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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTMENT OF RAILWAY ENGINEERING

DEVELOPMENT OF NEW IMPROVED GEOMETRY OF SWICH IN ETHIOPIAN RAILROAD TRACK

(EMAMY SWITCH)

A thesis submitted to the Graduate School of the Addis Ababa Institute of Technology in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Railway Engineering Stream)

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled as "**DEVELOPMENT OF NEW IMPROVED GEOMETRY OF SWICH IN ETHIOPIAN RAILROAD TRACK (EMAMY SWITCH)**" is my original work except where indicated by full references, prepared under the guidance of Mr. Abdulsetar.M . All sources of materials used for the thesis have been duly acknowledged. I further confirm that the thesis has not been submitted either in part or in full to any other higher learning institution for the purpose of earning any degree or professional qualification.

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ABSTRACT

A railroad switch is a device, which enable a rail vehicle to change from one track to another track by means of pair of linked tapering rails known as points or point blades that are lying between the diverging outer rails (the stock rails). These points can be moved laterally in to one of the two positions to direct a train coming from the point blades toward the straight path or the diverging path.

A rail track switching system has been designed to control railway track and such controlling is exercised through the use of various track circuits which detect the presence of trains on a particular track, signals within a given area from a single point and central room which monitors the train's safety. But, something electric failure or signals not gives exact location, the switch machine doesn't detect the train is there, due to this, the switch doesn't shift its position, this makes, train in danger or no ways to change direction. Therefore, this research will solve such grate problem by development of new improved geometry of switch with lock rail, due to this improvement, the structural geometry become very easy, simple and applicable in anywhere in railroad line.

Referring to the design analysis of improved switch rail from the geometry and ANSYS result and Referring to the design analysis of existing switch rail from literature review, for the same structural support stiffness, existing railway switch shows 2.248 mm at section A-A, 2.158 mm at section B-B and 1.398 mm at section C-C vertical deflection, which are relatively smaller than 3.14mm ISW rail deformation. Hence, the results are within the range of AREMA maximum vertical rail deflection limit which is 6.35mm.This mean that, both rail sections are sufficient enough for the maximum design load. According to the shear parameter, the existing railway switch, for the same radius of wheel and for the same steel structure with equal sleeper spacing shows 149.09 MPa Maximum shears which is greater than 140MPa allowable maximum shear stress. For this reason, the sections are less resistance for high force and vibration than the ISW rail one, which is 8.8 MPa. In case of stress, the current switch shows 137.826MPa at section A-A, 69.468 at section B-B and 45.603 at section c-c maximum stress which is very high comparing to the improved one, switch is 16.277 MPa, this is due to section modulus variation.

KEYWORDS: Existing railway switch, section design, geometry design, improved switch, guard-wing rail, 3D ANSIS ISW model, deformation, Equivalent stresses, maximum shear stresses

LIST OF TABLES

Table 2.1: AREA Tee Rail Guard Rail Design Dimensions……………………………….……24

Table 3.1: Choice of the rail section in relation to traffic load………………………….…29

Table 3.2: Property of rail section (50kg/m)……. From GB-standard……………………......31

Table 3.3: Eisenmann DAF (Dynamic Amplification Factor) approximation…………………35

Table 3.4: Classic ballast track stiffnes and dumping ……………….…………………………37

Table 3.5: Distribution of deflection, bending moment and rail supporting force through 21 sleepers.....38

Table 3.6: Mechanical properties of rail……………………………………………………43

Table 3.7: Steel grade and chemical composition GB…………………………………..….44

Table 3.8: Chemical composition and tensile properties of a rail steel according to UIC...........44

Table 3.9: Centroids of composite switch geometry for section AA-CC………………………..48

Table 3.10: Moment of inertia for section AA-CC……………………………...……………49

Table 3.11: Maximum deflection, maximum moment and maximum bending stress for section AA-CC.51

Table 3.12: ANSYS result of ISW……………………………………………………………..51

Table 4.1: Basic differences between existing railways switch and improved switch ……..….56

Table 4.2: Method -1 design turnout ……………………………………………….…….66

Table 4.3: Relation of angle constant between crossing angle and switch angle…………….…67

Table 4.4: Improved switch length for all turnout number..……………………………………72

Table 4.5: Area tee guard rail set back distance ………………………...…….……………….75

Table 4.6: Straight (parallel) length of guard-wing rail……………….…...……………….………. 78

Table 4.7: Plane length (from the given guard-wing rail length)…………….………….……….80

Table 4.8: Guard-wing rail length relation……………….……………….……….……......80

LIST OF FIGURES

Figure 2.1: Switch and crossing ……………………………………………………………..5

Figure 2.2: Details of crossing …………………………………………...…………………….6

Figure 2.3: Split switch……………………………………………………………….....…7

Figure 2.4: Fixed heel type switch……………………………………………………………..8

Figure 2.5: Electric switch machine ……………………………………………………………9

Figure 2.6: Low switch stand……………………………………………………………......10

Figure 2.7: Section at heel of tongue rail……………………………………………………...12

Figure 2.8: A stub switch……………………………………………………………..13

Figure 2.9: Line diagram of fixed heel type switch…………………………………………...14

Figure 2.10: Undercut switch…………………………………………………………....15

Figure 2.11: Overriding switch……………………………………………………….……16

Figure 2.12: Straight cut switches……………………………………………………….…16

Figure 2.13: Cole's method -1 turnout design…………………………………………….….18

Figure 2.14: Cole's method -2 lead curve……………………………………………….……20

Figure: 2.15: IRS method ……………………………………………………………..21

Figure 2.16: Tee Rail Guard Rail Geometry……………………………………………….……25

Figure 2.17: Guard Rail Position ………………..……………………….…………………27

Figure 2.18: Tee Rail Guard Rail End Flare……………………………………………….27

Figure 2.19: One-Piece Guard Rail Position………………………….……………………28

Figure 3.1: Rail profile 50kg/m………………………………..………………….……….31

Figure 3.2: Winkler support model...32

Figure 3.3: Equilibrium condition of beam element..33

Figure 3.4: Distribution graph of, deflection, bending moment and rail supporting force…........40

Figure 3.5: Shear stress distribution in the rail head..42

Figure 3.6: Assumed contact pressure distribution between wheel and rail according to Eisenmenn……………………………..……………………………………………………42

Figure 3.7: Vertical track deflection range ……………………………………...……………45

Figure 3.8: Different cross section of switch blade within three sleepers…………………..…47

Figure 4.1: Right turning, improved railway switch turnout…………………..……...…………55

Figure 4.2: Symmetrical spilt improved switch……………………………….....……..………58

Figure 4.3: Three-throw improved Switch………………………………………………………59

Figure 4.4: Double Turnout……………………………………………………………...…60

Figure 4.5: Scissor Cross-over or double cross-over……………………………………………60

Figure 4.6: Right angle methods for numbering the ISW…………………………...……..…..…63

Figure 4.7: Center line method of numbering the ISW…………………………………………64

Figure 4.8: Isosceles triangle method of numbering the ISW……………………………..…64

Figure 4.9: Relation of angle constant between crossing angle and switch angle……………..…68

Figure 4.10: Improved switch heel divergent ……………………………………...……70

Figure 4.11: Switch length and switch lead curve relation …………………………..………73

Figure 4.12: Setback distance ……………………………………………………….....…75

Figure 4.13: Gap of improved switch……………………………………………………………76

Figure 4.14: Guard-wing rail length…………………………………………….......……77

Figure 4.15: Straight and curved lock rail ……………………………………………...……81

NOTATION

Notations…………………………………………………………….....definition

- ✓ S ………………………………………………………..theoretical length of switch rail in(m)
- ✓ R………………………………….………..…………..…radius of the curve at turnout in(m)
- ✓ ∝…………………………………………………………………….…………..……switch angle
- ✓ CL……………………………………………………………….……………..……..Curve lead
- ✓ SL………………………………………………………………………………….………Switch lead
- ✓ L………………………………………………………………………………...Lead of crossing
- ✓ G……………………………………………………………….………………………..Gauge
- ✓ α ………………………………………………...………………………..Angle of crossing
- ✓ β ………………………………………………………………………………Angle of switch
- ✓ N…………………………………………...…………………………..Number of crossing
- ✓ Ro………………………………………….………………………radius of outer curve
- ✓ R…………………………………………………radius of center line of turnout $R = Ro - 0.5G$
- ✓ D(d)……………………………………...……………………heel divergence or clearance
- ✓ Fc……………………………………………………………………..flange way clearance
- ✓ L_{PL}……………………………………………………………………...straight portion
- ✓ L_{PN}…………………………………………………………………………planed section
- ✓ L_{BV}……………………………………………………………………..beveled section
- ✓ L_{ISG}………………………...…………………………………...total length of guard-wing rail
- ✓ S_{ISG}…………………..……...………………………..straight length of improved switch guard rail
- ✓ P_{ISWG}……………...……………………………………plane length of improved switch guard rail
- ✓ B_{ISW}…………………...………………………………bevel length of improved switch guard rail
- ✓ Wh………………………………………………………….……………width of head of rail
- ✓ a……………………………………………………….………………..………..Impact factor
- ✓ Wo……………………………………………...…………………… Weight of rail (lb/yd)
- ✓ σ..Local compressive stress on the support [N/rn2];
- ✓ y.. local subsidence of the support [m];
- ✓ C ....foundation modulus [N/rn3].
- ✓ E... Young's modulus of rail steel
- ✓ I ....moment or inertia
- ✓ w ....vertical track deflection

- ✓ q.. vertical load distribution (wheel loads) on the rail
- ✓ x ....point on rail axis
- ✓ k.. elastic modulus of rail support (truck modulus)
- ✓ y(x)..rail deflection
- ✓ M(x)..bending moment
- ✓ R...rail support force
- ✓ K……………………………………………………………………Stiffness ratio coefficient
- ✓ μ……………………………………………………………………..rail foundation stiffness
- ✓ EI………………………………………………………………………… bending stiffness
- ✓ L..Characteristic length
- ✓ a..sleeper spacing
- ✓ D..rail support stiffness
- ✓ $\boldsymbol{\theta}$ ………………………………………………………………..Dynamic amplification factor
- ✓ **t** ………………………………………………………………………multiplication factor
- ✓ **φ** …………………………………..…………………………factor depending on track quality,
- ✓ V…………………………………………………….…………………………..train speed [km/h].
- ✓ Df…………………………………………………..……………………..fastener stiffness
- ✓ Ds…………………………………………………..………………………sleeper stiffness
- ✓ Db……………………………………………………….…………..…………ballast stiffness
- ✓ N...number of sleeper
- ✓ Q...wheel load
- ✓ σ_{max}..maximum stress on the rail.
- ✓ M_{max}^{d} .... Maximum design moment.
- ✓ Z_b..section modulus for rail base
- ✓ σ_{mean} .... the mean contact pressure (N/mm^2)
- ✓ σ_{all}...allowable contact stress
- ✓ σ_{ult}...ultimate tensile strength
- ✓ τ_{max}...maximum shear
- ✓ τ_{all}..shear allowable

Table of Contents

ACKNOWLEDGEMENT i

ABSTRACT ii

KEYWORDS: ii

LIST OF TABLES iii

LIST OF FIGURES iv

NOTATION vi

1. INTRODUCTION ..... - 1 -

1.1. BACKGROUND ..... - 1 -

1.2. STATEMENT OF THE PROBLEM ..... - 2 -

1.3. OBJECTIVE OF THE RESEARCH ..... - 3 -

1.3.1. GENERAL OBJECTIVES ..... - 3 -

1.3.2. SPECIFIC OBJECTIVES ..... - 3 -

1.4. RESEARCH METHODOLOGY ..... - 3 -

1.5. SCOPE OF THE RESEARCH ..... - 4 -

1.6. APPLICATION ..... - 4 -

2. LITERATURE REVIEW ..... - 5 -

2.1. INTRODUCTION ..... - 5 -

2.2. TURNOUT ..... - 5 -

2.3. CROSSING ..... - 6 -

2.4. SWITCHES ..... - 7 -

2.4.1. Switches - components ..... - 8 -

2.4.2. Important Terms used in switches ..... - 10 -

2.4.3. Types of Switches ..... - 13 -

2.5. GEOMETRICL DESIGN METHODS OF TURNOUT ..... - 17 -

2.5.1. Cole's method -1 ..... - 17 -

2.5.2. Cole's method -2 ..... - 19 -

2.5.3. IRS method ..... - 21 -

2.6. GEOMETRY OF GUARD (CHECK) RAIL ..... - 23 -

2.6.1. Guard (check) rail ..... - 23 -

2.6.2. Guard (restraining) rails on curve ..... - 23 -

2.7. GEOMETRIC DESIGN OF AREA GUARD RAIL - 24 -
2.7.1. Tee rail guard rail - 24 -
2.7.2. One piece guard rail - 25 -
2.7.3. GUARD RAIL AND SETTING - 26 -
3. ANALYSIS AND DESIGN OF RAIL SECTION FOR ISW - 29 -
3.1. PRELIMINARY SELECTION OF RAIL SECTION - 29 -
3.1.1. According To International Union of Railway (UIC) - 29 -
3.1.2. According To USA Department of Defense (USADOD) - 29 -
3.2. STRUCTURAL DESIGN OF IMPROVED SWITCH RAIL SECTION - 32 -
3.2.1. Basic assumption of Winkler support model - 32 -
3.2.2. Beam on elastic foundation model - 33 -
3.2.3. Dynamic amplification factor ($\boldsymbol{\theta}$) and maximum design load - 35 -
3.2.4. Maximum rail bending moment - 37 -
3.2.5. Maximum dynamic bending stress - 40 -
3.2.6. Verification of rail section - 41 -
3.2.7. Ultimate tensile strength of rail - 41 -
3.2.8. Check for serviceability - 45 -
3.3. EXISTING RAILWAY SWITCH DESIGN - 46 -
3.3.1. Design parameter of existing railway switch - 46 -
3.4. ISW ANSYS SOFTWARE RESULT OUTPUT - 51 -
4. GEOMETRICAL DESIGN OF IMPROVED RAILWAY SWITCH - 52 -
4.1. BACKGROUND OF ISW (IMPROVED SWITCH) GEOMETRY - 52 -
4.2. THE BASIC DIFFERENCE BETWEEN THE EXISTING RAILWAY SWITCH AND THE IMPROVED ONE - 56 -
4.3. IMPROVED SWITCH TRACK LAYOUT COMPATIBILITY WITH TRACK JUNCTION - 58 -
4.3.1. Symmetrical Split - 58 -
4.3.2. Three-throw improved Switch - 59 -
4.3.3. Double Turnout - 59 -
4.3.4. Scissor Cross-over or double cross-over - 60 -
4.4. GENERAL VIEW OF DESIGN OF ISW - 61 -
4.5. NUMBER AND ANGLE OF IMPROVED SWITCH - 61 -
4.5.1. Right angle or Cole’s method - 62 -
4.5.2. Center line method - 63 -

