes) on each axle of a locomotive when the total weight of locomotive is known, and they are expressed [29] as:

$$P_{w2} = (L_w \times (43.5 + 0.104\, C_1)) / (0.417\, C_1 + 86.9\, n + 0.208\, C_1\, n - 117) \quad (27)$$

where, L_w = Total weight of locomotive in tonnes

n = Number of axles

P_{w2} = Wheel load on any of the internal axles

Also, $$P_{w1} = (L_w / 4) - ((n-2).\, P_{w2}) / 2) \quad (28)$$

where, P_{w1}=Wheel load on any of the outer axles.

3.2.3.1 Speed Coefficient for Rail Stresses

To cater for the effects of dynamic loads an impact or dynamic factor [42] is used to modify the above loading equations. The rail resistance to stress contributed up to 15 percent of the total stresses induced on the track.

$$I_d = V/(18.2\sqrt{U}) = 0.055V / \sqrt{U} \quad (29)$$

where, I_d= Dynamic factor or speed modifier factor

V = Speed at which experiment is carried out in km/h.

This dynamic factor is applied as illustrated in equation (30) to give the effective load, P_E, as:

$$P_E = P_w(1 + I_d) \quad \text{.....(30)}$$

This formular is useful from practical consideration. Another method of modifying static load is by obtaining moment theoretically [29] from the equation;

$$M = K.P_w.\ a.\ \alpha \quad \text{.....(31)}$$

where, K = wheel base coefficient [29] for wheel loading

$K = 0.057 + (C_1 + C_2)/2$ where $C_1 < 280cm$, $C_2 < 280cm$

where C_1 and C_2 are adjacent load distribution spacing for locomotive as in Fig. 4.8.

α = Speed coefficient

$\alpha = 1 + (V^2 / 30{,}000)$ for speed up to 100 Km/h (32)

There are other impact factors but only this speed factor is considered in checking theoretically, the validity of the practical impact. The value of α can be obtained using eqn (32) for velocity, V ranging from 0 to 100 Km/h.

For proper assessment of stresses on all condition of rail, the moment of resistance of the rail at the various conditions of wear is used in the formular of maximum rail stress induced in those parts of the rail section farthest from the central axis given [29] as:

$$f = KP_w.a\ \alpha\ /Z_i \text{ or } f = K\ P_w a\ \alpha\ / Z_a \quad (33)$$

where Z_i = moment of resistance (section modulus) of new rail (cm^3)

Z_a = moment of resistance of old rail or rail worn (cm^3)

f = maximum rail stress in kg/cm^2

a = sleeper spacing in metre = Length of rail / Sleeper density

$$a = L_m / (L_m + x) \quad (33a)$$

Sleeper density ($L_m + x$) measured in terms of number per metre.

L_m = Standard length of rail in metres

x = Mathematical number which varies according to: axle load and speed of train, type and section of rail, type and strength of sleepers, type and depth of ballast, and nature of formation,

x = 3 or 4 for cape gauge track.

The permissible stress, f_a, varies from 1600 to 1800 kg/cm^2 for new rail and it is taken as 0.8 of ruling value of stress for old rail. The section modulus of old rail is given as:

$$Z_a = Z_l - (\Delta h_r/30) \times (W_r + 0.53(h_r - \Delta h_r)) \quad (34)$$

where, W_r = Rail weight in kg/m

Δh_r = Wear of rail height in mm

h_r = Rail height in mm.

3.2.3.2 Speed Factor for sleeper stress:

It varies with the speed, the stiffness of the formation, and the nature of traffic moving on the rail joint. The sleeper resistance to stress which is due to the fastening and the sleeper, is approximately 15 to 40 percent of the critical resistance of track. The force, P_s, exerted on the sleeper by the rail is represented by the formular,

$$P_s = \beta_1 P_w \quad (35)$$

P_s = Load transmitted to the sleeper in Kg

β_1 = factor depending on coefficient of elasticity and the moments of inertia of the rail and the sleeper, it also depends on the spacing and width of the sleepers, and the coefficient of depression under stationary loading, β_1 = 0.5 to 0.7 but for moving load [45], β_1 = 0.4 to 0.8

$\beta_1 = V^2/30{,}000$ for $V \leq 100$ Km/h or $(4.5\ V^2/100{,}000) - (1.5\ V^3/10{,}000{,}000)$ for $V > 100$ Km/h

For maximum value of $\beta_1 = 0.8$

So, $P_s = 0.8P_w$ **(36)**

Since max $\beta_1 = 0.8$, then:

$$M_{max} = 0.1P_w(l - G - b_1) \quad (37)$$

where M_{max} = Maximum bending moment

l = Length of sleeper in cm

G = Dynamic gauge

b_1 = Width of the base plate or width of rail botton in cm

3.2.3.3 Ballast Stresses:

Assessing ballast stresses due to dynamic load is essential since the ballast resistance is between 40 to 70 percent of the track resistance. The ballast stress is assessed by the formular given [29] as;

$$f_b = P_s / (2.18(l-G)\, h \tan \theta) \qquad (38)$$

where, f_b = Ballast stress in kg/cm^2

θ = Angle varying from 30° to 50° (usually 45°)

i.e. tan θ = Spread of ballast depending on quality of ballast

h = Minimum depth of ballast given [29] as;

$$h = (a-b_2)/ 2\tan\theta \text{ or } (a-b_{11}) /2 \qquad (39)$$

a =Sleeper spacing in cm as in eqn (33a)

b_2 = Sleeper width in cm

b_{11} = Sleeper bearing width in cm.

3.3 TRACK GEOMETRY

Track geometry plays a vital role in the dynamics of wheel - rail interaction especially at speeds of the order of 100km/h and higher. A proper track geometry is attained by ensuring good alignment and high standard of maintenability of track. This is achieved by keeping track irregularities of alignment, cross levels, twist, unevenness and gauge, to the bearest minimum variation.

In assessing track geometry, the safety and comfort of rail travel is considered.

3.3.1 Safety of Rail Travel

Under perfect condition of track, the forces acting on the rail - wheel contact during train motion as shown in Fig. 3.6. should be in equilibrium.

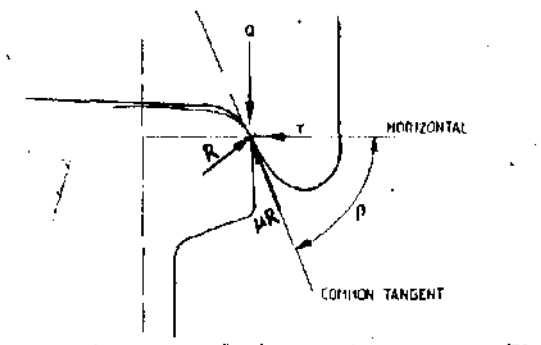


Fig. 3.6 Rail/Flange Contact Forces and Climbing Condition

For safety, derailing forces should be less than stabilizing forces and this is by Nadal's equation [24] given as

$$Y < Q(\tan\beta - \mu)/(1 + \mu\tan\beta) \qquad (40)$$

or $$Y/Q < (\tan\beta - \mu)/(1 + \mu\tan\beta) \qquad (41)$$

where Y/Q = Coefficient of derailment

Q = Wheel load (instantaneous) =1/2 of axle load

μ = Coefficient of friction wheel/rail (range 1/3 to 1/4)

β =Flange angle of derailment

Y = Impact force KN at leading outer wheel which can be analysed using Clark's analytical method [9] given as,

$$Y = (\alpha_1 V')^2 m_u \times 10^{-6}/2S^* \qquad (42)$$

α_1 = Impact angle (rad/m) ranging from 0 to 0.02 radian (= 5.70 m/rad.)

m_u = Laterally unsprung mass (in tonnes) of vehicle and is usually less than or equal to 10 percent of static axle load

V ' = Vehicle speed (m/sec).

S* = Constant having dimension of length and basically the radial distance over which the radial velocity V ', is developed usually the value of S* has been confirmed [9] from

experiment to be about 3.6×10^{-4}m. For practical purposes, with normal values for μ and β, it is often assumed that the coefficient of derailment should not be greater than unity i.e.,

$Y/Q < 1$, but the allowable limits are given in equation 43, i.e.

$Y/Q = \{0.8$ for German Railway, 0.8 for Japan Railway, 1.0 for Indian Railway$\}$ (43)

when dealing with plain track it is normal to take $Y/Q = 1.2$ and for switches $Y/Q = 0.79$ at a safety height 8.51mm above bottom of flange [9].

3.3.2 Track Maintenance and Maintenance Tolerances

Track maintenance or renewal are planned such as to lessen speed restrictions, permit heavier axle loads, and introduce higher speed while cutting down maintenance cost. Maintenance is undertaken by manual methods on route with speed less than 80 Km/h and by mechanical methods on route with speed more than 80 Km/h.

Rating of the condition of track segment in a relative manner is by using track quality indices method. It is the usual practice to plot TQI on a route as in Fig. 3.7.

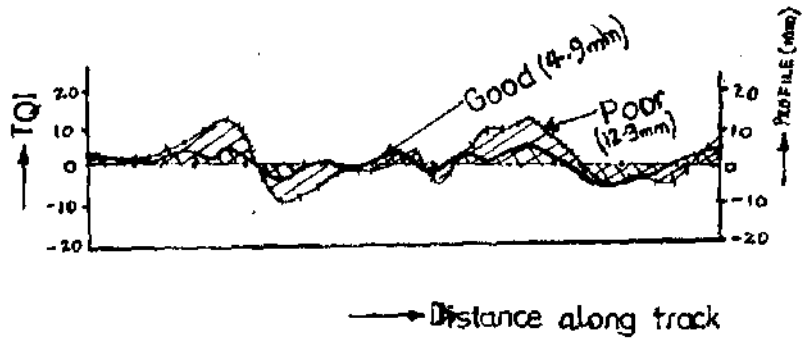


Fig. 3.7 Concept of Track Quality Index (TQI).

From the Figure, the horizontal line represents the ideal track condition. The solid line represents the actual measurement, and the shaded region represents the area between the actual line and the ideal line. TQI = 12mm depicts poor track condition while TQI = 5mm indicates good track condition. This method is useful in analysing the record sheet (chart) of the Matisa Trolley Track recording machine as shown in Appendix G.

3.3.3 Interpretation of the TQI Record; is done by use of a "foot-rule" or a "six-inch transparent scale" to measure the following parameter on the TQI chart of the Track recording machine.

Twist is the rate of change of cross levels between two points on a track and is measured over the main axle or wheel base of the machine and is calculated using the formular.

Twist= Wheel base width/ Measured departure from datum to one side

of the Twist TQI Chart (44)

where, wheel base of the machine = 300cm (3000mm). The locations on the chart having variation from datum greater than 10mm i.e. 3000/10 = 300), are noted since it indicates departure from the maximum permissible design cant gradient of 1-in-300 or 3mm per metre.

-Gauge is the minimum distance between the running faces of the two rails and is calculated using the formular;

Gauge = G1 ± deviation (45)

Deviation = Measured gauge TQI from chart, measurement done to full size from datum.

Gauge variation tolerance = 6mm on straight track, and 12mm for curve up to 4 degrees; 18mm for curve greater than 4 degree.

-Versine or alignment variation is measured in terms of variation in versine over a base length of 7.5m or 10m for both rails separately. It is usually assessed for curves using the formular;

Radius = (503/ Measured Versine in inches) in metres. (45a)

For the recording machine chord length = 503 metres

The measured versine from the versine TQI chart represents the full size deviation to the datum.

Alignment tolerance on straight track < 6mm

-Cant or cross level difference is the relative difference in the levels of two rail tops measured at the same point. On a curve, cant is calculated from the formular;

Cant = 2 x measured deviation in inches

The measure deviation on the cant TQI Chart give measurement deviation to the datum in half scale.

Tolerance variation on Curve < 6mm.

3.4 SWITCH-CUM-CROSSING ASSEMBLY

The switch and crossing assembly (i.e. turnout) exist to facilitate the branching or joining of tracks and thereby provide flexibility within a route so that the trains may move from one track to another parallel track and for marshalling of wagons in yards. A typical turnout is illustrated in Fig. 3.8

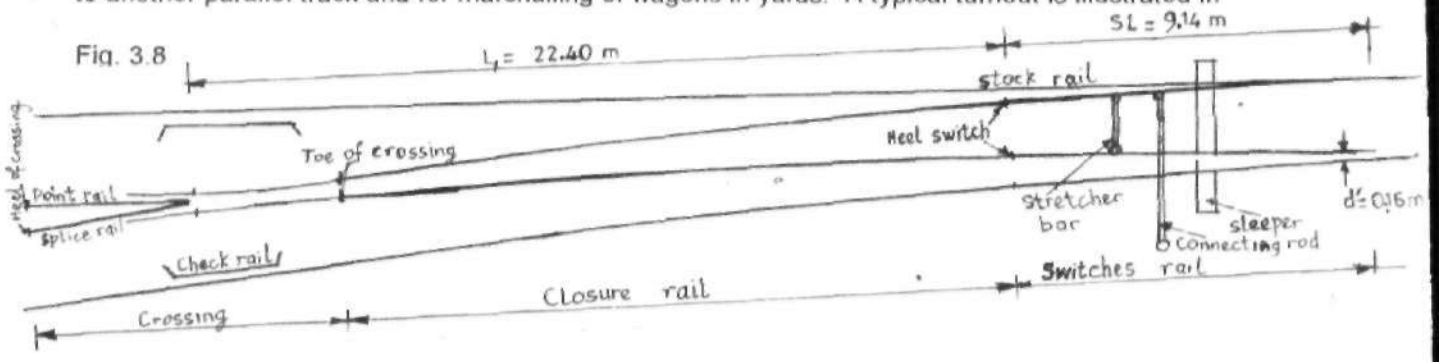


Fig. 3.8: Typical 1:16, 80R (NTR) Turnout Assembly.

In checking the adequacy of a turnout to permit a specific speed, use is made of maximum permissible speed [17] given as:

$$V_{max} = 0.29\sqrt{(RD)} \quad (46)$$

where V_{max} = maximum permissible speed in km/h

R = radius of turnout in metre

$$R = R_o - G_1/2 \quad (46a)$$

R_o = radius of outer Curve of turnout in metre

$$R_o = (G_1 - d')/(\cos\theta_s - \cos\alpha_c) \quad (46b)$$

G_1 =gauge of the track

θ_s = angle of switch (angle between the gauge faces of the switch rail and stock rail)

α_c = angle of crossing

d' = heel divergence

The above described parameters are shown in Fig. 3.19.

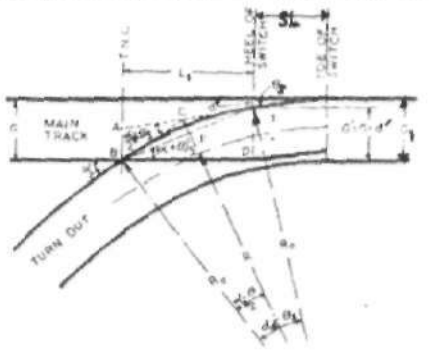


Fig. 3.9. Elements of Turnout Design.

From Fig. 3.10, the switch lead length (SL) which is the distance between the tanget point D and the heel of switch measured along the length of track is given as:

$$S.L = d'/ \tan\theta_s \quad (47)$$

The number of crossing is usually specified in ratio as 1:N, where N = cot α_c and from Fig. 3.9,

$$\tan(\alpha_c / 2) = 0.5\ N = 1/2\ N \quad (48)$$

3.4.1 Ride Index

The riding comfort experienced by a rail-passenger is an important consideration in assessing train motion at a target speed. There are two methods of evaluation of comfort level; Fatigue method and Ride Index method. The basic concept in the Ride Index method is that level of discomfort of a passenger in a vehicle is proportional to the product of acceleration, impulse and displacement.

Ride Index in terms of quality of running can be analysed by the formular [3];

$$W_z = 0.89(a_L^3 / f_k \times 0.8 f_k^2)^{0.1} \quad (49)$$

where,

W_Z = Ride Index

a_L = Permissible lateral acceleration as in equation (2) given as 1.0m /sec^2 or 100 cm/sec^2

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f_k = frequency in cycle per second (Hz). The wheel parameter of a train is shwon in Fig. 3.10.



Fig. 3.10. Train Wheel Dimension

For a very flexible track, the corresponding expression is,

$$f_k = V/2\pi \sqrt{(\alpha'/r_1 b)} \quad (50)$$

The frequency for rigid bogie of a train is given [31] by,

$$f_k = (V/2\pi \sqrt{(\alpha'/r_1 b)})(1+ C_x^2/b^2)^{-0.5} \quad (51)$$

where, α' = effective conicity, range 0.1 to 0.6

r_1 = wheel radius in mm

b = half wheel gauge in mm

C_x = half wheel base in mm

Ride Index, W_z, varies from unity (very good) to 5 (dangerous). For coaches, W_z = 3.5 to 3.75 (desirable limit), for locomotive W_z = 3.75 to 4.00 standards of Ride Index values against speed are given in Fig. 3.11.

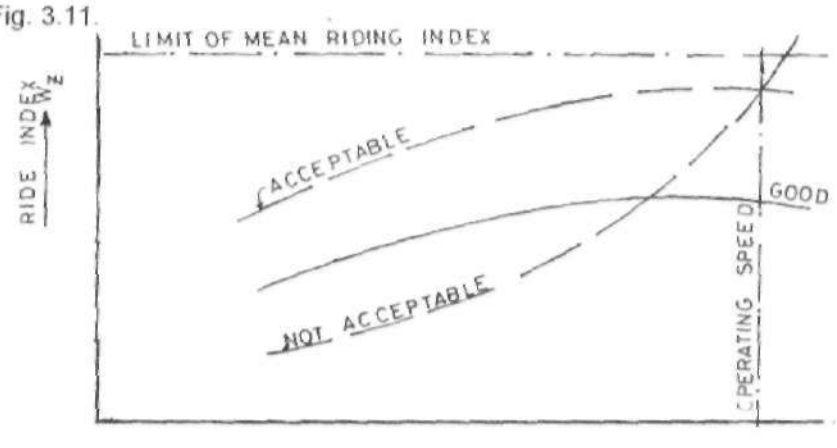


Fig. 3.11 Trend of Ride Index Curves [Source [5]]

Drawing in the acceptable limit, the maximum safe running speed may be determined. The trend of the curve reveal a limited margin of stability above the safe speed. Universal value of Ride Index based on European Riding Quality standard is given [27] in Table 3.1

Table 3.1 Ride Index of Train on the Link

Riding Index Wz	Riding Quality.
1 to 0	Very Good
1.5	Nearly very good
2.0	Good
2.5	Nearly Good
3.0	Satisfactory
3.5	Still satisfactory
4.0	Fit for operation serviceable
4.5	Unfit for operation
5.0	Dangerous

3.5 TRAVEL TIME ANALYSIS

In analysing travel time of train, the basic considerations are:

i) specified stopping time at the various stations en-route

ii) specified maximum speed

iii) Specified scheduled speed, Vs = Total distance / Total time including stops (52)

iv) specified average speed, Va = Total distance/ Total time excluding stops (53)

To facilitate the analysis of the speed-time curve, the speed-time curve is idealized as a trapezium OXYD as illustrated in Fig. 3.12. Acceleration is assumed constant from zero to the maximum speed (V_1km/h) at a rate (a_f km/h/sec), coasting is assumed at a constant speed, V_1, and braking at a constant deceleration (b_f km/h/sec) from the speed V_1 to zero. Distance, D_t covered is represented as area under OXYD. This method is an approximate representation of

Railway train speed chart (Fig. 3. Appendix A).

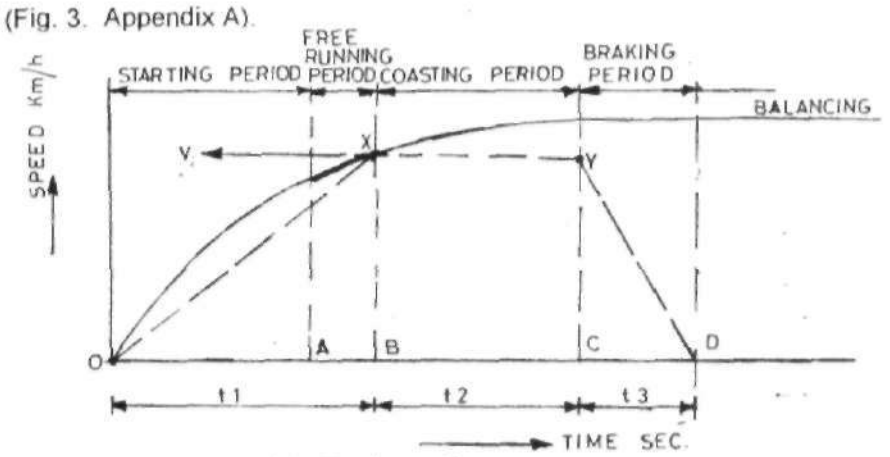


Fig. 3.12. Basic Speed-Time Curve on level straight Track per Journey.

From the figure above,

t_1 = time taken to accerate to speed V_1 (corresponding to OB)

t_2 = coasting speriod i.e. BC

t_3 = braking period i.e. CD

T = total time taken for the journey = $t_1 + t_2 + t_3$

whereas, distance covered, D_i = area OBX + area BXYC + area CYD,

$$D_i = V_1t_1/2 + V_1 t_2 + V_1t_3/2 \quad (54)$$

If D_i is measured in km, V_1 in km/h and time in seconds and substituting

$$a_f = V_1/t_1 \text{ and } b_f = V_1/t_3 \quad (55)$$

where a_f = acceleration rate, b_f = deceleration rate, then equation (54) becomes

$$D_i = ((V_1^2/2a_f + V_1(T - V_1/a_f - V_1/b_f) + V_1^2/2b_f)) \times 1/3600 \quad (56)$$

As a check, the acceleration rate is estimated [11] by

$$a_f = TE_{(accel)}/28.3K_iW \quad (57)$$

where, a_f = acceleration rate (km/h/sec).

$T.E_{(accel)}$ = acceleration resistance of a locomotive in Newton

K_i = constant ranging 1.08 to 1.12

W = train weight (metric tons)

3.6 OTHER ELEMENTS FOR MAXIMIZATION OF LINE CAPACITY

In maximising line capacity as shown in Fig. 1.1., the other elements, apart from those evaluated in the sections above include;

i) line-related infrastructure in general, such as signalling and communication

ii) traction (e.g. Lomotive utilization and locomotive condition)

iii) Operation of the system in general (e.g. loading/offloading, shunting and train crossing arrangement).

The maximum line capacity for optimum traffic at high speed to obtain high efficiency, can be evaluated [41] as:

$$C_T = 2 \times 24 \times 60 \times L / (n_1 + 1)\ .l_{max}\ [(r_{tup} + r_{tdown}) + S_{tup} + S_{tdown} + 5] \quad (58)$$

where,

C_T = traffic capacity in number of trains per 24 hour-day

L = length of line section in kilometer

n_1 = Number of stations on the line section

l_{max} = *maximum length of line between station in kilometer*

r_{tup} = running time in minute between two stations for up trains

r_{tdown} =running time in minute between the same station for down trains

S_{tup} = stopping time at a station in minutes for up trains

S_{tdown} = stopping time at a station for down trains

If stopping time for up trains and down trains are equal assuming 4 minutes (optimum headway of a train in a station which is dependent of the signal type in use), then

$$C_T = 2880L/ (n_1 + 1)\ l_{max}\ [(r_{tup} + r_{tdown})_{max} + 13] \quad (59)$$

where,

$$r_{tup,down} = 60\ l\ /V \quad (60)$$

V = *specified speed of train in km/h*

l = individual section (station to station) length in km.

CHAPTER FOUR

DATA COLLECTION

4.1 INTRODUCTION

This chapter gives the description of existing infrastructure within the framework of the thesis. It also contains data relevant to the proposed rehabilitation of the Kaduna to Zaria rail link needed to achieve goals and objective earlier set. The data collected relate to physical structures now in place and standard specifications governing the operation of trains on the system.

The data were collected by way of field survey of the track, signalling, train movement and data from Nigerian Railway Instruction books. Also field experiments, traffic survey and trial runs of rolling stock and track recorder were undertaken. The data so gathered are presented in this chapter.

4.2 SECONDARY DATA

Some secondary data relevant to the work were collected from Railway instructional and operational manuals and standard Dimensions. These include; Train, line and operational characteristics of the Railway link.

4.2.1 Line Characteristics.

The track layout consist of a long welded rail of 70A section flash-butt welded in ribbon length of 98m and in-situ thermit welded to form up to 750m length. The sleepers are A1 type (thin-block head) concrete sleepers on straight track and K type steel sleepers on curves. Timber sleepers of various sizes are used on level crossing, bridges and on turnouts. Track within stations especially within facing points are jointed rail track. Data collected on the track structure and layout are presented in Fig. 4.1 and Table 4.1.

4.2.1.1 Rail section: The full detail dimension of rail section in use is given in Fig. 4.1 and also summarized in table 4.1. The data were collected from Railway archives [32].

Table 4.1 Dimension of Rail Sections for stress Determination.

S/N	Dimension description	Letter	60RBS	70A
1.	Depth	A (cm)	11.43	12.38
2.	Width bottom flange	B(cm)	10.95	11.11
3.	Width Head	C(cm) or h	5.72	6.03
4.	Width web	D(cm)	1.11	1.23
5.	Depth Head	E(cm)	2.62	2.86
6.	Depth slope-top	F(cm)	0.95	1.11
7.	Depth Web	G(cm)	6.19	6.27
8.	Depth slope-bottom	H(cm)	1.67	1.51&2.30
9.	Depth to Centre Fish Bolt + TP of Curve webs	J(cm)	4.76	6.19
10.	Depth botton Flange at edge	V(cm)	-	0.79
11.	Diameter of Fish-hole	K(cm)	2.54	2.70
12.	Slope at tope 2.45 cm	S_1	1:3	1:2.75
13.	Slope at bottom (inner)	S_2	1:6	1:2.75
14.	Slope at bottom (outer)	S_3	1:6	1:6
15.	Radius crown	R_1(cm)	22.86	30.48
16.	*Top of check*	R_2(cm)	0.87	0.95
17.	Bottom of check	R_3 (cm)	0.16	0.16
18.	Top of Web	R_4 (cm)	0.56	0.56
19.	Bottom of Web	R_5 (cm)	--	1.11
20.	Web (RBS)	R_6 (cm)	22.86	50.80
21.	Bottom Flange	R_7(cm)	0.40	0.32
22.	Area	A_r(cm^2)	38.00	44.39
23.	Moment of inertia	I_x(cm^4)	676.79	911.96
24.	Section modulus	Z_x(cm^3)	115.37	145.85
25.	Modulus of Elasticity for Rail Section	E = 2.15 x 10 kg/cm^2 or 2150 tone/cm^2		
26.	Instance top Rail to neutral axis	cm	5.87	6.25
27.	Bottom Flange (RBS)	R_8 (cm)	0.87	1.27
28.	Weight per unit length	W_r (kg/m)	29.76	34.7
29.	Maximum Axle load vehicle	Tonnes	15.24	17.27
30.	Maximum Axle load locomotive	Tonnes	14.22	16.26
31.	Acceptable average life span Rails	Years	55	55
32.	Acceptable limit of wear (Rail condition)	Percent wear or (mm)	10%or12.38	5%or 6.19
33.	Total number in section	No.	3968	9589
34.	*Date Laid*	*Year*	*1915*	*1972*
35.	Switch Expansion Joint of LWR	mm	---	6.40
36.	Expansion gaps (Joint Track)	mm	6 to 9.5	---
37.	Standard Rail length	L_m(m)	11.9	12.2
38.	Maximum permissible Rail stress	Tonnes /cm^2	2.21 (216.13N/cm^2)	2.21

Source:- Engineering Departmental Instruction

4.2.1.2.2 Sleepers Types

The detail of various types of sleepers available in the studied section are shown in Table 4.2. steel sleepers are used in curves; concrete sleeper on straights (tangets); and timber sleeper on point and crossing, and bridges.

Table 4.2: - Sleeper Type Details

Item No.	Sleeper Type	Weight (kg)	Life span (years)	Quantity Section (No)
1.	70A 'K' Steel	44.23	35	11,940
2.	70A Pandrol steel	47	35	151,961
3.	70A Twin block (A1) concrete	143	40	151,961
4.	Timber (Track)	---	33	919
5.	Bridge Timber.	---	33	513

4.2.1.3 Fastenings for Sleepers and Rails

a) Sleeper fastenings for timber sleepers are mainly elastic spike of T3 types and coach screw.

- For 'K' type on 70A sleepers, the fastenings are termed AB and K clips because of the arrangement of the bolts and the nuts. The number of fastenings per sleeper is 4 No.
- For concrete sleepers, the 70A spring coil wedge pandrol clips are used.

Elastic rubber pad of 4.5mm thick are placed between rail and concrete sleepers to damp the effect of rail oscillation.

b) Rail to Rail fastenings is mainly the Fish plates consisting of two plates with fish nuts and bolts. One pair of fish plates with six nuts and bolts are available per joint to hold the two rails together both in horizontal and vertical planes.

4.2.1.4 Ballast

The ballast is of two main types, broken - stone ballast used in section and laterite ballast, used in yards and stations. The nominal size for stone ballast ranges between 37 to 50 mm. The standard Ballast section is shown in Fig. 4.2

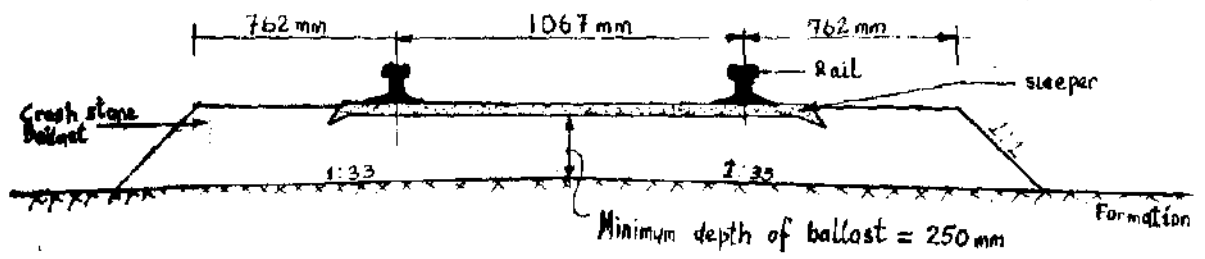


Fig 4.2 Ballast Section and Details

-The width of Ballast at foot level of rail is around 2620mm with the minimum value of 2285mm. The base width is given as 3120 mm.

-The depth of ballast below top of sleeper rail seat = 330mm.

The ballast depth should not be below 150mm, otherwise, it is to be regarded as ballast defficient location and should be promptly attended to.

-The volume of ballast per kilometer works out to be 370 cubic metre.

-Permissible ballast stress, f_{cb} = 456.86kg/cm^2.

Data on location of ballast deficiency is omitted due to volume of data.

-The minimum depth of ballast in the system = 150mm

4.2.1.5 Bridge Types

The details of bridge types and description were obtained from Bridge Design Book of Nigerian Railway. The details are given in Table 4.3

Table 4.3. Description of Bridges along the Zaria -Kadina Rail Line.

