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INVESTIGATION OF DERAILMENTS

by

W.K.B. Weragama

Introduction

I consider it a great honour and privilege to have been invited to deliver this year's commemoration lecture in memory of Prof. E.O.E. Pereira who was a true gentleman. Great Leaders and respected individuals are not born but they achieve it.

My first encounter with Professor E.O.E. Perera was in 1960 when I was interviewed as a candidate for admission to the University. On that occasion I was reminded of a saying I had heard about great men "The greater the achievements of a man are, the humbler does he become". Professor E.O.E. Pereira personified that saying.

During my days as an undergraduate two incidents distinctly remain in my memory regarding Professor Pereira. The first was during the beginning of my period as an undergraduate. We had an undergraduate who even in later life went out of his way to make the acquaintance of highly placed individuals. In order to show his batchmates that he was well acquainted with the Dean of the Faculty of Engineering, one day while Professor Pereira was driving down Galle Road he waved him to a stop, introduced himself and got into the car. He regularly did this until later on Professor E.O.E. Pereira even stopped the vehicle to look for him.

The other incident took place towards the end of my period as an undergraduate. One morning at 7.30 a.m. the Final Year students photograph was to be taken at Peradeniya in front of the main office. The photographer had arrived, the faculty members were present. Chairs could not be taken out as the building was locked. One of my batchmates went round the building and seeing a damaged louvre managed to gain entrance through it and opened the main door to enable chairs to be taken out. It so happened that my batchmate had entered the room of a Professor in whose room a question paper had been locked up in a cabinet. My friend who sadly passed away recently was suspended and debarred from sitting the examination. Professor E.O.E. Pereira was not the Dean at this time and he vehemently opposed the decision to debar my batchmate from sitting the examination and was finally able to obtain permission from him to sit. The question paper was however changed.

Professor E.O.E. Pereira always stood for Justice and it is with great respect that I remember a principled gentleman who stood for Justice.

In selecting a topic for todays lecture I thought of an Engineering topic within my field of experience and I therefore selected 'Investigation of Derailments'.

The Last Major Derailment

The last major derailment occurred on 17th October 1964 at Wilwatte between Mirigama and Ambepussa. Twenty five passengers lost their lives and eighty eight were seriously injured. The cause of the derailment was uncertain and was investigated by a Public Commission of Inquiry, appointed on a warrant.

This warrant was issued by the then Governor General in terms of section 2 of the Commissions of Inquiry act. The Commission comprised of 3 members with Mr. D.E.N. Wijewardena then a retired Commissioner of Assize as Chairman, Prof. E.O.E. Pereira as a member and Mr. A.K. Gupta the Additional Commissioner of Railway Safety, Govt. of India as the 3rd member.

The terms of reference of the Commission were investigating and reporting on

(i) the causes that led to the derailment of the down train No. 400 on the main line of the Ceylon Government Railway between Ambepussa and Mirigama on the morning of Saturday the 17th October 1964.

(ii) the measures that should be taken to prevent a recurrence of such accidents

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The Commission was requested to submit their report within a period of two months. The period was later extended by a further one and a half months at the request of the Commission.

Basic Components of the Railway System Involved in Derailments

Fig. 1 shows a typical cross section of the Railway track indicating the Rails, Sleepers, Ballast and formation.

Fig. 2 shows a schematic arrangement of a typical coach (Rolling Stock) and its suspension system.

Theoretical Background

The motion of rolling stock on a Railway Track is a complex phenomenon since a large number of factors contribute to the safety and stability of the system which consists of

(a) the track Fig. 1
(b) the rolling stock Fig. 2
(c) the dynamic track rolling stock system

It is due to the contribution of a series of factors to a derailment that at times it becomes difficult to establish the cause of a derailment.

Railways over the world have laid down safety limits or tolerances for various components of the Railway Track and Rolling Stock. A derailment occurs when one or more of these tolerance limits are exceeded. In investigating a derailment it must be borne in mind that even if the same rolling stock is moved over the same track at the same speed it may not derail, since it would be impossible to simulate all the conditions exactly.

Derailment Mechanism

Fig. 3 shows the irregular movements that rolling stock could be subjected to due to irregularities on the track or rolling stock or both track and rolling stock.

Fig. 4 shows the forces acting at Rail-wheel contact.

There are two broad categories of derailments

(i) Sudden derailments caused by wheel sets jumping off the rails
(ii) Gradual derailment caused by the wheel flange climbing the rail head

Research over the world Railway has shown that 0.05 seconds as the time duration which approximately defines the boundary between the two categories.

Fig. 5 shows limiting values of Y/Q vs. time duration

Sudden Derailments

Sudden derailments are characterized by a short mark across the rail head or just a scratch on the rail head edge or no mark at all on the rail head but drop marks on the sleeper or ballast.