4.5.3. Isosceles triangle method - 64 -
4.6. GEOMETRICAL DESIGN OF IMPROVED SWITCH - 65 -
4.6.1. IMPROVED SWITCH TURNOUT DESIGN - 65 -
4.7. IMPROVED GUARD-WING RAIL DESIGN - 73 -
4.7.1. Guard-wing rail given data and requirements - 74 -
4.7.2. Straight (parallel) portion of guard-wing rail design - 76 -
4.7.3. Plane and bevel length of guard-wing rail design - 78 -
4.8. IMPROVED SWITCH LOCK RAIL DESIGN - 81 -
4.9. LIMITATION OF EXISTING SWITCH AND THEIR SOLUTIONS ACCORDING TO IMPROVED SWITCH - 82 -
5. CONCLUSION AND RECOMMENDATION - 83 -
5.1. CONCLUSION - 83 -
5.2. RECOMMENDATION - 84 -
5.2.1. RECOMMENDATION FOR FUTURE WORK - 84 -
6. APPENDIX - 85 -
APPENDIX A: ABBRVATION - 85 -
APPENDIX B: 3D ISW ANSIS MODEL AND RESULT - 86 -
1) IMPROVED RAILWAY SWITCH (SYMMETRIC SECTION) - 86 -
[1] 3D ISW solid geometry section - 86 -
[2] Coordinate system - 87 -
[3] Contact - 87 -
[4] Mesh - 87 -
[5] The static structural input data - 88 -
[6] ANSYS result out put - 90 -
[7] VERIFICATION OF ISW RAIL - 95 -
7. REFERENCE - 99 -

1. INTRODUCTION

1.1. BACKGROUND

Railway transportation is one of the safest transportation systems and a best alternative to the other modes of transport system, by energy efficient, safety, and cost effective way of carrying large number of people and goods in narrow area with a single trip, this makes railway transport is a best alternative land transport in many countries of the world. As a case of this Ethiopian railway corporation construct the national and international ballasted railroad track to meet this rapid grow up transport demand need and has planned to transfer the technology specially on railway operation, maintenance design and constriction areas.

Railway track is designed to provide an economical and safe transportation system for passenger and freight traffic. There is a possibility of track getting disturbed by the moving wheel load. The track should therefore be constructed and maintained keeping the requirements of a permanent way, in view, so as to a chive higher speed and better riding qualities with less future maintenance. A current Ethiopian ballasted railway track system consists of a superstructure and substructure. The superstructure includes the following components: rail, fastening system, sleepers and the substructure is composed of ballast, sub-ballast, and subgrade. The rails are jointed in series by fish plates, bolts and they are fixed to sleepers by fastenings. The sleepers properly spaced, resting on ballast, are suitably packed and boxed with ballast. The layer of ballast rests on the prepared subgrade then ground. The rail act as girders to transmit the wheel load to the sleepers and the sleeper holds the rail in proper position with respect to the proper tilt, gauge and level, and transmit the load from rails to the ballast then the ballast distribute the load over the formation and holds the sleeper in position.

The devices in the railway superstructure that allow trains to change from one track to another are called switches. The devices that allow trains to cross tracks are called crossings. This changing or crossing of tracks is a necessity to use the railway tracks in the most optimal way and to allow trains to be directed in different directions. At the same time switches and crossings are also relatively delicate devices with moving parts, subjected to high, local, repetitive forces and vibrations. Due to this, the different parts of the switch and crossing will wear and the geometry will deteriorate, up to a certain predefined limit and detected through regular inspections. To avoid any incidents or interruptions of the timetable, maintenance and renewal actions are carried out before this limit is reached. Otherwise you can imagine the problem.

This research develops and design, improved new type of railway switch that will give a solution for geometry and structure of switch that wills enables as, train crosses or change direction with relative speed like normal track, except in those sharp curve sections. so that, it minimize by grate number the derailment happen specially in switch area and subjected nearly similar stresses with normal track, upgrade its life period of switch, generally it is the best option for the safety.

1.2. STATEMENT OF THE PROBLEM

The general structural parts of switch rail are design to transfer train from one track to another track. Such shifting of train direction is facilitated by using various track components like switch machine, signal, track circuit, lifting bar, sliding chair, and stretcher bar….so on. However something like electric failure or if one of the above components fails to do its function, the whole switching system stops working (existing switch rail by itself not change train direction) this makes the train unable to change direction. Current switch rails are movable rails that flex back and forth in to one of the stock rails to intercept the wheel flange by over lapping, because of this, it shows high discontinuity. For this reason, the switch rails are faced for high load and vibration. Therefore, these results high maintenance cost, speed limitation, and decrease life time. In nature, the section at the head of the switch rail is thin and sensitive structural part of rail, from the rest one. Due to this, it becomes worn when long train negotiate the section, as a result of this, the area become sensitive for high derailment.

Existing switch rail length determines train adjacent wheel distance. Whereas, this is not; the switch are tends to rise and makes a gap at the toe which in turn leads train derailment and A train which is coming from trailing direction should be responsible to force the switch to shift on other side by the help of wheel flange, when the switch is locked; otherwise the train could be derails.

1.3. OBJECTIVE OF THE RESEARCH

1.3.1. GENERAL OBJECTIVES

The general objective of this research is to develop and design new improved geometry of switch that will give a solution for existing geometry of switch, by avoiding unnecessary materials and equipment which facilitate movement of existing switch using new improved geometry one. These results minimize switch area maintenance cost, wastage of time (weighting time) up to the switch shift the required position, train derailment, keeps better safety and upgrades switch area speed.

1.3.2. SPECIFIC OBJECTIVES

- ✓ To develop new improved geometry of switch and to show their basic difference between improved railway switch and existing railway switch.
- ✓ to show limitation of existing switch and their solutions according to improved switch

1.4. RESEARCH METHODOLOGY

The study of new improved geometry of railway switch model, design and analysis conducted by reviewing literatures, using different data collection and discussion regarding to existing railway switch and its related equipment, from sources of Ethiopian Railways Corporation (ERC), American Railway Engineering and Maintenance of Way Association (AREMA) manual, National Modeling Railroad Association (NMRA), Indian Railway Standard(IRS), Chinese Standard(GB) and different types of books and journals from Google, then those types of data collected from the above sources should be interpreted and analyzed in well organized form. From these, the critical ones are converted to as input data manner, according to the input for the computer software application and for hand calculation work. Magnifying design load system, is used for design and analysis of improved railway switch section, according to hand work, in place of dynamic load effect, whereas, in case of ANSYS, the analysis is statics but, the applied load is moveable load, due to this, the ANSYS by itself considers the dynamic effect. Finally from the output of ANSYS and hand calculation the improved switch is verified.

1.5. SCOPE OF THE RESEARCH

The scope of the study has been limited to the geometric design, analysis, and development of new improved geometry of switch and guard-wing rail. So for smooth geometrical design of improved switch, some of the special railway track components studied on this thesis, but the study does not include: the study of rail pad, sleeper, ballast, sub ballast sub grad and formation (total sub structure) and from super structure tangent track and curves. Therefore this study only concentrates on special super track structure, basically focused on improved switch and by using ANSYS software the geometrical 3D model, deformation, stresses and shear are generated and analysis.

1.6. APPLICATION

In the research of development of new improved geometry of switch, there are different types of sensors are installed in train and rail track. From this sensors, two different types of them are installed in front axle left side and right side wheel and the same is true in rail track left and right side in facing direction (but, the left side wheel sensor should be similar with the left side rail track and the same is true for the right side one) however, in trailing direction, for rail track, it is possible to use similar sensors or different sensors that's should be similar with one of the left side or right side wheel sensor. When the driver press the key and turn's ON the left side wheel sensor, in right turning turnout, in facing direction results, straight passing movement but, the right sensor become ON results, diverging direction movement. On the other hand, the train coming on the trailing direction, one of the two side sensors should be ON or two of them should be ON to move safely in turnout. Inter locking system, that are applied on improved switch lock rails should be perfect enough that's locks perfectly one side movement with another one. In principle one side movement off's the other side movement and the other one must be off's the rest one, this is work like two way light switching system.

2. LITERATURE REVIEW

2.1. INTRODUCTION

In railway engineering, direction is changed by switching devices, or switches, defined as the equipment or a devices in the railway superstructure that allow a rail vehicle to change from one track to another without interrupting its course.[1,2,3,and 23]

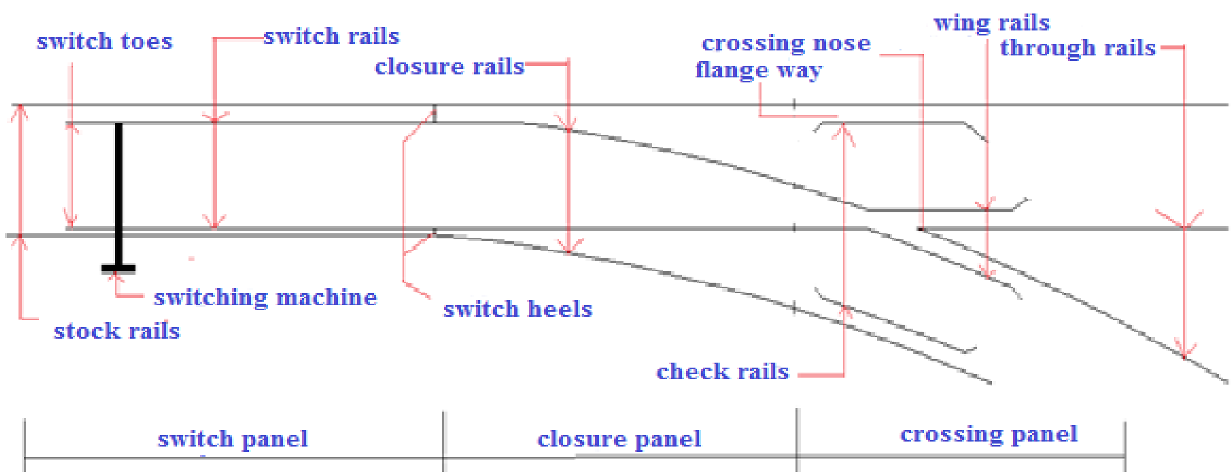


Figure 2.1: switch and crossing [33]

In its usual form, a switch point rail consists of a plain tee rail that has been machined into a tapered shape by ¼-in or 1/8- in at one end and full section at the other end. The tapered end is called the toe or point of switch and the other end is called the heel of the switch. In general, the longer the switch point rail, the more gradual the angle of divergence from the main track and the faster the rail vehicle can travel through it. [6, 9]

2.2. TURNOUT

Turnout is the simplest combination of switches and crossings which have movable component and flange way gap due to this reason we call it special track structure from railway track. . The points or switches aid in diverting the vehicles and the crossings provide gaps in the rails so as to help the flanged wheels to roll over them. [6] A train moving from the switch to the frog (i.e. it can be directed to one of the two paths depending on the position of the points) is said to be facing-point movement and a train moving from the crossing to the switch is said to be trailing-movement. In trailing-point movement, the wheels will force the points to the proper position. This is sometimes known as running through the switch. If the points are rigidly connected to the switch control mechanism, the control mechanism's linkages may be bent, requiring repair before the switch is again usable. For this reason, switches are normally set to the proper position before performing trailing-point movement. [11, 12, 15]

From many types of turnout arrangements, straight turnouts with rigid frogs and split switches are the most common. There are two types of split switches, one with a straight switch rail for the diverging route and the other with a curved switch rail. The switch rail for the straight route is always straight, however, flangeway width and switch point spread, critically important dimensions specified by NMRA standards, do affect the model turnout and reliable operation. In the model they affect frog design and switch heel spread, and thus directly affect gauge-line geometry. [28] For an AREA turnout with a specified frog number, the most important dimension for the switch is the specified switch rail length. For a straight switch rail, the switch heel angle is a direct consequence of the switch rail length and the switch heel spread. Because the switch is straight, the point angle is the same as the heel angle. For a curved switch, the point angle depends on the curved switch rail length, a specified heel angle, and the heel spread. [28]

2.3. CROSSING

A crossing or frog is a device introduced at the point where two gauge faces cross each other to permit the flanges of a railway vehicle to pass from one track to another. So to do such task, gap is provided from throw to the nose of crossing and the Check rails assures the correct movement and guides the wheels properly. This makes as, the vehicle negotiate the crossing smoothly. [13, 21, 22, 23]