Item	Characteristics	1	2	3	4
1.	Section	KDJ-KDN	RCN-BYO	DB-SYI	SYI-ZRX
2.	Bridge No.	96	97	98	99
3.	Name of River	Kaduna	Quoro	Sayi	Kubani
4.	Location (km)	903 + 13poles	924 + 5 poles	973 + 3poles	984+ 5poles
5.	Number of spans	8	3	3	4
6	Length	3 x 30m(D) 2x16.5m(A) 2x12m(A) 1x9m(A)	3x12(A)	2x9m(A) 1x16.5m(A)	4x12m (A)
7.	Overall length(m)	156	36	24.5	48
B.	No. of sleepers	292	69	64	88
9.	Description of piers and abutment	Concrete piers and abutments founded on rock	Concrete piers and abutment founded on rock.	Concrete abut-ment and piers All spans strengthened	Concrete. abutment and piers
10.	Rail levels(m) above sea level	49.41	51.58	.	53.30
11.	Stream bed level(m)	48.13	59.81	-	-
12	Design speed(km/h)	100	100	100	100
13.	Speed restriction (km/h	60	60	60	80

Source. NRC Bridge Register.

Station Codes:

KDJ = Kaduna Junction

KDN = Kaduna North

RCN = Riga Chukun

BYO = Barin Yaro

DB = Dumbi

SYI = Sayi

ZRX = Zaria

Note: The type of bridges are indicated as:

D = Through truss with loads transmitted to the lower flange of girder

A = Plain deck bridge with loads transmitted to the upper flange of goods

B = Half through span bridge, loads are transmitted to wed members

4.2.1.6 Track Layout of Horizontal Curves

Data on horizontal curves were obtained from Railway section book and confirmed from field survey and observation. The full details of all the curves in the link is given in Table 4.4. The locations of the curves is represented in Fig. A1. Appendix A.

4.2.1.7 Track Layout of Vertical Curve

The vertical profiles along the studied link were obtained from gradient post at site where changes of gradient along formation occur and plotted in Fig. A2 Appendix A. The data indicates that:

Maximum gradient of the section = 1.25% or (1:80)

Average gradient = 0.8% or (1:125)

4.2.1.8 Track Geometry of Maintenance Tolerance

The service tolerance which relates to the acceptable limits of riding comfort with reference to track geometry in use is given in Table 4.5

Table 4.4. Details of Horizontal Curves

Item	Curve Location(km)		Curve No	Intersection	Hand of	Degree	Tangent	Max. Cant
	From	To		angle(Δ°)	Curve	D°	Length(m)	C(mm)
1.	903.63	903.93	190	53.23	RH	6	198.13	50
2.	904.07	904.53	191	57.7	LH	6	257.04	50
3.	904.63	905.10	192	48.17	LH	4	210.50	50
4.	905.37	905.87	193	56.97	RH	5	217.02	63
5.	907.00	907.53	194	56.21	LH	4	263.96	50
6.	907.67	908.13	195	49.67	RH	4	232.99	50
7.	909.27	909.97	196	65.80	RH	3.5	341.13	38
8.	910.67	911.00	197	21.32	LH	3	126.37	38
9.	911.37	912.00	198	69.92	LH	5	271.92	63
10.	913.50	913.87	199	20.41	RH	3	125.00	38
11.	914.20	914.57	200	8.64	RH	1	131.98	13
12.	916.57	917.57	201	21.15	LH	1	398.28	13
13.	919.57	919.97	202	37.79	LH	4	170.78	50
14.	921.30	921.47	203	2.77	RH	1	42.18	13
15.	922.33	922.60	204	19.57	RH	3	80.35	38
16.	924.40	924.63	205	21.10	LH	4	101.33	50
17.	925.97	926.07	206	2.64	RH	1	40.23	13
18.	927.30	927.67	207	20.31	RH	2	156.38	25
19.	928.17	928.67	208	8.70	LH	2	66.45	25
20.	930.07	930.27	209	8.87	RH	2	67.73	25
21.	934.73	935.13	210	57.37	RH	6	178.30	75
22.	935.23	935.60	211	45.98	LH	6	155.50	75
23.	935.87	936.17	212	14.45	LH	2	110.60	25
24.	936.83	937.27	213	21.98	LH	2	161.72	25
25.	938.20	938.50	214	30.14	RH	4	138.93	50
26.	944.13	944.33	215	16.04	RH	4	82.88	65
27.	948.33	948.53	216	9.97	RH	2	60.87	25
28.	950.13	950.47	217	16.23	LH	2	123.87	25
29.	954.66	954.17	218	4.88	RH	2	37.19	25
30.	955.97	956.17	219	21.59	LH	4	104.61	50
31.	957.47	957.67	220	15.87	RH	4	82.17	50
32.	958.33	958.50	221	11.14	RH	4	63.93	50
33.	961.00	961.33	222	34.52	LH	4	158.26	50
34.	962.87	963.30	223	24.99	LH	2	193.47	25
35.	965.37	965.70	224	30.23	RH	3	157.84	38
36.	966.60	966.80	225	14.17	LH	3	89.15	38
37.	966.93	967.13	226	7.17	RH	1.5	109.39	38
38.	968.27	968.47	227	9.46	LH	2	72.28	25
39.	969.60	970.33	228	39.33	RH	2	312.04	25
40.	970.13	971.03	229	10.98	RH	2	83.88	25
41.	971.17	971.33	230	15.33	LH	5	71.20	63
42.	972.07	972.40	231	59.90	RH	6	199.78	75
43.	972.60	973.03	232	51.02	LH	6	170.91	75
44.	973.37	973.93	233	58.47	LH	4	265.73	50
45.	976.13	976.70	234	29.74	RH	2	232.36	25
46.	977.67	978.40	235	39.07	RH	2	292.82	25
47.	979.60	980.10	236	24.62	LH	2	190.53	25
48.	980.83	982.67	237	32.21	RH	4	146.79	25
49.	982.53	982.65	238	7.69	RH	2	58.64	25
50.	983.00	983.43	239	56.00	RH	6	186.84	75
51.	983.47	983.93	240	47.92	LH	4	215.40	50
52.	984.17	984.30	241	7.82	RH	2	47.62	25

Table 4.4 Cont.

53.	984.47	984.67	242	31.29	RH	8	113.54	50
54.	985.07	985.53	243	82.00	LH	10	242.44	25

Source: Railway Section Profile Book.

Maximum cant occurs at the body of the curve while the cant will vary at the transition with a rate equal to cant gradient.

From existing data book[32], the following data are applicable on the section;

Maximum permissible cant = 75 mm

Maximum excess cant = 50 mm

Maximum cant deficiency permissible in superelevation = 50 mm.

Table 4.5 Track Tolerance and Maintenance Parameters

S/NO.	Description	Tolerance (mm)	Service condition (mm)	Very Serious condition (mm)
1.	Alignment;			
	On 10m chord straight.	+5 to +10	10 to 12	> 12
	Curve	+5 to +7	7 to 14	> 18
2.	Uneveness (Longitu-dinal level) at centre of 3.5m base			
	Tops	6 to 10	10 to 12	> 12
3.	Cross level (Cant)	+6	10 to 12	> 12
4.	Twist, relative cross level over length of 3m	4 to 7	6 to 10	> 12
5.	Gauge:- Straight track	+6 to -3	12 to 18	>8
	Curve up to 4°	+13 to -3		
	Curve above 4°	+19		

Source [29]

4.2.1.9 Matisa Track Recording Trolley Chart

The Matisa track Recorder gives indications of the conditions of track on a continuous basis, as the train moves along the track. The record chart for the study link was obtained for the portion between Dumbi station (DB) and Zaria station (ZRX). The recording was done on 22/7/85 when the machine was in good condition. Part of this record (i.e. 2km stretch) is presented in Appendix G for the purpose of assessment of geometrical condition of the track and to enable comparison with the present condition using the versine survey assessment described in Appendix C.

The track features recorded on the drawing Fig. G.1 shown in Appendix G, are:

Line No. 1: Reference points or physical features such as kilometre post, bridges, switches and crossing, station, etc. recorded on a scale of 1:5000 in chains.

Line No. 2: Twist recorded full size scale 1:1

Line No. 3: Track gauge (variation from 1067mm) recorded on full size, scale 1:1

Line No. 4: Speed at which the recording was taken

Line No. 5: Versines (measured radius in chains) on one running rail recorded full size, scale 1:1

Line No. 6: Cant or cross level (measured in inches) recorded on half full size, scale 1:2

Line No. 7: Versines on other running rail recorded full size, scale 1:1

Line No. 8: High and low points (uneveness) on one running (left rail) recorded full size, scale 1:1

Line No. 9: High and low points on other running rail (right rail) recorded full size, scale 1:1

Portions of the graph alone the datum indicate positive value while those below the datum indicate negative value. The analysis of the record chart is given in the later chapter using the concept described in Fig. 3.7.

4.2.2 Train Control of the Railway Link.

The Nigerian Railway uses the absolute block system whereby only one train is allowed in a block at a time. The control mechanism is operated by means of a "Tyres key" Token instrument. The authority to proceed into a block section comes in the form of a key token which is extracted from the instrument with the cooperation of the station being approached where a current is generated to enable the station, being departed from, extract the key token.

The token is handed over to the driver of the train as authority and on arrival at the station in advance the driver hands over the key token for the normalization of the instrument for the next operation.

Train control is by means of a Block Telephone system between the block sections and a party line connecting control Telephone system is used for communication and this is illustrated in Fig. 4.3.

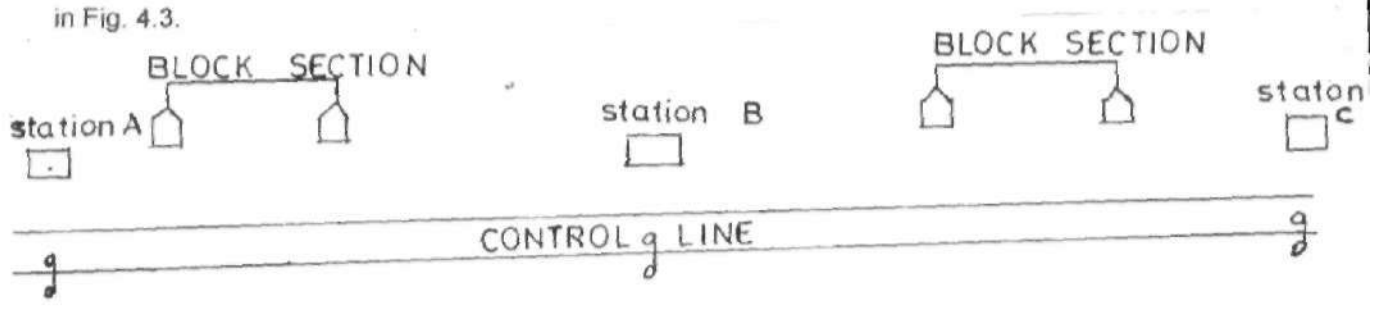


Fig. 4.3 Block Telephone system for communication

4.2.3 Line Capacity Data

The data gathered on line capacity include, length of line section or station to station distance, running time between stations for trains in the up and down directions, and stopping time at station for the up and down trains. The data is presented in Table 4.6. The signal system at each station is represented by; DW = Double-wire interlocked, /U = uni-directional, + = Block instrument installed in signal cabin, SW = Non-interlocked. Signal facilities provided vary from station to station. Those stations classified as class "A" have more facilities than the class "B" station. For the latter, minimum facilities are provided.

Table 4.6 Existing Line Capacity for Maximum Speed of 65km/h

Item	Signallling System	Class of Station	Station (code)	Location (km)	Length to Next stn.	Running Time rt_{up}	Running Time rt_{down} (min)	Stopping Time St_{up}	Stopping Time St_d (min)
1.	+DW/U	A	ZRX	987.80			-	10	10
2.	DW	A	SYI	975.00	12.80	18	17	-	-
3.	DW	A	DB	967.00	8.00	14	20	-	-
4.	DW	A	RUR	956.00	11.00	13	16	-	-
5.	DW	A	WSN	944.00	12.00	12	19	-	-
6.	DW	A	BYO	938.00	6.00	9	11	-	-
7.	DW	A	RCN	924.00	14.00	17	20	-	-
8,	DW	A	KDN	909.00	15.00	16	18	-	-
9.	SW	-	KDJ	903.00	6.00	12	12	20	20
			Total		=	111	129	30	30

4.2.4 Passenger Train Time Table

The express train time table being operated by Nigerian Railway along Kaduna to Zaria section at the time of field work is given in Table 4.7.

Table 4.7 Express Train Time Table

Item	Train Type	Date Running	Station (Code)	ArrivalTime (Hr:Min)	Depature time (Hr:Min)
1	1 KL	Tuesdays	KDJ	12:45	13:05
		Saturdays	ZRX	15:10	15:20
2.	2LL	Mondays	ZRX	11:25	11:35
		Wednesdays	KDJ	13:40	14.00
3.	9KL	Wednesdays	KDJ	11:42	12:02
		and Fridays	ZRX	14:17	14:27
4.	10GCL	Thursdays	ZRX	10:15	10:25
		Saturdays	KDJ	12:25	12:45

Source: Nigerian Railway Train Time Table 30/4/92

1KL = No. 1 Kano Limited or Lagos to Kano Express, 2LL = No.2 Lagos Limited or Kano to Lagos Express, 9 KL = No. 9 Kano Limited or PortHarcourt to Kano Express, 10GCL = No. 10 Garden City Limited or Kano to PortHarcourt Express.

4.2.5 Speed Profile for the line

The speed profile of Kaduna to Zaria line was obtained from the locomotive after a trial run of the section. The Chart obtained (Appendix A Fig. A3) shows the speed profile along the line. The graph resembles the basic speed-time curve of Fig. 3.12.

4.2.6 Data on Locomotive and Rolling Stock

Data presented in Table 4.8 relates to performance of locomotive engines operated on the line. The data is from engine manual of locomotive used on the section.

Table 4.8 Locomotive Features for different Traction on the line.

Item	Description	Types of Locomotive (Class)					
		11	14	16	17	18	19
1.	Classification(Wheel Arrangement)	AIA-AIA	co-co	Ico-col	Ico-col	co-co	co-co
2.	Engine Horse Power(HP)	-	1400	1500	1500	1800	3310
3.	Engine Idle Speed(RPM)	275	340	509	400	450	315
4.	Engine Maximum Speed(RPM)	835	800	925	1000	1050	908
5.	Fuel Oil Capacity(Litre)	2840	2700	3000	4545	6056	4000
6.	Notch setting	-	0 to 8	1 to 16	0 to 8	0 to 8	0 to 8
7.	Tare Weight Locomotive(tons)	72	78.5	79.7	98.2	96	91
8.	Weight of Loco. in working Cond.(tons)	77.5	-	84	-	-	96
9.	Loco. max. speed of level ground(km/h)	100	68.8	80.5	96.5	96	120
10.	Maximum Speed on 1.25% grade(km/h)	-	65	-	80	89.6	104
11.	Tractive force max.	-	-	1940kg	-	-	-
12.	Acceleration/deceleration rate($msec^{-2}$)	-	-	-	-	0.37	0.37
13.	Wheel radius of bogie(mm)	-	493.1	476.8	508	508	482.5
14.	Wheel base(mm)	3600	3658	3600	-	-	3600
15.	Lateral unsprung mass(Tons)	1.20	1.48	1.27	1.74	1.60	1.58
16.	Axle loads(tons)	12.00	14.75	12.70	17.33	16.00	15.80
17.	Loco. carrying capacity(tons)	750	-	-	750	800	1500
18.	Length of locomotive(m)	-	-	-	-	14.76	14.76

Source: Lomocotive Manual of Instruction(NRC).

4.3 PRIMARY DATA

Some primary data herein were generated in the course of field survey, investigation, observation and measurement at site. These are presented in the subsequent sub-sections.

4.3.1 Depression Peg Experiment

Rail stresses under moving load were determined by undertaking depression peg experiment. Depression peg readings were taken after observing the motion of train over some pegs buried under the rails spaced 5m apart. These readings were obtained from the peg deflection inside the ballast after passage of the train. The deflection peg and the measuring device are shown in Fig. 4.4 while the data is summarised in Table 4.9 and 4.10

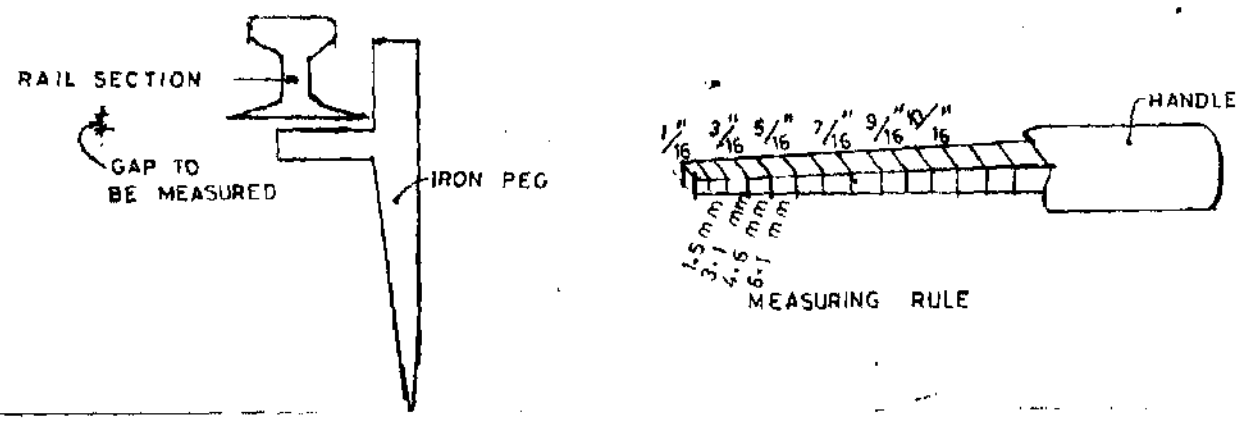


Fig. 4.4 Depression Peg under Rail section and Measuring rule

Table 4.9 Typical Rail Depression Peg Reading for Assessing Track Modulus for location at Km 984 + 10 poles

Date: 21/2/92

Time: 10:25hrs

Gauge of Wheel:	997mm
Gauge of Track:	1067mm
Direction of Movement:	Towards Zaria

Table 4.9 cont.

Engine Number: 1803 at speed of 30km/h over the site

Peg No.	Deflection (y_{iL}) in mm Left hand	Right Hand	Distance(m)
1.	(1.59)	(3.18)	0
2.	(3.18)	(3.18)	5
3.	(1.59)	(1.59)	10
4.	-	(1.59)	15
5.	(1.59)	(1.59)	20
6.	(1.59)	(1.59)	25
7.	(1.59)	(1.59)	30
8.	-	-	35
9.	(1.59)	(1.59)	40
10.	(1.59)	(1.59)	45
11.	(1.59)	(1.59)	50
12.	-	(1.59)	55
13.	(1.59)	(1.59)	60
14.	(1.59)	(1.59)	65
15.	(1.59)	(1.59)	70
16.	(3.18)	(3.18)	75
Total Deflection (y_{ij})	23.85	30.21	

Remarks

Distance between pegs = 5 metre

Sleeper spacing at site of experiment, a = 70.00 cm.

There are 5 length of loco in the 75 m confirment of the experiment

So total deflection under the locomotive, $y_{ij} = y_{iL}/5 = 0.5((23.85 + 30.21) / 5) = 5.406$ mm

Table 4.10 Typical Rail Depression Peg Reading for assessing Track Modulus for Location at km. 982 + 14 poles

Date: 2/3/94

Time: 15:15 hrs

Table 4.10 cont. Engine number:19 class of speed 45km/h over the site

Gauge of wheel:686mm

Peg No.	Deflection, y_i(mm)		Distance
	LH	RH	
1.	(3.18)	(3.18)	0
2.	(1.59)	(1.59)	5
3.	(3.18)	(3.18)	10
4.	(3.18)	(1.59)	15
5.	(1.59)	(1.59)	20
6.	(3.18)	(3.18)	25
7.	(1.59)	(1.59)	30
8.	(3.18)	(1.59)	35
9.	(3.18)	(1.59)	40
10.	-	-	45
11.	-	-	50
12.	(1.59)	-	55
13.	(3.18)	(3.18)	60
14.	(3.18)	(3.18)	65
15.	(1.59)	(1.59)	70
16.	(3.18)	(3.18)	75
Total y_{ij} =	41.26mm	28.62mm	

Remarks:

Sleeper spacing at site of experiment = 70.00 cm

y_{iL} = 0.70 cm

4.3.2 Sleepers Dimension

The dimensions of two type of sleepers, given in Table 4.2 were taken by measurement using steel tape. Sketches of the sleeper are shown in Fig. 4.5 and Fig. 4.6.

The twin block concrete sleepers have two concrete heads joined together by a 75mm diameter iron pipe.

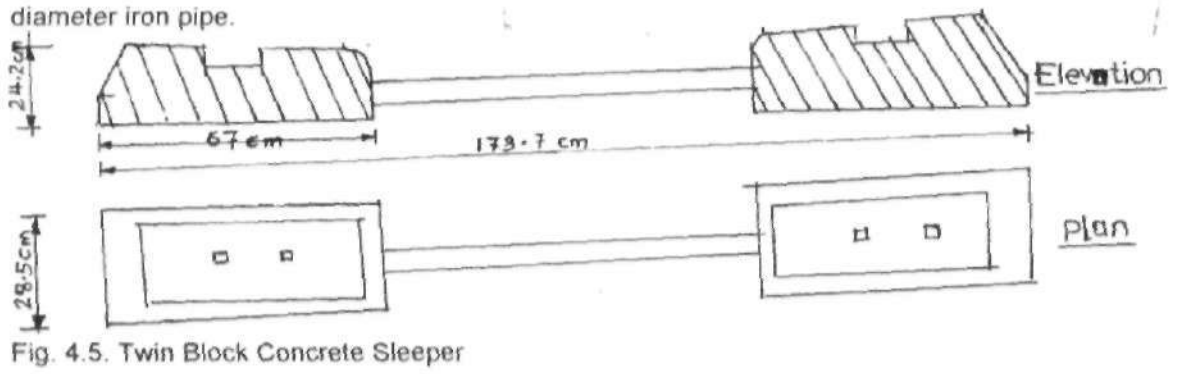


Fig. 4.5. Twin Block Concrete Sleeper

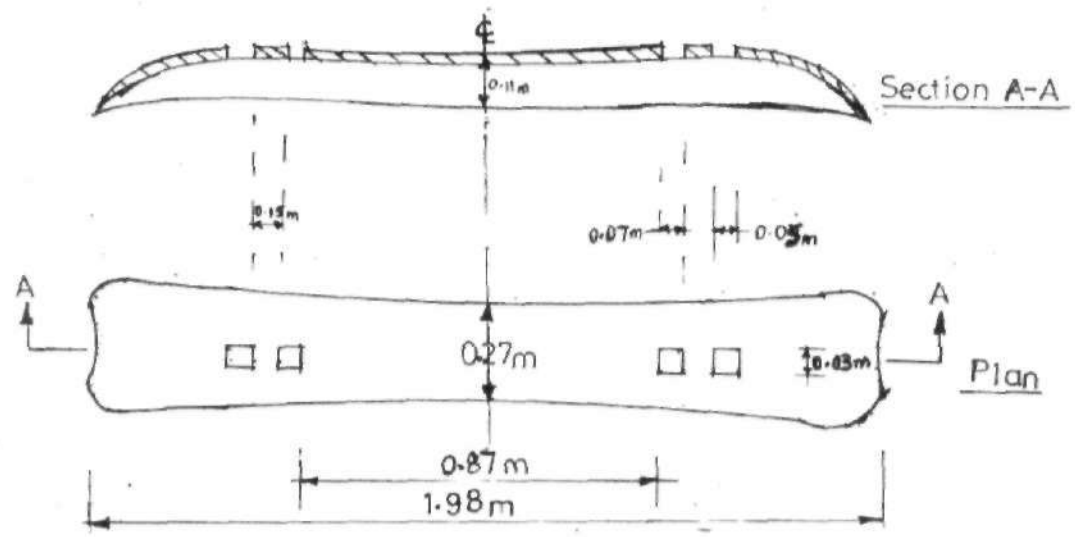


Fig. 4.6 'K' Type Steel Sleeper

4.3.3 Turnout on Running Track

The component part and layout of typical turnout was shown in Fig. 3.8. The different turnouts on the studied track in station are described in Table 4.11. The angle of crossing is determined by taking measurement for number of crossing, N, along the` Vee' when the spread of the `Vee' measured perpendicular to one leg is one unit or 1 metra

Table 4.11 Dimension for Point and Crossing (turnout) in the Stations for Running line Track.

Item	Station	Weight of Rail (lbs)	Lead Crossing Li (m)	Switch Length S.L. (m)	Heel divergence, d'(m)	No of Crossing,N
1.	KDJ	60R(NTR)	16.55	6.64	0.102	12
2.	KDN	60R(NTR)	16.55	6.64	0.102	12
3.	RCN	80R(NTR)	22.40	9.14	0.159	16
4.	BYO	80R(NTR)	22.40	9.14	0.159	16
5.	WSN	80R(NTR)	22.40	9.14	0.159	16
6.	RUR	80R(NTR)	22.40	9.14	0.159	16
7.	DB	80R(NTR)	22.40	9.14	0.159	16
8.	SYI	80R(NTR)	22.40	9.14	0.159	16
9.	ZRX	60R(NTR)	16.55	6.64	0.102	12

4.3.4 Level Crossing on Main Line Track

Crossing between railways and highways are on the same level throughout the section under study except two locations between ZRX to SYI with overhead road crossing. The types of crossing used are indicated in Table 4.12. Trains have to slow down at level crossing without adequate protection.

Table 4.12 Details of Level Crossing on Main Line of KDJ - ZRX section

Item	Location (Km/Poles)	Length(m)	Protection	Permissible speed(km/h)
1.	903/12.5 poles KDJ near bridge w/shop	6.10	Ungated	30
2.	904/12.5 polesKDJ-KDN (Skew 45°)	9.14	Barrier gate manned	40
3.	906/11.5 KDJ Central market	6.40	Barrier gate manned	45
4.	908/7 military Hospital Sokoto Rd, KDJ	6.40	Barrier gate manned	40
5.	910/14 Abakpa Road KDJ	6.10	Ungated and Not manned	30
6.	912/12 NDA Road KDJ	9.07	Gated and Manned	45
7.	914/10.5 Baptist Pastoral Sch. Rd KDN	6.10	Ungated and not manned	40
8.	915/7.5 Airport Road Kawo	18.70	Ungated and not manned	30
9.	923/1.5RCN-BYO Section	6.70	Ungated and not manned	30
10.	936/10.5 RCN-BYO Section	5.18	Ungated and not manned	35
11.	945/12 WSN-RUR Military Range	3.66	Ungated and manned	35
12.	960/2 RUR-DB Section	3.66	Ungated and not manned	35
13.	965/9 RUR-DB Section	3.66	Ungated and not manned	35
14.	970/6 SYI-ZRX Kufena College	3.66	Ungated and not manned	35
15.	974/8 SYI-ZRX	3.04	Ungated and not manned	35
16.	985/3 Sokoto Rd, ZRX	9.14	Gated and manned	15

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4.3.5 Speed Restriction Zones

At the current pattern of operations of the Nigerian railway, Speed restrictions are in general, imposed in the following circumstances:

a) Over turnouts and at turnouts on Curve = 25 to 40 km/h

b) Over sharp and/or reserve curves (greater than 6°) = 30 to 40km/h

c) Over bridges and bridge approaches on curves = 40km/h

d) Over road/rail bridges or level crossing = 30 to 40 km/h

e) Over bad formation = 30 to 40km/h

f) Through all station because of exchange of electric train staff or key token = 20 to 30km/h

g) Over vertical gradient greater than 1% (1:100) = 40 to 50 km/h

The locations of specific speed restriction zones on the studied links are indicated in Table 4.13.

Table 4.13 Permanent Speed Restriction Zones

Item	Location (km) From	To	Length(m)	Speed Restriction	Reason for Restriction
1.	903.27	904.87	1,600	40	Bridge approach on Curves
2.	934.67	935.47	800	56	Sharp reverse curves
3.	972.07	973.27	1,200	56	Sharp curve, R=218.3m
4.	982.93	983.33	400	56	Sharp Curve, R=174.7m
5.	984.93	985.33	400	16	Level crossing and sharp curves
6.	Various Locations		7,880	45	Vertical curves between 1.10 to 1.25%
7.	Various locations		4,980	50	Vertical curves between 1.00 to 1.10%
8.	Various Locations		22,340	53	Vertical curves less than 1.00%

Length of curves are approximated from distance of telegraph post (i.e. distance between post at beginning and end of curve).

4.3.6 Curve Realignment Survey

Field surveys, including chain survey, to establish existing features and theodolite transversing to determine the existing track layout were undertaken for curve No. 202 at Km 919 + 12 poles and curve No. 210 to 212 combined at km 935 to 936. However, curve No. 202 is presented for this thesis. The intersection point, intersection angle, tangent points and other details are determined as shown in Table 4.14 and Drawing No. 1. Appendix F.

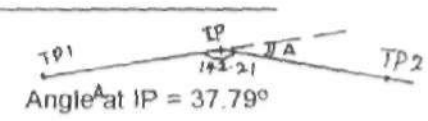
Table 4.14. Chain Survey of Existing Layout Curve No. 202.

Item	Point	Distance(m)	Location(m)	Remark
1.	CH 0+00	0	68.50	Reference point telegraph Poles km916 + 5 pls
2.	CH 0+00	0	7.20	Reference point Telegraph poles km919 + 4 pls
3.	CH0+30	30	28.56	Reference point telegraph poles km919 + 4 pls
4.	CH 0+30	30	38.70	Reference point Telegraph poles km919 + 5 pls
5.	TP1	310	310	Reference point CHO+00
6.	IP	510	195	Reference point TP1
7.	IP	510	34.5	Reference point Telegraph pole km919 + 12 pls
8.	TP2	663.98	19	Reference point Telegraph pole km919 + 14 pls

Using theodolite, ranging poles/arrows and steel tape, the proposed alignment with 1.5 degree curvature was set out and levelling instrument to get the level along chainages. Drawing No. 1 Appendix F was produced to indicate the horizontal layouts of existing and the design curves. It also shows final design profile with consideration to allowable grade and balance for earthwork. The cross section levels along chainages is undertaken for earthwork computation as shown in Drawing No. 2 Appendix F.

The traverse angles for the salient point of the curve is established as in Table 4.15.