A sudden derailment indicates that the derailing forces were high enough to suddenly force the wheels off the rail. It is relatively easy to arrive at the possible cause of this category of derailment.

Possible causes acting singly or on combination may be

- sudden shifting of load
- improperly loaded vehicle
- speed in excess of maximum permissible speed
- resonant rolling nosing or hunting
- sudden variation in draw bar forces induced by improper train operation broken wheels
- failure of track components
- obstructions on the track

Gradual Derailment by Flange Climbing

These derailments are characterized by a long mark which may be as much as 10 m or more which indicates a gradual derailment by flange climbing.

This indicates that the derailing forces overcame the stabilizing forces and this adverse situation continued till the wheel climbed the rail, rode the rail head and then slipped off. The derailing forces were not high enough to cause a sudden derailment.

Establishing the cause of such a derailment is relatively more difficult.

Site Investigation

The inspection of a site in investigating and establishing the cause of a derailment should cover the following aspects :-

- locating wheel marks on the site to identify the wheel sets and the vehicle which derailed first
- Investigating and recording defects condition and history of the rolling stock
- Investigating and recording track particulars
- Investigating and recording operating features and analysing the dynamic behaviour of the rolling stock on the same track

Fig. 4 indicates the forces acting at the rail wheel contact at a moment prior to derailment.

Y	Flange force
Q	Instantaneous wheel load
R	Normal reaction from the Rail

$(Q \cos\beta + Y \sin\beta)$

β = Flange angle

For safety against derailment

Derailing Forces Stabilising Forces

$Y \cos\beta + \mu (Q \cos\beta + Y \sin\beta) \quad Q \sin\beta$

$$\frac{Y}{Q} \quad \frac{\tan\beta - \mu}{1 + \mu \tan\beta}$$

$\frac{Y}{Q}$ is known as the derailment coefficient and the formula is known as Nadals Formula. The formula was first enunciated in 1908 and many have tried to refine it but it remains and due to its simplicity is the most widely used formula in investigating derailments around the world and is one of the criteria for assessment of stability of rolling stock.

Application of Nadals Formula in Derailment Investigation

For safety against derailment $\frac{Q}{Y}$ should be smaller or

$\frac{\tan\beta - \mu}{1 + Y \tan\beta}$ should be larger.

Fig. 4 shows the variations of the RHS of Nadals formula with the flange angel β and the coefficient of friction μ

In investigating a derailment the quantitative values of Y, Q, μ, β, are not looked into, but the contribution of track and rolling stock defects are analysed qualitatively to establish causes that contribute for

Y to increase
Q to decrease
μ to increase
(+ ve angle of attack to increase)
(+ ve eccentricity to increase)
(persistent angular running of the axle to occur)

In the Japanese Railway limiting values of $\frac{Y}{Q}$ are 0.8 for durations more than 0.05 seconds. When the duration is less the 0.05 seconds the limiting value is $\frac{.04}{t}$ and is approximately indicated in Fig. 5.

For a large majority of wheels with a new profile $\beta = 68^\circ$ and μ varies from 0.25 to 0.33.

Assuming $\beta = 68^\circ \quad \mu = 0.25$

$\frac{Y}{Q} \quad 1.4$

Allowing for wear and tear the Indian Railway and SLr adopt.

$\frac{Y}{Q} \quad 1.0$

Some Aspects of Interaction Between Rolling Stock and Track

Vehicle Oscillations

As a result of the rolling stock not running smoothly over the railway track due to various reasons, the rolling stock is subject to oscillations of different modes as shown in Fig. 3. These oscillations affect Y and Q values and are called parasitic oscillations. The combined oscillation of rolling and nosing is called hunting.

There are two broad categories of oscillations :-

- self excited (due to wheel clonicity)
- other than self excited, (due to track irregularities, suspension irregularities of rolling stock, disposition of load on vehicle, operational irregularities

Rolling Stock Suspension Systems and Defects

Fig. 2 illustrates schematically the layout of typical rolling stock which consists of 3 distinct portions

- wheel set (two wheels and axle)
- suspension system (spring and dampers)
- vehicle body

Wheel set :- The wheels are coned to provide a built in system of stability. Due to wear of the wheel profiles as indicated in Fig. 6 rolling stock oscillations are caused.

Springs :- In addition to improving riding comfort provide the rolling stock, the ability to negotiate track irregularities without increasing the Q value. Any spring defect affects Q and makes the rolling stock derailment prone. In most modern rolling stock we have the double stage suspension system. (See Fig. 2)

Primary Stage :- Springs bear on the axles directly or indirectly

Secondary Stage :- Springs which transmit the weight of the body to the bogey frame which further rests on the primary springs. Springs when subjected to an excitation continues to oscillate for some time unless the oscillations are damped. A damping system (shock absorbers) are therefore introduced for comfort and safety.