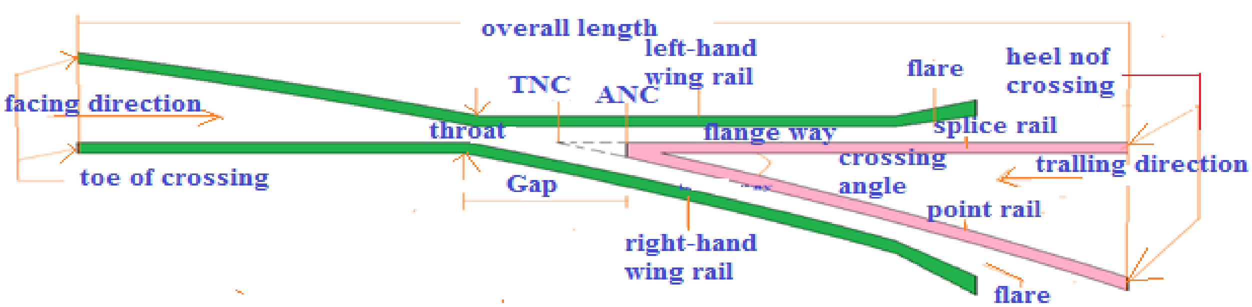


Figure 2.2: Details of crossing

2.4. SWITCHES

The switch is an arrangement of special structure which consists of the pair of linked tapering rails, known as points (switch rails or point blades), lying between the diverging outer rails (the stock rails). These points can be moved laterally into one of two positions to direct a train coming from the point blades toward the straight path or the diverging path. [1, 6, 9, 23]

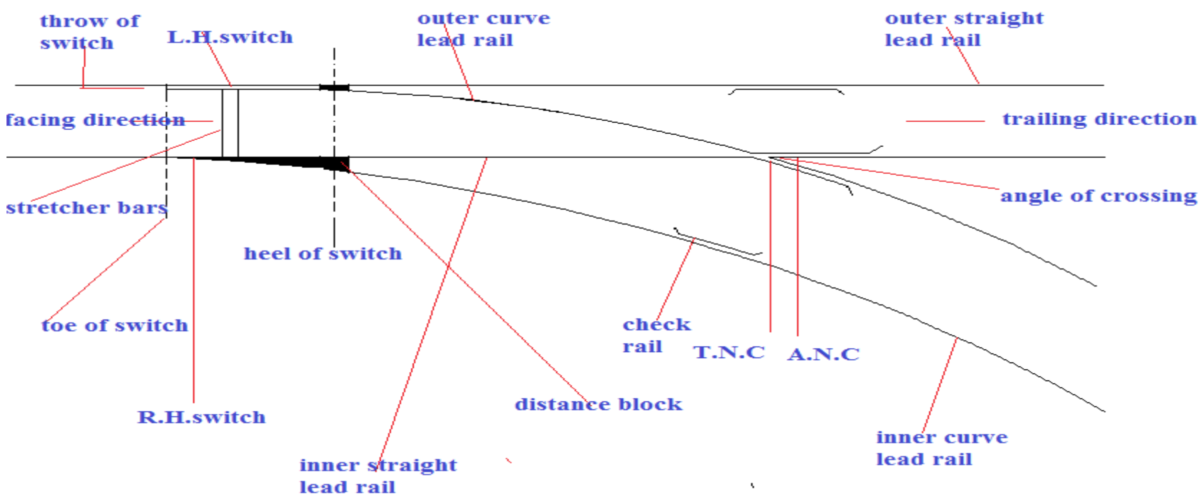


Figure 2.3: split switch

A mechanism is provided to move the points from one position to the other (change the points), historically, this would require a lever to be moved by a human operator, and some switches are still controlled on this way. However, most are now operated by a remotely controlled electric motor or by pneumatic or hydraulic mechanism. The tongue rails are tapered on most switches, but on stub switches they have square ends and machined to a very thin section to obtain a snug fit with the stock rail. [10, 27]

The Straight switch rails have the advantage that they are easily manufactured and can be used for right-hand as well as left-hand turnouts. However, Straight tongue rails are normally used for 1 in 8.5 and 1 in 12 turnouts on most railway used countries. Curved tongue rails are shaped according to the curvature of the turnout from the toe to the heel of the switch. Curved tongue rails allow for smooth turning of trains, but can only be used for the specific curvature for which they are designed. Curved switches are normally used for 1 in 16 and1 in 20 according to IRS (Indian Railway Standard). [6, 9]

According to maintenance 20 to 40 percent of the track maintenance budget is spent on the inspection, maintenance and renewal of switch and crossing. the maintenance cost of one switch or crossing equals the maintenance costs of 300 to 500 meters of plain track, This relative high expenditure is mainly due to the nature of switch and crossing that makes them absolute and relative more expensive to maintain than plain track (straights and curves):[5, 9]

Examination of the FRA safety data base shows that switch point derailments are among the largest categories of track caused derailments, representing approximately 10% of all track caused derailments [19]. A large number of these derailments are related to worn switch points; particularly switch points that exhibit large gauge face angles or poor wheel rail contact [16, 19].Noting that approximately 50 to 60 derailments per year are associated with worn or broken switch points [17, 18, 20], (the number would be much higher if non-FRA reportable derailments were included

2.4.1. Switches - components

A set of points or switches consists of the following main Components:

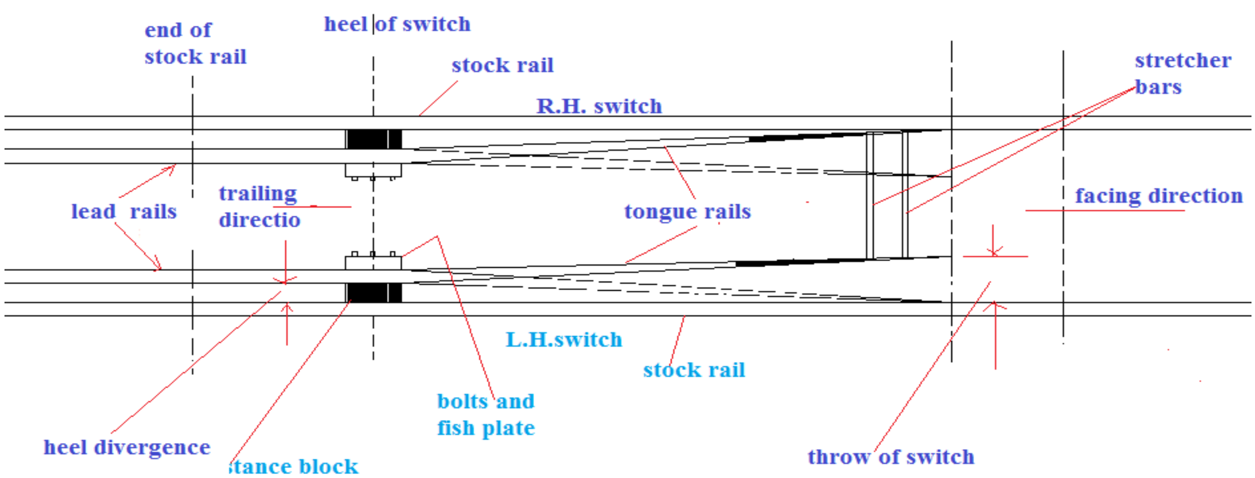


Figure 2.4: fixed heel type switch

[1] **Stock rail :-**They are the main rails of the track to which the tongue rails are fit closely[4, 5, 8, 6]

[2] **Stretcher bar**:-Used to connect the toe of the tongue rails so that both the tongues moves through the same distance or gap and generally 2 or 3 bars are used near and behind the toe[4, 5, 8, 6]

[3] **Heel blocks or distance blocks: -** which connects the heel of the tongue rail with the stock rail, by using ordinary fish plate and bolts for providing clear gap for the wheel flange[4, 8, 6]

[4] **Sliding plate :-**These are the special plates which are provided for supporting and sliding the tongue rails (to move toward and away from stock rails) [10]

[5] **A gauge tie plate: -** A gauge ties plate to fix gauges and ensure correct gauge at the points. [10]

[6] **Switch motor: -** A switch motor (also known as a switch machine, point motor or point machine) is an electric, hydraulic or pneumatic mechanism that aligns the points with one of the possible routes. The switch motor also includes electrical contacts to detect that the switch has completely set and locked. If the switch fails to do this, the governing signal is kept at red (stop). [10]

Figure 2.5: Electric switch machine

[7] **Points lever:-**A points lever, ground throw (switch stand) is a lever that are used to align the points of a switch manually. This lever and its accompanying hardware are usually mounted to a pair of long sleepers that extend from the switch at the points. They are often used in a place of a switch motor on infrequently used switches. In some places, the

lever may be some distance from the points, as part of a lever frame or ground frame. To prevent the tampering of switches by outside means.[10]

Figure 2.6: low switch stand.

[8] Point indicators:-As it is difficult to see the line of a switch from a distance, especially at night, European railways and their subsidiaries provide point indicators.[8]

2.4.2. Important Terms used in switches

The following are the important terms which come in general use in connection with asset of point or switches

Switch angle:-this the angles between the gauges face of the stock rail and that of the tongue rail at the theoretical toe of the switch in its closed position. For smooth entry and movement of trains, it is desirable to have a small switch angles on the track which is going to be used for fast moving train and on the other hand greater switch angles should be adopted on those section which are going to be used for slow moving trains as in case of station yards. Switch angle is the function of heel divergent and tongue rail length. [8, 27]

Length of switch rail and stock rail:-The length of a switch rail from heel to toe varies with the gauge and depends upon the value of switch angle .The longer the length of the switch rail, the smoother the entry to the switch because of the smaller angle the switch rail would make with the fixed heel divergence. The longer length of the switch rail, however, occupies too much layout space in station yards where a number of turnouts have to be laid in limited space. For a given heel divergence the length of tongue rail depends upon the value of switch angle, the length of switch rail should be carefully selected because use of long switch rails will increase the overall length of turnout whereas the short switch rails will increase the angle of switch. The length of the tongue rail should be longer than the rigid wheel base of four-wheel vehicle so that before a wheel leave the tongue rail another wheel behind it must come on the tongue rail to prevent the opening of the toe. However to reduce the switch angle for a given heel divergence and to maintain high speed at turnouts, the actual length of the tongue rails should be as large as possible. With longer tongue rails, the jolting effect also reduced. [8, 27]

Heel clearance/ Heel divergence :-It is the distance between the running face of the stock rail (gauge face of the stock rail) and gauge face of the tongue rail when measured at the heel of the switch shown in Figure 2.7: above. Heel divergence is kept equal to flange way clearance plus tolerance for the wear plus the width of head of rail. [8] Heel clearance according to Indian standards for different gauges:

- B.G Track:- 13.3cm to 13.7cm
- M.G Track: - 11.7cm to 12. 1cm
- N.G Track:- 9.8cm

Therefore the heel of the switch is located at the point where the offset of the curve is equal to the heel divergence

Flange way clearance

- ✓ It is the distance between the adjacent faces of the stock rail and the check rail.
- ✓ It is provided as a clearance for the free movement of the wheel flange
- ✓ Flange way should take into account the amount of wear. It is observed that up to 6cm flange way clearance, wear takes place. [8]

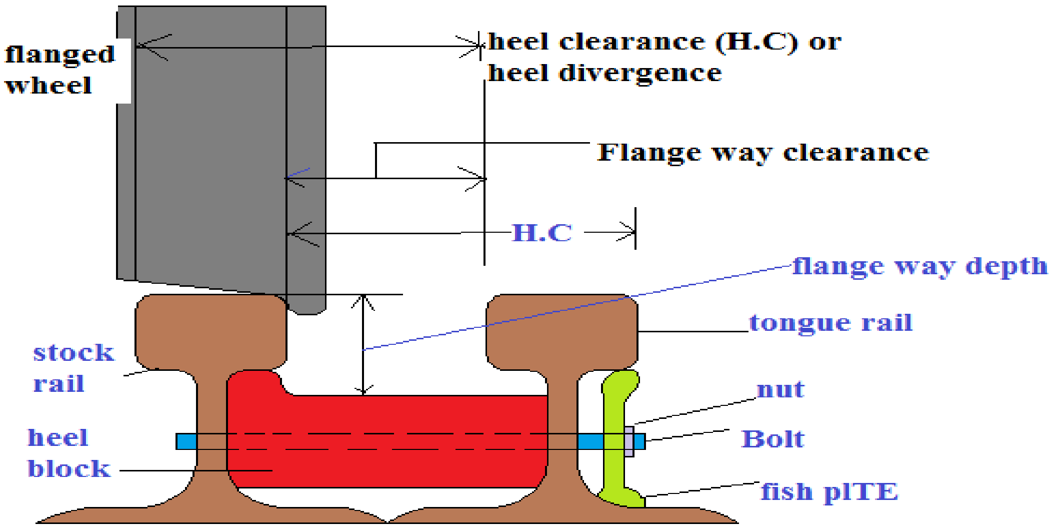


Figure 2.7: section at heel of tongue rail.

Indian standards for the value of Flange way clearance on the basis of wear are:

- For 1 in 12 crossing angle, F.C = 6.0+0.3cm=6.3cm
- For 1 in 8 crossing angle, F.C = 6.0+0.6cm=6.6cm

Flange way depth: - It is the vertical distance between the top surfaces of the running rail to the top surface of heel block used between the stock rail and the switch rail. See in figure 2.7: above. [8, 27]

Throw of Switch:-It is the distance through which the toe of the tongue rail moves sideways (with heel of tongue rail as the center of rotation) to provide desired direction over the turnout. Simply Distance by which the tongue rail moves laterally at the toe of switch shown in Figure 2.11: above [8]

- ✓ In U.S.A throw of switch =12.1cm
- ✓ In U.K "" " " =10.8cm
- ✓ In India "" "" =9.5cm for B.G
- ✓ In India “" "" =8.9cm for M.G and N.