Table 4.15 Traverse Angle for Curve No. 202

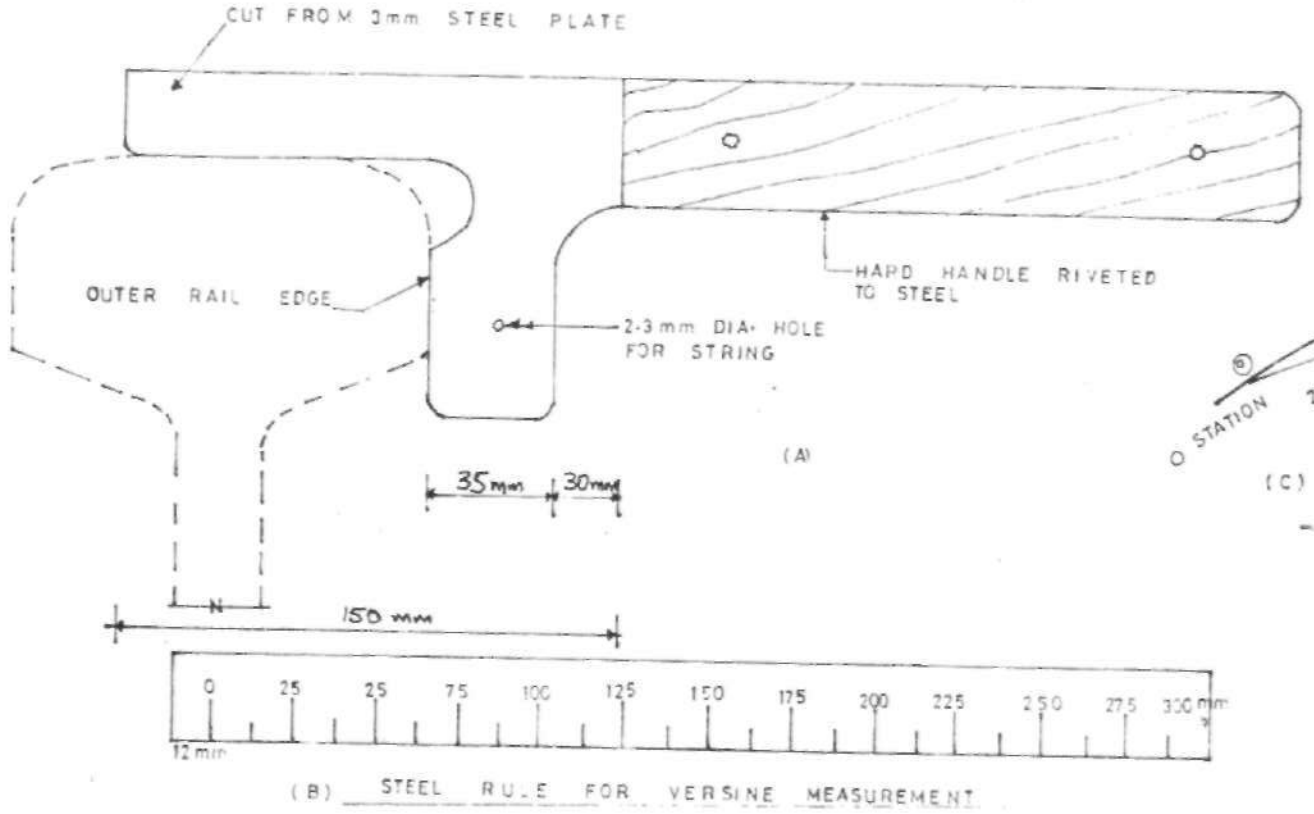
Item	Instrument at point	Sight on point	Vernier A Right	Vernier A Left	Deflection Angle Right	Deflection Angle Left	Mean Measure Angles	Computation and sketch
1.	IP	TP1	0.00°	180.00°	-	-	-	
2.	-	TP2	142.21°	322.22°	37.78°	37.79°	37.79°	

Angle A at IP = 37.79°

Table 4.16 Delay Distribution of Passenger Train at Zaria, for whole System and Adjusted to KDJ-ZRX Section for August 1993.

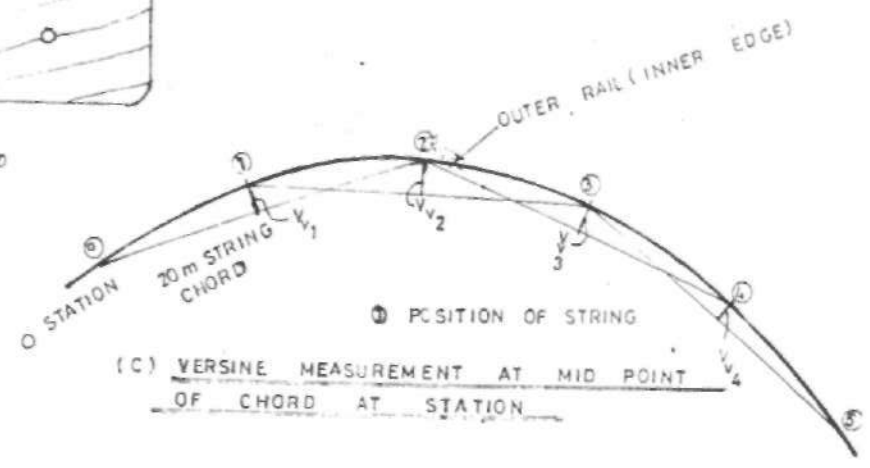
Item	Arrival Delay at ZRX(Hrs)		Frequency of Delay			
	Actual	Adjusted	Actual for Zaria		Adjusted to ZRX-KDJ	
			Class,i (hr)	Frequency	Class,i(hr)	Frequency
1.	0.08	0.03	9.92	1	0.125	5
2.	0.58	0.220	12.92	4	0.375	-
3.	0	0	15.92	4	0.625	2
4.	5.58	2.120	18.92	1	0.875	1
5.	1.77	0.673	21.92	3	1.125	4
6.	17.87	6.791	24.92	4	1.375	-
7.	12.08	5.590	27.92	1	1.625	1
8.	4.52	1.718	30.92	-	1.875	2
9.	13.92	1.197	33.92	1	2.125	3
10.	13.25	1.140	36.92	2	2.375	-
11.	5.25	0.007	39.92	-	2.625	-
12.	13.57	1.167	42.92	-	2.875	-
13.	9.45	0.813	45.92	-	3.125	-
14.	7.83	0.673	48.92	-	3.375	-
15.	12.00	1.032	51.92	2	3.625	2
16.	21.10	1.815	-	-	3.875	-
17.	25.28	2.149	-	-	4.125	-
18.	24.05	2.044	-	-	4.375	-
19.	40.45	3.438	-	-	4.625	-
20.	41.78	3.551	-	-	4.875	-
21.	0.48	0.182	-	-	5.125	-
22.	4.88	1.854	-	-	5.375	-
23.	11.67	4.435	-	-	5.625	1
24.	-	-	-	-	5.875	-
25.	-	-	-	-	6.125	-
26.	-	-	-	-	6.375	-
27.	-	-	-	-	6.625	-
28.	-	-	-	-	6.875	1
Total	287.44	42.640	-	23	-	23

Adjusted Arrival Delay considered Length of Section KDJ-ZRX = 84.8 km / Length of Train Travel e.g. length of travel of 9KL = 999 km, 1KL = 987.8 km, 2LL = 223 km, 10GCL = 223 km. The adjustment is done by multiplying the factor for length of train travel by actual delay for whole section. Only Passenger express is considered because these set of trains are scheduled.



(A)

(B) STEEL RULE FOR VERSINE MEASUREMENT



(C) VERSINE MEASUREMENT AT MID POINT OF CHORD AT STATION

FIG. 4.7. CHORD HOLDER FOR MEASUREMENT OF VERSINES

4.3.7 Versine Survey$

Versine surveys were undertaken on each curve along the route and the results are recorded in Appendix C. The survey involved using a string held at both ends by a chord holder 20 metre apart as shown in Fig. 4.7. Readings were then taken at intermediate stations marked at 10m apart. A steel rule is used to take readings at mid point (i.e. stations) of the extended string along the outer rail. The versine reading were recorded against each station starting from station zero.

4.3.8 Delay Distribution of Express Trains

Surveys of passenger express train - isolated from general train traffic operation, were conducted for trains passing through KDJ and ZRX. The results as represented in Appendix F wherein train punctuality has been evaluated in terms of delay. The causes of delay were also recorded. Arrival delay is the difference between actual and scheduled arrival indicated in Table 4.7 while departure delay is the difference between departure time and actual arrival time including the waiting time at the station. The distribution of train arrival delay at Zaria station for August, 1993 is given in Table 4.16.

4.3.9 Data of Rolling Stock Dimension

Wheel load distribution of locomotive is dependent on wheel spacing. Physical measurement of wheel spacing for 1904 class locomotive (19 class) was taken at Zaria (ZRX) Diesel workshop as shown in Fig. 4.8. Linear tape was used in the measurment.

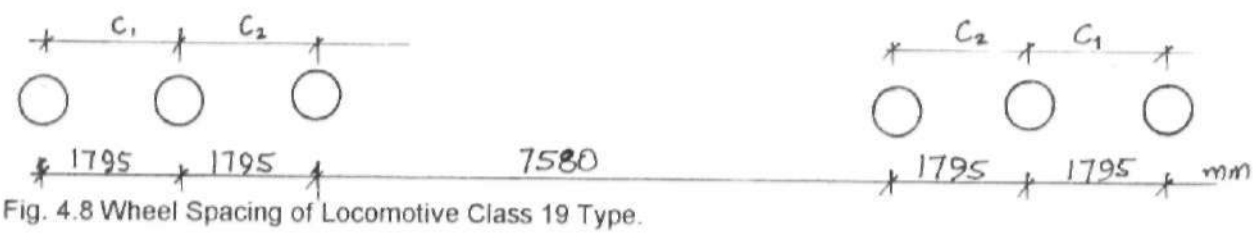


Fig. 4.8 Wheel Spacing of Locomotive Class 19 Type.

The data of wheels for the set of rolling stock in Nigerian Railway was obtained using

tape measurement and the result is shown in Fig. 4.9.

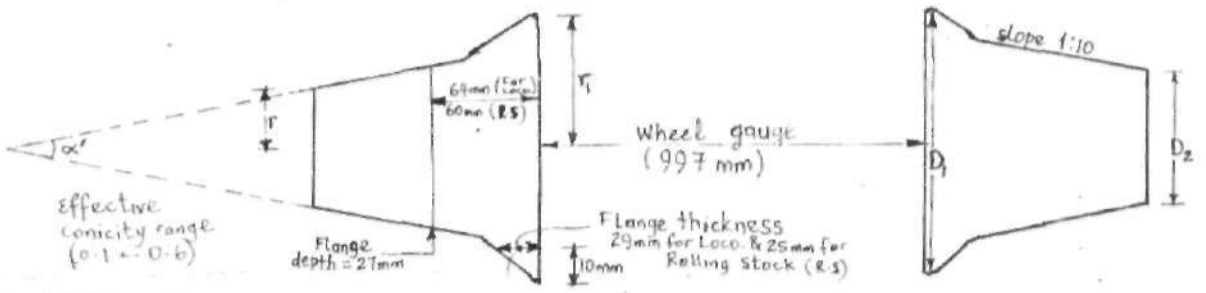


Fig. 4.9 Wheel Dimension Measurement.

Wheel gauge = 997mm

Wheel base = 114mm

Outer wheel radius, r_1 = 498.5mm

Inner wheel radius, r_1 = 492.8mm

CHAPTER FIVE

ANALYSIS OF DATA

The data presented in the preceeding chapters are analysed in this chapter. The focus of the analysis is on speed components, constraints to speed such as the adequacy of existing track to withstand the dynamic stresses. Other constraints to speed are also checked using the theoretical framework developed in chapter four to ascertain the maximum speed which the existing layout, geometry, turnouts and maintenance level, can accommodate.

5.1 STABILITY OF TRACK STRUCTURE BASED ON TARGET SPEED.

5.1.1 Theoretical Rail Stress Analysis

Rail stresses are computed under the following assumptions

i) Single wheel load considered i.e. the worst case that can be expected.

ii) Rail are within the range of 5% - 10% wear according to their service age on track .

iii) Maximum allowable axle loads in the system = 17.27 tonnes

Calculations of stresses

Calculations are based on elastic theory, i.e.

Stress, $f = M/Z_l$ or $M/Z_a = K.P_w.\ a\ .\alpha / Z_a$ .....from Equation (33)

The wheel base coefficient, $K = 0.057 + (C_1 + C_2) / 2$) when $C_1 < 2800mm$ (or 0.28) and

$C_2 < 2800mm$ .....From Eqn. (31a)

From Fig. 4.8 $C_1 = C_2 = 1795$ mm = 179.5cm

$K = 0.057 + (0.1795 + 0.1795) / 2 = 0.24$

Since it is a single load, usually the maximum value of K = 0.29 is taken Rf [29]

The maximum wheel load, P_w = maximum axle load / 2 = 17.27/2 = 8.64 tonnes

Sleeper spacing, a = 12.2 / 17.0 = 0.72.....from Eqn. (33a)

The speed coefficient, $a = 1 + V^2/ 30,000$.....from Eqn. (30)

Moment of resistance of new rail, $Z_l = 145.85\ cm^3$.....from item 24Table3.1

Moment of resistance of wornout rail, $Z_a = Z_l + (\Delta h/30[W_r + 0.53(h + \Delta h]$.....from Eqn. (34)

Rail height, h_{70} = 123.8mm.....from item 1 table 4.1

Rail height wear, Δh = 5% of 123.8 and 10% of 123.8 mm

Rail weight, W_r = 34.7kg/m.....from item 28 Table 4.1

For 70A Rails:

$Z_{5\%} = 124.46\ cm^3$

$Z_{10\%} = 101.73 cm^3$

For 60RBS Rails: h_{60} = 114.3mm, Δh = 5% of 114.3 and 10% of 114.3

$W_r = 29.76 kg/m$, $Z_t = 115.37 cm^3$

$Z_{10\%} = 78.63 cm^3$

$Z_{5\%} = 97.57 cm^3$

So, Rail stress $f = 17,188.87 \times \alpha / Z$

With the above, f values in Table 5.1 were calculated.

The values of rail stresses given in Table 5.1 have been plotted against the speed in Fig. 5.1. From the graph, 70A rails worn out beyond 10% head wear of rails should be worst level of tolerable wear on rails if speed of 90km/h and above are expected.

5.1.2 Practical Rail Stresses.

The computation is based on Track modulus,

$U = P_w / a y_{iL}$ ..... from eqn (24)

For the locomotive 19 class used in the experiment, the total deflection under the loco,

$y_{iL} = 0.70cm$ ..... from Table 4.10

Sleeper spacing at site of experiment, a = 70cm

Loco. middle wheel load, P_{w2} = 8.173 tonnes .....from eqn.(27)

when, number of axle, n = 6 ..... from Fig. 3.5

Bogie Axle spacing, C = 179.5cm ..... from Fig. 4.8

i.e. P_{w2} = 8.173 tonnes

Therefore, $U = 8.173 / 70 \times 0.70 = 0.167 tonnes/cm^2$ or $167 kg/cm^2$

The constant, $\lambda = 0.012\ cm^{-1}$ .....from eqn. (26)

when, $I = 911.96 cm^4$ ..... from Item 23 Table 4.1

Table 5.1 Rail Stresses at varying Speed

Item	Rail/Wear	Z(cm^3)	f at V=65	f at V=75	f at V=80	f at V=90	f at V= 100
1.	60RBS/New	115.37	170.64	177.51	180.45	187.31	194.18
2.	" / 5%	97.57	202.02	209.87	213.79	220.66	229.48
3.	" /10%	78.63	251.06	259.89	264.79	274.60	284.40
4.	70A/New	145.85	135.34	140.24	143.18	148.09	152.99
5.	"/5%	124.46	158.87	164.76	167.70	173.58	179.47
6.	"/10%	101.73	194.18	201.04	204.97	211.83	219.68

Value of α from equation (30).
Maximum permissible Rail Stress, f_a = 216.73 N/mm^2 from Item 38 Table 4.1
f = Stress in N/mm^2 at speed V in Km/h

Table 5.2 Stresses Computation for Static and Dynamic Condition for 19 Class Locomotive

Item	V(km/h)	I_d	P_E(Outer)	P_E(Inner)	M_{max}(t-cm)	f_t(N/mm^2)	f_c(N/mm^2)
1.	0	0	8.173	6.769	186.07	123.61	125.57
2.	30	0.128	9.219	7.645	209.88	140.28	142.25
3.	45	0.194	9.759	8.082	222.17	148.13	150.09
4.	65	0.280	10.461	8.664	238.15	158.92	160.88
5.	75	0.323	10.813	8.955	246.17	163.83	166.77
6.	80	0.344	10.985	9.095	250.08	166.77	169.71
7.	100	0.430	11.687	9.650	266.00	177.56	182.50

f_t =M/I x J_y, f_c=M/I x J_x where J_y= 6.19cm(from Item 9 Table 4.1), I=911.96 cm^4,
J_x=6.25 cm(Item 26 Table 4.1), Allowable Stress f_a =216.73 N/mm^2. So, f_t,f_c < f_a

Fig.5.1 Theoretical Stress Versus Speed for 70A Rail Section

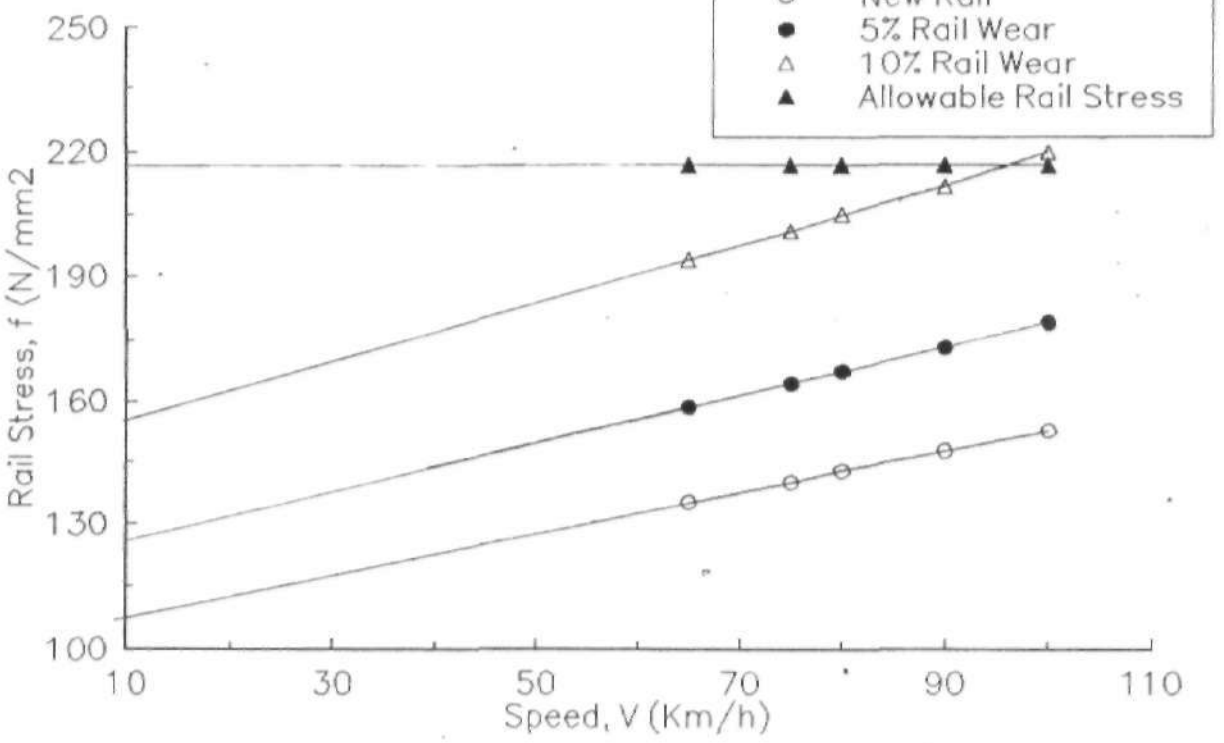
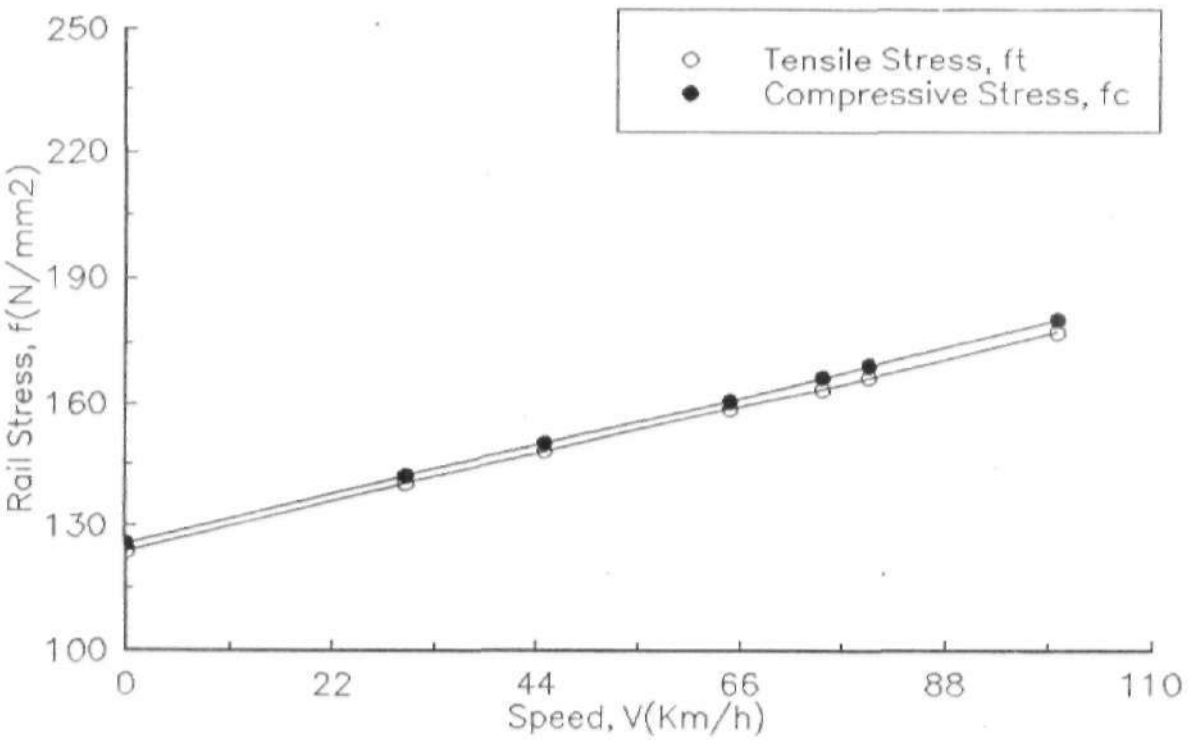


Fig.5.2 Practical Stress versus Speed for 70A Rail Section
for Dynamic condition of 19 Class Locomotive



E_{mo} = 2150 tonnes/cm^2.....from item 25 Table 4.1

Dynamic stress factor, for V = 30 km/h i.e. speed at which experiment was carried out,

I_d = 0.128 .....from eqn. (29)

The maximum bending moment under the locomotive, M_{max} =P_{E1} / 0.048 + (0.112P_{E2} / 0.048)

.....from eqn. (25)

Values of I_d for other situations are calculated and their effects on loading are obtained by assuming that y_{iL} and U are constant. Effective wheel load, P_E is obtained using Eqn. (30) for different speeds. The results are given in Table 5.2.

Based on calculation results and Fig. 5.2, it is seen that the stress likely to be induced by increase in speed up to 100km/h is less than the permissible rail stress (f_a = 216.73 N/ mm^2). This hypothesis is also confirmed by the results of Sec. 5.1.1 and Fig. 5.1. That is, the 70A rail section can permit speed higher than 100km/h for new rail condition.

5.1.3 Adequacy Checks for Sleeper Stresses.

Sleeper stresses are checked to evaluate the appropriateness of using steel or concrete sleepers. Maximum bending moment on sleeper.

$M_{max} = P_s / 8(l - G - b_1)$..... from eqn (37).

i) For Concrete Sleeper

Total length of sleeper, l = 173.7cm = 1737mm ..... from Fig. 4.5

Width of rail botton flange, b_1 = 11.11cm = 111.1mm ..... from item 2 table 4.1

Dynamic gauge of track, G = 1067 + 60.3 = 1127.3mm = 112.73cm

since, width of rail table, C = 60.3mm from Item 3 Table 4.1 and Track gauge, G_1 = 1067mm

Maximum wheel load in the system, P_k = 8.64 tonnes = 8640 kg

P_s = 0.8 x 8640 = 6912 kg ..... from eqn (36)

M = 43,079.04 kg-cm.

The sleeper stress, $S_s = M / Z_s$

where, sleeper section modulus, $Z_s = b.d^{*2} / 6$

for sleeper width, b = 28.5cm ..... from Fig. 4.5

Sleeper depth, d = 24.2 cm .....from Fig. 4.5

Therefore Z_s = 2781.79 cm^3

S_s = 15.49 kg/ cm^2 < permissible maximum service stress for concrete(S_{ac}=184kg/cm^2)

ii) Pandrol or 'K' Steel Sleepers used on Curves

l = 191cm, b_1 = 11.11cm, d* = 7.5cm.....{ from table 4.1}

G = 112.73 cm, b = 23 cm {and from Fig. 4.6}

M =6912/8 (191-112.73-11.11) = 58026.24 kg-cm

Z_s = 215.63cm^3

S_s = 269.10kg/cm^2 < permissible working stress for steel sleeper, S_{as} =2,300kg/cm^2

These above results show that the sleepers suitability is dependent on load more than the speed and that there is more stress induced on the steel sleepers than concrete sleepers, which is true due to higher stability (or high resistive force) of concrete sleepers.

5.1.4 Adequacy Checks of Ballast Stress and Ballast depth.

The ballast stress is given by;

$f_b = \beta P_k / (2.18(l-G).h.\tan\theta)$.....from eqn. (38)

where β = 0.58 for speed of up to 180 km/h

G = 112.73 cm

l = 173.7 cm

θ = 45..... from Fig. 4.2

Minimum ballast depth, $h = (a-b_{11}) / 2$..... from eqn (39)

sleeper bearing width, b_{11} = 22.33cm .....from fig. 4.5

So, h = 24.84 cm

and P_k = 8640kg

f_{cb} = 1.52 kg / cm^2 < permissible stress of ballast f_{cb} = 456.86kg/cm^2

Checking the stress for h = 15cm (i.e. least depth recorded in the link as in sec. 4.2.1.4)

Then, f_b = 2.42kg/cm^2 < f_{cb} stress is okey for average depth of h = 15cm

ii) **For Steel Sleeper on Ballast.**

a = 12.19 /18 = 68 cm

b_{11} = 14.09 cm ..... from Fig. 4.6

h = 26.96 cm

This shows that for lower depth of ballast the concrete sleeper is preferable otherwise the depth of ballast on steel sleepers should be greater than 15cm. So the ballast stress on steel sleepers,

f_{bs} =1.40 kg/ cm^2 < f_{cb}

5.2 ADEQUACY CHECKS OF TRACK LAYOUT FOR TARGET SPEED

The element of horizontal curves analysed for adequacy checks include cant and transition. The computations have been undertaken for the curvature ranging from 1 degree to 10 degrees which covers the existing situations. The theorem in Sec. 3.2.1.1 has been adopted for this assessment.

5.2.1 Cant (or superelevation) Determination.

Allowable cant is derived from the following assumptions:

i) Passenger comfort limit and overturning limit not to be exceeded with the given condition that maximum cant permissible

$C_{max} < 0.1G_1$ ..... from eqn (5a)

ii) Equilibrium cant, C =GV^2 / 0.127 R in mm.....from eqn (5)

Calculated cant (Balancing) for 100km/h maximum for passenger trains for curve with radius, R = 174.65m

Cant, C = 509.46 mm

Calculated balancing cant for 65 km/h maximum speed of freight (goods) trains for curve with, R = 174.65m

C = 215.30 mm

iii) Prescribed Cant at site, Cp = (C_{max} + C_{min}) / 2 .....from eqn (6a)

Prescribed maximum cant that can be allowed at site keeping in view the fast passenger train,

C_p = 362.33 mm > C_{max}, so not okay.

iv) Maximum cant defficiency, D_{max}= 4/5C_{max} = 80 mm

Prescribed cant defficient at site, $D_p = C_{max} - C_p$

Actual cant defficiency, D_p = 147.03 > C_{max}

If the speed of goods train is increased to 80km/h (i.e. 4/5 of V_{max}), then

C_{80} = 326.05

Therefore, prescribed maximum cant allowable at site

C_p = 417.76 mm > C_{max}

v) Maximum excess cant allowable, E_{max} = 4/5 D_{max} = 65 mm

Prescribed maximum excess cant, $E_c = C_p - C_{min}$ ..... from eqn (7)

E_c = 417.76 - 326.05 = 91.71mm > D_{max}

vi) Rate of run-out of cant along body of curve = 10 mm per 10m or 45mm per sec.

The focus is to find the range of curvature which can accommodate the target speed. The details of existing curves in the link from Table 4.4 and Appendix C are used for the calculation as prescribed in Table 5.3.

Table 5.3 relates the curvature with cant above the allowable cant and cant defficiency.

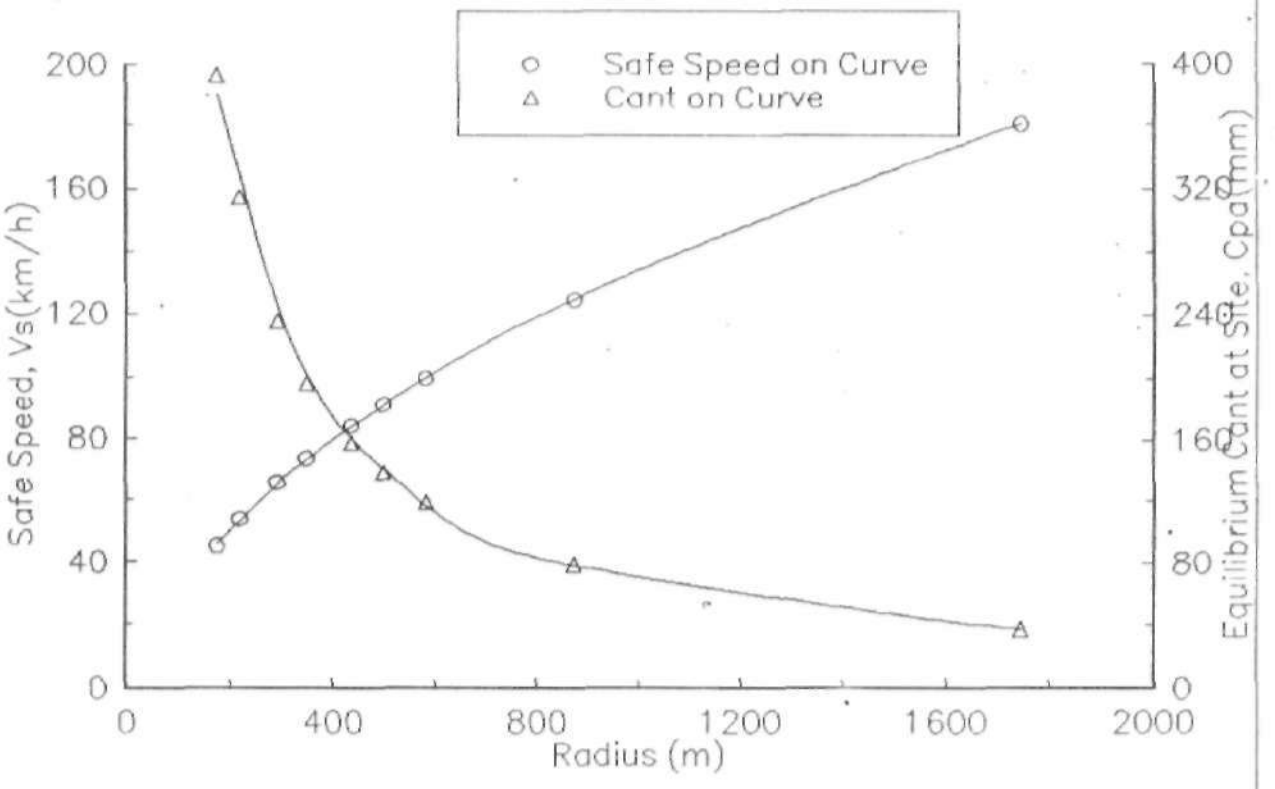
The set of cant and cant defficiency found adequate for the set objective shows that only 3 deg., 2 deg, and 1 deg. curves have C_p, D_p, E_p, suitable for all speeds. A graphical representation of cant versus radius of curvature is shown in Figs. 5.3 and 5.4. From the graph the suitable cant at 100km/h speed is 116mm for radius of 580m.