Without adequate damping the amplitude of oscillations tends to become very large. Inadequate or defective vertical and horizontal dampers affect Q and Y forces.

Defects in Wheel Sets

Fig. 7 illustrates worn profiles of wheels.

A thin flange implies greater play between the wheel set and the rails and the oscillations adversely affect Y and Q.

A sharp flange causes μ to increase due to the change in geometry of the wheel and may split open points and increase positive eccentricity.

A worn root :- causes μ to increase due to reduction in the taper of the wheel flange is owing to increase in the value of β.

Deep flange :- This coupled with vertical rail wear damages distant bolts and fish bolts.

Improper Operating Features

- Train travelling in excess of permissible speed
- Eccentric load or sudden shifting of load has an adverse effect on Q
- Improper train operation viz. sudden application of brakes or tractive forces
- Incorrect formation of trains

Track Irregularities

Track irregularities may be defined as defects in alignment of rail surface either horizontally or vertically and are responsible for initiating a disturbance of load distribution adversely affecting Q. Uneven support of sleepers due to lack of ballast can set up oscillations and lurches which will disturb the distribution of load.

Wasted rails See Fig. 7. Wastage can be vertical, lateral or angular and tolerance limits are specified. Angular wear is the most critical and occurs mainly on the outer rail of sharp curves.

Track irregularities frequently constitute a contributory cause of derailment.

Investigation of Derailments

Unless the cause of a derailment is obvious such as a locomotive ploughing into a tree or boulder fallen across the track or an earthslip or washway of the formation the task of investigating a derailment is a formidable one since a large number of variables are involved.

The anguish of passengers stranded after a derailment, the delay to train services, the high financial losses and possible loss of life are all factors which necessitate proper investigation of derailments for preventing their recurrence.

Derailments have been the subject of much criticism of the Sri Lanka Transport system and the Hon. Minister of Transport appointed a special committee to investigate derailments.

Fig. 8 shows a flow chart adopted by British Rail Research for derailment investigation. All railways have some procedure for investigating a derailment. Methods and technology vary considerably and the accurate determination of cause may be prevented by lack of techniques to measure and evaluate track geometry, inadequate systems of measurement and testing of vehicles and imprecise methods of recording evidence at the accident site or inexperience in deductive processes.

Investigation of the Wilwatte Derailment

The derailment took place on 17th October 1964 and the commission was appointed on the 29th October 1964. The commission met on the 30th October 1964 and visited the site on the same day. The track had been cleared and repaired. The vehicles which had capsized were lying by the side of the Railway line. The train services had been restored. Three subsequent trips were made by the commission who carried out detailed examinations of the track and vehicles which were damaged and a number of tests were conducted.

The accident had occurred on a reverse curve, the derailed vehicles were lying on either side of the track on the straight portion between the two curves. The train consisted of twenty four vehicles. The commission recorded the evidence of eyewitnesses and the train crew. The commission on four occasions made a detailed examination of the site, derailed vehicles as regards wheels, suspension system spring gear etc. as stated in page 11 of their report. Tensile and other tests were carried out on rivets and other components which had fractured. In order to estimate the speed, tests were carried out with a trial train constituted in exactly the same manner both in respect of type of vehicles and loading. On these runs vacuum brakes were applied when travelling at various speeds and it was, established that the speed of the train at the time of derailment was about 48 MPH. The commission concluded that the cause of the derailment was overspeeding, by running at about 48 MPH when the permissible speed was 35 MPH. The commission also concluded that a four wheeled wagon prione to nosing and oscillation derailed first. Allegations that the driver was not in the locomotive and that the driver was under the influence of liquor were carefully examined and investigated and the commission was satisfied that these charges were without foundation. The speedometer was not functioning and the driver could not estimate the speed with any degree of accuracy. The driver had been on duty for over 14 hours with a short break of less than 2 hours.

Investigation of a Derailment in July 1987 by British Rail Research

The train had been running at 30/35 MPH where the permissible speed was 50 MPH. The local staff had identified the point of derailment where the wheel flange of a bogey wheel wagon had crossed the high rail over a distance of 4.46 mm.

The track at the derailment site was measured for data processing by Computer Programme. Standard measurements taken were as follows.

(i) Cumulative spacing of each sleeper (accuracy 10 mm)
(ii) Optical levels on one rail head (accuracy 1 mm)
(iii) Cross levels (accuracy 1 mm)
(iv) Voidmeter readings each rail (accuracy 1 mm)
(v) Gauge (accuracy 1 mm)
(vi) Lateral "off sets" from one rail to a straight line datum (accuracy 1 mm)
(vii) Sidewear

Computer produced track chart on a reduced scale is shown.