2.4.3. Types of Switches

Switch classified in to two basic parts, this are:

- ✓ 1-Stub switch and
- ✓ 2-Split switch

2.4.3. 1. Stub switch

In a stub type of switch, no separate tongue rail is provided and same portion of the track is moved from one side to the other side ,First developed for steam railways and its straight and diverging tracks were completely separate and side by side see in figure 2.8: below. Stub switches are no more in use on current railway system. They have been replaced by spilt switches which are practical, known and universally adopted. [6, 8, 9, 27]

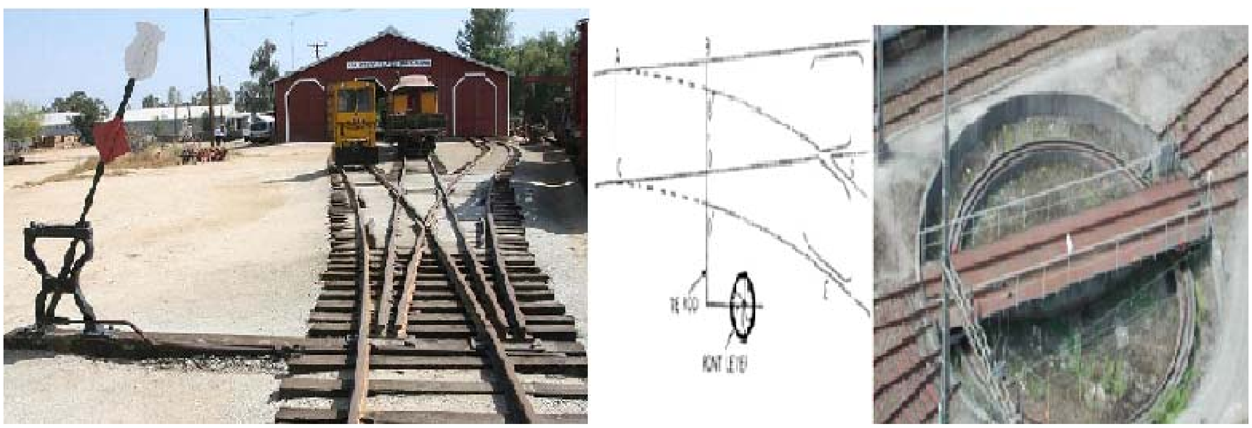


Figure 2.8: a stub switch

2.4.3.2. Split switch

A split switch essentially consist of two parts a stock rail and a tongue rail. Spilt switch are classified as two and three types depending on the basis of fixation at heel and depending on the shape of switches below

(a) On the basis of fixation at heel two types:

1) Loose heel type or articulated type
2) Fixed heel type or spring type or flexible type

(b) On the basis of shape of switch rail:

I. under Cut Switches

II. over riding Switches

III. straight cut Switches

1) **Loose heel type or articulated type: -** In this type of split switch, the switch or tongue rail ends at the heel of the switch to enable movement of the free end of the tongue rail. So the tongue rails are joined to lead rails by means of fish plates. The two front bolts are kept looses to allow the throw of switches and the rest bolts are kept tight when the tongue is open. Therefore this type of switch is suitable for the short length of switches, but as the discontinuity of the track at the heel, there is a weakness in the structure, so that, the use of these switches is not preferred [6, 8, 9, 27]

2) **Fixed Heel Type or spring type (Flexible Type):-** In this type of split switch, the tongue rail does not end at the heel of the switch, but extends further and is rigidly connected. The movement at the toe of the switch is made possible on account of the flexibility of the tongue rail [6, 8, 9, 27]

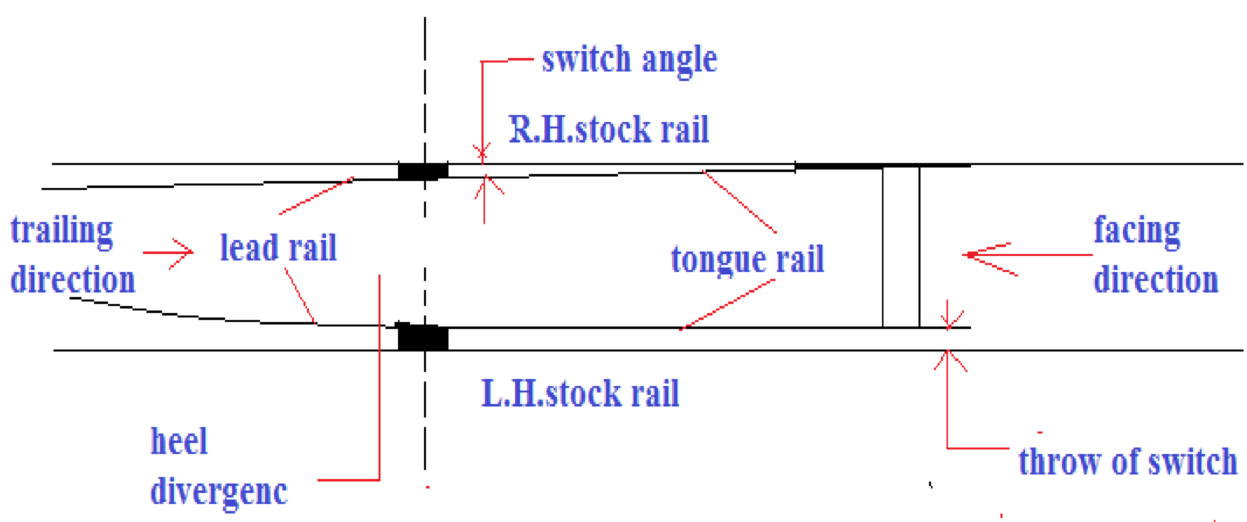


Figure 2.9: line diagram of fixed heel type switch

I. Under Cut Switches

In case the height of the stock and tongue rail is same, it is desirable to cut out a portion of flange at the foot of the stock rail so that toe of tongue rail is accommodated under head of the stock rail. [8] The disadvantage of this type of switch is that it becomes weak because flange portion is cut out.

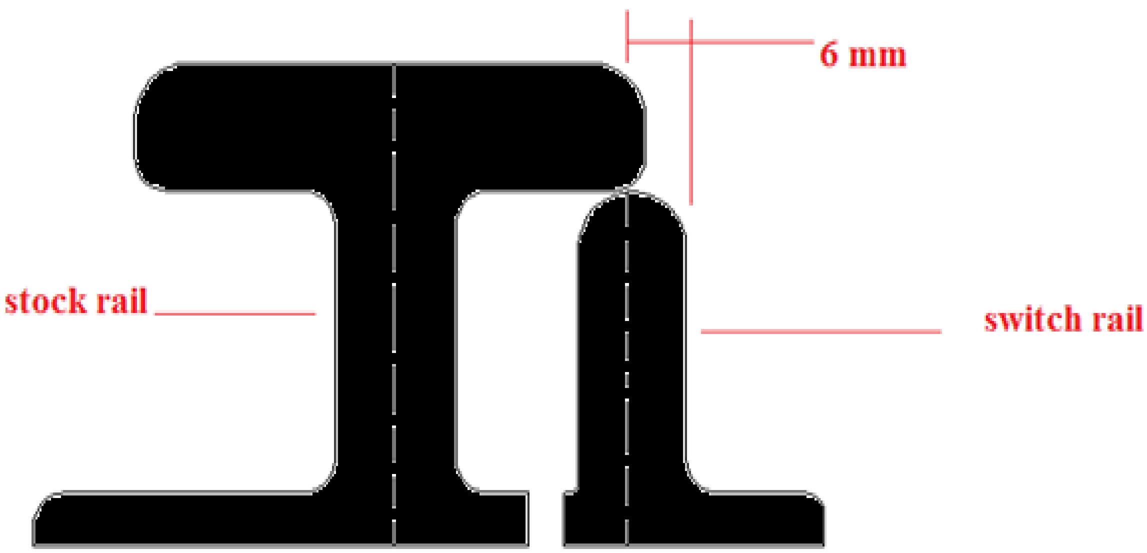


Figure 2.10: undercut switch

II. Overriding Switches:

In this case, the stock rail occupies the full section and the switch rail is kept 6mm (0.25”) higher than the stock rail from the heel to the point towards the toe where the planning starts. This is done to eliminate the possibility of splitting caused by any false flange moving in the trailing direction. [6, 8, 9, 27] Override switch design is considered to be an economical and superior design due to the following reasons:

- **(a)** Since the stock rail is uncut, it much stronger.
- **(b)** Manufacturing work is confined only to the tongue rail, which is very economical.
- **(c)** Although the tongue rail has a thin edge of only 6mm (.25 “), it is supported by the stock rail for the entire weakened portion of its length. As such, the combined

strength of the rails between the sleepers is greater than that of the tongue rail alone in the undercut switch.

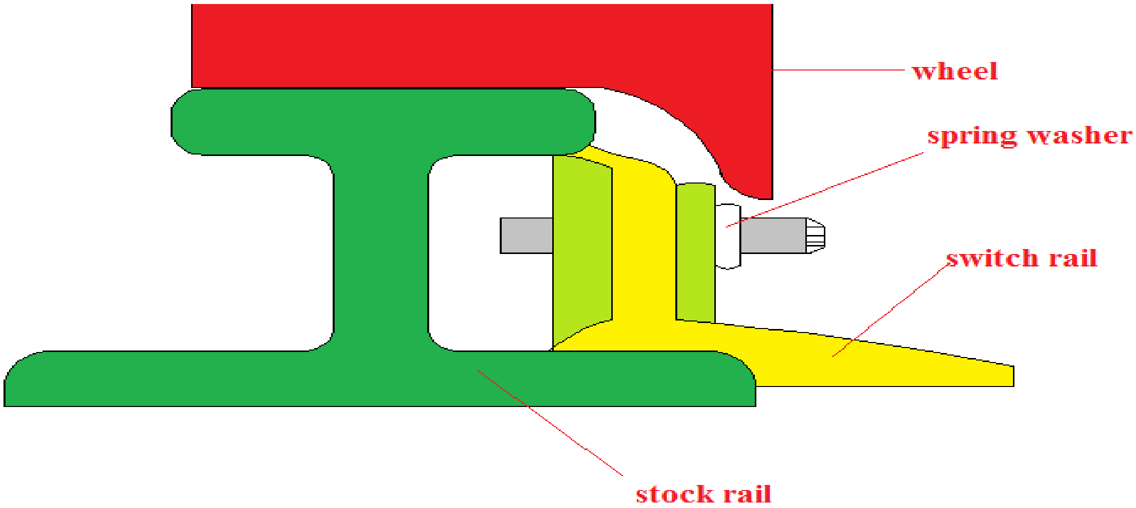


Figure 2.11: overriding switch

III. Straight cut Switches: [6, 8, 9, 27]

- ✓ In this type the tongue rail is cut straight in the line with the stock rail.
- ✓ This is done to increase the thickness of toe of the tongue rail, which as result increases its strength
- ✓ This type of switch is suitable for Bull Headed (BH) rails.

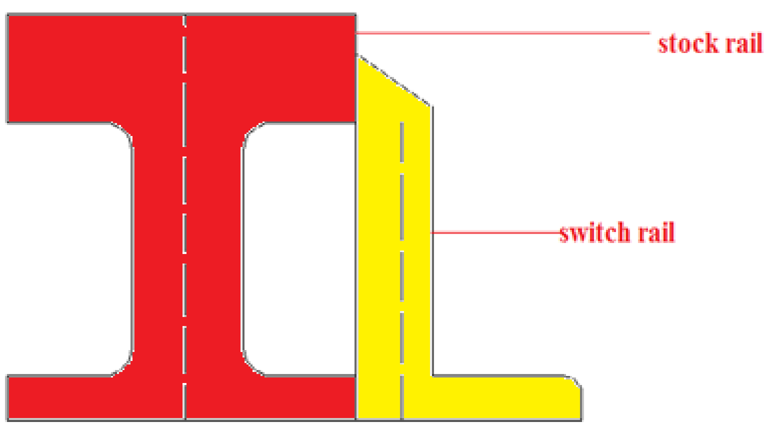


Figure 2.12: straight cut switches

2.5. GEOMETRICL DESIGN METHODS OF TURNOUT

The simplest arrangement of points and crossing can be found on a turnout taking off from a straight track. There are two standard methods prevalent for designing a turnout. These are the (a) Coles method and the (b) IRS method. These methods are described in detail in the following sections. The important terms used in describing the design of turnouts are defined as follows [8, 6, and 9].

- ✓ Curve lead (CL) this is the distance from the tangent point (T) to the theoretical nose of crossing (TNC) measured along the length of the main track.
- ✓ Switch lead (SL) this is the distance from the tangent point (T) to the heel of the switch (H.S) measured along the length of the main track.
- ✓ Lead of crossing (L) distance between T.N.C and the heel of switch (H.S) measured along the length of the main track. Lead of crossing (L) = curve lead (CL) – switch lead (SL)
- ✓ Gauge (G) this is the gauge of the track.
- ✓ Angle of crossing (α) this is the angle between the main line and the tangent of the turnout line.
- ✓ Angle of switch (β) the angle between the switch rail
- ✓ Number of crossing(N)
- ✓ Ro=radius of outer curve
- ✓ R=radius of center line of turnout $R = R\text{o} - 0.5G$
- ✓ d= heel divergence or clearance

2.5.1. Cole's method -1

All the three lead CL, SL, and L are calculated in this method and crossing angle is calculated by using right angle method, in this simple design of turnout, a crossing curve is considered to start from an imaginary tangent point head actual toe of the switch and end at theoretical nose of crossing. These arrangements result in the formation of three kinks, namely [8, 6, and 9].

a kink at the toe of a switch , this is because the switch rail is straight

- ✓ a kink at the heel of switch , this is because the switch rail is not tangential to the curve

- ✓ a kink at the toe of crossing, this because the curve is carried theoretically up to T.N.C. but the crossing actually is straight