Table 5.3 Computation of Cant, Cant deficiency and Excess cant for Target Speed.

R(m)	Deg.	V	C	C_1	C_{p65}	C_{p75}	C_{p80}	D_{65}	D_{75}	D_{80}	E_{65}	E_{75}	E_{80}
174.65	10	65	215.3	25	362.4	398.1	417.8	147.2	111.4	91.7	147.0	111.4	91.7
"	"	75	286.7	25	362.4	398.1	417.8	147.2	111.4	91.7	147.0	111.4	91.7
"	"	80	326.1	25	362.4	398.1	417.8	147.2	111.4	91.7	147.0	111.4	91.7
"	"	90	412.7	25	362.4	398.1	417.8	147.2	111.4	91.7	147.0	111.4	91.7
"	"	100	509.5	25	362.4	398.1	417.8	147.2	111.4	91.7	147.0	111.4	91.7
218.31	8	65	172.2	50	289.9	318.4	334.2	117.7	89.2	73.4	117.7	89.2	73.4
"	"	75	229.3	50	289.9	318.4	334.2	117.7	89.2	73.4	117.7	89.2	73.4
"	"	80	260.8	50	289.9	318.4	334.2	117.7	89.2	73.4	117.7	89.2	73.4
"	"	90	330.1	50	289.9	318.4	334.2	117.7	89.2	73.4	117.7	89.2	73.4
"	"	100	407.6	50	289.9	318.4	334.2	117.7	89.2	73.4	117.7	89.2	73.4
219.08	6	65	129.2	75	217.4	238.8	250.6	88.3	66.9	55.0	88.3	66.9	55.0
"	"	75	171.9	75	217.4	238.8	250.6	88.3	66.9	55.0	88.3	66.9	55.0
"	"	80	195.6	75	217.4	238.8	250.6	88.3	66.9	55.0	88.3	66.9	55.0
"	"	90	247.6	75	217.4	238.8	250.6	88.3	66.9	55.0	88.3	66.9	55.0
"	"	100	305.7	75	217.4	238.8	250.6	88.3	66.9	55.0	88.3	66.9	55.0
349.30	5	65	107.6	63	181.2	199.0	208.9	73.6	55.7	45.9	73.6	55.7	45.9
"	"	75	143.3	63	181.2	199.0	208.9	73.6	55.7	45.9	73.6	55.7	45.9
"	"	80	163.0	63	181.2	199.0	208.9	73.6	55.7	45.9	73.6	55.7	45.9
"	"	90	206.3	63	181.2	199.0	208.9	73.6	55.7	45.9	73.6	55.7	45.9
"	"	100	254.7	63	181.2	199.0	208.9	73.6	55.7	45.9	73.6	55.7	45.9
436.63	4	65	86.1	50	144.9	159.2	167.0	58.8	44.6	36.7	58.8	44.6	36.7
"	"	75	114.6	50	144.9	159.2	167.0	58.8	44.6	36.7	58.8	44.6	36.7
"	"	80	130.4	50	144.9	159.2	167.0	58.8	44.6	36.7	58.8	44.6	36.7
"	"	90	165.0	50	144.9	159.2	167.0	58.8	44.6	36.7	58.8	44.6	36.7
"	"	100	203.7	50	144.9	159.2	167.0	58.8	44.6	36.7	58.8	44.6	36.7
499.00	3.5	65	75.3	40	126.8	139.3	146.2	51.5	39.0	32.1	51.5	39.0	32.1
"	"	75	100.3	40	126.8	139.3	146.2	51.5	39.0	32.1	51.5	39.0	32.1
"	"	80	114.1	40	126.8	139.3	146.2	51.5	39.0	32.1	51.5	39.0	32.1
"	"	90	144.4	40	126.8	139.3	146.2	51.5	39.0	32.1	51.5	39.0	32.1
"	"	100	178.3	40	126.8	139.3	146.2	51.5	39.0	32.1	51.5	39.0	32.1
582.17	3	65	64.6	38	108.7	119.4	125.3	44.1	33.4	27.5	44.1	33.4	27.5
"	"	75	86.0	38	108.7	119.4	125.3	44.1	33.4	27.5	44.1	33.4	27.5
"	"	80	97.8	38	108.7	119.4	125.3	44.1	33.4	27.5	44.1	33.4	27.5
"	"	90	123.8	38	108.7	119.4	125.3	44.1	33.4	27.5	44.1	33.4	27.5
"	"	100	152.8	38	108.7	119.4	125.3	44.1	33.4	27.5	44.1	33.4	27.5
873.25	2	65	43.1	25	72.5	79.6	86.6	29.4	22.3	18.4	29.4	22.3	18.3
"	"	75	57.3	25	72.5	79.6	86.6	29.4	22.3	18.4	29.4	22.3	18.3
"	"	80	65.2	25	72.5	79.6	86.6	29.4	22.3	18.4	29.4	22.3	18.3
"	"	90	82.5	25	72.5	79.6	86.6	29.4	22.3	18.4	29.4	22.3	18.3
"	"	100	101.9	25	72.5	79.6	86.6	29.4	22.3	18.4	29.4	22.3	18.3
1746.50	1	65	20.3	13	34.2	37.6	39.5	13.9	10.5	8.7	13.9	10.5	8.7
"	"	75	27.1	13	34.2	37.6	39.5	13.9	10.5	8.7	13.9	10.5	8.7
"	"	80	30.8	13	34.2	37.6	39.5	13.9	10.5	8.7	13.9	10.5	8.7
"	"	90	39.0	13	34.2	37.6	39.5	13.9	10.5	8.7	13.9	10.5	8.7
"	"	100	48.1	13	34.2	37.6	39.5	13.9	10.5	8.7	13.9	10.5	8.7

C_1 = Existing Cant at site in mm, C_{p65} = Proposed Cant at 65 Km/h, D_{65} = Actual Cant deficiency in mm at 65 km/h, E_{65} = Actual Excess cant in mm at 65 km/h

Fig. 5.3/5.4 Equilibrium Cant and Safe Speed on Curve versus Radius



5.2.2 Adequacy Checks of Maximum Speed and Safe Speed on Curve

Another set of calculations has been undertaken for the maximum permissible and safe speeds for the set of cant and cant defficiency obtained from Table 5.3. The formulae used in the calculations are:

$V_{max} = 0.27 \sqrt{(R(C + D))}$ (maximum speed) ..... from eqn (7)

Safe speed, $V_s = 4.4 \sqrt{(R-70)}$, $V'_s = 0.8$ Vs if not transition ..... from eqn (9)

Average equilibrium cant, $C_{pa} = (C_{p1} + C_{p2} + C_{p3}) / 3$ .....from Table 5.3

Average cant defficiency,

$D_{pa} = (D_{p1} + D_{p2} + D_{p3}) / 3$.....from Table 5.3

The results are given in Table 5.4

From Table 5.4, it can be seen that curvatures having radius greater than 582.17m will safely permit speed of 100km/h. Also improvement in cant and cant defficiency from the present existing values of C_p = 75mm and D_p = 50mm, will enhance the speed potential of the curvature. A plot of average equilibrium cant column (4) against radius and safe speed is shown in Figs. 5.3 and 5.4 from which a safe speed of 100km/h gives a radius of 580m and maximum cant of 116mm.

5.2.3 Adequacy Checks on Radius of Curvature

i) Theoretical consideration:

Assuming train can attain the target maximum speed

i.e.maximum speed, V_{max} = 100km/h, C_{max} = 106mm, D_{max} = 80mm

Minimum radius, $R = 13.72 V^2_{max} / (C_{max} + D_{max})$.....from eqn(9)

= 737.63m

Degree of curvature, $D^o = 1746.48 / R$ ..... from eqn (11)

$= 2.37^o$

ii) From consideration of Existing Infrastructure at site;

The section is a long welded track with the following characteristics:

Resistance to lateral displacement, Q_s for:

Concrete sleepers, Q_{sc} = 5 kg/cm

Steel sleepers, Q_{ss} = 7kg/cm

Permissible misalignment for LWR, f_m = 2.5cm ..... from [24]

Moment of inertia for rail related to vertical axis, I_y = 300cm^4 (Table 4.1)

Cross sectional area of one rail, A = 44.39 cm^2 .... from Table 4.1

Temperature surge above the section laying temperature,

Δt = 40^{o}C ..... from [24]

Minimum radius of curvature allowable for long welded rail,

$R = 1000/ (1012Q_s/ A.\Delta t -(A.\Delta t.f_{ma})/ 13.92I_y)$ .....from eqn.(19)

i) For concrete sleepers,

R = 559.67m

or D^o = 3.12

ii) For steel sleepers,

R = 314.69m

or D^0 = 5.11

From the calculations in Sec. 5.2.2 and Sec. 5.2.3, the maximum curvature that should be allowed is curvature less than or equal to 3 deg. of radius, R = 582.17 m.

5.2.4. Adequacy Checks for Cants

Working with the adopted radius, R = 582.17 m and speed of fastest train = 100km/h, for assumed speed of slowest train of 75km/h.

From eqn (4), C_{100} = 152.84 mm .....from Table 5.3 Item 35.

C_{75} = 85.97mm .....from Table 5.3 Item 32

Table 5.4 Maximum Permissible Speed and Safe Speed on the various Curvatures

Item	Deg.	R(m)	C_{100}	C_pa	D_pa	V_{max}	V_s	V'_s	V'_{max}
1.	10	174.65	109.46	392.71	116.75	39.89	45.01	36.01	48.66
2.	8	218.31	407.57	314.17	93.40	44.60	53.58	42.86	54.41
3.	6	291.08	305.65	235.60	70.04	51.50	65.42	52.34	62.82
4.	5	349.30	254.75	196.35	58.38	56.42	73.52	58.82	68.82
5.	4	436.63	203.71	157.03	46.68	63.08	84.25	67.40	76.94
6.	3.5	499.00	178.31	137.45	40.86	67.43	91.13	72.91	82.26
7.	3	582.17	152.84	117.82	35.02	72.84	99.58	79.66	88.85
8.	2	873.25	101.90	78.55	23.25	89.21	124.70	99.76	108.82
9.	1	1746.50	48.10	37.08	11.02	126.16	180.16	144.13	153.89

C_{100} = Theoretical maximum Cant in mm at V = 100 km/h, C_pa = Proposed Average Cant in mm, D_pa = Proposed Average Cant deficiency in mm, V'_{max} = Maximum Speed for C_{max} of 106 mm and D_{max} of 80 mm

Table 5.5 Recommended Changes in Existing Curves

Item	Freq.	R(exist)	D°(exist)	R(prop.)	D°(prop)	C_1	C_p	D_p	E_p
1.	1	174.6	10	> 582.17	< 3	25	106	50	40
2.	1	218.31	8	> 582.17	< 3	5	106	50	40
3.	8	291.08	6	> 582.17	< 3	75	106	50	40
4.	2	349.30	5	> 582.17	< 3	63	106	50	40
5.	14	436.30	4	> 582.17	< 3	50	106	50	40
6.	1	499.00	3.5	> 582.17	< 3	40	106	50	40
7.	4	582.17	3	582.17	3	38	75	50	20
8.	18	873.28	2	873.28	2	25	50	50	10
9.	5	1746.5	1	1746.50	1	12	25	25	10

Freq. = Number to be considered, R(exist) = Existing Curvature Radius in metres,

D°(exist) = Existing Curvature in degrees, D°(prop) = Proposed degree of Curvature in degrees.

Table 5.6 Recommended Transition Length and Shift for Proposed Curves.

Item	R(m)	D°	V (Km/h)	C (mm)	D(mm)	L_s (m)	S (m)
1.	582.17	3	100	75	50	46.50	0.155
2.	698.80	2.5	100	63	50	39.06	0.091
3.	873.25	2	100	50	50	31.00	0.046
4.	1164.33	1.5	100	38	38	23.56	0.020
5.	1746.50	1	100	25	25	15.50	0 006

L_s = transition length as obtained from the formula(0.0062CV), S = shift

Observing the limits of maximum cant = 106 mm, cant defficiency = 80mm and excess cant = 70m, cant that can be provided at site for R = 582.17m.

C_{75} = 119.41mm > C_{max}. So slowest train speed not okay. Reduce speed of slow train, V_{min} = 65km/h for which C_{65} = 108mm ≈ C_{max}. So slow train speed of 65km/h is okay on that account and since D_p = 44.13mm < D_{max} and E_p = 44.13 min < E_{max}.

5.2.5 Recommended Curvature

Based on calculations in Sec. 5.2.1 to 5.2.4, the new curvature to be adopted in the section is given in Table 5.5.

Excess cant for 2 deg. curve = 50 - 43.05 = 6.95 mm

Excess cant for 1 deg. curve = 25 - 20.33 = 4.67mm

From Table 5.5, the maximum raise in existing cant in item 7 to 9 for curve not to be completely relocated = 75 - 38 = 37mm. However, items 1 to 6 are to be completely realigned to cuvature less than or equal to 3 deg. (R > 582.17m)

5.2.6 Analysis of Transition Lengths

From data on existing curvature given in Appendix C, appropriate transition length is calculated against the proposed speed ranges 65km/h (minimum) and 100km/h (max.). The desirable length of transition, L_s = max (0.0062 CV, 0.0062DV, 0.40C) .....from eqn.(14). and shift, $S = L_s^2 / 24 R$.....from eqn.(15)

The most suitable transition length is determined;

i) For better transition length, the limit is to gain or lose cant all through the curve at the rate of 45 mm/sec. (i.e. condition of eqn (13)). Taking the maximum speed of 100km/h or 27.8m/sec we have,

$1/N_1 = 45/(27.78 \times 1000)$ mm/sec.

or N_1 = 729.13mm or gradient of 1mm in 729.13 mm.

Also the maximum superelevation (cant) gradient = 1:6.17 V (i.e. condition of eqn (13)) = 1:6.17 x 100 or 1:617. Therefore, the appropriate transition length can be computed based on cant gradient of 1:617 against the background of recommended cant of Table 5.5. That is,

$1:N_1 = C_p:L_s$

$1:617 = 75:L_s$ .....from Item 7 Table 5.5

i.e. $L_s = 617 \times 75 = 46275mm$ or 46.28m

Therefore to run-out 75mm cant at site at the rate of 45mm per sec., we require a distance of 46.28m (i.e. transition length L_s = 46.28m), compare this value with the transition lengths obtained from other methods;

ii) $L_s = 0.0062 \times 75 \times 100 = 46.50m$

iii) $L_s = 0.0062 \times 50 \times 100 = 31.00m$

iv) $L_s = 0.40 \times 75 = 30m$

v) $L_s = 0.0715 \times 1003 = 122.82m$

but this last value is bogus and not attainable so need not be considered.

Choosing the maximum of the transition length calculated in (i) to (iv) above, i.e. L_s = 46.50m. The transition lengths and shifts for the recommended curvature throughout the section is calculated as shown in Table 5.6.

5.2.7 Calculations for Curve Realignment and Flattening for Target Higher Speed

For those curves that do not need to be completely reconstructed, they have to be resolved and made to have proper running in line with the recommendations in Table 5.6. The actual conditions of all curves as existing are summarized in Appendix C. From the data, the versine of the curve is obtained using `bracket figure' to get average value representing the versine e.g. for curve No. 190, $V_v = (185 + 173 + 180 + 170)/4 = 117mm$ or 0.117m

The radius of the curvature as they exist is computed from the formula,

$R = C_h^2 / 8 V_v$ .....from eqn. (20)

and actual degree of curvature, $D^o = 0.0349 V_v$

This is shown in Table 5.7 with a comparison shown from the theoretical value as obtained in Table 4.4. The theoretical radius,

$R = 1746.5 / Deg_{(theo)}$ .....from eqn. (11)

The length of curvature, L_c is obtained from Appendix C considering the fact that distance between peg station is 10m apart. e.g. for curve No. 190,

L_c = No. of station x 10m = 37 x 10 = 370m.

This analysis has revealed that the existing curvatures have changed from their original position as in column (5) and (6) as per calculation in column (8) in Table 5.7 below.

The frequency of occurence of the different curvatures is given in Table 5.8. Actual degree of curvature rather than theoretical is used for derivation of frequencies from Table 5.7. From the table, the frequency distribution diagram is shown in Fig. 5.5.

The saving in travel time, likely to acrue if all curves having curvature greater than 3 deg. are eliminated to enable increase in speed from existing maximum safe speed of 65 km/h, is computed as follows;

Time gain in increasing speed from 65 km/h to 100km/h is:

$t = (V-V_1)/a_f$ .....from eqn. (45)

where V_1 = 65km/h, V = 100 km/h

a_f = 0.37 m/sec^2 ..... from item 12 Table 4.9

Time for acceleration,

t_1 = (100-65) x 0.3 / 0.37 = 28.38 sec.

The linear relationship adopted in eqn (56) is actually an approximation of reality.

Time for deceleration, t_3 = 28.38 sec.

Time (t_2) taken to cover length of curves as in Table 5.8, if total length of curves greater than 3 degree, L_T = 10.20km = 10200m

t_2 =(L_T/ frequency of such curves) / (speed in m/sec).

= 18.7 sec. per curve

Total time gained per curve, T_T = 28.38 + 18.7 + 28.38 = 75.46sec.

Overal time gain for all the curves greater than 3 degree = 28 x 75.46 = 2112.88 sec.

i.e. T_T = 35.22 min or 0.59hr

Table 5.7 Calculation of Existing Versines, Radius and Degrees for all Curves.

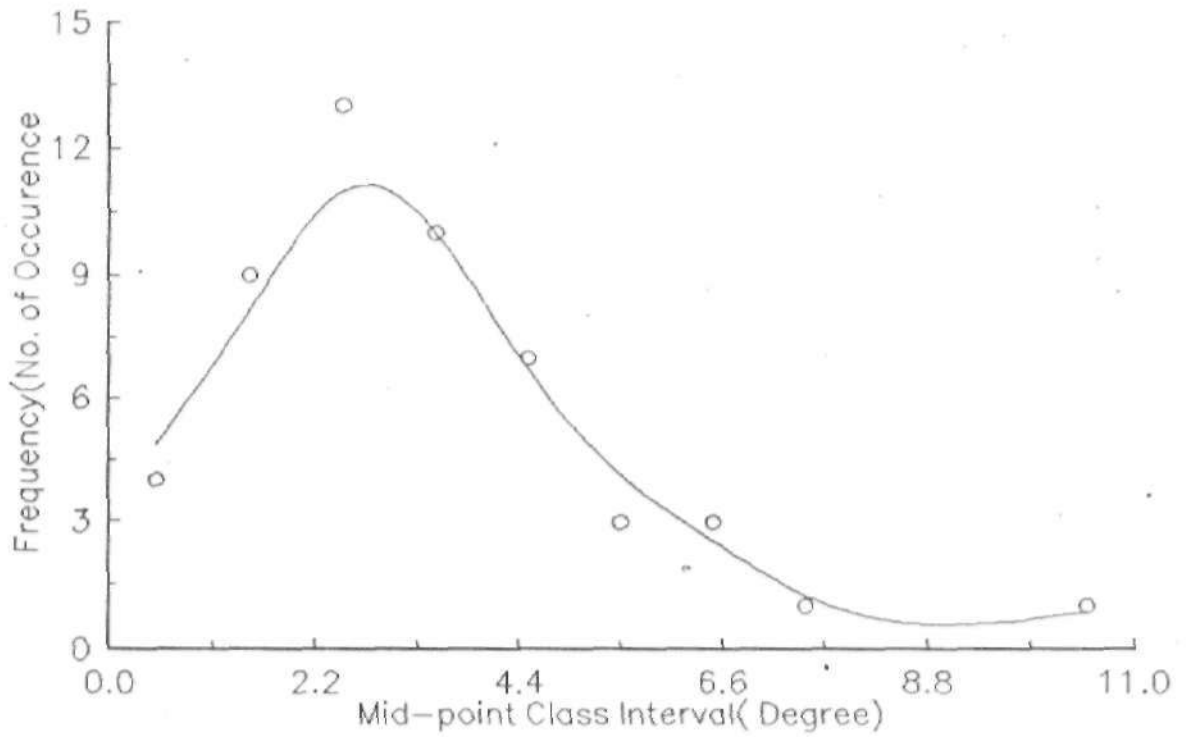
Item	Curve No.	V_v(m)	R(actual)	R(theo.)	D°(actual)	D°(theo.)	L_c(m)	Condition(%)
1.	190	0.177	282.49	291.20	6.18	6	370	1.00
2.	191	0.173	290.70	298.70	6.04	6	410	0.00
3.	192	0.106	471.70	454.20	3.70	4	450	7.50
4.	193	0.140	357.14	457.20	4.90	5	450	2.00
5.	194	0.105	476.20	499.00	3.67	4	550	8.25
6.	195	0.108	462.96	582.20	3.77	4	500	5.75
7.	196	0.098	510.20	349.40	3.42	3.5	670	2.29
8.	197	0.086	578.70	582.20	3.00	3	330	0.00
9.	198	0.145	344.83	349.40	5.07	5	520	1.40
10.	199	0.083	604.23	582.20	2.90	3	290	3.33
11.	200	0.028	1785.71	1746.48	0.98	1	310	2.00
12.	201	0.025	2000.00	1746.48	0.87	1	870	13.00
13.	202	0.115	435.41	436.70	4.01	4	390	4.50
14.	203	0.023	2272.73	1746.48	0.80	1	170	19.73
15.	204	0.080	609.76	582.20	2.79	3	260	6.93
16.	205	0.106	471.70	429.50	3.70	4	260	7.50
17.	206	0.025	2016.13	1746.48	0.87	1	160	13.00
18.	207	0.057	877.19	873.20	1.99	2	400	0.50
19.	208	0.059	843.88	873.20	2.06	2	190	3.00
20.	209	0.057	877.19	873.20	1.99	2	220	0.50
21.	210	0.170	294.99	291.10	5.92	6	390	1.33
22.	211	0.166	301.21	291.10	5.80	6	350	3.33
23.	212	0.058	867.05	873.30	2.01	2	290	0.50
24.	213	0.060	838.93	873.30	2.09	2	410	4.70
25.	214	0.118	424.63	436.60	4.12	4	310	3.00
26.	215	0.126	352.61	429.50	4.40	4	200	10.00
27	216	0.060	838.93	873.30	2.09	2	200	4.50
28.	217	0.059	841.75	873.30	2.06	2	320	3.00
29.	218	0.057	880.28	873.30	1.99	2	140	0.54
30	219	0.113	441.50	436.60	3.95	4	230	1.25
31.	220	0.117	427.35	436.60	4.08	4	220	2.09
32.	221	0.110	450.45	436.60	3.84	4	160	4.25
33.	222	0.117	427.35	436.60	4.08	4	350	2.09
34.	223	0.059	862.07	873.30	2.06	2	420	3.00
35.	224	0.086	581.40	582.20	3.00	3	390	0.00
36.	225	0.092	545.85	582.20	3.21	3	190	7.00
37.	226	0.051	833.33	1164.32	1.78	1.5	150	18.66
38.	227	0.062	806.45	873.30	2.17	2	230	8.50
39.	228	0.056	909.09	873.30	1.95	2	680	2.28
40.	229	0.058	868.06	873.30	2.02	2	220	1.00
41.	230	0.146	356.13	349.30	5.06	5	180	1.21
42.	231	0.170	294.12	291.10	5.94	6	410	1.00
43.	232	0.173	289.86	291.10	6.03	6	360	0.50
44.	233	0.115	435.54	436.60	4.01	4	560	0.25
45.	234	0.054	925.93	873.30	1.80	2	550	5.77
46.	235	0.055	909.09	873.30	1.92	2	670	4.03
47.	236	0.057	869.57	873.30	1.99	2	450	0.54
48.	237	0.114	444.44	436.60	3.98	4	330	0.54
49.	238	0.058	854.70	873.30	2.02	2	210	1.00
50.	239	0.169	294.12	291.10	5.91	6	400	1.50

Table 5.7 cont.

51.	240	0.114	438.60	436.60	3.98	4	440	0.50
52.	241	0.052	943.40	873.30	1.82	2	130	9.26
53.	242	0.205	243.90	218.30	7.16	8	230	10.48
54.	243	0.291	175.35	174.70	10.14	10	320	1.40
				Total		=	18860	

V_v = Versine, R(actual) = Actual Radius in metres, R(theo) = Theoretical Radius in metres, D°(actual) = Actual Degree of Curvature in Degrees, D°(theo) = Theoretical Degree of Curvature, L_c = Actual length of Curve in metres.

Fig. 5.5 Frequency Distribution of existing Curvature on the Link



This value of T_T = 35.22 min is the actual time lost between Kaduna and Zaria due to restriction of curvature greater than 3 deg. which are constraints to attainment of speed of 100km/h.

5.2.8 Analysis for Reconstruction of Curves greater than 3 degree.

Those curves established in Table 5.4 are constraints to safe operation of 100km/h speed target and have been earmarked for improvement. The planning of relocation is outlined below. In these exercises, existing stations and bridges are maintained as obligatory points. From Table 5.7 and Table 4.4, the following are considered under Phase I Exercise as part of Appendix D:

i) 4° curve No. 202 at Km 919.5 to be realigned to 1.5° or flatter

ii) 2 No. 6° curves and 1 No. 2° curve combine between km 935.33 and km 936.33 to be realigned to 2 No. 2.5° curves or flatter

iii) 4° curve No. 220 to be realigned to 2.5° or flatter

iv) 4° curve No. 221 to be realigned to 2.5° or flatter

v) 4° curve No. 222 to be realigned to 2.5° or flatter

vi) 5° curve No. 230 to be realigned to 2.5° or flatter

vii) 6° curve No. 231 to be realigned to 2.5° or flatter

viii) 6° curve No. 232 to be realigned to 2.5° or flatter

ix) 4° curve No. 233 to be realigned to 2.5° or flatter.

Detailed calculations needed for the realignment were undertaken for all the listed cases but curve No. 202 only has been presented. The survey data in Table 4.4 is used for the analysis. The data used in the assessment include:

R(actual) = 435.41m, D(actual) =4.01°.....from Table 5.7

Δ = 37°47' 17"

Existing cant or superelevation, C = 50 mm

Total length of curvature, L_T = 361.67m

L_s = 42.67m

Existing Railway maximum design speed, V = 65 km/h

Adopted new design; maximum speed, V_{max} = 120 km/h

(a) Check design of existing layout curve No. 202 at km 919.57 to km 919.97, left hand (LH) curve.

L_s = 45.10m .....from eqn (13)

This value is slightly larger than the existing value of 42.67m

S = 0.195m .....from eqn.(15)

Total tanget length, T_L = 169.10m ≈ 170m (actual) compares enough.

Length of circular arc, $L_{cir} = R(\Delta - 2\phi_1)$

but $\phi_1 = L_s/2R = 0.052m$

or $\phi_1 = 0.052 \times 360/2\pi = 2.97^o$

L_{cir} = 264.63m

Total length of curvature including transition lengths,

$L_T = L_{cir} + 2L_s$ = 354.83m which is close to the value L_T = 361.67m

The little difference in the value of tangent lengths and length of curvature could be as a result of deterioration of curve due to maybe lack of maintenance.

b) Proposed Curve Realignment Calculation for Curve No. 202

Assume intersection angle as unnchanged i.e,

$\Delta = 37^o\ 47'\ 10" = 37.79^o$

From proposal in item(i), of Phase 1 Exercise, the curve is to be realigned to 1.5 Deg. Curve, i.e. $D^o = 1.5$

R = 1164.34 m

Design speed, V_{max} = 120 km/h which should normally be higher than the maximum target speed of 100 km/h

L_s = 106.11 m > limiting value of L_s in Table 5.6 Item 4, so okay.

Taking, L_s = 100m

S = 0.36 m

T_L = 448.65 m

Lcir = 667.97 m

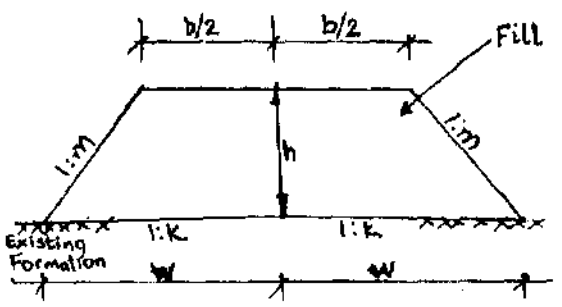
and, L_T = 867.97m

The result of this calculation is plotted into drawing No. 1 Appendix F.

c) Earthwork Computation and Cost of Relocation of Proposed Curve

For earthwork computation the following geometric properties are used [38] ;

- For earth filling or embankment of the form Fig. 5.3a, the area of fill is calculated from the formula;



b =.top width

w= longer bottom half width

h= height of bank at centre

k= gradient at formation

m= side gradient of bank = 2

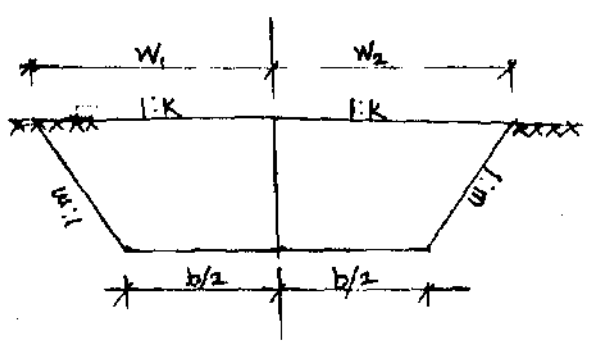
Fig. 5.3a Earthwork in Embankment (filling)

$w = (b/2 + mh)((k/(k-m))$

$A_1 = 1/2m(2w(mh + b/2) - b^2/2)$

where A_1 = Area of fill in square metre.

- For earth cutting of the form Fig. 5.3b, the area of cut is calculated from the formula;



m= side gradient of cut =0.25

l = slope of right hand formation

k= slope of left hand formation

w_1= longer bottom half width left hand

w_2= longer bottom half width right hand

b = shorter width of cut = 3 66 m

Fig. 5.3b Earthwork in Cutting

$w_1=(b/2 + mh)(k/(k-m))$

$w_2 = (b/2 + mh)(l /(l + m))$

$A_i = 1/2m((w_1 + w_2)(mh + b/2)-b^2/2)$

- Volume of Earthwork is calculated from the formula [38];

$V_T = D_1(A_1 + A_2)/2 + ...+ D_{n-1}(A_{n-1} + A_n)/2$

where A_i = Area of cross section, i = 1,2,3,4 .... (m^2)

D_i = distance apart e.g. D_1 = distance between cross sections 1 & 2

V_T =total volume of earthwork in (m^3)

- At CHO + 150, the Area, A_3 of cross - section is given when;

b = 5.18m.....from drawing No. 2b Appendix B

m = 0.25.....since the land is rocky.