The track at the derailment site contained two serious irregularities

(a) A loaded dip of 32 mm dip in the left hand rail
(b) A peak to peak misalignment of 66 mm

Prototype vehicles are tested statically to determine wheel off loading on a progression of cant gradients. Reference to acceptance test reports for the derailed vehicle prototype gave the likely reduction in wheel load. A detailed examination of the wagon failed to reveal anything in its maintenance condition to account for any vehicle unloading or abnormal rotation of the bogie.

The peak to peak misalignment identified in the derailment site survey was considered a major factor in generating lateral response of the heavily laden vehicle travelling close to the equilibrium speed on the curve. The conditions of flange climb, sufficient loss of wheel load Q and increase in lateral flange force Y had occurred in the vicinity of the derailing mark for the $\frac{Y}{Q}$ critical value to be exceeded in Nadals formula.

With the measurement of track parameters and subsequent processing of data by Computer Programme, together with data obtained relating to the masses, stiffness and clearances of a particular vehicle, it is possible to predict the various aspects of its behaviour by modelling it dynamically over the derailment site. British Rail Research has developed a complex suite of Computer Programs into one package 'VAMPIRE'. For derailment investigation purposes VAMPIRE can be used to calculate vertical and lateral forces and $\frac{Y}{Q}$ ratios acting at a wheel set continuously along the derailment site.

SCALE :- 3/8 INCH TO A FOOT.