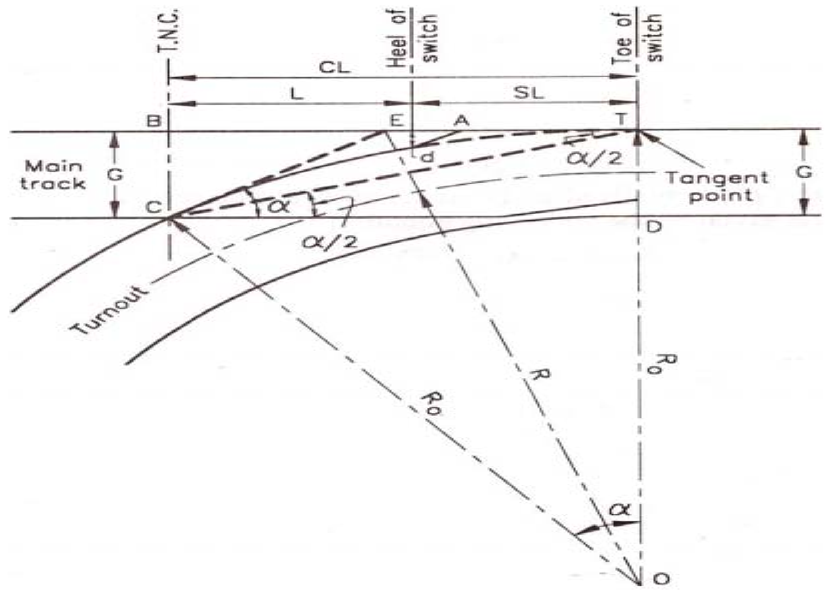


Figure 2.13: Cole's method -1 turnout design

1) Curve lead

From right angle (Cole's method) Number of the crossing (N) = cot α from triangle TBC (TCD)

$$\tan(\alpha/2) = G/CL$$

$$CL = G \cot(\alpha/2) \quad \text{......} \quad 2.1$$

From triangle CDO

$$CL^2 + (Ro-G)^2 = Ro^2$$

$$CL^2 = G\,(2Ro-G)$$

$CL^2 = 2RoG$....neglecting G^2 which is small as compared to 2GRo

$$CL^2 = 2RoG \quad \text{......} \quad 2.2$$

From line BT

CL= BA + AT

CL= BA + AC :- AC=AT

CL= G cot α +G cosec α

$CL= G\sqrt{1 + cot2 \propto}$ + G cot α

$CL= G\sqrt{1 + N2}$ + GN……………………….N=cot α

CL= 2GN ……………………………….……approximately

CL= 2GN…………………………….………..…… 2.3

2) R-radius

From triangle OCD

Ro=CL/sin α

R= Ro-G/2

Ro=TD+OD

Ro= G + CL cot α………….where CL=2GN and N= cot α

Ro= G + 2GN. N… because CL is actually slightly greater than 2GN and hence more accurate value of Ro is given by

$Ro=1.5 G + 2GN^2$…………………………..……2.4

R= Ro-G/2…………………………...…… 2.5

3) Switch lead (S.L)

$SL^2+ (Ro-d)^2=Ro^2$

$SL^2 = d (2Ro-d)$

$SL^2 =2Rod$ ……….as d2 is very small as compared to2Rod

$SL =\sqrt{2Rod}$ ……………………………2.6

4) Lead or crossing lead (L)

L=CL-SL

$L= G \cot (\alpha/2)-\sqrt{2Rod}$

$L= 2GN-\sqrt{2Rod}$ ……………………………..2.7

5) Heel divergence (d)

From equation ……………………..… 2.6

$d=SL^2/2Ro$………………………...……….……2.8

2.5.2. Cole's method -2

In this method only the crossing lead (L) is calculated and the curve is tangent to the switch heel rail. It springs from the heel of switch and ends at T.N.C with the help of this method, out of three types of kinks; a kink which is formed at the heel of the switch is removed. The design calculations with the given value of (G, d, β and α) the turnout design as follows: [8, 6, and 9].

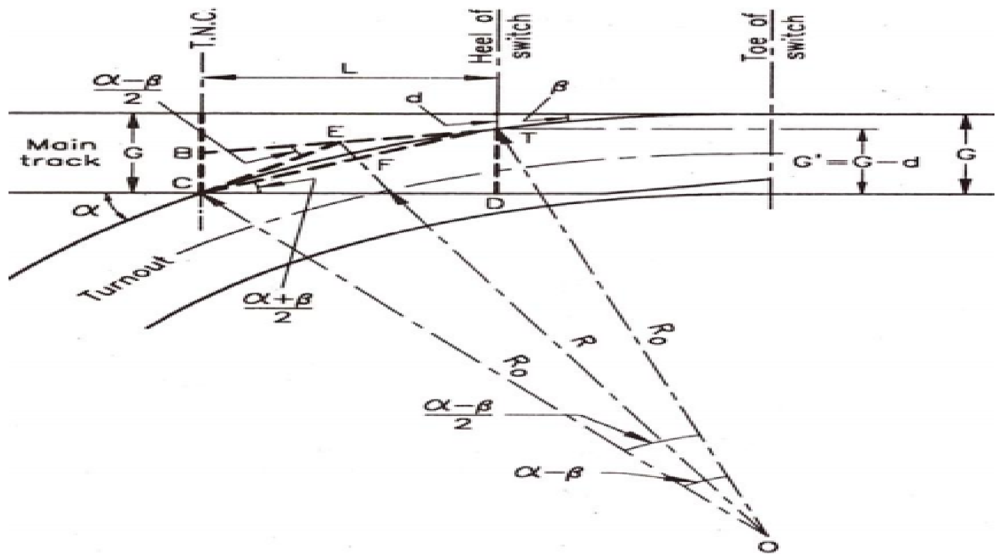


Figure 2.14: Cole's method -2 lead curve

I. Lead or crossing lead (L)

From figure 2.14: triangle TDC

$$L=\frac{G-d}{\tan(\frac{\alpha+\beta}{2})}$$

$$L=(G-d)\cot((\alpha+\beta)/2)\text{.......................................}2.9$$

II. R-radius

From triangle OCF

$$\text{Sin}\left(\frac{(\alpha-\beta)}{2}\right)=\frac{\text{CF}}{\text{Ro}}=\frac{\text{CT}}{2\text{Ro}}$$

$$\text{Sin}\left(\frac{(\alpha-\beta)}{2}\right)=\text{TD}/\sin\left(\frac{(\alpha+\beta)}{2}\right)*\frac{1}{2\text{Ro}}$$

$$\text{Sin}\left(\frac{(\alpha-\beta)}{2}\right)=\frac{\text{G}-\text{D}}{2\text{Ro}\sin(\frac{(\alpha+\beta)}{2})}$$

$$\text{Ro}=\frac{\text{G}-\text{D}}{2\sin(\frac{(\alpha+\beta)}{2}).\ \sin(\frac{(\alpha-\beta)}{2})}$$

$$Ro = \frac{G-D}{\cos\beta - \cos\alpha} \quad \text{.....2.10}$$

$$R = Ro - \frac{G}{2} \quad \text{.....2.11}$$

2.5.3. IRS method

This method is very similar to method -2 but in this case the straight length at the crossing is provided, so in this method one end of the carve is tangential to the switch heel rail and springs from the heel of the switch and the other end springs from the toe of the crossing and is tangential to the straight length of the crossing. With the use of this method, out of the three kinks, two kinks, namely a kink at the toe of the crossing and a kink at the heel of switch is removed, Only one kink, namely at the nose of the switch. This method is very much suitable where tongue rails and crossing are straight. The value of L and R obtained by this method will be given the value as obtained by method-2, let the straight length or arm at crossing be x=T'C shown in figure 2.15: below: [8, 6, and 9].

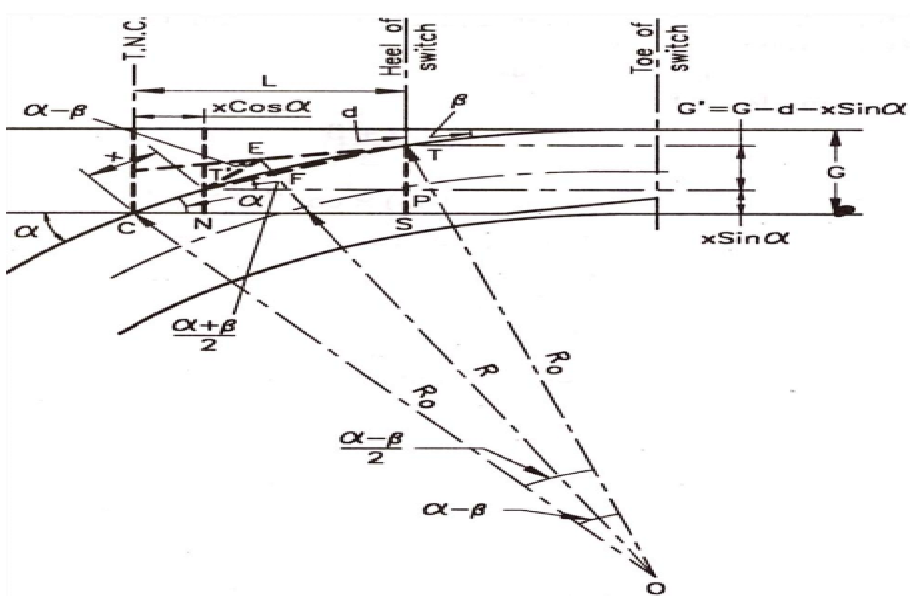


Figure: 2.15: IRS method

[1]. . R-radius

Now with the given value of G, d, β, α and x the turnout design as follows:

From triangle TPT'

$$TT'=TP\ \text{cosec}\ \frac{(\alpha+\beta)}{2}$$

$$TF=TT/2=1/2(TP\ \text{cosec}(\frac{(\alpha+\beta)}{2})) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.12$$

From triangle OFT'

$$Ro=TF\ \text{cosec}\ (\frac{\alpha-\beta}{2}) \ldots\ldots\ldots\ldots \text{substitute TF from equation} \ldots\ldots\ldots\ldots 2.12$$

$$Ro=1/2(TP\ \text{cosec}\ (\frac{(\alpha+\beta)}{2})).\ \text{Cosec}\ (\frac{\alpha-\beta}{2})$$

$$Ro=\frac{TP}{2\sin(\frac{\alpha+\beta}{2}).\ \sin(\frac{\alpha-\beta}{2})}=\frac{TP}{\cos\beta-\cos\alpha}$$

$$Ro=\frac{G-d-x\sin\alpha}{\cos\beta-\cos\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.13$$

$$R=Ro-\frac{G}{2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.14$$

[2]. . Crossing lead (L)

From triangle CNT' and from line CNS

$$L=CN+NS=CN+T'P$$

$$L=x\cos\alpha+G'\cot\frac{\alpha+\beta}{2}$$

$$L=x\cos\alpha+(G-d-x\sin\alpha)\cot(\frac{\alpha+\beta}{2}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.15$$

N.B for getting values of method-2, put x=0 in equation 2.13 and 2.15 you will get

$$Ro=\frac{G-D}{\cos\beta-\cos\alpha}$$

$$L=(G-d)\cot((\alpha+\beta)/2)$$

2.6. GEOMETRY OF GUARD (CHECK) RAIL

2.6.1. Guard (check) rail

A guard rail (check rail) is a short piece of rail placed alongside the main (stock) rail opposite the frog. These exist to ensure that the wheels follow the appropriate flange way through the frog and it is A necessary device that's ensures the frog from strike of flange of wheel, by guiding to one side, which keep the backs of the opposite wheels far enough away, this means, in other way, the train does not derail. Generally, there are two of these for each frog, one by each outer rail. Guardrails are not required with a "self-guarding cast manganese" frog, as the raised part of the casting serves the same purpose. These frogs are for low-speed use and are common in rail yards. [14, 28]

2.6.2. Guard (restraining) rails on curve

Check rails (also known as Guard rail) laid parallel to a running track to guide wheels through points sharp curves, slope, and round curves, to reduce wear as well as to increase the track's resistance to flange climb derailment. Check rails are also used on very sharp curves, even where there are no switches and are also installed in track curves, where the high rail wears rapidly, as they are considered beneficial in reducing the frequency and cost of high-rail replacements. Guard/restraining rail design and maintenance standards in transit systems came from railroad industry practices, however, guard rail were mainly used on switches and frogs. Guard/restraining rail design and maintenance standards for curves had to differ from those for switches and frogs because of their different running surroundings and functions.
The following factors lead to guard/restraining rails being more commonly used on curves in railroad operations. [14, 28]

- Sharp curves
- High traffic densities—frequent trains and very limited time periods for track maintenance, making replacement of worn running rails difficult;
- Narrow wheel treads— much more sensitive to the gage-widening effects of gage face wear in curves; and

- Independent rotating wheel (IRW)—the use of IRW in some transit cars increases the risk of flange climb derailment.

2.7. GEOMETRIC DESIGN OF AREA GUARD RAIL

The AREA specifies two types of guard rails, the tee rail guard rail with planed flares and the one piece guard rail. While the AREA specifies five standard guard rail lengths shown in table 2.1: below, none longer than 13 feet, lengths used by various railroads can vary widely. [14, 28]

Table 2.1: AREA Tee Rail Guard Rail Design Dimensions

L_{GR} (ft.-in.)	L_{GR} (in.)	L_{PL} (in.)	L_{PN} (in.)	L_{BV} (in.)
8’-3”	99	41	16	13
11’-0”	132	66	20	13
13’-0”	156	84	23	13
16’-6”	198	116	28	13
19’-6”	234	142	33	13

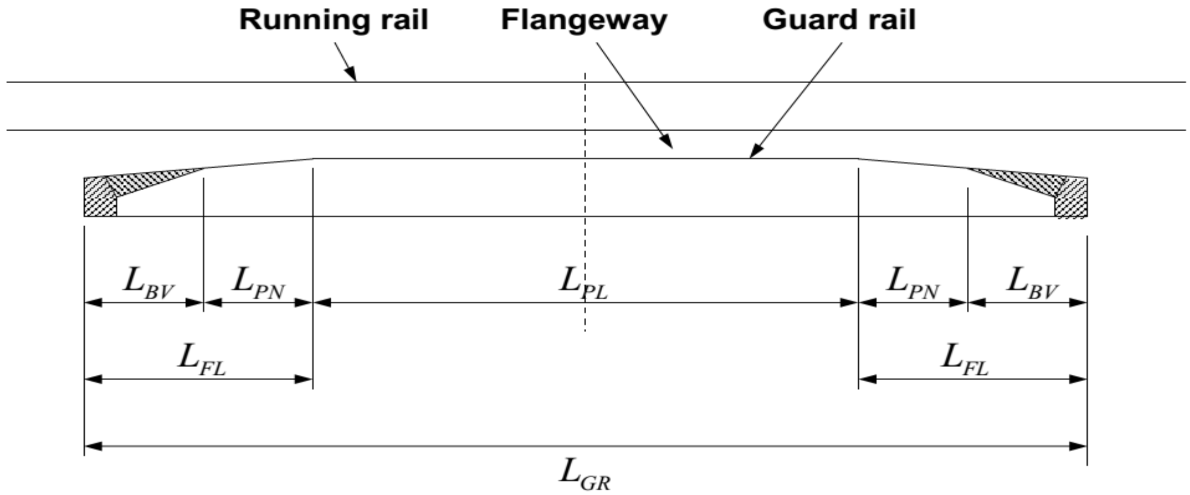
AREA specify the minimum guard rail lengths for specific frogs,

- 8’-3” for frog numbers 14 and lower, and
- 11’-0” for frog numbers 15 and higher, These sizes apply to rigid frogs, and
- With the longer 13’-0” guard rail, also apply to spring frogs.