1:k =(95.339– 95.329)/5 = 0.002

k= 500

1:l = (95.339–95.214)/5=0.025

l = 40

h = 95.339 - 94.870 = 0.469m

w_1 = 2.71m

w_2 =2.64m

i.e A_3 =2.136m^2

- At CHO + 160, the Area A_4 of cross section is obtained when;

b = 5.18m, m = 0.25, k = 16.9, l = 27.5

h = 0.367m

gives w_1 = 2.85m, w_2 = 2.59m

and A_4 = 2.346m^2

- Distance, D_4 = distance between CHO + 150 and CHO + 160 = 10m

- Volume of earthwork in cut, $V_4= D_4 (A_3 + A_4)/ 2$

V_4 = 22.408m^3

The earthwork sections taken along the CHO + 90 to CH 0 + 740 is shown in Drawing No. 3 Appendix F. the result of earthwork volume computation exemplified above is given in Table 5.9. The cost of realignment of curve No. 202 is given in Appendix B.

From Table 5.9 and Appendix F Drawing No. (2a), (2b), (3) and (4), the bill of quantity and cost estimate of the proposed alignment is computed as shown in Appendix B. The cost of realignment of curve 202 between km 919 + 4 poles to km 920 + 3 poles is N929,764.39 excluding the cost of released track material (rails, fastening and sleepers) which is re-usable. For Appendix F drawing No. 1, length of recoverd track material = 903 m instead of the shorter proposed alignment of 867.97m (i.e. cost of track material is excluded).

5.2.9 Maximum Speed on Vertical Curves

The maximum gradient obtainable on the link is 1:80 (i.e 1.25%). The maximum permissible speed on the vertical curve can be computed as follows::

i) For 19 Class Locomotive :

$W_r = V\{(5 + 0.003\ V^2) + 2240/N_1\}$

where N_1 = 80, W_r = horse power rating of 19 Class Loco. = 2310 HP.....from Table 4.9.

V = 55 mile/hr or 88 km/h

ii) For 18 Class Locomotive having horse power rating = 1,820 HP

V = 45 mile/hr or 72 km/h

iii) For 17 class locomotive having horse power rating = 1,500 HP

V = 38 mile/hr or 60.8km/h.

This calculation shows that the 19 Class Locomotive has potential for speed of 88km/h on the gradient of 1.25% and can conveniently make our target average speed 100km/h throughout the link.

5.2.10 Calculation of Maximum Speed on Turnout Track.

Train speed is greatly affected when running over turnout track. The calculation for permissible speed on the turnouts is based on data in Table 4.11 and fomula for permissible speed on turnouts:

i) For 1:12 turnout of 60 R NTR

From Table 4.11, the following data are available;

Heel divergence d' = 0.102m

Switch length, SL = 6.64m

Number of crossings, N = 12

Also existing cant defficiency, D = 50mm while the proposed cant defficiency = 80mm. Crossing angle,

$\tan \alpha_c / 2 = 1/2N$ or 1/24.....from eqn.(48)

$\alpha_c = 4.77^o$

Switch angle $\theta_s = 0.88^o$ .....from eqn.(47)

Radius of outer curve of turnout, R_O = 286.91.m.....from eqn. (46)

Radius of turnout, $R = R_O - 1.067/2$ = 286.37m .....from eqn 46

For un-canted turnout; $V_{max} = 2.4N$ = 28.80km/h

For canted turnout.

Existing V_{max} = 34.70km/h .....from eqn.(45)

Proposed, V_{max} = 43.89km/h

ii) For 1:16 Turnout of 80lb NTR

From Table 4:11, d' = 0.159m

N = 16m, SL = 9.14m

Also, D = 80mm (Proposed), D = 50mm (Existing)

Calculating, $\alpha_c = 3.58o$

$\theta = 0.997o$

$R_o = 490.44m$

R = 489.90m

Existing, V_{max} = 45.39km/h

Proposed, V_{max} = 57.41 km/h

For un-canted turnout, V_{max} = 38.4 km/h

Turnouts are speed constraints structure which can be improved by increasing cant defficiency rules on them or by making them have higher value of radius (flatter tunrout radius).

5.3 SAFETY COEFFICIENT CALCULATION FOR TRAIN MOVEMENT ON THE LINK

The safety of rolling stock against derailment when running at varying speed is assessed on the basis of data contained on Table 4.8and Fig. 4.9.

For safety the value, Y/Q < 1 .....from eqn. (43)

where, instantaneous wheel load, Q = 1/2 of axle load loco. = 8.38 tonnes or 83.3KN

but, impact load $Y = (\alpha_1 V')^2 m_u /2S^* \times 10^{-6}$ .....from eqn. (42)

where

impact angle of wheel on straight track = 0 ----> 0.02 rad

Impact angle when entering a 1:16 turnout,

$\theta_1 = 0.997^o = 0.997 \times 2\pi /360 = 0.0174$rad ... .from Sec. 5.2.10

From Fig. 4.9, width of tyre or wheel base,

b = 114 mm = 0.114m

α_1= 6.55m/rad

For running on turnout 1:12;

Impact angle $\theta_1 = 0.88^o = 0.015$ rad.

α_1 = 7.60 m/rad.

For running on straight track, take maximum value of impact angle, $\theta_1 = 0.02$ rad.

α_1 = 5.70 m/ rad.

$S^* = 3.6 \times 10^{-4}$m (known constant) .....form eqn. (42)

m_u = 10% static axle load of vehicle = 0.1 x 17.27 = 1.73 tonnes ....from Item 29 Table 4.1

So, $Y = 0.0024\ \alpha_1^2 (V')^2$

The safety coefficient calculation of trains movement at varying speed on the existing Railway link is represented in Table 5.10 below.

A graphical representation of the above calculation is shown in Fig. 5.6. This indicates that the set of rolling stock will operate safely at the target speed with 60km/h on turnout of 1:16 or greater. However, turnout of 1:12 is not fit safetywise for speed higher than 100km/h

5.4 RIDE INDEX ASSESSMENT FOR TRAIN MOVEMENT ON THE LINK

The ride Index in terms of running quality of trains on track is assessed using the data Fig. 4.9. Ride index,

$W_z = 0.896(a^3_L/f_k \times 0.8\, f_k^2)^{0.1}$ .....from eqn.(49)

For rigid bogie of a train (i.e. the type in the system),

frequency, $f_k = V/2\pi\ (\alpha'/r_1 b)^{0.5}(1 + C_x^2/\ b^2)^{-0.5}$.....from eqn.(50)

$\tan \alpha'/2 = 492.86/4928.6 = 0.10^o$ .....from Fig. 4.9

or $\alpha' = 11.421^o = 0.20$ rad

wheel radius, $r_1 = 495.65$mm .....from Fig.4.9

half gauge, b = 495.5mm

Half wheel base, $C_x = 57$mm

Therefore $f_k = 1.43 \times 10^{-4}\ V$ Hz

Since permissible lateral acceleration, $a_L = 100$cm/sec^2

then, $W_Z = 3.49(f_k)^{0.1}$

The effect of Ride Index at varying speed is calculated in Table 5.11 and represented graphically in Fig. 5.7.

The value of Ride Index calculated above shows that with the present Nigerian Railway rolling stock(when the flange of the wheels are not worn) ranges from 2.19 to 2.30 for speed up to 100km/h as observed from Table 3.2. Also from the graphical representation Fig. 5.7 shows a trend resembling Fig. 3.11.

Table 5.10 Safety Assessment of Rolling Stock on Track

Item	Description	α'	V (Km/h)	V' (m/sec)	Y	Y/Q
1.	Plain Track	5.70	100	27.8	60.26	0.72
2.	" "	"	90	25.0	48.74	0.58
3.	" "	"	80	22.2	38.43	0.46
4.	" "	"	75	20.9	34.06	0.41
5.	" "	"	65	18.1	25.55	0.31
6.	" "	"	40	11.1	9.63	0.12
7.	1:12 Turnout	7.60	100	27.8	107.13	1.28
8.	" "	"	90	25.0	86.64	1.04
9.	" "	"	80	22.2	68.32	0.82
10	" "	"	75	20.8	59.97	0.72
11.	" "	"	65	18.1	45.42	0.54
12.	" "	"	40	11.1	17.08	0.19
13.	1:16 Turnout	6.55	100	27.8	79.58	0.95
14.	" "	"	90	25.0	64.35	0.77
15.	" "	"	80	22.2	50.75	0.60
16.	" "	"	75	20.8	44.55	0.52
17.	" "	"	65	18.1	33.73	0.40
18.	" "	"	40	11.1	12.69	0.14

Table 5.11 Ride Index Assessment for Railway System

Item	Speed, V(km/hr)	Frequency, f_K(Hz)	Ride Index, W_Z
1.	65	0.0093	2.19
2.	75	0.0107	2.22
3.	80	0.0114	2.23
4.	90	0.0129	2.26
5.	100	0.0143	2.28
6.	110	0.0157	2.30
7.	120	0.0172	2.32
8.	130	0.0186	2.34
9.	140	0.0200	2.36
10.	150	0.0215	2.38
11.	160	0.0229	2.39
12.	180	0.0257	2.42

Fig. 5.6 Safety Coefficient versus Speed

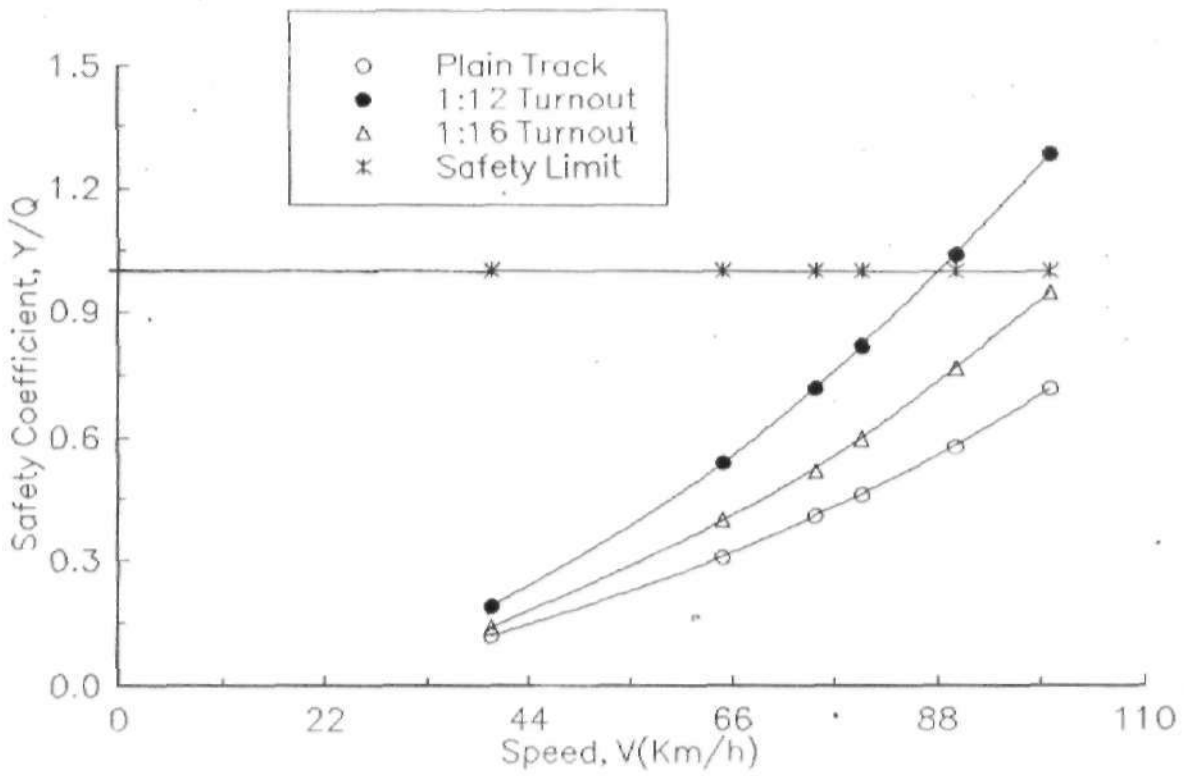
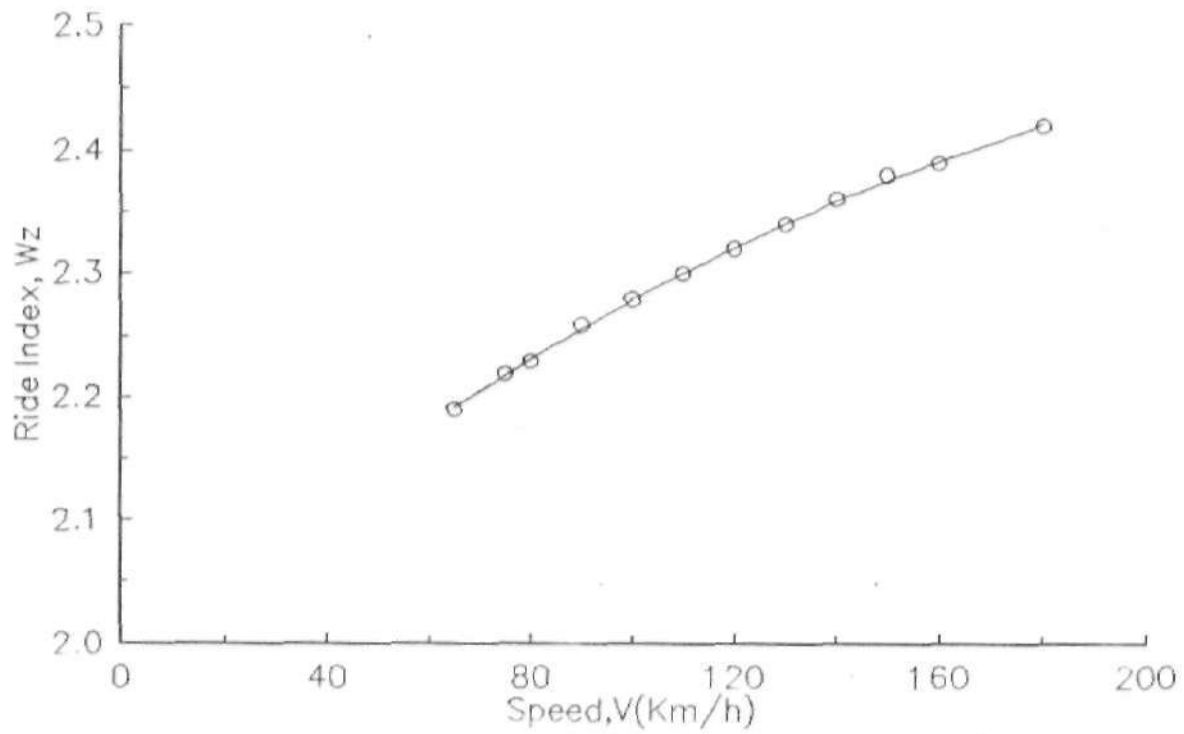


Fig. 5.7 Ride Index as a function of Speed



5.5 TRACK QUALITY INDEX (MAINTENABILITY LEVEL)

Data got from the Matisa Recording Trolley given in Appendix G and the theoretical concepts developed in Sec. 3.3.2, were used to assess capability to meet functional requirements of the infrastructure. The parameters used for the assessment are:

(i) Twist: Assessment of line 2 of the chart shows that km 966 + 10 pls to 11 poles and km 965 + 3½ poles are having deviation of 0.5 ins, greater than the tolerance = 0.4 ins.

The twist = 118/0.5 = 236 .....from eqn.(45a)

Cant gradient or Twist of 1:236 > permissible cant gradient 1:300

(ii) Track gauge: Assessment of line 3 of the record shows that there are no locations having deviation greater than 0.25" on straight and 0.5" on curve except on the level crossing and point and crossing locations because the probe of the machine is withdrawn to avoid damage from striking the nose of the crossing, etc.

(iii) Speed of machine line 4 is not required for assessment since the Transparent cursor (or overlay) scale is not used for measurement of the record, instead, a foot-rule is used.

(iv) Versines on left and right rail lines 5 and 7: Assessment of lines 5 and 7 of the chart shows that on straight track portion the measurement is within 0.31" i.e. permissible tolerance. On curves, the versine and radius of the curve are computed as in Table 5. 12. From the table, it is seen that the physical measurement result of Table 5.7 is a good estimator and that the curvature variation greater than 5% is a bad curve (Item 3 Table 5.12) and needs to be attended to.

From this assessment and those in Table 5.7, it is seen that the track geometry is not being properly maintained at the curved track since they have deviated from the original position.

Table 5.12 Calculated Radius from Record Chart based on Versine from Lines 5 and 7

Item	Curve No	Location(Km/pole)	V_v(inches	R in metres	D°	D° theo.	Condition %
1.	224	965/6.5p to 11.5p	0.94	536.53	3.26	3	8.7
2.	225	966/10p to 12p	0.88	571.59	3.06	3	2.0
3.	226	966/14p to 967/1.5p	0.41	1226.83	1.42	1.50	5.3

Condition = Difference of Curvature ((D°-D°theo.)/D°theo.)

Table 5.13 Train Traffic Capacity for Various Speeds on the Link

Item	l_{max}(m)	L (Km)	V (Km/h)	r_{tup}	C	C(approx.)
1.	**15.0**	84.8	40	22.50	35.09	35
2.	**15.0**	84.8	65	13.85	50.01	50
3.	**15.0**	84.8	75	12.00	50.01	55
4.	**15.0**	84.8	80	11.25	57.33	57
5.	**15.0**	84.8	90	10.00	61.67	61
6.	**15.0**	84.8	100	9.00	65.65	65

5.6 TRAFFIC CAPACITY DETERMINATION OF THE LINK

The train traffic capacity between Kaduna and Zaria line is determined at speeds ranging from 40 km/h to 140 km/h.

Train traffic capacity, $C_T = 2880L / ((n_1 + 1)\, l_{max}\, [(r_{tup} + r_{tdown})_{max} + 13])$ .....from eqn. (29)

Total length of section, L = 84.8 km..... from Table 4.6

Number of stations on the line section between the depot station, $n_1 = 7$ .. from table 4.6

For section speed V, the running time between two stations,

$r_{tup} = 60\, l_{max} / V = r_{tdown}$.....from eqn.(60)

For V = 65km/h and taking Zaria to Sayi section of l_{max} = 12.80km,

i.e. $r_{tup} = 60 \times 12.80 / 65.00 = 11.8$ minutes

From Table 4.6, take the maximum value of l_{max}, to calculate the maximum running for up and down train i.e. for l_{max} = 15km

$r_{tup} = 60.\, l_{max} / V = 15 \times 60 / V$

Assuming, $r_{tup} = r_{tdown} = 900/V$ minutes

So, $C_T = (288 \times 84.8) /((8 \times 15)(2r_{tup} + 13)) = 2035.2 / (2r_{tup} + 13)$

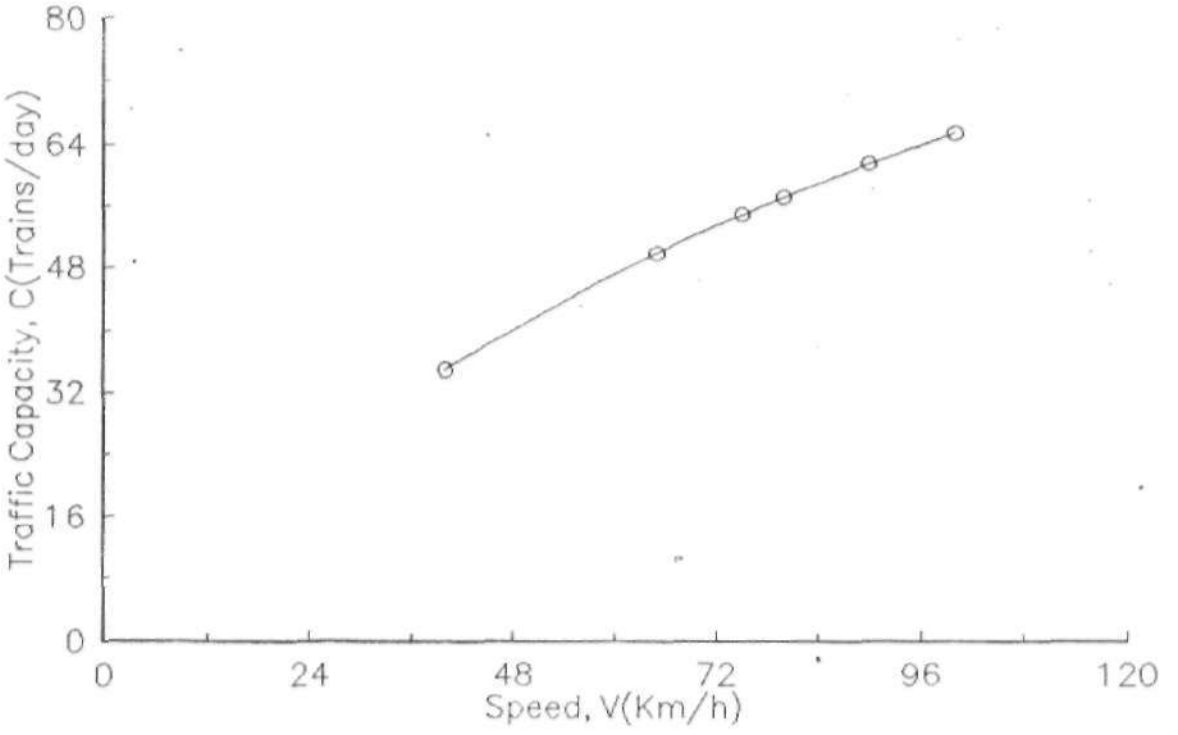
The result of Sectional Capacity is represented in Table 5.13.

From the Table 5.13, it is seen that capacity will increase by 30% from actual existing capacity of 50 trains/day if the train speed is enhanced. The existing capacity as now prevalent is as low as 20 trains/day showing underutilization of the actual capacity of 35 at the section average speed of 40km/h. The plot of capacity against speed (Fig. 5.8) shows the situation clearly.

5.7 TRAVEL TIME BETWEEN STATION LIMIT

Evidently Table 5.13 confirms that speed affects capacity. The other elements of speed constraint are the journey times of trains within stations in the link. These aspects are analysed so as to bring out the repercursions of changes in speed on the link. At the moment, speed has to be reduced to 25 km/h when passing through a station in order to collect key token (i.e. permission to proceed) and because of geometrical limitations of turnouts.

Fig. 5.8 Train Traffic Capacity versus Speed of Train



(i) Time loss at station yards for present situation

Assuming the acceleration and deceleration rate of train,

$a_f = b_f = 0.37 m/sec^2$ .....from item 12 Table 4.9

The time lost presently in reducing speed from V = 65 km/h to V_1 = 25km/h can be calculated as,

$t_1 = V-U / a_f = V_1 / a_f$ .....from eqn.(55)

$t_1 = ((65-25) \times 0.3) / 0.37 = 32.43$ sec.

Since there is acceleration on leaving the station and deceleration on entering (Fig. 3.13) and since $a_f = b_f$, total time lost for acceleration and deceleration in a station,

$T_a = t_1 + t_3 = 2 \times t_1 = 2 \times 32.43 = 64.86$ sec.

Time taken to cover station yards,

$t_2 = L_{st} / V_1$ .....from Fig. 3.14

L_{st} = BC = length of station yard = 1219.2m.....from [32]

Therefore, t_2 =170.56 sec.

So, total time loss to train, $T = t_1 + t_3 + t_2$ ..... from Fig. 3.14

i.e. $T = 64.86 + 170.56 = 235.42$ sec or 3.92 min.

But there are 7 wayside stations between KDJ - ZRX, so existing overall time loss due to station restriction;

$T_T = 7 \times 235.42 = 1647.94$ sec or 27.47min.. This is time presently lost due to speed restrictions at station between KDJ - ZRX section. Time to cover section other than that at station at present maximum speed of V = 65 km/h for distance between KDJ - ZRX,

$L = D_s = 84.8$ km, i.e.

$T_1 = D_s / V_{max} = 84.8/65 = 1.31$ hr or 78.6 min.

Sectional Timing for the Link, $T_{sc} = T_1 + T_T$

$T_{sc} = 78.6 + 27.47 = 106.07$min or 1.78 hr

(ii) Time loss at station yards for proposed improvement

Assume the use of target speed of section, V= 100 km/h and speed passing through, V_1 = 40 to 60 km/h - which is speed permissible on turnout of the section.

(a) Take lower limit, V_1 = 40 km/h

t_1 =48.65 sec

t_2 = 101.60 sec

T = 2 x 48.65 + 101.60 = 198.50 sec or 3.32 min

T_T = 7 x 3.32 = 23.24 min

T_1 = 0.85 hr = 51 min

Improved sectional timing as a result of target improvement,

T_{sc} = 51 + 23.24 = 74.24min or 1.24 hr

(b) Taking V_1 = 50 km/h and V = 100 km/h

t_1 = 40.45 sec or 0.67min

t_2 =81.28 sec or 1.36 min.

T = 2 x 40.45 + 81.28 = 162.36 sec or 2.71 min

T_T = 7 x 2.71 = 18.94 min

T_1 = 0.85hr or 51 min

T_{sc} = 51 + 18.94 = 69.94 min or 1.17 hrs

(c) Taking V_1 = 25 km/h and and V = 100 km/h

t_1 = 60.81 sec or 1.01 min

t_2 = 162.56 sec or 2.71 min

T = 385.93 sec or 6.43 min

T_T = 7 x 6.43 = 45.03 min

T_1 = 51 min

T_{sc} = 51 + 45.03 = 96.03 min or 1.60 hr

This calculation implies that improvement of journey time is enhanced by improved opeational arrangement (requirement Fig. 1.1) especially those relating signalling at the stations

and better turnouts with adequate cant. For example, if 1:16 turnouts is canted up to C = 80 mm then comfortable speed on them is V = 60 km/h

(d) Taking enhanced station speed, V_1 = 60km/h

t_1 = 32.43 sec. or 0.54 min

t_2 =67.73 sec. or 1.13 min

T = 2 x 32.43 + 67.73 = 132.59 sec or 2.21

T_T = 15.47 min

T_1 = 51 min or 0.85 hrs

T_{sc} = 66.47 min or 1.11 hrs

5.8 SECONDARY DELAY FOR TRAINS RUN ALONG THE LINK

The primary delay to train movement has been treated in the preceeding sections under line factor of track infrastructure, signalling and traction factor. Secondary delay also occurs due to operation factor, and interdiscipline delay due to minor causes within the primary delay. The secondary delay is analysed from data in Appendix E and Table F.1 to F.4. From the result of total secondary delay Table F.1, the distribution of which is shown in Fig. 5.9 and Fig. 5.10, fits a normal distribution at 5% significant level.

Also from Appendix E, cause of delay between KDJ to ZRX in both directions is obtained and represented in Table 5.14. The delays causewise are computed for all the months.

From the result of Table 5.14, a large part of secondary delay (40.8%) is attributed to operation.