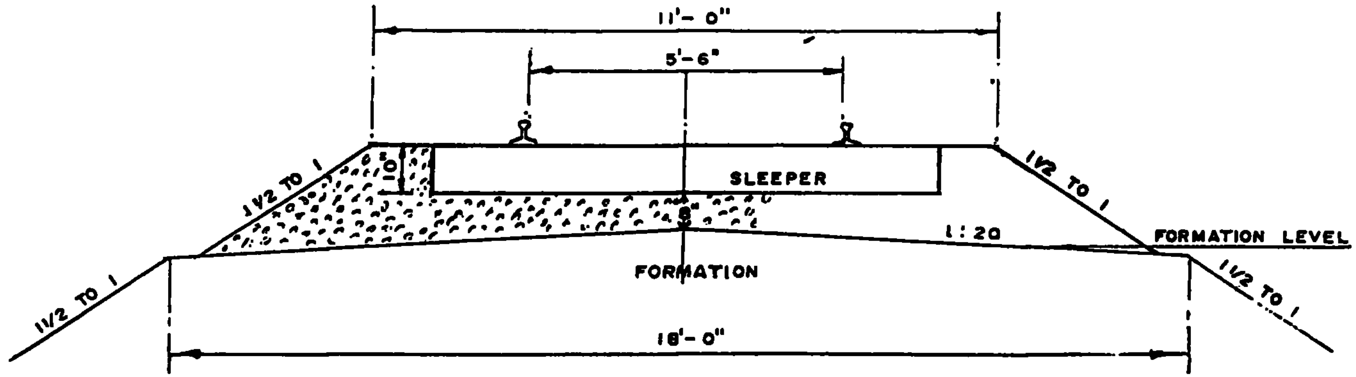


Figure 1 - S.L.R. Standard Cross Section of Broad Gauge