These rules are logical because the parallel length for the 8’-3” guard rail exceeds the total flange way gap plus the 6-inch setback for frog numbers 14 and lower. Frog numbers 15 through 20 require the 11’-0” guard rail so its parallel length exceeds the total flange way gap plus the 6-inch setback

2.7.1. Tee rail guard rail

AREA Plans show designs for three tee rail guard rail lengths, 8’-3”, 11’-0” and 13’-0”. The AREA apparently selected these lengths because they can be cut from standard 33-foot or 39-foot rails, [14, 28]



Where:

- ✓ L_{PL}-straight portion
- ✓ L_{PN}-planed section
- ✓ L_{BV}-beveled section

Figure 2.16: Tee Rail Guard Rail Geometry

The total tee rail guard rail length LGR is:

$$L_{GR} = L_{PL} + 2\,(L_{PN} + L_{BV})$$

2.7.2. One piece guard rail

The AREA specifies only two guard rail designs, one constructed from rail stock and the other made as a single casting. The rail stock design adapts well to the model turnout, but the cast design (one piece guard rail) is too restrictive because it requires specific tie spacing under the frog and the minimum distance of the straight portion of the guard rail behind the ½ - inch point is 2 inches [14, 28]

2.7.3. GUARD RAIL AND SETTING

For a guard rail to function properly, its parallel (straight) portion must be in proper position relative to the ½-inch point of the frog .Guard rails and their proper setting in relation to the frog flange way gap are also important to reliable operation. With wider flange way gaps needing protection, require a set of longer guard rails. The lengths of these longer guard rails come from the standard-length rail stock. For this reason the new RP format includes guard rail length, flare and parallel-section setback dimensions that are dependent on frog number. Figure 2.16: figure 2.17: and figure 2.18: show the geometric details of a Tee Rail Guard Rail, likely constructed as follows. Tratman [24] states the center of the guard rail should normally be located about a foot in front of the frog point. Hay [25] states the center should be a few inches ahead of the frog point. The AREA is more specific. Notes on the guard rail plans in [26] specify minimum distances the ends of the straight portion of a guard rail must be, a small distance greater than, the distance between throat of crossing up to actual nose of crossing (from the sharp nose of crossing up to the ½-inch rigid frog). Therefore the center of the guard rail should be located at the center of the flange way gap in crossings. [14, 28]

2.7.3.1. Tee rail Guard Rail Setting

For tee rail guard rails the Parallel portion of Guard Rails to extend:

(a) In back of ½" frog point, not less than 6", for all frogs (in back of means- towards the frog heel)

(b) In advance of ½" frog point for rigid frogs and The Guard Rail opposite the spring flange way of spring frogs:

- Not less than (twice frog number in inches) for frogs of smaller angle than No. 9.
- Not less than 18" for No. 9 frogs and frogs of larger angle.

(In advance of means -towards the frog toe)

The presumed purpose of these minimums is to ensure that the guard rail properly protects the flange way gap through the frog, because the straight length is considerably longer than the flange way gap. [14, 28]

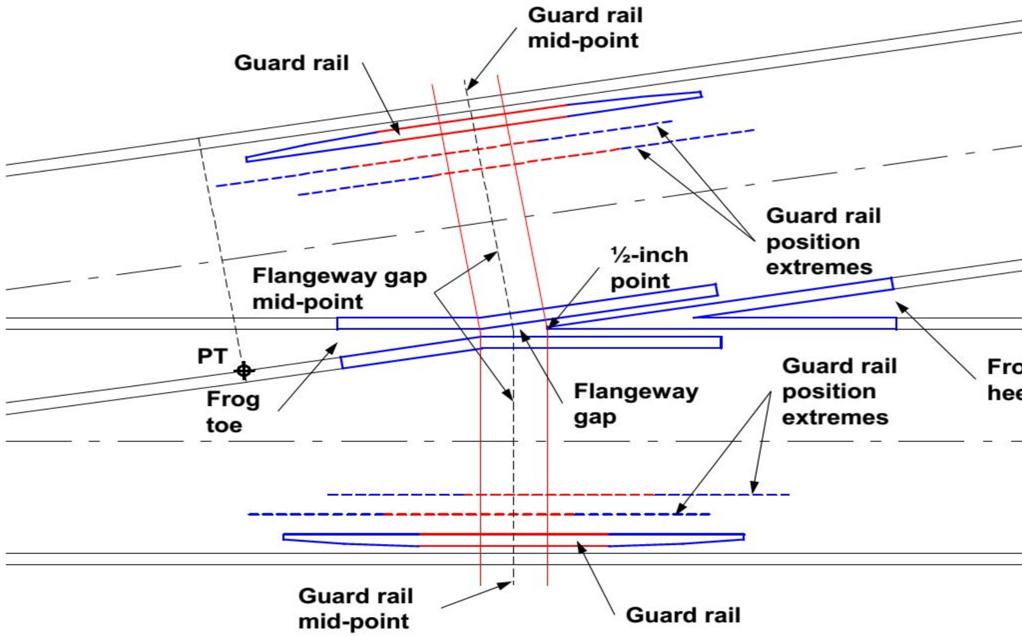


Figure 2.17: Guard Rail Position

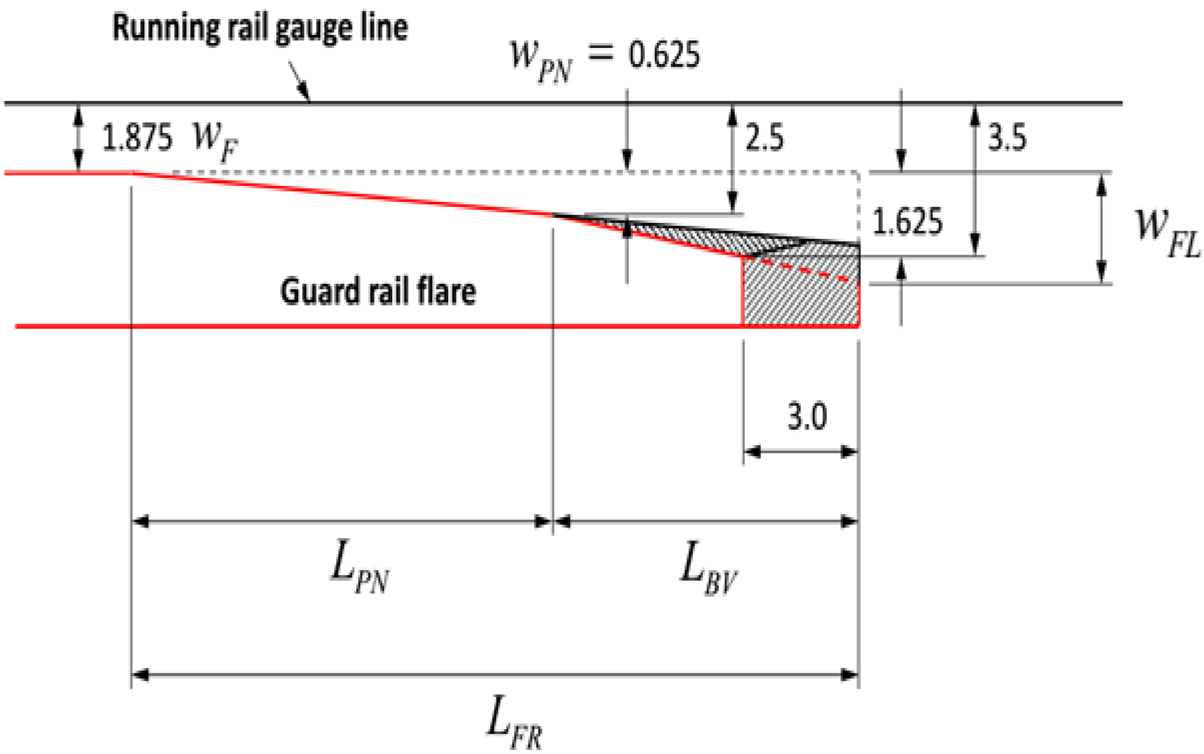


Figure 2.18: Tee Rail Guard Rail End Flare

2.7.3.2. One-piece Guard Rail Setting

AREA settings for one-piece guard rails are even more specific. In this case the minimum distance of the straight portion of the guard rail behind the ½ - inch point is 2 inches. The minimum length in front of the frog ½-point is even more restrictive, as follows: [14, 28]

Frogs 4-5…………………………………..….…………. 12 inches
Frogs 6-10………………………………..………………. 14 inches
Frog 11…………………………………….…………….…16 inches
Frogs 12, 14………………………………………………....18 inches
Frog 15………………………………….….…..…………..24 inches
Frog 16…………………………………….……………..….26 inches
Frogs 18, 20……………………………..…….…………..…30 inches

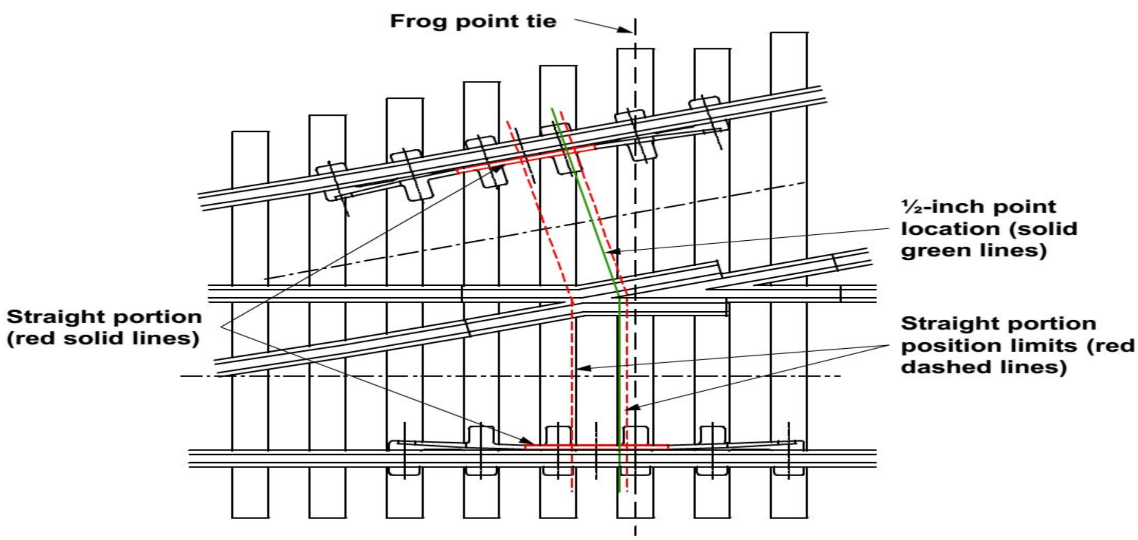


Figure 2.19: One-Piece Guard Rail Position

3. ANALYSIS AND DESIGN OF RAIL SECTION FOR ISW

3.1. PRELIMINARY SELECTION OF RAIL SECTION

3.1.1. According To International Union of Railway (UIC)

The choice of rail section mainly depends on the traffic load as well as on the intervals between renewal sessions. For a standard-gauge track, it is customary to use UIC 50 rail for low traffic load and UIC 60 for medium and heavy load. Table 3.1: gives the rail section choice criteria as a function of traffic load,

Table 3.1: Choice of the rail section in relation to traffic load

Daily line traffic load (tons)	≤25,000 t	25,000<A. load>35,000t	≥ 35,000t
Required weight of the rail per meter of length	50 kg/m	• For timber sleepers: 50 kg/m • For concrete sleepers: 60 kg/rn	60 kg/m

3.1.2. According To USA Department of Defense (USADOD)

The rail road design and rehabilitation by department of defense, USA, gives recommendation on rail section selection primarily by the following formula

$$Wo = 315 - \left(\frac{21200}{\frac{p}{1120} * a + 67}\right) \qquad 3.1$$

Where Wo =Weight of rail (lb/yd)

P=design wheel load (lb)

a=Impact factor, where:

a=1, where design operating speed is 25 mph or less than 25mph

a=1.4, where design operating speed is more than 25 mph

By using different types of wheel load for different types of train, selecting the one which is produces maximum dynamic design load and you can insert this maximum load in to the above formula, than you will get easily the preliminary section of the rail, but according to our study, the maximum design speed 70Km/h and the maximum design axel load that are taken from AALRT is 11t which is very high compared to the other load due to this, no need of comparisons for selection of the design load , we can use this design load as it is, so for this design load, the wheel load become 55kN (Axle load/2)

Notice:

- ✓ 1miles=1.609344km therefore 70km/h = 43.5mph
- ✓ a =1.4 since the design speed (V)>25 mph

By taking the maximum wheel load (design load) P=55KN (12,125.42 lb), the rail weight will be:

$$Wo = 315 - \left(\frac{21200}{\frac{12,125.42}{1120} * 1.4 + 67}\right) = 56.95 \text{ lb/yd}$$

➔ lb/yd=0.496kg/m

Wo =0.496*56.95

Wo =27.9 kg/m

But we have no such rail weight per meter in Chinese rail section standard so we can take the approximate rail section which is 50kg/m and according to INTERNATIONAL UINION OF RAILWAY from (table 3.1: above Choice of the rail section in relation to traffic load) it is possible to select 50 kg/m rail section for 11t design axel load.