Fig 5.9 NORMAL CURVE FITTED TO DATA OF ARRIVAL TIME OF EXPRESS TRAIN AT ZRX FOR AUGUST 1993

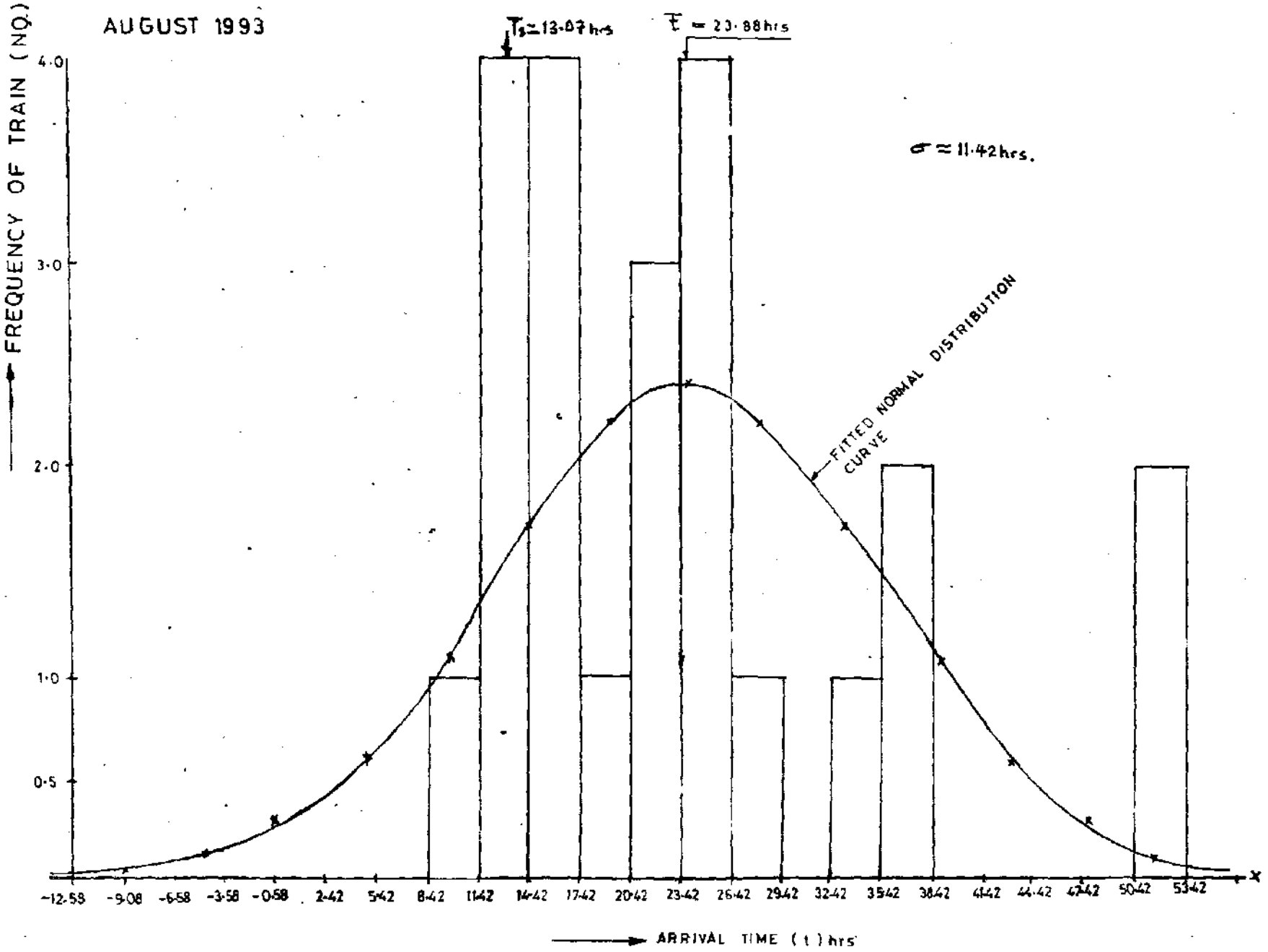


Fig 5.10 NORMAL CURVE FITTED TO DATA OF ADJUSTED DELAY TIME OF EXPRESS TRAIN FOR KDJ ZRX SECTION AUGUST 1993

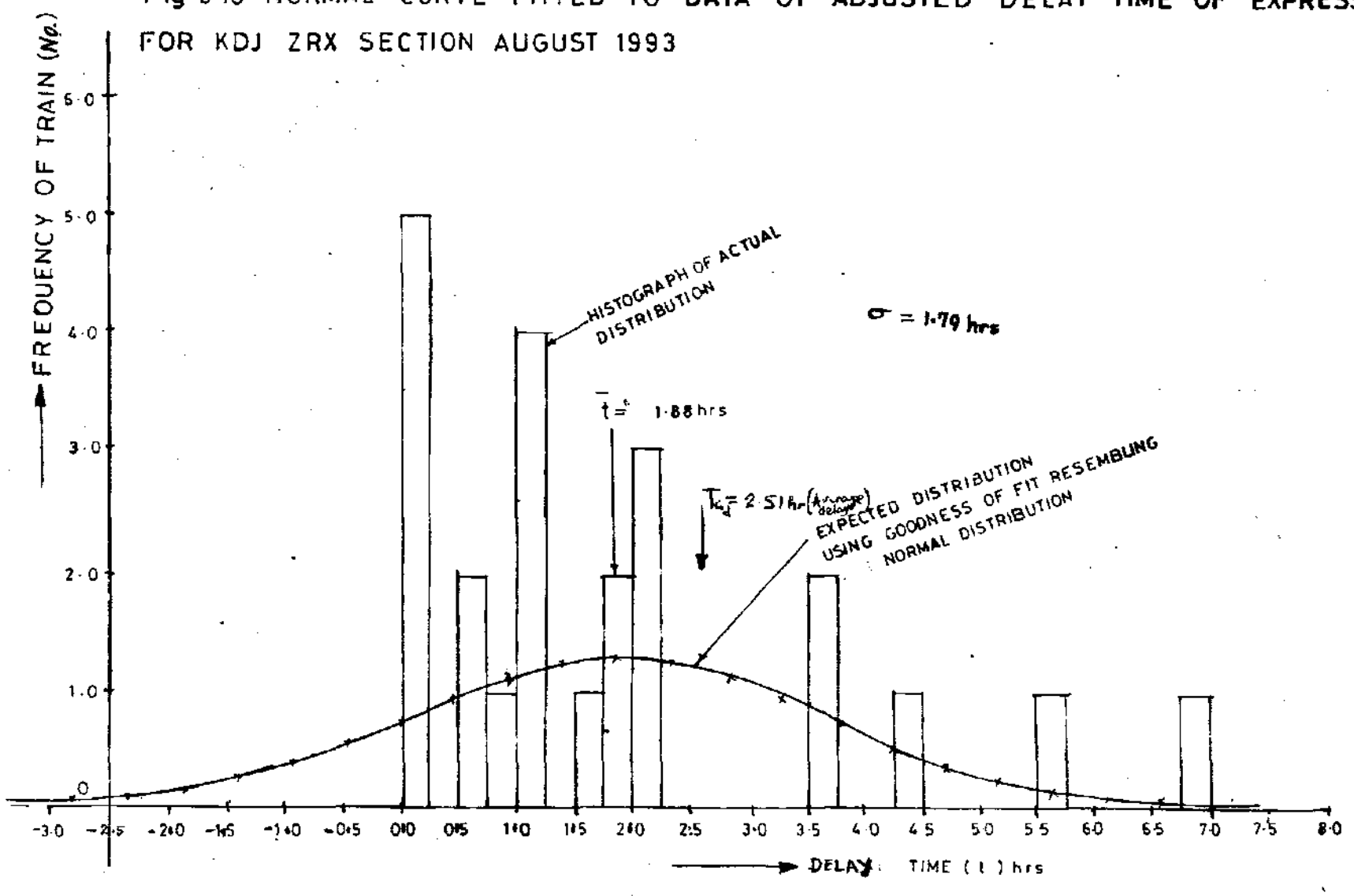


Table 5.14 Total Delay Cause wise for Express Trains Running on the Link

Description	LAug '93	LNov. '93	LDec. '93	LJan. '94	TAug '93	TNov '93	TDec. '93	TJan. '94	OAug '93	ONov 93	ODec '93	OJan '94	AAug '93	ANov '93	ADec '93	AJan '93
KDJ/ ZRX	118	84	92	681	639	437	271	924	1128	1127	1206	910	2094	454	-	-
ZRX/ KDJ	150	794	227	655	781	471	299	828	1100	506	393	998	688	-	-	-
Total/ month	268	878	319	1336	1420	908	560	1752	2228	1633	1599	1908	2782	454	-	-

Causewise total for four months ° Line Delay, L = 2801 min, Traction Delay, T = 4640 min, Operation delay, O =7368 min, Accident Delay, A = 3236 min.

Delay per Month both directions(Total Causewise/ Total Delay) ≡ Line Delay= 700.3 min or 15.5 %, Traction Delay = 1160min or 25.7 %, Operational Delay = 1842 min or 40.8 %. Accident Delay = 809 min or 17 9 %.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 PREAMBLE

This research work has investigated the constraints to increased speed on the rail link. The studied link is that between Kaduna (KDJ) and Zaria (ZRX). The focus of the thesis has been to determine how speed can be increased and operating delays reduced. Basic data on the operating conditions and link geometry were collated and analysed. Improvements that can facilitate speeds of up to 100 km/h were then proposed.

Check calculation could not be performed for all existing bridges due to limitation of research but record book of Nigerian Railways [41] shows that they were initially designed for 100 km/h but over the years they have shown sign of failure as discovered during investigation (Table 4.3).

The ability of a train to move safely at 100km/h is dependent on impact force from leading wheel of train on track. Impact force as track diverges increases from plain track to turnout track. The plain track is safest as shown in Fig. 5.3. It is also dependent on inclination of riding wheel surface and rail. Riding quality of the set of rolling stock with reference to wheel type and bogie arrangement and to the track; ranges between 2.19 to 2.39 which means nearly good riding condition is possible. This is expected in terms of track because the track is long welded rail section.

The maximum train traffic capacity of the section at 100km/h worked out to be 65 trains/day. It was found that capacity is almost linearly related to the speed Fig. 5.5. The more the stopping time of train the less the capacity. The arrival puntuality of a station (e.g. ZRX) generally, closely resembles a normal distribution at 5% level of significance. Also the delay within the section also resembles the normal distribution (Fig. 5.10) at 5% significance level.

6.2 CONCLUSIONS

The analysis and discussion of results have established the following:

i) The stresses, deflection and deformation in rails were found to increase with speed and these effects are the same regardless of the loads being static or dynamic. The heavier the rail section, the higher the speed that can be sustained. The 70A (35.4kg/m) rail section used in the system is capable of sustaining speeds higher than 100km/h when in new condition and at 5 percent head worn but 10% head worn can only permit speed less than 90km/h.

ii) The sleeper suitability was found to depend on load more than on speed and that concrete sleeper is more appropriate because of its higher resistance in comparison to steel sleepers. The use of concrete sleepers will permit higher sleeper spacing than the existing 70cm, even at higher speeds.

iii) The minimum existing ballast cushion of 15cm for the maximum axle load of the section is found safe but since greater depth of cushion facilitates less stress on ballast (i.e. more the resistance of ballast), greater depth would be prefered.

iv) Curvature of 6°, 5°, 4° and 3.5° are not compatible with up to 100km/h speed but only between 45 to 91km/h. Curvature of 3 Deg. can permit speed of 100km/h, 2 Deg. can permit up to 120 km/h and 1 Deg. have speed potential of 180 km/h

v) The cant of 75mm, cant defficiency of 50mm and excess cant of 50mm were found adequate for curvature between 1 Deg. to 3 Deg. which follows that the current prescribed Railway rules will remain valid after all curves are realigned to 3 Deg. and lesser.

vi) For curvature higher than 3 Deg. that can not be realigned to less curvatures for whatever reasons, the review of existing cant to 106 mm, cant defficiency to 80mm and excess cant to 65mm will greatly increase the maximum speeds by 22 percent in individual cases. Thus, the speed on them will be enhanced.

vii) Even curvatures having speed potential of 100 km/h were found to have shifted from their true state and will have to be resolutioned in conformity with the new set of cant and transition length and then finally slued to their theoretical position.

viii) The existing safe speed on turnout are 35 km/h for 1:12 and 45 km/h for 1:16 on the turnout side. Canting of turnout at its curve portion will enhance their speed potential to 44 and 58 km/h respectively on the turnout side and 100 km/h on the straight portion. The speed potential of turnout is directly proportional to the number (angle of crossing) of turnout.

ix) The 19 class locomotive carrying 1,500 tons load can maintain a maximum speed of 100 km/h on vertical profile less than 1.25 percent, while 18 class locomotive at 800 tons load will maintain 72 km/h speed on 1.25 percent grade. The 17 class locomotive is having speed potential of 60km/h on 1.25% grade (Sec. 5.2.9). The maximum gradient of the track profile is 1.25 percent.

x) A loss of 27.47 minutes from journey time of the link was found to be attributed to slow ordering of trains at the wayside stations when picking up "key token" (i.e. permission to pass to the next station).

xi) If speed potential of the stations are increased to at least 60 km/h from their present average speed of 25km/h, a gain in travel time, if maximum speed of train is 100 km/h on entry, will be 15.47 minute (Sec. 5.7). This will mean that the schedule sectional time of travel will be 66.47 min. or 1.11 hr. instead of the present 123 minutes or 2 hours 3 min.

xii) If the present constaints to speed as a result of curvature greater than 3 deg. are removed, a gain in travel time of 35.22 min or 0.59 hr in the link will be achieved for fast trains.

6.3 RECOMMENDATIONS

On the basis of findings summarized in the preceding sections, the following specific recommendations are proposed as means to achieve rapid and reliable train operation;

i) Track improvement

ii) Improved methods of maintenance

iii) Improvement to curves

iv) Grade reduction

v) Formation improvement

vi) Turnouts and yard improvement

vii) Modernization of signalling and communication equipment

viii) Rolling stock modernization

ix) Improved operational efficiency.

These measures are expantiated below as to give broad outlines. Details still have to be worked out in each and every case individually to suit the requirement for technical and planned target of each sector as in Table E.2 Appendix D.

6.3.1 Track Improvement

The specific tasks to be performed under track improvement include:

I) Wornout rails with more than 5 percent worn to be renewed. All rail section should be 70A or heavier (e.g. 80RBS or 90 BS) throughout the section.

II) Resleepering of steel sleepers to concrete sleepers with strong rail-sleeper fastening of the elastic type. Replacement of missing rubber groove pad between rail seats and concrete sleepers.

iii) Sleeper spacing is to be maintained at 1,690 sleepers per kilometer. Introduction of additional 18,000 No. sleepers excluding the 11,940 No. to be replaced under item (ii) is still recommended.

iv) Ballast cushion is to be increased to 20cm with additional ballast 12.33 m^3 per kilometre or 1048.86m^3 added for the whole stretch of track excluding area of ballast defficiency which should also be made up.

v) Bridges are to be strengthened by either re-girdering or changing bridges to ballasted plain deck type. Rail joint on bridge to be avoided. Bridge approaches should be maintained to correct level always, after reballasting. All bad bridge timbers are to be changed. Any crack on abutment, piers and wing walls of bridges to be treated by either completely changing them or by providing additional reinforced walls to serve as support.

vi) Level crossing without automatic protection (10No. in the section) should be provided with gate barrier (interlocking of gate barriers with signals) and properly manned. At 4 locations on major highways, the protection is to be changed to automatic barriers, with colours light signals. The road surface on the level crossing within 5 metre either side of the approach to be

resurfaced with asphaltic concrete. Rail joint on level crossing should be eliminated. All level crossings should be maintained to standard (e.g. top level, gauge and alignment). Also, the provision of approach warning device e.g. bells to ring long before the train approaches the level crossing.

6.3.2 Improved Method of Maintenance

A judicious combination of mechanised maintenance by "On Track" tampers and the modified manual maintenance methods are to be introduced, such that:

i) Heavy duty machined track maintenance of track tampering, levelling, lifting and lining, rail renewal, resleepering, should be done once every two years.

ii) Subsequent programmed periodic or direct maintenance should be done using light weight tampering, portable track liner. The manual method is to be done on isolated location using the measured shovel packing method which include the use of lighter equipment or improved permanent way tools; especially the use of Viseur Instrument to detect uneveness and voids under sleeper bed, etc.

iii) Track quality should be ascertained by use of Matisa Trolley Recorder or Hallide Recording Machines once every six months since it is less cumbersome and gives faster results than the manual methods of versine survey and visual observation.

iv) Caution should be taken to shorten the period of construction or maintenance or other works on the line, so as to minimise delays. Maintenance requiring high possession time to be programmed at sections separated 30km apart.

6.3.3 Improvement to Curvature

The desired improvement should be such that;

i) Maximum degree of curvature for the line should be 3 degree or less. All curves higher than 3 deg. should be earmarked for realignment as detailed in the text.

ii) Maximum permissible cant should be 100mm while cant difficiency and excess cant should be 80mm and 65 mm respectively.

iii) Maximum transition length is to be set at 46.50m, rate of run-off of cant on transition is 45/sec at both ends and on body of curve at 1:720.

iv) In areas where the curvature cannot be realigned the maximum cant and defficiency of cant which is 106mm and 80mm respectively are to be applied.

6.3.4 Grade Reduction

I) Maximum gradient of the vertical profile of track should be reduced to 0.5%. the lowering of grade is to be done by cutting and filling so that frequent change of gradient is removed. The method in overcoming elevation with minimum gradient is to lengthen the grade line.

6.3.5 Formation Improvement

Bad formation is to be identified in the section and treated by stabilization using cementing additives or consolidation materials. Proper drainage are to be provided on both sides of the track.

6.3.6 Turnouts and Yard Improvement

i) Turnout on running main line at station should be changed to 1:18 or 1:20 or at least 1:16 with transition curves provided between the toe of the switch and the nose of crossing. Cant defficiency of 80mm to be provided on the curved portion of turnout. If transition cannot be provided, the switch length should be increased to up to 13 metres or equal to length of wheel base.

ii) 3mm tight gauged on the straight portion of turnout to be provided.

iii) Curved switches should have flatter angle of switch and flatter radius of curvature. The switch should be of flexible type. Facing points should not be fitted with economical mechanisms. i.e. a separate lever must be used for operating the point and another lever for operating the lock bar. This ensures better locking of the points which is essential for higher speeds.

iv) Spacing of sleepers to be at least 70cm. All overaged or damaged turnout timbers should be changed.

v) Yard to be relaid such that through trains will always pass on the through route of turnout which must be laid on the tangent track to make it truly straight. Isolation between the mainline and loop at wayside stations should be ensured by either providing trap points at both ends of the loop or installing turnouts with short dead-ends and sand drags.

vi) Special marshalling yard to be provided mid-way with semi-automatic devices with capacity of handling up to 1,800 wagons.

vii) Interlocking of point on turnout to be centrally operated through an electrical interlock device via power machines.

viii) Key token method should be replaced with mechanical pick-up apparatus near the main line track and a corresponding pick-up equipment on the locomotive.

Suggestion on how to implement the recommendations above are given in Appendix D

6.3.7 Recommendation for Further Research

In the final analysis, research activity should be undertaken in the following areas:

i) Civil Engineering: High speed experiment on track especially Oscillatory/vibrational acceleration of all track components using measuring devices, stresses analysis of track structure and their effect on different track curvature; Research activity should be undertaken in area of Bridges, grade separation and physical protection of lines Development of analytical approach to track maintenance planning and model formulation in all these aspects.

ii) Mechanical Engineering: Development of Rolling stock for high speed operation. Train movement simulation in traction operation in term of efficiency. (energy and fuel resources). Power units of locomotive and self-propelled vehicles brake and coupling system for high speed trains especially in area of braking distance.

iii) Signal Engineering: Automatic block signal system, and centralized traffic control including research in use of colour light signals. Research activity in economical signal equipment at stations, between block sections, Gang work sites and at level crossing.

iv) Telecommunication Engineering: The investigation of modern telecommunication techniques equipment and installation such as Telephone Radio, Microwave, UHF and VHF.

v) Operation Research: Time table studies, Economic decision strategy e.g. probability, reliability, sensitivity reporting; assessing cost-Benefit and organization methods. Tactical planning for coordination of the whole department.

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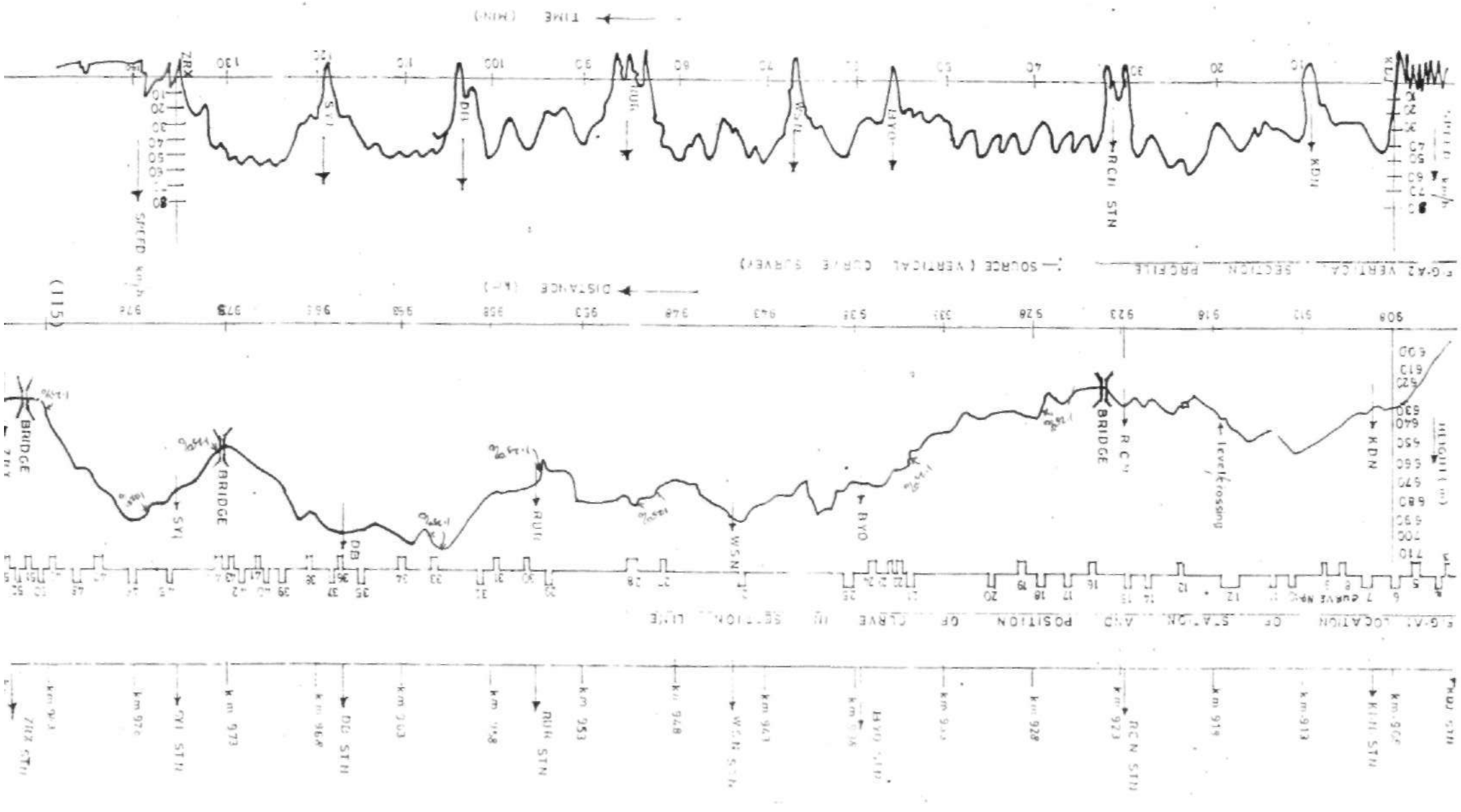


FIG A1 SPEED CHART OF THE SECTION FOR LOCO 1801 CLASS ENGINE

FIG A2 VERTICAL SECTION PROFILE

FIG A3 LOCATION OF STATION AND POSITION OF CURVE IN SECTION LINE

APPENDIX B

Table B.1 BILL OF QUANTITY/COST ESTIMATE FOR REALIGNMENT OF CURVE NO. 202

Item	Description	Unit	Quantity	Rate	Amount(N : K)
A	PRELIMINARY WORKS				
1.	Clear site of Vegetation(corridor approx. 10 m. wide)	m^2	8680	2:50	21700:00
2.	Fall trees average girth 300-500mm including cutting into logs stumping up and carting away logs clear of of site including 60m free lead	No.	100	400	40000:00
3.	Strip top soil average 150mm deep and remove excavated material, deposit, spread and level in catch water bands, spoil banks including 60 m free lead.	m^2	3970	3:00	11910:00
4.	Ditto 300mm deep ditto.	m^2	1980	3:50	6930:00
5.	Excavate any material except rock in cutting and side drains, depth not exceeding 1.5m, shape formation and trim slopes to required section and remove excavated material, deposit, spread and level in catch water banks, spoil banks including 60m free lead.	m^3	1337	21:19	28331:03
6.	Ditto 1.5 to 3 m deep ditto.	m^3	4870	25:50	124185:00
7.	Extra over item 5 for excavating in rock.	m^3	100	50:00	5000:00
8.	Excavate side drains including trimming bottoms and side slope to specified profile, remove excavated material, deposit, spread and level in catch water banks, spoil banks.	m^3	563	21:19	11929:97
					249,986:00
B.	PROVISION OF 610mm DIAMETER ARMCO RING CULVERT AT CHAINNAGE 0 + 220				
9.	Earthwork excavation in foundation.	m^3	16:20	21:19	343:28
10.	Cement concrete 1:4:8 mix in foundation brick ballast.	m^3	13:90	857:27	11916:05
11.	First Class brickwork in 1:6 Concrete mortar mix for wing walls and head wall.	m^3	11:49	700:00	8043:00
12.	Cement pointing 1:2 mix in exposed surfaces.	m^2	333:50	15:50	519:25
13.	Armco ring heavy type 610 mm diameter.	m	9.10	1500	13650:00
					34, 471:58
C.	LAYING OF TRACK STRUCTURE 867.98m LENGTH				
14.	Cost of 70A (35.4 Kg/m) rail and fastenings with 0.7m spaced twin head concrete sleepers.	(RECOVERED TRACK MATERIAL TO BE RE-USED)			
15.	Labour for dismantling and relaying track at the new alignment at 560 men/ km.	men/ day	300	120:00	36,000:00
16.	Supply and lay 37-50mm stone ballast to a depth of 330mm.	m^3	837:80	727:27	609,306:81
					645,306:81

SUMMARY OF COST

A. PRELIMINARY WORKS	= N 249,986:00
B. PROVISION OF CULVERTS	= N 34,471:58
C. LAYING OF TRACK STRUCTURE	= N 645,306:81
GRAND TOTAL	= N 929,764:39

Cost of Construction = N 929,764.39/ 867.98 = N 1071.18 per meter

SAFE IN REVENUE DUE TO REMOVAL OF SHARP CURVES AND STATION RESTRICTION

Revenue Gain = ((Enhanced Section time in hours) x (Train Revenue per annum)/ 8760)

Enhanced Section time or journey time saving due to removal of sharp curves and station restriction= 0.66hrs from Sec. 5.7(iib).

Train Revenue = 15,676,812.00/ 8760 per hour from Appendix F.

Therefore, revenue gain = 0.66 x 1789.5 = N 1181.13 per hour

APPENDIX C

Table C.1 Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 190		Curve No.191		Curve No. 192		Curve No. 193		Curve No. 194	
0	0	0	0	0	0	0	0	0	0
1	5	1	10	1	2	1	6	1	0
2	16	2	20	2	10	2	20	2	11
3	41	3	45	3	25	3	31	3	19
4	39	4	62	4	52	4	67	4	43
5	80	5	80	5	75	5	90	5	50
6	100	6	110	6	102	6	112	6	69
7	135	7	146	7	116	7	129	7	95
8	150	8	171	8	106	8	139	8	114
9	170	9	150	9	110	9	146	9	98
10	168	10	180	10	111	10	141	10	106
11	168	11	182	11	111	11	133	11	108
12	168	12	170	12	106	12	154	12	106
13	173	13	162	13	113	13	131	13	108
14	170	14	156	14	115	14	150	14	106
15	175	15	174	15	104	15	149	15	112
16	175	16	140	16	110	16	133	16	96
17	157	17	[218]	17	113	17	145	17	114
18	[185]	18	[161]	18	106	18	140	18	96
19	[173]	19	[160]	19	113	19	151	19	105
20	[180]	20	[170]	20	107	20	[140]	20	113
21	[170]	21	[170]	21	[105]	21	[146]	21	94
22	168	22	[169]	22	[111]	22	[136]	22	105
23	167	23	[163]	23	[104]	23	[140]	23	107
24	172	24	163	24	[102]	24	[135]	24	[108]
25	160	25	175	25	Level	25	[141]	25	[106]
26	175	26	150	26	Level	26	140	26	[100]
27	155	27	180	27	Level	27	135	27	[102]
28	170	28	170	28	105	28	150	28	[103]
29	160	29	165	29	110	29	141	29	[106]
30	149	30	160	30	110	30	146	30	[114]
31	117	31	177	31	115	31	134	31	[102]
32	95	32	160	32	107	32	144	32	[103]
33	57	33	130	33	115	33	134	33	[103]
34	40	34	100	34	107	34	142	34	105
35	17	35	75	35	108	35	142	35	108
36	6	36	63	36	112	36	128	36	106
37	0	37	30	37	110	37	106	37	113
		38	10	38	107	38	82	38	100
		39	13	39	105	39	52	39	110
		40	3	40	91	40	27	40	104
		41	0	41	68	41	9	41	113
				42	48	42	5	42	108
				43	20	43	7	43	104
				44	6	44	0	44	113
				45	0	45	0	45	102
								46	104
								47	103
								48	87
								49	65
								50	40
								51	19
								52	15
								53	2
								54	2
								55	0

Table C 1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 195		Curve No.196		Curve No. 197		Curve No. 198		Curve No. 199	
0	0	0	0	0	0	0	0	0	0
1	0	1	0	1	7	1	2	1	1
2	2	2	4	2	9	2	5	2	4
3	8	3	19	3	13	3	39	3	25
4	32	4	41	4	23	4	49	4	50
5	53	5	63	5	29	5	78	5	55
6	76	6	85	6	55	6	86	6	77
7	98	7	98	7	69	7	126	7	83
8	105	8	98	8	80	8	158	8	80
9	111	9	100	9	96	9	133	9	91
10	116	10	100	10	97	10	141	10	83
11	106	11	102	11	88	11	135	11	85
12	119	12	102	12	86	12	145	12	84
13	108	13	102	13	[90]	13	140	13	[80]
14	116	14	100	14	[91]	14	135	14	[84]
15	97	15	101	15	[86]	15	154	15	[80]
16	110	16	99	16	[84]	16	138	16	[87]
17	106	17	100	17	[81]	17	144	17	84
18	107	18	101	18	TP	18	134	18	80
19	110	19	98	19	TP	19	143	19	83
20	105	20	100	20	TP	20	135	20	79
21	111	21	98	21	87	21	145	21	82
22	113	22	98	22	90	22	136	22	81
23	[110]	23	97	23	80	23	135	23	90
24	[111]	24	99	24	86	24	[161]	24	55
25	[106]	25	98	25	73	25	[135]	25	47
26	[108]	26	98	26	51	26	[148]	26	25
27	[107]	27	98	27	46	27	[138]	27	4
28	104	28	100	28	31	28	[140]	28	0
29	106	29	98	29	23	29	140	29	0
30	110	30	98	30	10	30	137		
31	105	31	98	31	3	31	134		
32	114	32	[100]	32	11	32	148		
33	114	33	[97]	33	0	33	134		
34	107	34	[98]			34	138		
35	108	35	[98]			35	156		
36	104	36	99			36	141		
37	101	37	97			37	153		
38	97	38	100			38	135		
39	104	39	98			39	138		
40	105	40	98			40	144		
41	109	41	100			41	134		
42	110	42	100			42	138		
43	87	43	100			43	147		
44	80	44	99			44	138		
45	55	45	98			45	134		
46	31	46	98			46	117		
47	6	47	98			47	78		
48	0	48	98			48	67		
49	0	49	96			49	29		
50	0	50	100			50	14		
		51	97			51	4		
		52	98			52	0		
		53	98						
		54	100						
		55	100						
		56	100						
		57	98						
		58	100						
		59	100						
		60	98						
		61	88						
		62	57						
		63	27						

Table C.1 cont Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 200		Curve No.201		Curve No. 202		Curve No. 203		Curve No. 204	
0	0	0	0	0	6	0	0	0	0
1	2	1	0	1	0	1	0	1	37
2	10	2	0	2	0	2	2	2	58
3	20	3	6	3	10	3	20	3	78
4	32	4	13	4	24	4	22	4	90
5	35	5	18	5	45	5	22	5	81
6	26	6	25	6	65	6	25	6	87
7	29	7	27	7	90	7	[25]	7	86
8	31	8	26	8	110	8	[20]	8	101
9	27	9	27	9	112	9	[22]	9	90
10	35	10	25	10	111	10	[24]	10	84
11	29	11	25	11	112	11	20	11	[72]
12	35	12	24	12	23	12	23	12	[86]
13	[29]	13	26	13	112	13	19	13	[80]
14	[30]	14	27	14	116	14	4	14	[70]
15	[22]	15	25	15	106	15	4	15	[83]
16	[31]	16	25	16	115	16	5	16	83
17	[25]	17	26	17	113	17	0	17	73
18	[30]	18	24	18	[111]			18	86
19	29	19	25	19	[115]			19	73
20	25	20	26	20	[114]			20	65
21	37	21	26	21	[119]			21	53
22	25	22	26	22	[112]			22	40
23	35	23	25	23	[118]			23	25
24	26	24	27	24	109			24	6
25	29	25	26	25	120			25	6
26	22	26	26	26	122			26	0
27	35	27	26	27	118				
28	20	28	26	28	110				
29	6	29	25	29	110				
30	2	30	25	30	115				
31	0	31	25	31	114				
		32	25	32	112				
		33	25	33	91				
		34	24	34	68				
		35	25	35	45				
		36	25	36	21				
		37	24	37	5				
		38	24	38	3				
		39	25	39	2				
		40	25						
		41	[25]						
		42	[25]						
		43	[26]						
		44	[25]						
		45	[25]						
		46	[25]						
		47	25						
		48	26						
		49	24						
		50	24						
		51	26						
		52	25						
		53	25						
		54	26						
		55	26						
		56	26						
		57	25						
		58	25						
		59	24						
		60	26						
		61	25						
		62	24						

Curve No. 201 cont.