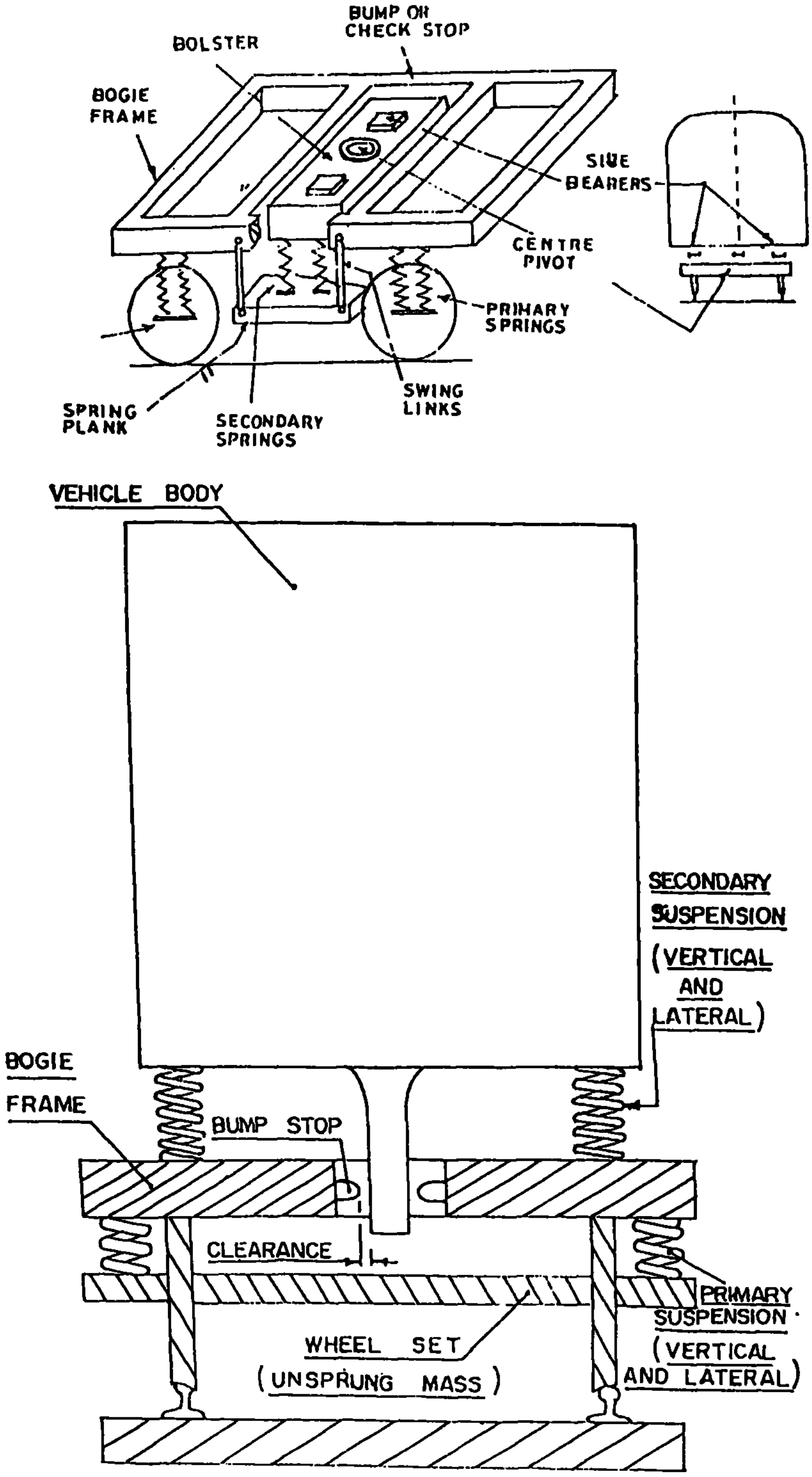
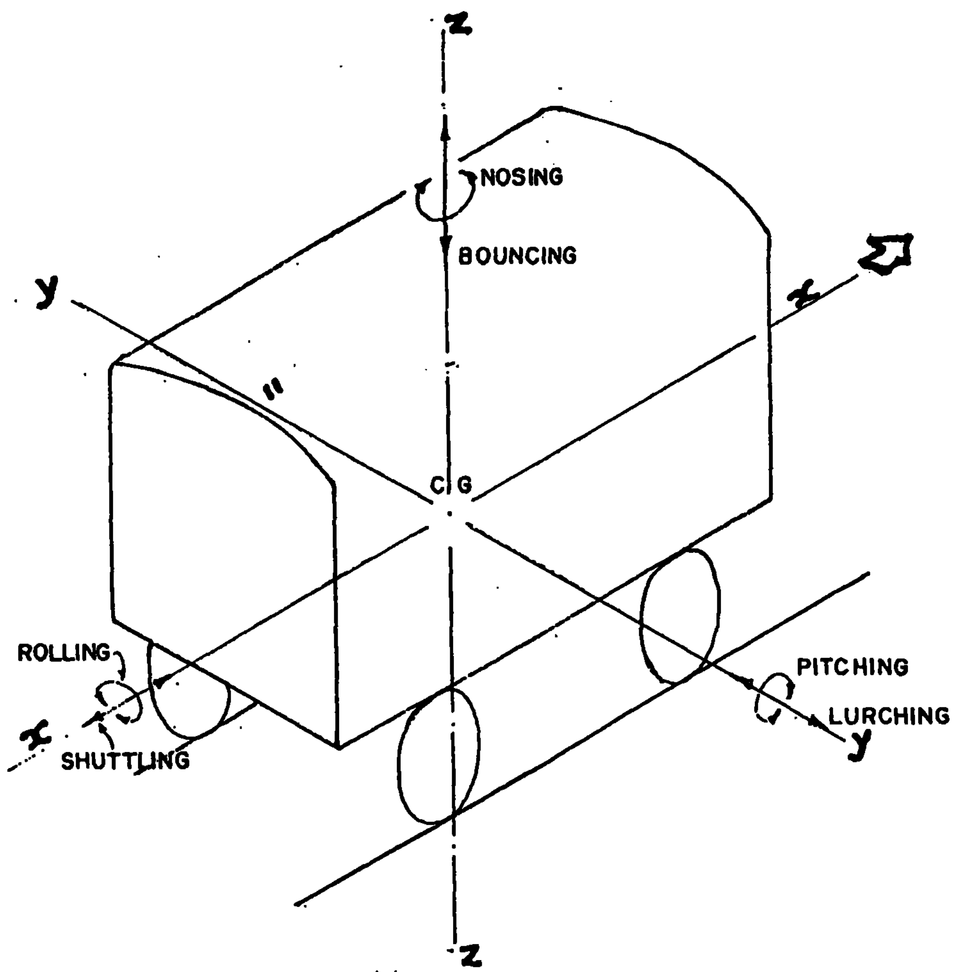
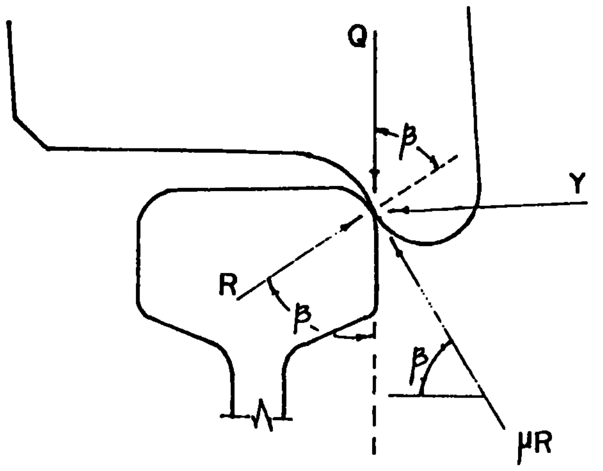