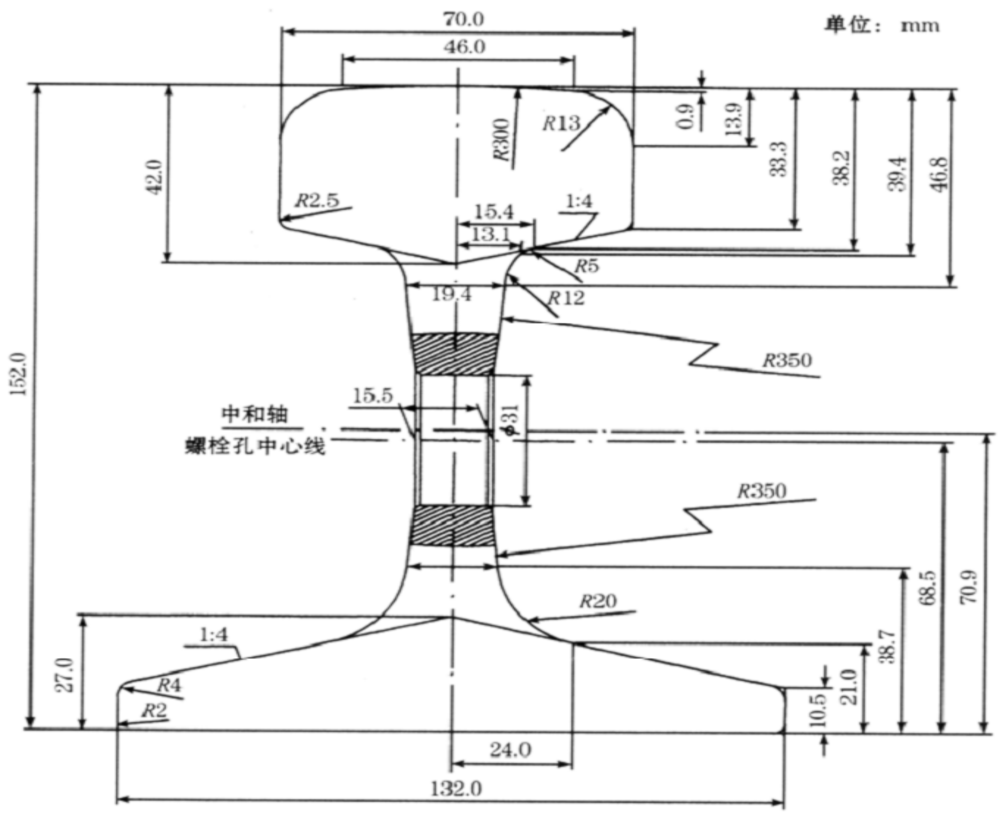


Figure 3.1: Rail profile 50kg/m

Table 3.2: Property of rail section (50kg/m)……. From GB-standard

rail style(kg/m)	50
section area (cm2)	65.8
center of gravity from bottom of rail (cm)	7.1
center of gravity from end of rail (cm)	8.1
moment inertia horizontal axis (cm4)	2037
moment inertia vertical axis (cm4)	377
cross-section coefficient of bottom (cm3)	287.2
cross-section coefficient of top (cm3)	251.3
cross-section coefficient of bottom side edge (cm3)	57.1

3.2. STRUCTURAL DESIGN OF IMPROVED SWITCH RAIL SECTION

3.2.1. Basic assumption of Winkler support model

- ✓ The two continuous parallel rail as abeam with infinite length on elastic foundation
- ✓ the rail which are fixed at regular interval on to sleepers supported from below and from the side by a medium which cannot be deformed
- ✓ the ballast bed rests on a formation which also cannot be deformed
- ✓ vehicle wheel load equally distributed to the two continuous parallel rail
- ✓ the track weight should not be considered (ignored)

In elementary calculations it is usually presupposed that the Winkler hypothesis applies to track support, this hypothesis was formulated in 1867 and reads: at each point of support the compressive stress is proportional to the local compression. This relation can be written as: [27]

$\sigma = C * w$ in which:

σ = local compressive stress on the support [N/rn2];

w = local subsidence of the support [m];

C = foundation modulus [N/rn3].

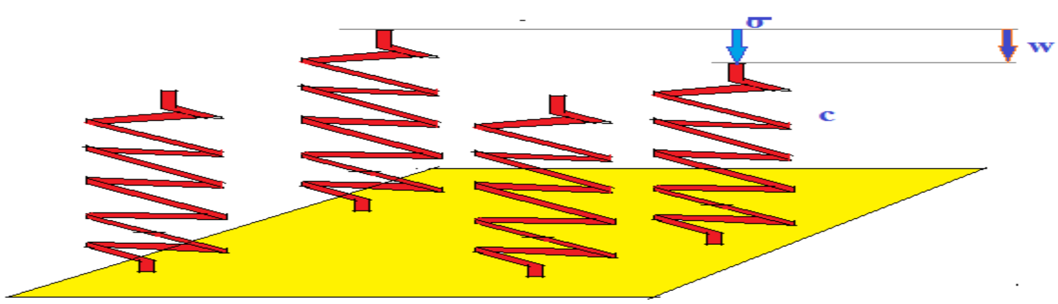


Figure 3.2: Winkler support model

3.2.2. Beam on elastic foundation model

Let us consider an infinitely long track (CWR) with bending stiffness EI which is continuously supported by an elastic foundation with foundation coefficient K loaded a wheel load Q at x = 0. This beam calculation was first proposed by Zimmermann. To derive the formula for the deflection y(x) of the beam, we first write down the equilibrium conditions of the beam element.

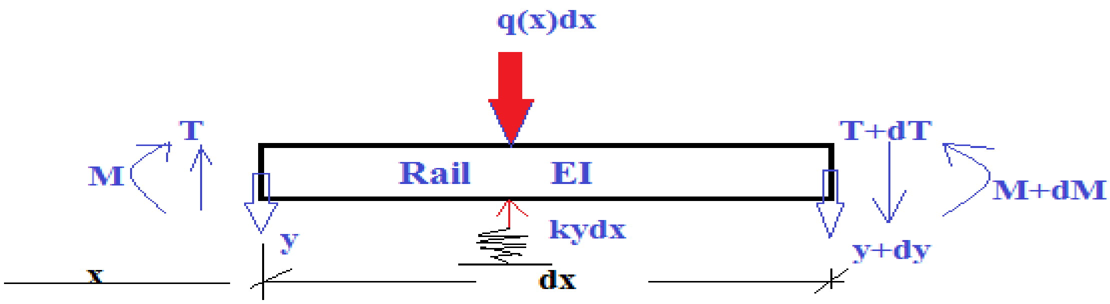


Figure 3.3: Equilibrium condition of beam element

Equilibrium requires:

$$\sum F v = 0$$

$$T + kydx - (T + dT) - q(x)dx = 0$$

$$kydx - dT - q(x)dx = 0$$

$$q(x)dx = kydx - dT$$

$$q(x) = ky - dT/dx$$

Where:

From elastic liner equation $d^2y/dx^2 = - M/EI$

$$M = -EI\, d^2y/dx^2$$

$$dT/dx = d^2M/dx^2$$

$$dT/dx = -EId^4y/dx^4$$

$$q(x) = ky - (-EId^4y/dx^4)$$

$$q(x) = \frac{EId^4Y}{dx^4} + ky$$

From these equations the differential equation for the rail deflections become is:

$$q(x) = \frac{EId^4Y}{dx^4} + ky$$

Where:

E = Young's modulus of rail steel

I = moment or inertia of one rail with respect to the horizontal centroidal axis

y = vertical track deflection

q = vertical load distribution (wheel loads) on the rail

x = point on rail axis

k = elastic modulus of rail support (truck modulus), for one rail

Since we deal only with point loads, the distributed load q(x) will not be considered here (q ≡ 0).therefore the general solution of the differential equation is

$$y = C_1e^{kx} \cos kx + C_2e^{kx} \sin kx + C_3e^{-kx} \cos kx + C4e^{-kx} \sin kx$$

After substituting the boundary condition in the general equation, than the magnitude of the deflection (y), at point x of track, rail support force (R) and bending moment (M) can be expressed by the following expressions:

$$y(x) = \frac{PK}{2u} e^{-kx} (\cos kx + \sin kx) = \frac{PK}{2u} \eta(kx) \quad \text{……3.2}$$

$$M(x) = \frac{P}{4K} e^{-kx} (\cos kx - \sin kx) = \frac{P}{4K} \mu(\boldsymbol{kx}) \quad \text{……3.3}$$

$$R = q(x) * a = u * y(x) * a = \frac{PKa}{2} e^{-kx} (\cos kx + \sin kx) = \frac{PKa}{2} \eta(kx) \quad \text{……3.4}$$

Where:

Stiffness ratio coefficient (K): a coefficient between rail foundation stiffness (μ) and the rail bending stiffness (EI) $K=\sqrt[4]{\mu/4EI}$

Characteristic length $L=\sqrt[4]{4EI}/\mu=1/K$

a-sleeper spacing

u-rail foundation stiffness=D/A

D−rail support stiffness

$P^d = (1 + \theta) P$ = dynamic wheel load

$Y(x)_{max}=\frac{P}{2Lu}$

$M(x)_{max}=\frac{P}{4K}$`

3.2.3. Dynamic amplification factor (θ) and maximum design load

It is common practice to carry out a strength or fatigue calculation for a static load system Or often a single wheel load, using the longitudinal beam theory, according to which the dynamic effects are taken into account by a speed coefficient or dynamic amplification factor. The effect of running speed on load is in reality highly complex because of the dynamic interaction between vehicle and track. In view of the nature of the load, it is also more correct to carry out a fatigue calculation. The Eisenmann scheme to determine the DAF (Dynamic Amplification Factor) is dependent on the train speed, the track quality, and chosen factor (t) and reads as follows

DAF- formula:

DAF= 1 + tφ………………………………….. if V < 60 km/h…………….…..3.5

DAF= 1 + tφ (1 + $\frac{V-60}{140}$)…………………. If 60 ≤ V ≤ 200 km/h ………3.6

Table 3.3: Eisenmann DAF (Dynamic Amplification Factor) approximation

Application	**T**	**Track condition**	**φ**
Contact stress, subgrade	1	Very good	0.1
Lateral load, ballast bed	2	Good	0.2
Rail stresses, fastenings, supports	3	bad	0.3

Where:

t = multiplication factor of standard deviation which depends on the confidence interval. Since the rail is so important for safety and reliability of rail traffic a value of 3 is recommended

φ = factor depending on track quality,

V = train speed [km/h].

P^d = DAF*P

1) According to Eisenmann DAF become:

Our track condition is very good➔ **φ=0.1**

For application of rail stress➔t=3

AALRT design speed➔70km/h

DAF= 1 + tφ (1 + $\frac{V-60}{140}$)

DAF=1 + 3* 0.1 (1 + $\frac{70-60}{140}$)

DAF=1.32

P^d = DAF*P

P^d =1.32*55kN

P^d =72.6kN

2) According to AREMA -2010, Maximum stresses in track occur under dynamic loading. the dynamite amplification factor for taking into consideration dynamic effect is given by:

$$\theta = \frac{33V}{100D} \quad \text{.......... 3.7}$$

Where: V=dominant train speed (mph)

D=diameter of wheel load (inch)

Dynamic load Amplification Factor:

$\theta = \frac{33V}{100D}$, Where:

V=70 Km/hr =43.5mph (source: AALRT)

D=840 mm = 33.071 inch (source: Chinese manufacturer manual)

$\theta = \frac{33*43.5}{100*33.071}$ =0.434

The design load will be:

P^d= (1+ θ) P= (1+0.434)*55KN

P^d==78.87KN

Therefore P^d =78.87 KN (AREMA) > P^d =72.6 kN (Eisenmann). Hence for our analysis we take the maximum design load that is P^d =78.87 KN (AREMA)

3.2.4. Maximum rail bending moment

For one wheel load, the maximum rail bending moment, M_{max}, take place at the wheel and it is provided by the following equation. $M_{max}= \frac{P^d}{4K}$, from china standard for 50kg/m rail section the modulus of elasticity and the moment of inertia from table 3.2: become E= 207Gpa and I=2037cm^4 And From the classic ballast track we can use the stiffnes of ballast and fastneening, than we can calculate the track modulus (u)

Table 3.4: Classic ballast track stiffnes and dumping

Track component	Stiffiness	Damping
UIC-50kg/m		
Rail pads(per rail)	100E3kN/m	15kNs/m
Sleeper per rail (for concret sleeper)	Infinity	
Ballast bad (distributed per rail)	27E3kN/m (per sleeper)	12.3kns/m

Sleeper spacing from sample model that taken is 0.6m

u=D/a……………………………………..…………………………………..3.8

$\frac{1}{D} = \frac{1}{Df} + \frac{1}{Ds} + \frac{1}{Db}$……………………..……………………………………………..3.9

Where:

Df=100kN/mm=100e6N/m

concrete sleeper, Ds=∞

Db=27 kN/mm=27e6N/m

$$\frac{1}{D} = \frac{1}{100e6N/m} + \frac{1}{\infty} + \frac{1}{27e6N/m}$$

D=21.27 e6N/m

u=D/a,

u=21.27 e6N/m /0.6m

u=35.45 e6N/m^2

Stiffness ratio coefficient (K) $=\sqrt[4]{\mu/4EI}$..3.10

$$(K)=\sqrt[4]{\frac{35.45e6\frac{N}{m2}}{4*\frac{207e9N}{m2}*2.037e-5m-4}}$$

K=1.2 m^{-1}

Thus the maximum moment will be: $M_{max}=\frac{p^d}{4K}$

$$M_{max}=\frac{78.87kN}{4*1.2\ m-1}$$

M_{max}=16.43 kNm

Table 3.5: Distribution of deflection, bending moment and rail supporting force through 21 sleepers