Station	Versine
Curve No. 201	
63	26
64	25
65	25
66	25
67	26
68	26
69	25
70	26
71	25
72	24
73	25
74	23
75	24
76	23
77	25
78	25
79	25
80	26
81	24
82	17
83	12
84	5
85	1
86	0
87	0

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 205		Curve No.206		Curve No. 207		Curve No. 208		Curve No. 209	
0	0	0	0	0	0	0	0	0	0
1	2	1	0	1	0	1	0	1	0
2	5	2	11	2	2	2	10	2	5
3	7	3	28	3	12	3	28	3	19
4	30	4	28	4	33	4	46	4	32
5	43	5	31	5	53	5	56	5	34
6	69	6	[24]	6	56	6	59	6	62
7	77	7	[25]	7	54	7	60	7	44
8	101	8	[25]	8	64	8	[59]	8	65
9	105	9	[23]	9	53	9	[59]	9	66
10	103	10	[27]	10	60	10	[60]	10	[50]
11	[112]	11	21	11	54	11	[59]	11	[64]
12	[99]	12	20	12	58	12	59	12	[60]
13	[105]	13	14	13	66	13	56	13	[52]
14	[102]	14	0	14	61	14	52	14	56
15	[112]	15	2	15	54	15	57	15	64
16	101	16	0	16	55	16	33	16	46
17	104			17	64	17	10	17	45
18	105			18	[53]	18	0	18	22
19	107			19	[63]	19	0	19	15
20	96			20	[57]			20	2
21	75			21	[58]			21	0
22	45			22	[53]			22	0
23	25			23	63				
24	10			24	55				
25	3			25	52				
26	0			26	60				
				27	54				
				28	62				
				29	50				
				30	60				
				31	56				
				32	50				
				33	67				
				34	42				
				35	33				
				36	8				
				37	10				
				38	5				
				39	0				
				40	0				

Table C.1 cont Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 210		Curve No. 211		Curve No. 212		Curve No. 213		Curve No. 214	
0	0	0	0	0	0	0	0	0	0
1	9	1	0	1	5	1	10	1	0
2	0	2	1	2	10	2	23	2	12
3	5	3	34	3	28	3	36	3	31
4	20	4	39	4	42	4	48	4	60
5	49	5	72	5	52	5	56	5	87
6	70	6	100	6	55	6	62	6	106
7	100	7	138	7	53	7	61	7	114
8	126	8	123	8	54	8	59	8	114
9	115	9	175	9	55	9	60	9	116
10	167	10	164	10	57	10	57	10	118
11	169	11	174	11	55	11	61	11	111
12	175	12	160	12	[54]	12	58	12	114
13	163	13	173	13	[58]	13	60	13	115
14	178	14	160	14	[57]	14	56	14	[118]
15	169	15	[163]	15	[59]	15	56	15	[115]
16	170	16	[167]	16	[61]	16	61	16	[119]
17	173	17	[173]	17	[57]	17	60	17	[119]
18	[167]	18	[165]	18	58	18	61	18	116
19	[173]	19	[166]	19	59	19	[59]	19	114
20	[176]	20	[160]	20	57	20	[58]	20	115
21	[162]	21	170	21	58	21	[61]	21	118
22	174	22	158	22	58	22	[56]	22	115
23	162	23	172	23	56	23	[64]	23	117
24	180	24	165	24	51	24	60	24	117
25	145	25	152	25	35	25	60	25	115
26	176	26	183	26	14	26	56	26	87
27	164	27	135	27	9	27	61	27	57
28	162	28	115	28	2	28	57	28	26
29	180	29	92	29	0	29	62	29	10
30	151	30	58			30	58	30	0
31	160	31	62			31	61	31	0
32	125	32	2			32	58		
33	104	33	6			33	60		
34	81	34	4			34	59		
35	44	35	0			35	59		
36	36					36	46		
37	2					37	30		
38	4					38	16		
39	0					39	6		
						40	2		
						41	0		

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 215		Curve No. 216		Curve No. 217		Curve No. 218		Curve No. 219	
0	0	0	0	0	0	0	0	0	0
1	2	1	3	1	6	1	7	1	6
2	11	2	6	2	6	2	29	2	12
3	35	3	7	3	20	3	40	3	37
4	52	4	11	4	36	4	58	4	64
5	79	5	25	5	50	5	[59]	5	85
6	[104]	6	49	6	58	6	[58]	6	113
7	[123]	7	57	7	58	7	[55]	7	113
8	[140]	8	[60]	8	57	8	[57]	8	114
9	[143]	9	[58]	9	58	9	[55]	9	111
10	[144]	10	[60]	10	57	10	47	10	[112]
11	[142]	11	[60]	11	58	11	24	11	[114]
12	[140]	12	[60]	12	59	12	12	12	[112]
13	[116]	13	59	13	59	13	3	13	[115]
14	[78]	14	58	14	[58]	14	0	14	113
15	51	15	56	15	[59]			15	118
16	30	16	43	16	[60]			16	116
17	11	17	30	17	[60]			17	114
18	2	18	17	18	[60]			18	117
19	0	19	5	19	59			19	96
20	0	20	0	20	59			20	63
				21	58			21	22
				22	58			22	12
				23	57			23	0
				24	57				
				25	58				
				26	57				
				27	56				
				28	36				
				29	20				
				30	6				
				31	0				
				32	0				

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 220		Curve No.221		Curve No. 222		Curve No. 223		Curve No. 224	
0	0	0	0	0	0	0	0	0	0
1	2	1	10	1	2	1	7	1	0
2	6	2	33	2	7	2	25	2	0
3	15	3	35	3	15	3	35	3	10
4	26	4	78	4	40	4	57	4	24
5	51	5	101	5	62	5	60	5	40
6	72	6	115	6	90	6	58	6	54
7	104	7	[112]	7	111	7	57	7	64
8	111	8	[109]	8	118	8	58	8	60
9	[117]	9	[109]	9	112	9	58	9	94
10	[117]	10	110	10	113	10	57	10	86
11	[118]	11	102	11	116	11	58	11	86
12	[116]	12	70	12	116	12	58	12	86
13	[117]	13	42	13	117	13	60	13	88
14	119	14	10	14	116	14	58	14	84
15	101	15	3	15	117	15	87	15	84
16	82	16	0	16	[119]	16	57	16	88
17	62			17	[117]	17	58	17	86
18	35			18	[116]	18	58	18	86
19	25			19	[116]	19	[56]	19	[86]
20	15			20	[116]	20	[59]	20	[86]
21	5			21	117	21	[58]	21	-
22	0			22	115	22	[58]	22	-
				23	115	23	[59]	23	84
				24	117	24	57	24	92
				25	119	25	58	25	80
				26	120	26	59	26	88
				27	118	27	58	27	84
				28	117	28	58	28	92
				29	106	29	58	29	92
				30	88	30	57	30	82
				31	63	31	59	31	84
				32	35	32	58	32	92
				33	10	33	58	33	74
				34	-2	34	59	34	58
				35	0	35	59	35	44
						36	53	36	24
						37	52	37	6
						38	59	38	0
						39	45	39	0
						40	24		
						41	6		
						42	0		

Table C. 1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 225		Curve No. 226		Curve No. 227		Curve No. 228		Curve No. 229	
0	0	0	0	0	0	0	0	0	0
1	0	1	0	1	8	1	0	1	4
2	10	2	4	2	-2	2	6	2	20
3	24	3	22	3	16	3	22	3	34
4	34	4	[26]	4	18	4	36	4	48
5	48	5	[50]	5	38	5	48	5	52
6	70	6	[60]	6	48	6	52	6	60
7	[84]	7	[60]	7	58	7	56	7	58
8	[98]	8	[60]	8	66	8	50	8	58
9	[92]	9	[60]	9	62	9	50	9	[56]
10	[84]	10	[50]	10	62	10	48	10	[58]
11	[100]	11	[38]	11	62	11	54	11	[58]
12	70	12	20	12	62	12	50	12	[58]
13	100	13	6	13	[62]	13	60	13	[58]
14	86	14	0	14	[62]	14	60	14	54
15	80	15	0	15	[62]	15	56	15	60
16	18			16	[62]	16	60	16	54
17	2			17	52	17	54	17	54
18	0			18	36	18	60	18	48
				19	16	19	54	19	28
				20	6	20	60	20	14
				21	0	21	54	21	0
				22	0	22	58	22	0
						23	60		
						24	56		
						25	46		
						26	58		
						27	56		
						28	56		
						29	52		
						30	[60]		
						31	[56]		
						32	[60]		
						33	[56]		
						34	[46]		
						35	[60]		
						36	[52]		
						37	[54]		
						38	46		
						39	56		
						40	60		
						41	52		
						42	56		
						43	58		
						44	52		
						45	56		
						46	56		
						47	52		
						48	56		
						49	56		
						50	56		
						51	56		
						52	50		
						53	58		
						54	60		
						55	54		
						56	58		
						57	56		
						58	56		
						59	56		
						60	56		
						61	56		
						62	52		
						63	40		

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 230		Curve No. 231		Curve No. 232		Curve No. 233		Curve No. 234	
0	0	0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0
2	12	2	10	2	14	2	0	2	0
3	36	3	32	3	26	3	9	3	0
4	62	4	58	4	47	4	24	4	4
5	86	5	80	5	71	5	40	5	26
6	108	6	104	6	93	6	56	6	42
7	130	7	126	7	112	7	74	7	54
8	138	8	150	8	134	8	89	8	50
9	[146]	9	168	9	157	9	104	9	56
10	[142]	10	172	10	171	10	114	10	84
11	[146]	11	170	11	172	11	113	11	56
12	130	12	170	12	171	12	114	12	54
13	100	13	170	13	172	13	114	13	54
14	72	14	170	14	172	14	116	14	54
15	42	15	170	15	172	15	114	15	54
16	14	16	170	16	[172]	16	114	16	50
17	0	17	170	17	[174]	17	116	17	52
18	0	18	170	18	[172]	18	116	18	54
		19	[170]	19	[172]	19	114	19	54
		20	[170]	20	[174]	20	116	20	54
		21	[170]	21	[172]	21	114	21	56
		22	[170]	22	172	22	114	22	54
		23	[170]	23	174	23	116	23	54
		24	170	24	174	24	116	24	54
		25	170	25	173	25	116	25	54
		26	170	26	174	26	[114]	26	[54]
		27	170	27	174	27	[114]	27	[54]
		28	166	28	168	28	[114]	28	[54]
		29	170	29	146	29	[118]	29	[54]
		30	166	30	124	30	[114]	30	[54]
		31	160	31	101	31	[114]	31	54
		32	168	32	78	32	116	32	54
		33	160	33	56	33	116	33	54
		34	132	34	31	34	113	34	54
		35	100	35	11	35	111	35	54
		36	74	36	0	36	116	36	54
		37	46			37	116	37	54
		38	18			38	114	38	54
		39	6			39	116	39	54
		40	0			40	116	40	54
		41	0			41	114	41	56
						42	114	42	54
						43	116	43	54
						44	113	44	54
						45	113	45	52
						46	114	46	52
						47	114	47	54
						48	106	48	52
						49	89	49	46
						50	73	50	39
						51	50	51	24
						52	38	52	10
						53	22	53	0
						54	4	54	0
						55	0	55	0
						56	0		

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 235		Curve No. 236		Curve No. 237		Curve No. 238		Curve No. 239	
0	0	0	0	0	0	0	0	0	0
1	0	1	0	1	0	1	0	1	0
2	10	2	10	2	4	2	0	2	0
3	28	3	16	3	22	3	10	3	16
4	46	4	36	4	40	4	26	4	40
5	54	5	48	5	60	5	46	5	80
6	54	6	54	6	82	6	56	6	100
7	54	7	60	7	108	7	54	7	134
8	54	8	56	8	110	8	56	8	160
9	54	9	60	9	110	9	[58]	9	168
10	54	10	58	10	112	10	[58]	10	162
11	54	11	58	11	114	11	[58]	11	170
12	54	12	60	12	112	12	[60]	12	170
13	54	13	60	13	110	13	[56]	13	168
14	54	14	60	14	116	14	54	14	170
15	56	15	56	15	106	15	46	15	170
16	54	16	62	16	[114]	16	32	16	168
17	54	17	60	17	[112]	17	12	17	170
18	52	18	58	18	[118]	18	0	18	[170]
19	54	19	56	19	[114]	19	0	19	[170]
20	54	20	60	20	[114]	20	0	20	[168]
21	54	21	[56]	21	114	21	0	21	[170]
22	54	22	[54]	22	114			22	[172]
23	54	23	[60]	23	110			23	[166]
24	54	24	[60]	24	116			24	166
25	54	25	[54]	25	116			25	164
26	54	26	58	26	112			26	178
27	54	27	60	27	110			27	162
28	54	28	60	28	76			28	162
29	54	29	60	29	60			29	180
30	56	30	56	30	36			30	158
31	54	31	60	31	12			31	168
32	[56]	32	60	32	0			32	146
33	[54]	33	58	33	0			33	120
34	[56]	34	60					34	80
35	[54]	35	62					35	68
36	[54]	36	62					36	30
37	54	37	58					37	0
38	54	38	60					38	10
39	54	39	66					39	0
40	54	40	54					40	0
41	54	41	36						
42	56	42	10						
43	52	43	0						
44	60	44	0						
45	54	45	0						
46	54								
47	56								
48	54								
49	54								
50	54								
51	54								
52	54								
53	54								
54	54								
55	54								
56	54								
57	54								
58	54								
59	Level Crossing								
60	54								
61	54								
62	50								
63	26								

Table C.1 cont. Existing Versine for Curves by String Lining Method

Station	Versine	Station	Versine	Station	Versine	Station	Versine	Station	Versine
Curve No. 235 Cont.		Curve No. 240		Curve No. 241		Curve No. 242		Curve No. 243	
64	10	0	0	0	0	0	0	0	0
65	0	1	0	1	4	1	4	1	12
66	0	2	10	2	14	2	48	2	72
67	0	3	10	3	30	3	70	3	134
		4	42	4	52	4	102	4	190
		5	64	5	[52]	5	134	5	250
		6	100	6	[54]	6	160	6	289
		7	114	7	[52]	7	190	7	289
		8	112	8	[54]	8	204	8	Level Crossing
		9	120	9	[48]	9	204	9	"
		10	114	10	32	10	[206]	10	"
		11	114	11	20	11	[206]	11	[292]
		12	114	12	8	12	[204]	12	[292]
		13	114	13	0	13	[204]	13	[292]
		14	114			14	[206]	14	[286]
		15	114			15	206	15	286
		16	114			16	204	16	285
		17	114			17	180	17	285
		18	114			18	140	18	284
		19	114			19	100	19	284
		20	[114]			20	54	20	285
		21	[114]			21	10	21	287
		22	[114]			22	0	22	289
		23	[114]			23	0	23	289
		24	[114]					24	288
		25	[114]					25	270
		26	114					26	222
		27	114					27	180
		28	114					28	113
		29	114					29	90
		30	116					30	50
		31	114					31	10
		32	114					32	0
		33	114						
		34	112						
		35	118						
		36	116						
		37	118						
		38	106						
		39	82						
		40	54						
		41	30						
		42	10						
		43	8						
		44	0						

Values in bracket were used to compute the mean Versine Vv of each curve. Versine in mm.

APPENDIX D

IMPLEMENTATION OF PLANNING TARGET RECOMMENDATION

From results obtained from this research, a phased planning programme is formulated to execute the recommendation within available resources. To achieve the projected speed increase during a period of 10 to 15 years, a coordinated planning is suggested in line with method in Fig. E.1. Accordingly, the planning target is achieved through a long and a short term plans as enumerated below.

1) Long Term Planning

The long term planning fixed 15 years period for attaining the projected improvement from Sec.6.3, in a coordinated fashion as in Fig. E.1. All department(Civil, Mechanical, Signalling, Operation and Personnel) are involved simultaneously. An independent department should be set up to coordinate the contributions of all the departments.

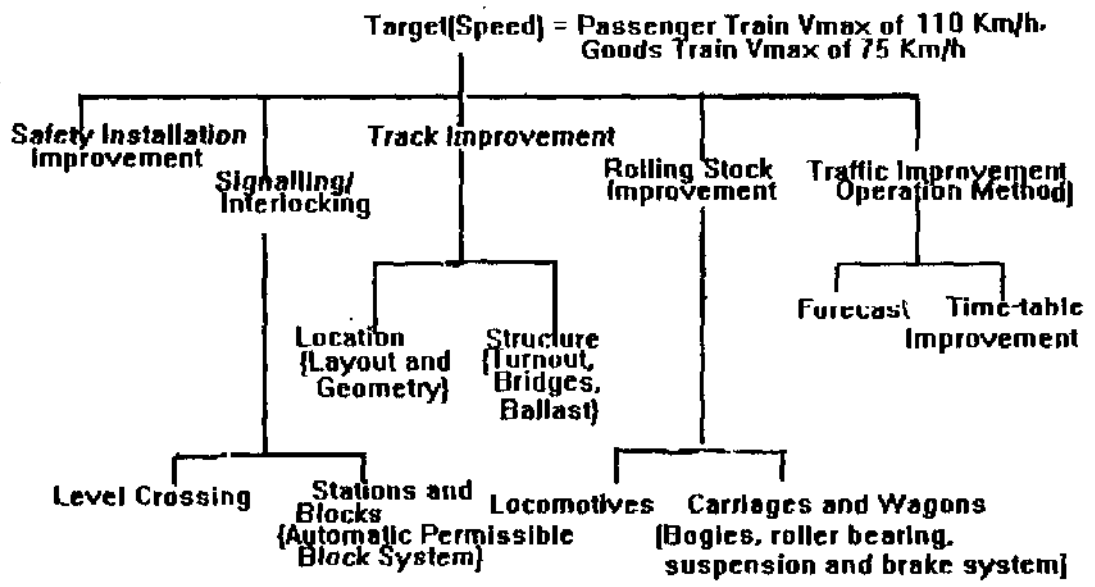


Fig. E.1. Co-ordinated Perspective Plan for Attainment of Recommended Inprovements.

2) Short Term Planning

The short term plan period is taken as 5 years in line with the National plans. This is part of the 15 years long term plan(i.e 3 short term plans) as in Table E.1. The priorities for the various tasks and works are stipulated for the overall perspective plan.

Table E.1. Speed Achievement Target Plan per Phase of Five Year Period

Phase	Period(Years)	Passenger Trains (Km/h)	Goods Trains (Km/h)
1	1995 to 2000	80	55
2	2001 to 2006	95	65
3	2007 to 2012	110	75

Existing Speed Limits; Passenger Trains = 65 Km/h, Goods Trains = 40 Km/h

A schematic chart showing the tasks to be performed yearly during the five year plans are to be drawn up as illustrated in Table E.2.

Table E.2. Five Year Execution Plan under each Phase

Phase One Task (30 percent of Long Term Plan)

1. Track
(a) Curve re-alignment of curvature greater than 4 degrees of 6.42 Km, 3 to 4 degree of 4.5 Km, undertaken as in Sec.5.2.8. At 2 years for each category.
(b) Strengthening bridges by reinforcing abutments, piers and wing walls, maintaining proper level of approaches under one year.
(c) Changing wornout and overaged material at 1km every year.
(d) Re-ballasting to depth of 20 cm at 8 Km every year.
(e) Change turnouts from 1 in12 and 1 in 16 to 1 in 18 or 1 in 20, or introduction of longer switch length for turnout of 1 in 16 at two stations every year.

2. Locomotive and Carriages
(a) Locomotives with higher acceleration and deceleration qualities e.g. 20 Class or 19 Class Locomotive at 5 new locomotives every year.
(b) Improved suspension and change to roller bearing at 20 Coaches and Wagons every year.
(c) Improved brake system at 50 Wagons and Coaches per year.
(d) Top level maintenance of locomotive(periodic overhauling) at 5 old locomotives every year including replacement of: control system, traction and generators, gears, gaskets, rubber parts etc.

3. Signal
(a) Improve Signalling with Central Electric Cabin equipment at one station per year.
(b) Replacement of key Token with Mechanical means, two stations/locomotive per year.
(c) Provision of UHF radio at two stations per year.
(d) Improvement of Central Control to Automatic System, at one depot station per year.
(e) Automatic level crossing barriers with warner colour light etc. at 13 locations, two number every year.

4. Operation
(a) Reduction in stoppages and elimination of bottle necks eg. operational research methods and forecasting.
(b) Enhanced headway of trains to 4 minutes and stoppages at depot stations, to 15 minutes maximum.
(c) Inculcation of discipline on operating staff through organised training and seminar every year.
(d) Training of operation and technical staff in developed countries at 10 staff every year.

APPENDIX E

Table F.1 :Train Arrival / Departure Survey of Express Trains for the Link(Month of August 1993)

Item	Date	Station	Train Type	T_s	T_a	T_d	D_a	D_d	D_T	Cause of Delay
1.	2.8.93	ZRX	2LL	11:25	11:30	12:32	5	47	52	47' Dead loco
	"	KDJ	"	13:40	14:15	15:05	35	65	100	35' Section and 65' loading
2.	4.8.93	ZRX	2LL	11:25	12:00	13:43	35	99	134	93' Fuelling
	"	KDJ	"	13:40	15:18	16:17	98	39	137	39' Off loading
3.	9.8.93	ZRX	2LL	11:25	11:20	12:35	0	65	65	65' Shunting
	"	KDJ	"	13:40	14:13	16:27	33	114	147	114' Shunting
4.	11.8.93	ZRX	2LL	11:25	16:55	19:00	335	115	450	115' Shunting
	"	KDJ	"	13:40	20:45	22:24	423	79	502	79' Crossing/Loading
5.	16.8.93	ZRX	2LL	11:25	13:11	14:34	106	73	179	73' Shunting
	"	KDJ	"	13:40	16:25	17:52	165	67	232	63' Train Examination
6.	18.8.93	ZRX	2LL	11:25	06:17	07:55	1072	88	1160	88' Loading
	"	KDJ	"	13:40	11:45	12:20	1160	15	1175	15' Loading
7.	23.8.93	ZRX	2LL	11:25	23:30	00:34	725	54	779	688' Accident, 54' Loading
	"	KDJ	"	13:40	02:24	05:00	765	136	901	136' Loading
8.	25.8.93	ZRX	2LL	11:25	15:56	16:37	271	31	302	31' Loading, 300' Fuelling
	"	KDJ	"	13:40	20:00	01:20	380	300	680	80' Section
9.	7.8.93	KDJ	1KL	12:45	23:44	01:22	658	86	745	78' Shunting, 37' Section
	"	ZRX	"	15:10	05:30	06:24	835	44	889	54' Shunting
10.	10.8.93	KDJ	1KL	12:45	22:23	02:00	578	197	775	197' Fuelling
	"	ZRX	"	15:10	04:24	04:43	795	9	804	21' Section, 9' Loading
11.	14.8.93	KDJ	1KL	12:45	18:05	18:55	320	30	350	30' Fuelling, 35' Servicing
	"	ZRX	1KL	15:10	20:25	21:15	350	40	390	15' Offloading
12.	17.8.93	KDJ	1KL	12:45	01:07	02:40	742	73	815	73' Shunting, 22' Offloading
	"	ZRX	"	15:10	04:44	05:25	814	29	843	9' Section
13.	21.8.93	KDJ	1KL	12:45	20:20	00:30	405	230	635	170' Shunting, 60' Loading
	"	ZRX	"	15:10	02:27	03:40	567	63	630	63' Shunting
14.	24.8.93	KDJ	1KL	12:45	19:04	21:12	379	108	487	308' Shunting/Fuelling
	"	ZRX	"	15:10	23:00	23:40	470	30	500	31' Section, 30' Offloading
15.	28.8.93	KDJ	1KL	12:45	22:00	01:17	555	117	772	20' Section, 117' Fuelling
	"	ZRX	"	15:10	03:10	03:55	720	35	755	35' Offloading
16.	31.8.93	KDJ	1KL	12:45	07:55	10:57	1130	162	1292	162' Fuelling
	"	ZRX	"	15:10	12:36	14:26	1266	100	1366	100' Crossing
17.	13.8.93	KDJ	9KL	11:42	11:00	12:20	1482	60	1542	130' Accident
	"	ZRX	"	14:17	14:10	14:50	1517	30	1547	60' Loading
18.	20.8.93	KDJ	9KL	11:42	22:06	03:43	1144	337	1481	30' Offloading
	"	ZRX	"	14:17	08:43	09:20	1443	27	1470	506' Accident
19.	21.8.93	KDJ	9KL	11:42	22:06	03:43	2124	337	2461	27' Offloading
	"	ZRX	"	14:17	05:43	23:54	2426	1141	3567	1458' Accident
20.	27.8.93	KDJ	9KL	11:42	05:59	08:45	2391	146	2537	146' Crossing
	"	ZRX	"	14:17	10:30	11:28	2507	48	2555	48' Offloading
21.	15.8.93	ZRX	10GCL	10:15	10:44	11:23	29	29	58	20' Loading
	"	KDJ	"	12:25	13:30	14:45	65	55	120	7' Section, 55' Shunting
22.	17.8.93	ZRX	10GCL	10:15	15:15	17:32	293	127	420	127' Fuelling, 13' Section
	"	KDJ	"	12:25	19:45	23:23	433	198	631	198' Shunting
23.	22.8.93	ZRX	10GCL	10:15	22:25	23:25	700	50	750	40' Loading, 50' Section
	"	KDJ	"	12:25	01:40	03:40	755	100	855	100' Fuelling

Table F.2 :Train Arrival / Departure Survey of Express Trains for the Link(Month of Nov 1993)

Item	Date	Station	Train Type	T_s	T_a	T_d	D_a	D_d	D_T	Cause of Delay
1.	1.11.93	ZRX	2LL	11:25	12:10	12:44	45	24	69	25' Section, 24' Examination
	"	KDJ	"	13:40	14:38	19:10	58	252	310	252' Traction
2.	5.11.93	ZRX	2LL	11:25	17:35	18:31	370	46	416	46' Examination
	"	KDJ	"	13:40	20:22	21:24	402	42	444	42' Loading
3.	8.11.93	ZRX	2LL	11:25	15:52	16:36	267	94	361	94' Loading
	"	KDJ	"	13:40	18:46	19:06	361	0	361	20' Section
4.	10.11.93	ZRX	2LL	11:25	17:35	18:10	415	25	440	25' Loading
	"	KDJ	"	13:40	20:00	03:50	425	450	875	450' Communi.
5.	15.11.93	ZRX	2LL	11:25	11:46	12:24	21	28	49	21' Section, 28' Tra.
	"	KDJ	"	13:40	14:30	16:20	50	90	140	90' Communication
6.	27.11.93	ZRX	2LL	11:25	23:24	00:30	719	60	779	60' Exa, 20' Section
	"	KDJ	"	13:40	02:55	04:00	799	45	844	45' Loading
7.	29.11.93	ZRX	2LL	11:25	13:15	13:57	110	32	142	32' Examination
	"	KDJ	"	13:40	15:52	16:41	257	29	286	29' Vacuum
8.	3.11.93	KDJ	1KL	12:45	20:25	22:27	460	102	562	102'Offload, 10' Se
"		ZRX	"	15:10	00:42	03:18	572	146	718	146' Offloading
9.	7.11.93	KDJ	1KL	12:45	13:03	14:00	1491	37	1528	37' Loading
	"	ZRX	"	15:10	16:16	17:46	1564	80	1644	80' Shunting
10.	9.11.93	KDJ	1KL	12:45	23:31	01:33	646	122	768	88' Fuelling, 34' Lo
	"	ZRX	"	15:10	03:24	04:50	754	76	830	76' Offloading
11.	13.11.93	KDJ	1KL	12:45	22:18	23:45	573	64	638	65' Shunting,22'Sec
	"	ZRX	"	15:10	02:10	03:12	660	52	712	52' Offloading
12.	23.11.93	KDJ	1KL	12:45	06:48	09:10	5403	132	5435	454' Acc, 47' Sec.
	"	ZRX	"	15:10	11:10	11:50	5530	30	560	30'Offload,132' Shu
13.	26.11.93	KDJ	1KL	12:45	06:12	08:12	1045	100	1147	100' Examination
	"	ZRX	"	15:10	10:00	10:40	1130	30	1160	30' Offloading
14.	4.11.93	KDJ	9KL	11:42	03:15	03:35	973	20	993	20' Loading
	"	ZRX	"	14:17	05:50	06:25	993	25	1018	25' Offloading
15.	13.11.93	KDJ	9KL	11:42	16:58	18:05	1756	114	1870	114' Service
	"	ZRX	"	14:17	20:25	22:50	1875	135	2010	5' Sect. 138' Serv
16.	20.11.93	KDJ	9KL	11:42	10:45	12:40	1377	95	1472	95' Offloading
	"	ZRX	"	14:17	14:42	16:05	1439	73	1512	73' Shunting
17.	26.11.93	KDJ	9KL	11:42	03:18	05:00	2376	82	2458	82' Loading
	"	ZRX	"	14:17	06:45	07:43	2428	48	2576	48' Shunting
18.	6.11.93	ZRX	10GCL	10:15	21:36	22:28	2121	12	2163	42' Loading
	"	KDJ	"	12:15	00:43	01:03	2163	0	2163	0'
19.	14.11.93	ZRX	10GCL	10:15	14:20	15:05	975	35	1010	35' Loading
	"	KDJ	"	12:15	16:55	18:30	1000	75	1075	75' Shunting 21.11.93 ZRX
20.	21.11.93	ZRX	10GCL	10:15	12:10	14:33	1555	133	1688	133' Section
	"	KDJ	"	12:15	16:40	17:15	1695	15	1710	7' Sect. 15' Load.
21.	29.11.93	ZRX	10GCL	10:15	21:17	21:52	3532	25	3557	23' Sect, 25 Load.
	"	KDJ	"	12:15	23:45	01:53	3557	108	3665	108 Shunting

Table F.3 :Train Arrival / Departure Survey of Express Trains for the Link(Month of Dec. 1993)