Figure 2 - Schematic Showing Essential Suspension Components



Axis	MODE OF OSCILLATION	
	Linear	Rotational
x	Shuttling	Rolling
y	Lurching	Pitching
z	Bouncing	Nosing (also called 'yaw'

Figure 3 - The Six Modes of Oscillation

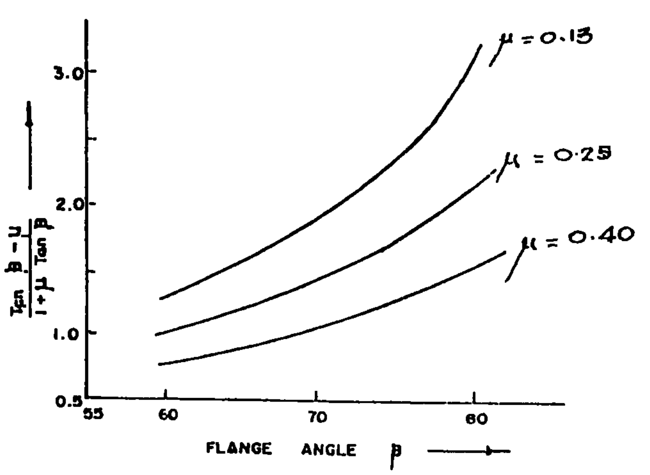


NADAL'S FORMULA

DERAILING FORCES $\ngtr$ STABILISING FORCES

$$Y \cos\beta + \mu(Q \cos\beta + Y \sin\beta) \ngtr Q \sin\beta$$

$$\frac{Y}{Q} \ngtr \frac{\tan\beta - \mu}{1 + \mu \tan\beta}$$



VARIATION OF R H S WITH FLANGE ANGLE β

Figure 4 - Forces at Rail-wheel contact at Moment of Incepient Derailment

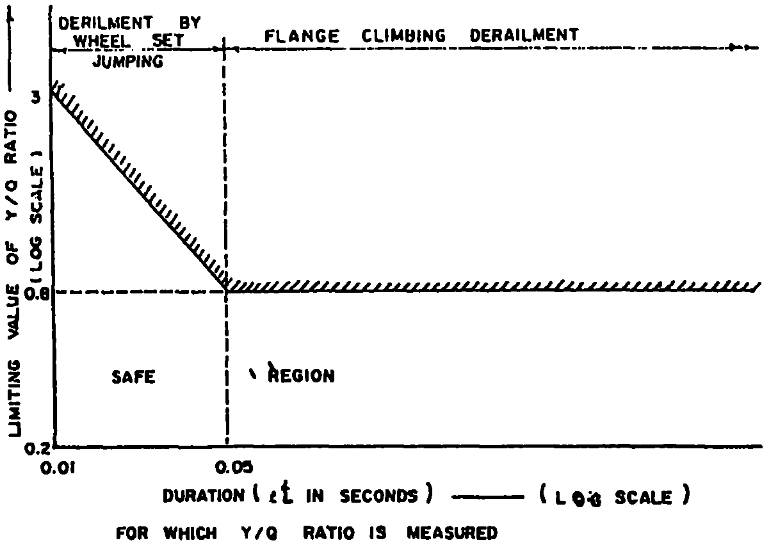


Figure 5 - Limiting Values of Y/Q Ratio Vs. Time Duration

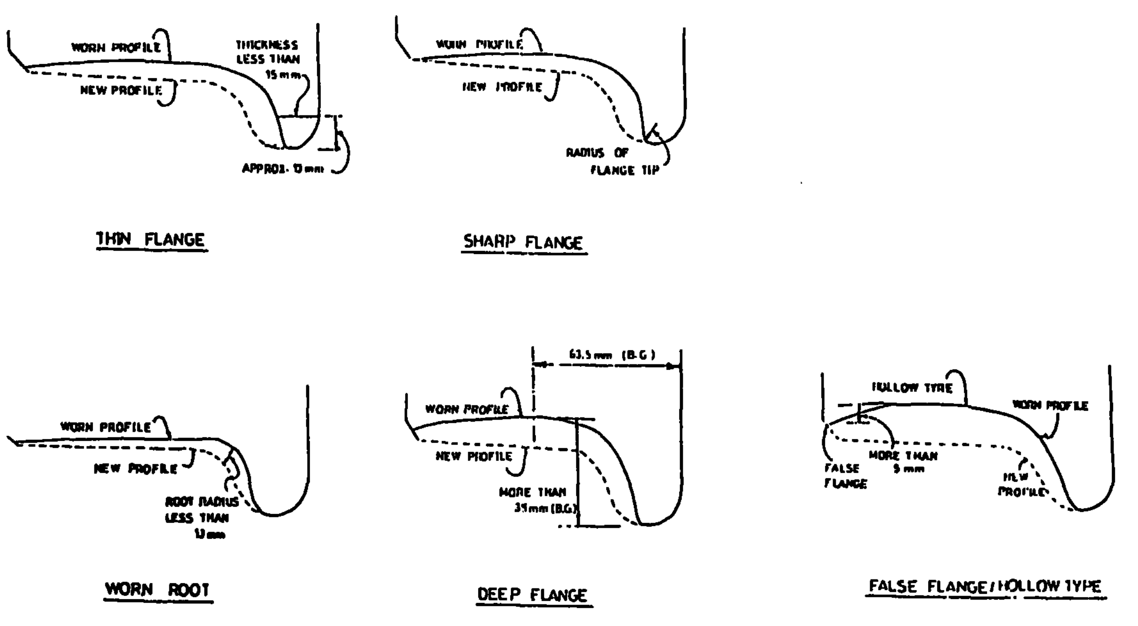
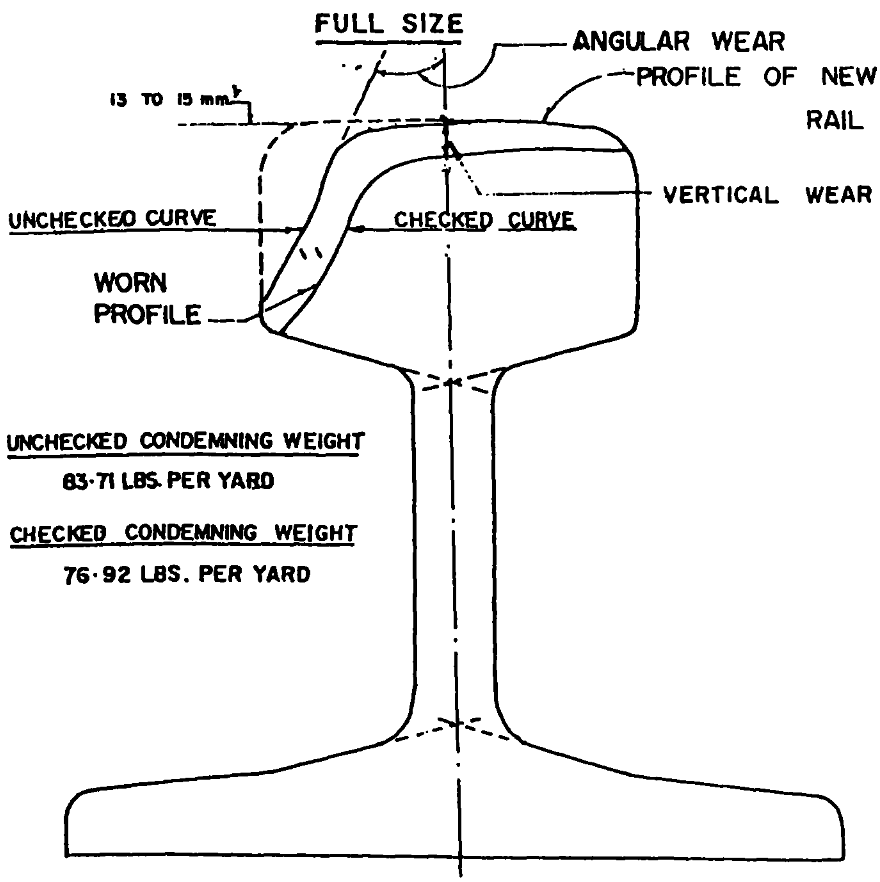