Item	Date	Station	Train Type	T_s	T_a	T_d	D_a	D_d	D_T	Cause of Delay
1.	10.12.93	KDJ	1KL	12:45	15:50	18:18	1625	128	1753	128' Offload, 17' Section
	"	ZRX	"	15:10	20:40	21:36	1770	46	1813	46' Offloading
2.	11.12.93	KDJ	1KL	12:45	04:40	06:49	945	109	1054	109' Offloading
	"	ZRX	"	15:10	08:44	09:30	1054	36	1090	36' Offloading
3.	17.12.93	KDJ	1KL	12:45	02:00	03:11	3765	51	3816	51' Fuelling
	"	ZRX	"	15:10	05:15	07:33	127	127	3945	127' Shunting
4.	21.12.93	KDJ	1KL	12:45	07:06	08:16	1101	70	1171	70' Loading
	"	ZRX	"	15:10	10:45	11:10	1175	15	1190	15' Offloading
5.	25.12.93	KDJ	1KL	12:45	21:09	23:35	5041	26	630	126' Offloading
	"	ZRX	"	15:10	02:17	03:33	667	66	733	37' Section, 66' Offloading
6.	11.12.93	ZRX	2LL	11:25	15:45	18:17	1703	139	1842	139' Fuelling
	"	KDJ	"	13:40	20:32	21:10	1852	18	1870	10' Section, 18' Offloading
7.	13.12.93	ZRX	2LL	11:25	11:20	13:19	0	109	104	104' Examination
	"	KDJ	"	13:40	14:52	15:40	72	28	100	28' Crossing
8.	15.12.93	ZRX	2LL	11:25	19:54	21:00	274	56	330	56' Examination
	"	KDJ	"	13:40	23:15	23:55	330	20	350	20' Shunting
9.	21.12.93	ZRX	2LL	11:25	17:49	19:08	384	69	453	2' Section, 69' Loading
	"	KDJ	"	13:40	19:23	20:08	453	25	478	25' Loading
10.	22.12.93	ZRX	2LL	11:25	01:40	05:10	292	200	492	200' Communication
	"	KDJ	"	13:40	06:44	07:24	461	20	481	20' Loading
11.	27.12.93	ZRX	2LL	11:25	11:17	12:08	0	33	33	33' Loading
	"	KDJ	"	13:40	13:44	14:35	22	31	53	31' Loading
12.	4.12.93	KDJ	9KL	11:42	06:50	08:42	11	48	93	1241 93' Shunting
	"	ZRX	"	14:17	10:45	12:18	1228	83	1311	83' Shunting
13.	13.12.93	KDJ	9KL	11:42	20:45	52:23	3423	82	3505	82' Service
	"	ZRX	"	14:17	01:12	02:56	3543	38	3681	38' Section, 86' Shunting
14.	27.12.93	KDJ	9KL	11:42	05:30	07:40	3888	138	4026	138' Service
	"	ZRX	"	14:17	10:15	11:48	4088	83	4171	83' Crossing
15.	5.12.93	ZRX	10GCL	10:15	10:45	11:18	1470	23	1493	23' Loading
	"	KDJ	"	12:25	13:20	14:30	1495	50	1545	2' Section, 50' Offloading
16.	28.12.93	ZRX	10GCL	10:15	11:33	13:02	4148	79	4227	79' Loading
	"	KDJ	"	12:25	15:15	16:22	4240	47	4287	13' Section, 47' Shunting

Table F.4 Train Arrival / Departure Survey of Express Trains for the Link(Month of Jan. 1994)

Item	Date	Station	Train Type	T_s	T_a	T_d	D_a	D_d	D_T	Cause of Delay
1.	1.1.94	KDJ	1KL	12:45	18:35	20:28	1790	93	1883	93' Loading
	"	ZRX	"	15:10	22:30	23:48	1940	128	2068	128' Offloading
2.	3.1.94	KDJ	1KL	12:45	04:07	05:57	922	90	1012	90' Servicing
	"	ZRX	1KL	15:10	08:12	08:50	1022	28	1050	10' Sect, 28'Loading
3.	9.1.94	KDJ	1KI	12:45	01:50	03:33	785	83	868	83' Loading
	"	ZRX	"	15:10	06:10	07:06	900	46	946	32' Sect, 46' Loading
4.	16.1.94	KDJ	1KL	12:45	10:22	12:14	1297	112	1409	125' Fuelling
	"	ZRX	"	15:10	14:23	16:15	1413	102	1515	4' Sect. 102 Loading
5.	19.1.94	KDJ	1KL	12:45	06:18	07:55	1053	77	1130	45' Servicing
	"	ZRX	"	15:10	12:41	13:01	1291	20	1311	28' Load. 20' Offload.
6.	23.1.94	KDJ	1KL	12:45	07:45	09:55	1194	110	1304	110' Servicing
	"	ZRX	1KL	15:10	11:35	12:32	1279	47	1336	47' Offloading
7.	29.1.94	KDJ	1KL	12:45	22:21	01:16	576	145	730	154' Fuelling/Shunting
	"	ZRX	"	15:10	03:30	10:20	730	400	1130	400' Traction
8.	3.1.94	ZRX	2LL	11:25	16:44	17:58	561	64	625	21' Section
	"	KDJ	"	13:40	20:36	21:00	625	4	629	64' Loading
9.	5.1.94	ZRX	2LL	11:25	16:00	16:44	240	24	264	24' Offloading
	"	KDJ	"	13:40	18:59	19:24	264	14	278	14' Loading
10.	10.1.94	ZRX	2LL	11:25	11:25	11:55	0	20	20	20' Shunting
	"	KDJ	"	13:40	14:05	14:25	25	68	93	5' Sect. 68' Shunting
11.	17.1.94	ZRX	2LL	11:25	15:05	17:17	220	122	342	5' Sect. 122' Cross/Load
	"	KDJ	"	13:40	20:26	21:00	406	14	420	14' Loading
12.	19.1.94	ZRX	2LL	11:25	01:14	03:00	829	96	925	96' Servicing
	"	KDJ	"	13:40	05:05	06:53	925	88	1013	88' Vacuum
13.	24.1.94	ZRX	2LL	12:25	11:58	15:57	98	239	337	239' Communication
	"	KDJ	"	13:40	17:42	20:18	317	136	453	136' Shunting
14.	31.1.94	ZRX	2LL	11:25	12:15	12:25	60	0	60	5' Section
	"	KDJ	"	13:40	14:40	15:20	60	20	80	-
15.	2.1.94	KDJ	9KL	11:42	03:35	05:10	2393	75	2468	75' Offloading
	"	ZRX	"	14:17	08:08	08:46	2511	28	2539	28' Loading
16.	11.1.94	KDJ	9KL	11:42	05:13	06:30	5371	57	5428	57' Loading
	"	ZRX	"	14:17	08:42	09:10	5425	0	5425	-
17.	16.1.94	KDJ	9KL	11:42	16:35	17:47	3173	52	3225	52' Offloading
	"	ZRX	"	14:17	20:00	20:55	3223	45	3264	45' Offloading
18.	22.1.94	KDJ	9KL	11:42	03:05	11:27	1223	202	1425	17' Sect. 31' Loading
	"	ZRX	"	14:17	13:59	14:40	1442	31	1473	202' Communication
19.	29.1.94	KDJ	9KL	11:42	13:05	15:43	1730	47	1779	147' Section
	"	ZRX	"	14:17	18:45	18:55	1777	1115	2892	47' Loading
20.	4.1.94	ZRX	10GCL	10:15	12:04	12:43	109	29	138	29' Loading
	"	KDJ	"	12:25	14:57	15:17	138	0	138	-
21.	11.1.94	ZRX	10GCL	10:15	21:05	22:50	4970	95	5065	95' Shunting
	"	KDJ	"	12:25	00:50	11:55	5065	650	5715	650' Traction
22.	17.1.94	ZRX	10GCL	10:15	11:36	12:36	2976	50	3026	50' Loading
	"	KDJ	"	12:25	18:21	18:41	3251	0	3251	225' Communication
23.	23.1.94	ZRX	10GCL	10:15	12:00	12:40	1539	30	1569	30' Loading
	"	KDJ	"	12:25	14:35	16:55	1548	120	1668	120' Loading
24.	30.1.94	ZRX	10GCL	10:15	01:57	03:25	2382	78	2460	78' Loading
	"	KDJ	"	12:25	07:20	09:58	2522	128	2650	128' Shunting

Sample calculation of Causewise delay for August 1993

1) Line Delay

KDJ-ZRX = 37+21+9+31+20 or 118 min.

ZRX-KDJ = 35+80+7+13+15 or 150 min.

2) Traction Delay

KDJ-ZRX = 197+30+108+117+162+25 or 639 min.

ZRX-KDJ = 47+93+63+31+300+20+127+100 or 781 min.

3) Operation Delay

KDJ-ZRX = 78+54+9+15+73+22+170+60+63+108+30+35+100+60+30+27+146+48 or 1128 min.

ZRX-KDJ = 39+65+114+115+79+73+88+15+54+136+29+54+136+29+55+198+40 or 1100 min.

4)Accident Delay

KDJ-ZRX = 130+506+1458 or 2094 min.

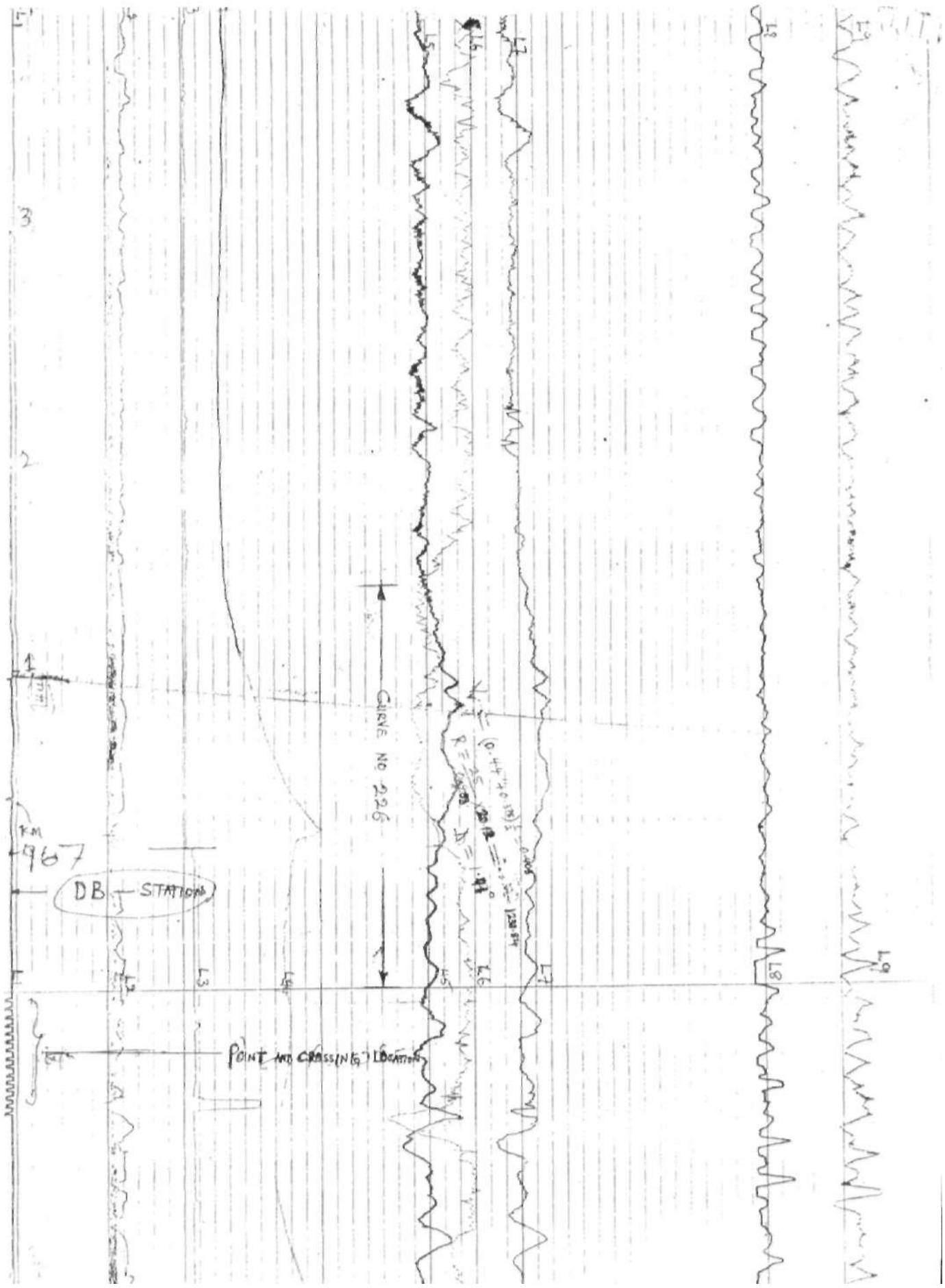
ZRX-KDJ = 688 min.

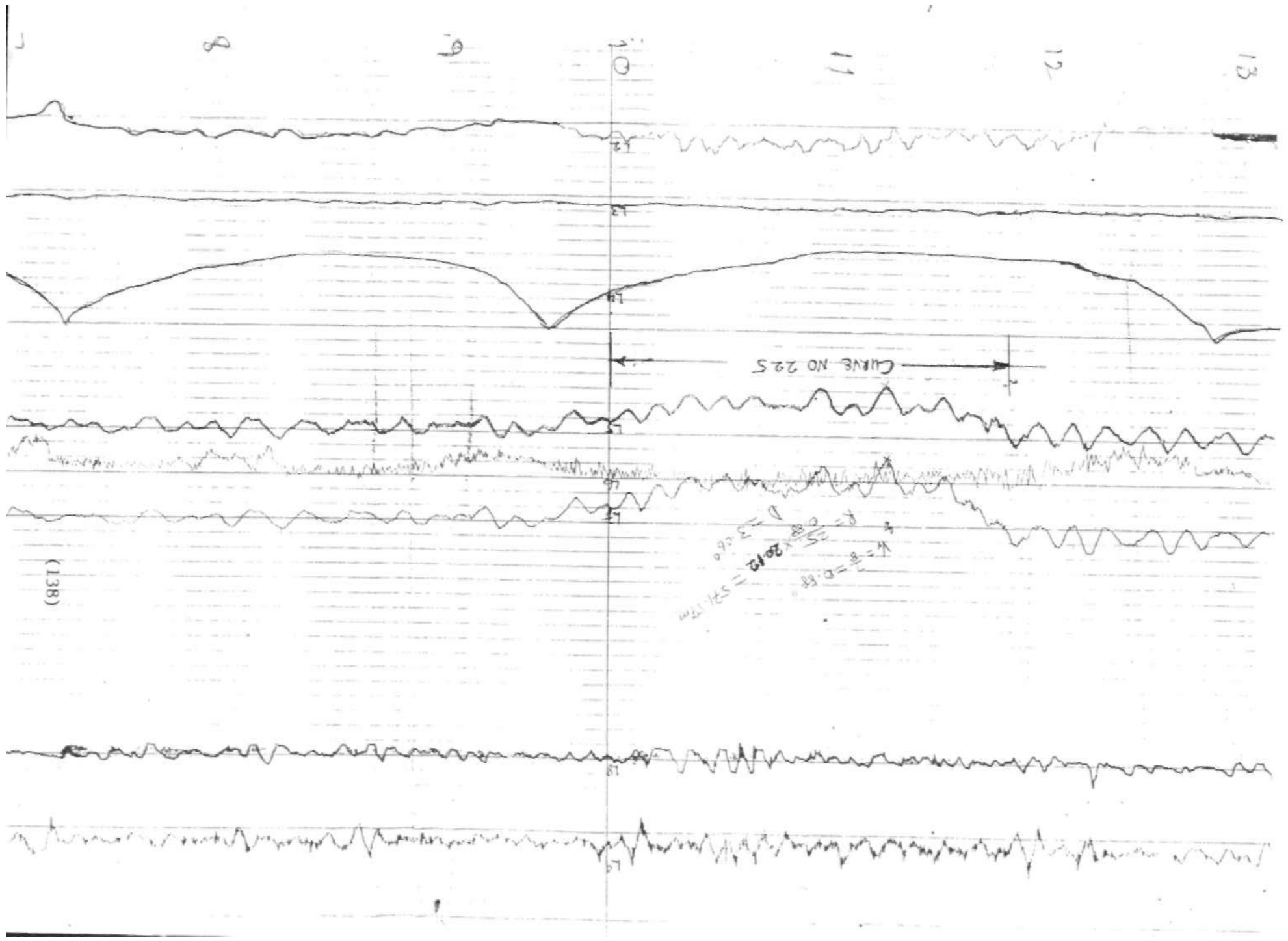
Table F.5. Train Earnings for 1994

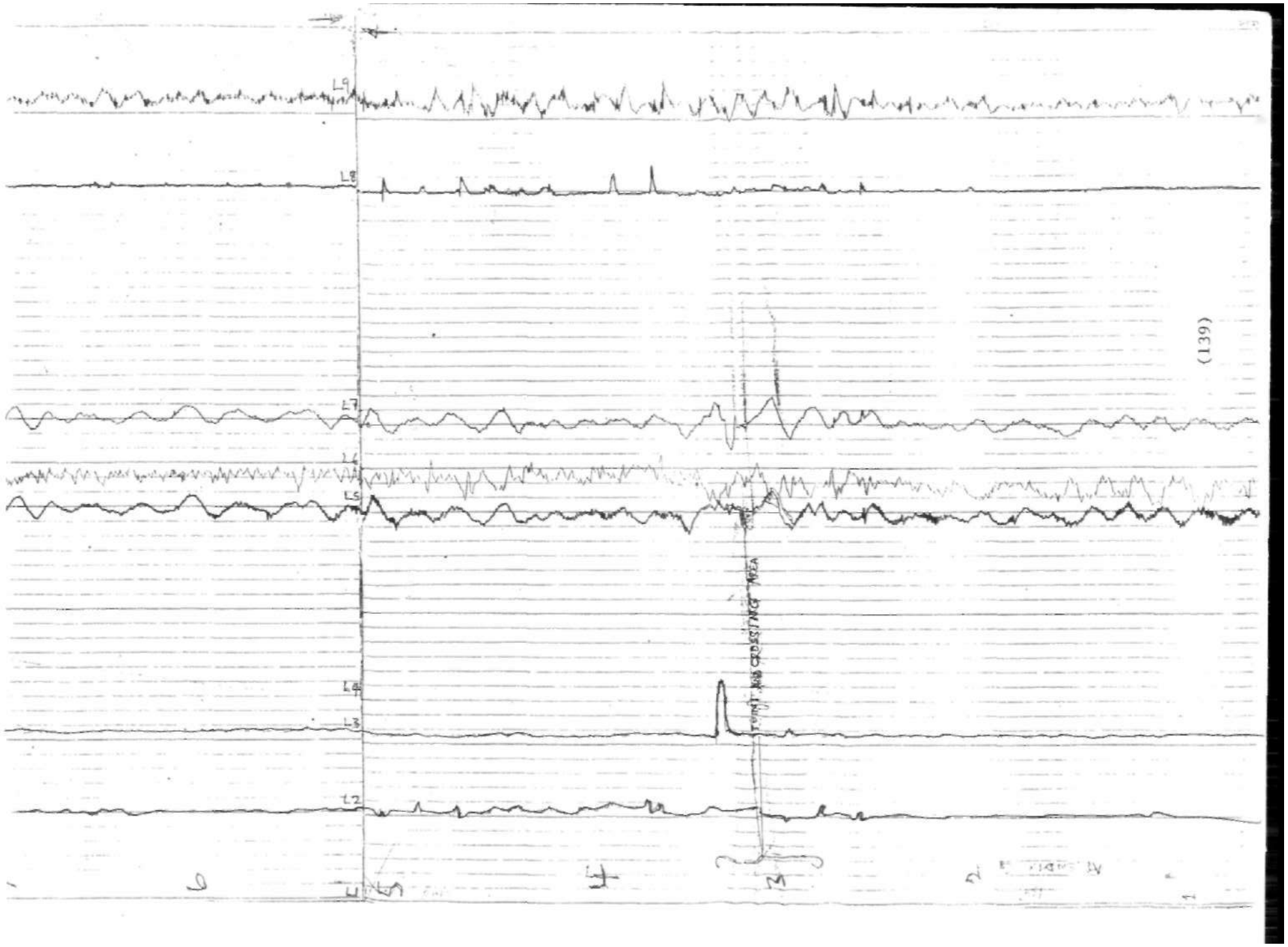
	JAN.	2,417,660
	FEB.	1,197,664
	MAR.	1,753,697
	APR.	1,272,685
	MAY	2,018,271
	JUNE	1,549,216
	JULY	914,008
	AUG.	461,141
	SEPT	1,023,896
	OCT.	1,406,608
	NOV	1,294,441
	DEC.	2,543,479
TOTAL	=	15,676,872·00 per annum or N 1,306,406·00 per month.

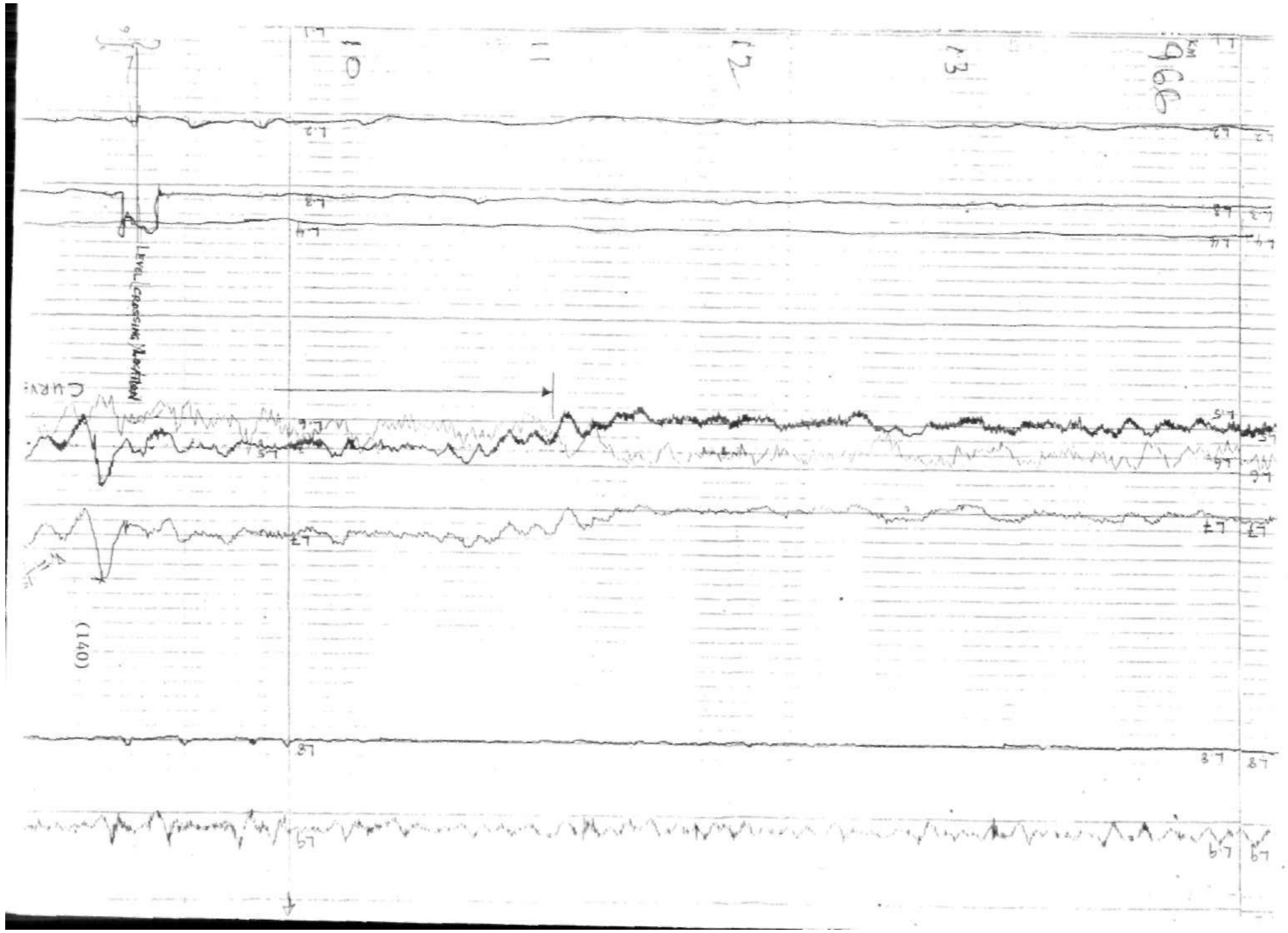
APPENDIX G

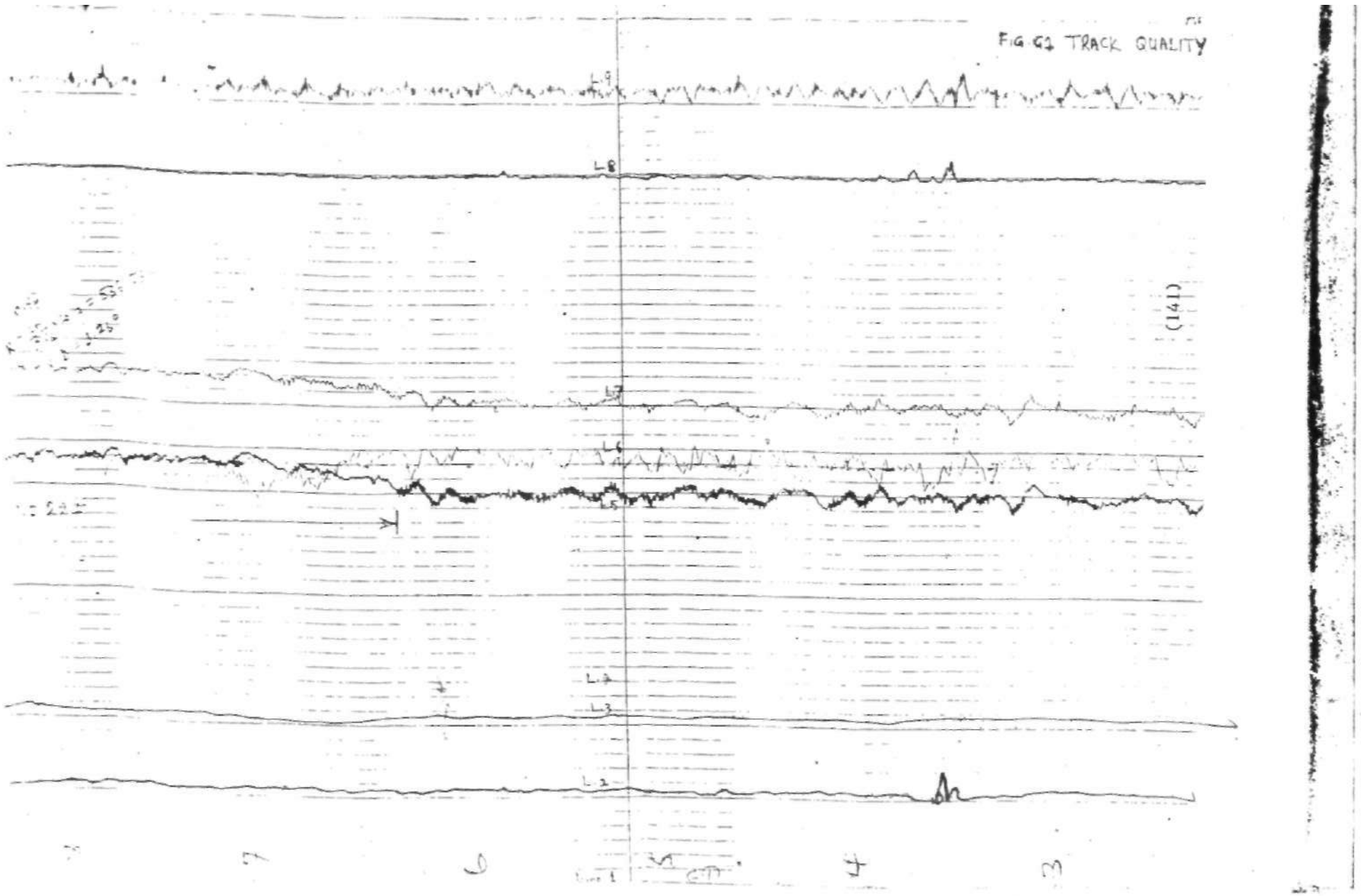
Fig. G.1 Track Quality Index Chart between KM 96 '4 - KM 966/3 Poles




CLINE NO 22S


L9
L8
L7
L6
L5
L4
L3
L2
(139)


10
11
12
13
9.66
KM
LEVEL CROSSING
CURV
(140)


FIG 62 TRACK QUALITY
L9
L8
L7
L6
L5
L4
L3
L2
L1
(141)

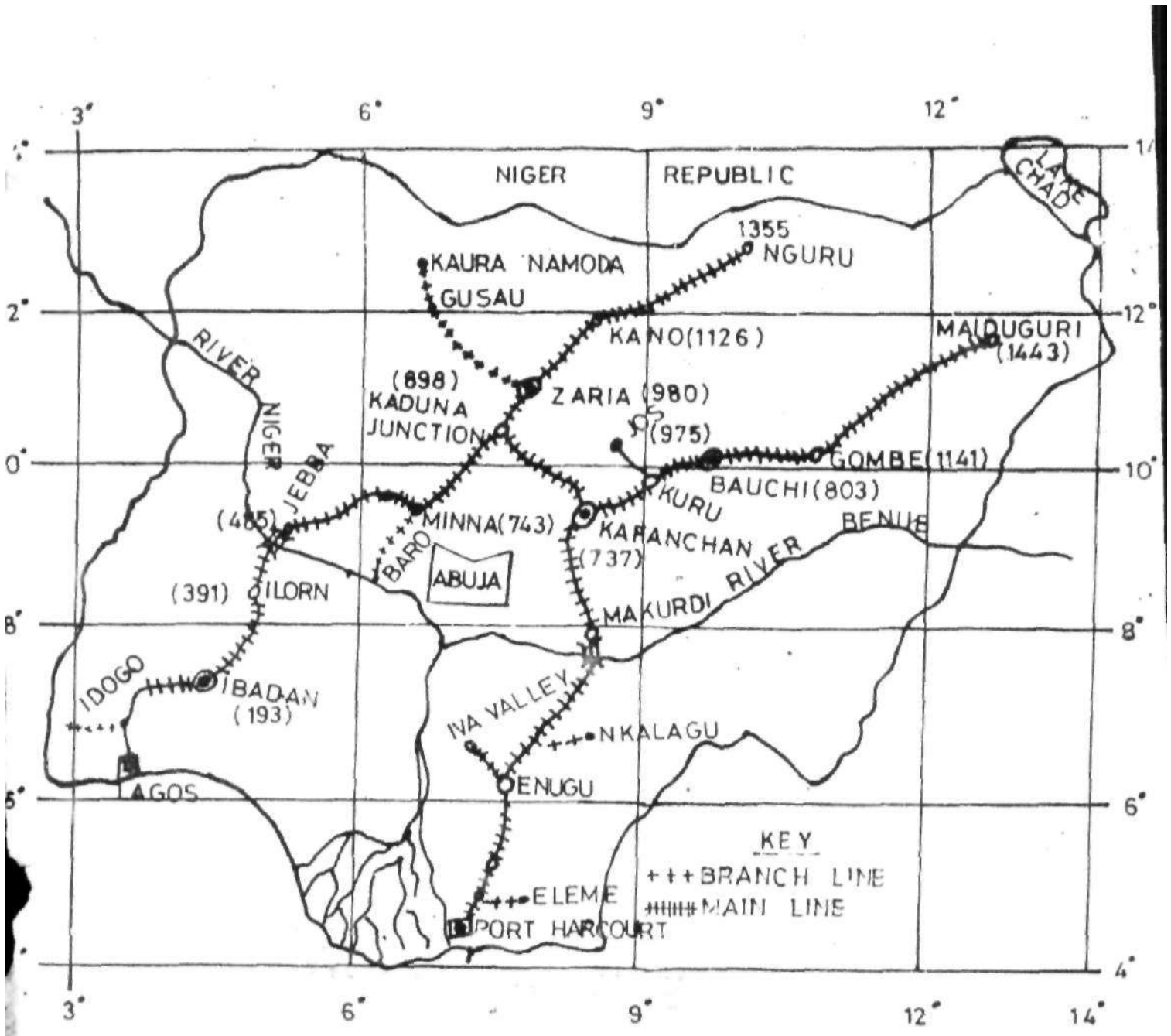


Fig K.1. THE NIGERIAN RAILWAY SYSTEM (SOURCE N·R·C·)