Figure 6 - Wear Profiles



HIGH RAIL

AREA OF FULL SECTION	8·41 SQ. INCHES
AREA OF RAIL HEAD	4·11 SQ. INCHES
AREA OF WEB & FLANGE	4·30 SQ. INCHES
AREA OF CONDEMNING SECTION HEAD CHECKED	3·06 SQ. INCHES
AREA OF CONDEMNING SECTION HEAD UNCHECKED	3·71 SQ. INCHES

PERCENTAGE LOSS IN CONDEMNING SECTION OF UNCHECKED HIGH RAIL 4·87% OF FULL SECTI
—— DO —— CHECKED — DO — 12·59% — DO —
—— DO —— UNCHECKED HIGH RAIL HEAD 9·97% OF HEAD.
—— DO —— CHECKED — DO — 25·76% — DO —

Figure 7 - Standard 88 lb Rail

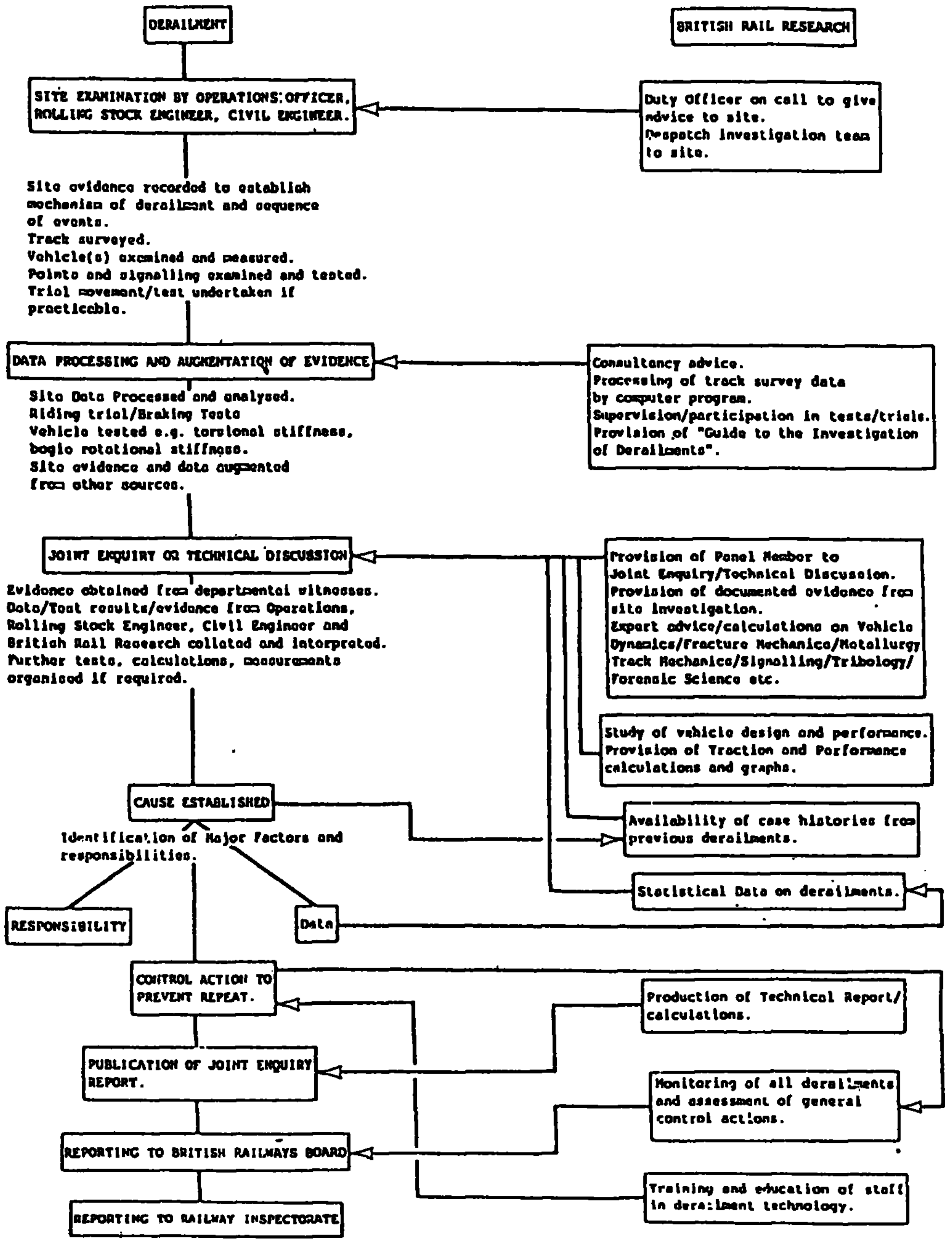


Figure 8 - Flow chart of derailment investigation