N	x[m]	|x|	kx	η(kx)	μ(kx)	y(x)[m]	M[Nm]	R[N]
-10	-6	6	7.22	0.00102	-0.00016	1.37E-06	-2.61E+00	2.90E+01
-9	-5.4	5.4	6.50	0.00179	0.00114	2.40E-06	1.87E+01	5.10E+01
-8	-4.8	4.8	5.78	0.00121	0.00420	1.63E-06	6.88E+01	3.45E+01
-7	-4.2	4.2	5.06	-0.00385	0.00814	-5.15E-06	1.33E+02	-1.10E+02
-6	-3.6	3.6		-0.01703	0.00734	-2.28E-05	1.20E+02	-4.85E+02

			4.33					
-5	-3	3	3.61	-0.03631	-0.01184	-4.86E-05	-1.94E+02	-1.03E+03
-4	-2.4	2.4	2.89	-0.03997	-0.06773	-5.36E-05	-1.11E+03	-1.14E+03
-3	-1.8	1.8	2.17	0.03045	-0.15906	4.08E-05	-2.61E+03	8.67E+02
-2	-1.2	1.2	1.44	0.26360	-0.20429	3.53E-04	-3.35E+03	7.51E+03
-1	-0.6	0.6	0.72	0.68539	0.04327	9.18E-04	7.09E+02	1.95E+04
0	**0**	**0**	**-**	**1.00000**	**1.00000**	**1.34E-03**	**1.64E+04**	**2.85E+04**
1	0.6	0.6	0.72	0.68539	0.04327	9.18E-04	7.09E+02	1.95E+04
2	1.2	1.2	1.44	0.26360	-0.20429	3.53E-04	-3.35E+03	7.51E+03
3	1.8	1.8	2.17	0.03045	-0.15906	4.08E-05	-2.61E+03	8.67E+02
4	2.4	2.4	2.89	-0.03997	-0.06773	-5.36E-05	-1.11E+03	-1.14E+03
5	3	3	3.61	-0.03631	-0.01184	-4.86E-05	-1.94E+02	-1.03E+03
6	3.6	3.6	4.33	-0.01703	0.00734	-2.28E-05	1.20E+02	-4.85E+02
7	4.2	4.2	5.06	-0.00385	0.00814	-5.15E-06	1.33E+02	-1.10E+02
8	4.8	4.8	5.78	0.00121	0.00420	1.63E-06	6.88E+01	3.45E+01
9	5.4	5.4	6.50	0.00179	0.00114	2.40E-06	1.87E+01	5.10E+01
10	6	6	7.22	0.00102	-0.00016	1.37E-06	-2.61E+00	2.90E+01

Where:

N-number of sleeper

X-distance from the centre of load to the needed sleeper number

Therefore From the above table and from the figure 3.4: below, we can use the maximum value of moment for stress verification :(which is at X=0)

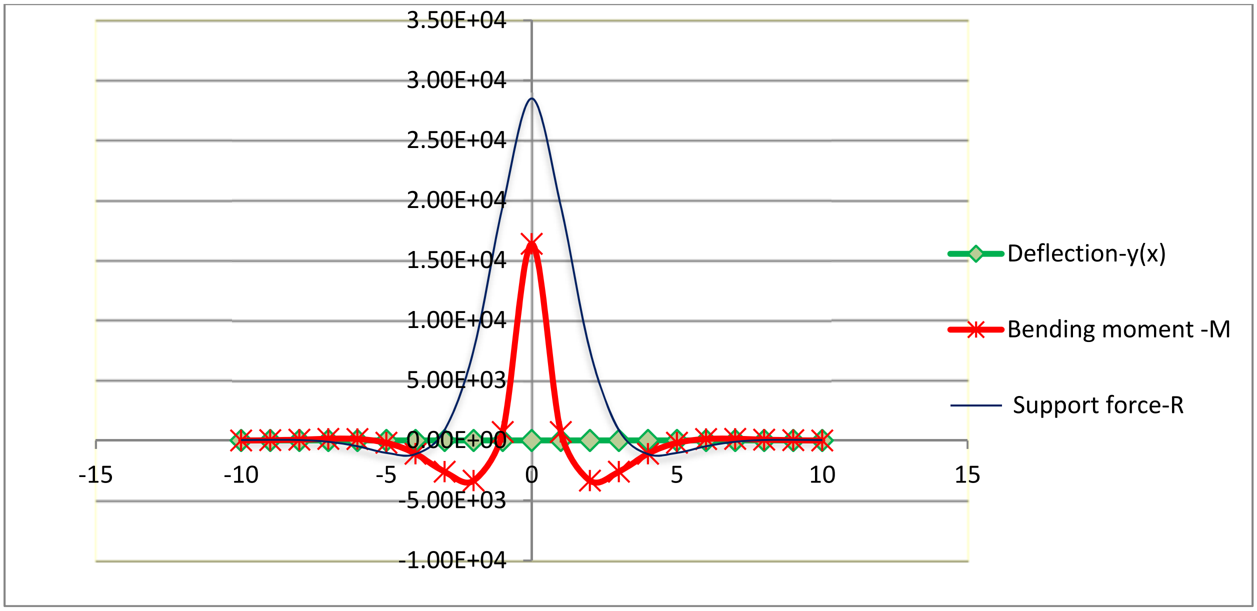


Figure 3.4: Distribution graph of, deflection, bending moment and rail supporting force

1. The maximum rail bending moment= 16.43 kNm
2. The maximum rail deflection= 0.00134m=1.34 mm and
3. The maximum rail support force =28.5 KN

3.2.5. Maximum dynamic bending stress

For design purposes, the maximum dynamic bending stress in the rail is:

$$\sigma_{max} = \frac{M^d_{max} * c}{I} = \frac{M^d_{max}}{Z_b} \quad \text{..........} 3.11$$

Where:

σ_{max} =The maximum stress on the rail

M^d_{max} = The maximum design moment.

C= Distance from neutral axis to rail base.

Z_b= section modulus for rail base (found from trial section of rail).

Z_b=287.2cm^3.............. (From table 3.2 :)
Z_b=2.872E-4m^3

$$\sigma_{max} = \frac{16.43 \text{ kNm}}{2.872\text{E}-4\text{m3}} = 57.207\text{MPa}$$

3.2.6. Verification of rail section

To verify the rail section (50kg/m), according to bending stress, the listed allowable stresses are mandatory. Therefore by using this stress we can verify our rail section:

Allowable bending stress typically:-

- 32,000 psi for jointed rail
- 25,000 psi for continuously welded rail (CWR)

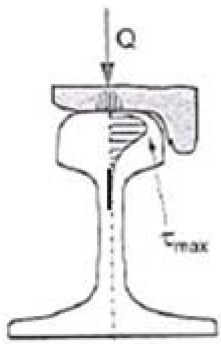
To convert this allowable bending stress to metric unit N/m^2 multiply by 7,030.696N/m2 (conversion factor) Than the allowable bending stress become;

- ✓ 221,982,272N/m2=222MPa for jointed rail
- ✓ 175,767,400N/m2=176MPa for continuously welded rail (CWR)

Therefore the verification of the rail section according to bending stress 57.207 MPa < 222MPa……………………………… ok! This means the calculated maximum design stress is less than the allowable stress (222Mpa), hence the preliminary rail section is enough!

3.2.7. Ultimate tensile strength of rail

The concentrated load between wheel and rail causes a shear stress distribution in the rail head at some depth a maximum which may give rise to fatigue fracture in the rail head (Esveld , 2001). The contact problem is most serious in the case of high wheel loads or relatively small wheel diameters. According to the Hertz theory, the contact area between two curved elastic bodies such as wheel and rail head is generally ellipsoidal and the contact stress distribution is semi ellipsoidal.



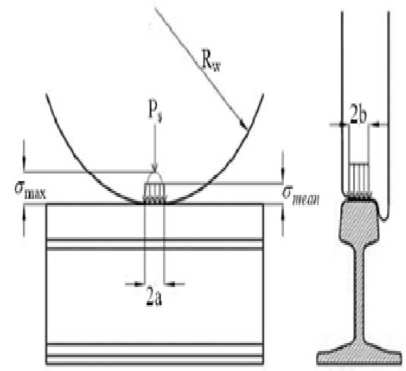


Figure 3.5: Shear stress distribution in the rail head

Figure 3.6: Assumed contact pressure distribution between wheel and rail According to Eisenmenn

3.2.7.1. Ultimate tensile strength of rail steel against allowable stress

The average or mean contact stress on the rail head is given by,

$$\sigma_{mean} = 1374\sqrt{\frac{Q}{r}} \quad \text{.......................................} 3.12$$

Where: σ_{mean} = the mean contact pressure (N/mm^2)

Q= Effective wheel load (KN) and

Q=55 KN

r = wheel radius (mm).

r =840mm/2=420mm

$$\sigma_{mean} = 1374\sqrt{\frac{Q}{r}}$$

$$\sigma_{mean} = 1374\sqrt{\frac{55\text{ KN}}{420\text{mm}}}$$

σ_{mean} =497.21 MPa

According Eisenmann, he proposed that, the limit value for allowable contact stress as a percentage of the ultimate tensile strength of rail steel, by considering required fatigue strength for rail steel. Based on this assumption, he suggests:

$$\boldsymbol{\sigma_{all} = 0.5\sigma_{ult}}$$

Therefore, at limiting condition,

$$\boldsymbol{\sigma_{mean} \leq \sigma_{all} = 0.5\sigma_{ult})} \textbf{ then}$$

$$\boldsymbol{\sigma_{ult} \geq 1.97\ \sigma_{mean}}$$

$$\sigma_{ult} \geq 1.97*497.21 \text{ MPa}$$

$$\sigma_{ult} \geq 979.5 \text{ MPa}$$

1) According to china standards (GB),

Thus, the numerical result shows that the tensile strength of the rail should be at least 979.5MPa to fulfil the requirement of wheel contacts stress. According to china standard from table 3.6: mechanical property of rail, for ultimate tensile strength of 979.5 MPA it become one of the two steel grade U75V and U76NbRE for our case we can use U75V steel grade and for this steel grad the chemical composition is shown in table 3.7:

Table 3.6: Mechanical properties of rail

Steel grade	Mechanical properties	
	Tensile strength R_m, N/mm^2 （min.）	Elongation A % （min.）
U74	780	10
U71Mn	880	9
U70MnSi		
U71MnSiCu		
U75V	980	9
U76NbRE		
U70Mn	880	
When the test pieces is taken from hot saw sample rails, the results of A can smaller 1% (absolute value) than the given value.		

Table 3.7: Steel grade and chemical composition GB

Steel grades	Chemical composition %							
	C	Si	Mn	S	P	V[a]	Nb[a]	RE
U74	0.68~0.79	0.13~0.28	0.70~1.00	≤0.030	≤0.030	≤0.030	≤0.010	—
U71Mn	0.65~0.76	0.15~0.35	1.10~1.40	≤0.030	≤0.030			—
U70MnSi	0.66~0.74	0.85~1.15	0.85~1.15	≤0.030	≤0.030			—
U71MnSiCu	0.64~0.76	0.70~1.10	0.80~1.20	≤0.030	≤0.030			—
U75V	0.71~0.80	0.50~0.80	0.70~1.05	≤0.030	≤0.030	0.04~0.12		—
U76NbRE	0.72~0.80	0.60~0.90	1.00~1.30	≤0.030	≤0.030	≤0.030	0.02~0.05	0.02~0.05
U70Mn	0.61~0.79	0.10~0.50	0.85~1.25	≤0.030	≤0.030		≤0.010	—
[a] Except V in U75V and Nb in U76NbRe are additional elements , Nb and V are residual elements in other steel grades.								

2) According to international union of railway (UIC)

For the ultimate tensile strength which is greater than or equal 979.5MPa, from table 3.8 you can select the grater steel grade, to become more safer but, as we can see from the table, 979.5MPa is greater than the first row of tensile strength that is between 680-830 so that we are forced to use steel grade R900A with C (0.6-0.8), Mn (0.8-1.3) and Si (0.1-0.5) in row two. (This makes as, safer)

Table 3.8: Chemical composition and tensile properties of a rail steel according to UIC

Grade of steel *	Chemical composition, elements in % of mass				Tensile strength, f_{yk} (N / m m ²)	Yield Strength, f_{yd} (N / m m ²)
	C	Mn	Si	Cr		
R700	0.4 - 0.6	0.8 - 1.25	0.05 - 0.35	-	680 - 830	380 - 460
R900A	0.6 - 0.8	0.8 - 1.3	0.1 - 0.5	-	880 - 1030	480 - 510
R900B	0.55 - 0.75	1.3 - 1.7	0.1 - 0.5	-	880 - 1030	480 - 510
R1100**	0.6 - 0.82	0.8 - 1.3	0.3 - 0.9	0.8 - 1.3	≥ 1080	≥ 650

3.2.7.2. Ultimate tensile strength against maximum shear

The maximum shear stress on the rail head is given by:

$\tau_{max} = 412\sqrt{\frac{Q}{r}} \cong 0.3\sigma_{mean}$, where: - Q (in KN), r (in mm) and τ_{max} in N/mm^2.

Therefore $\tau_{max} = 412\sqrt{\frac{55\,KN}{420mm}}$

τ_{max}= 149 N/mm^2=149 MPa

The allowable shear stress on the rail, taking account of the fatigue nature of the load, is given by $\tau_{all} \cong 0.3\sigma_t$, where σ_t is the ultimate tensile strength of the rail.

$\tau_{all} \cong 0.3\sigma_t$

$\tau_{all} = (0.3 * 979.5\text{MPa})$

τ_{all} = 293.85Mpa

Hence τ_{max}= 149 MPa $\leq$ τ_{all} = 293.85Mpa Therefore, the selected rail property satisfies the requirement to resist the maximum shear stress on the rail head.

3.2.8. Check for serviceability

AREMA has proposed a limiting range for the magnitudes of vertical rail deflections. According to this recommendation, extreme vertical rail deflections should be kept within the range of 3.175 to 6.35 millimetres. Lundgren and his colleagues has incorporated this recommendation and proposed the diagram presented in figure 3.7: as the limit values of vertical rail deflection. This diagram is based upon the capability of the track to carry out its design task. [12]

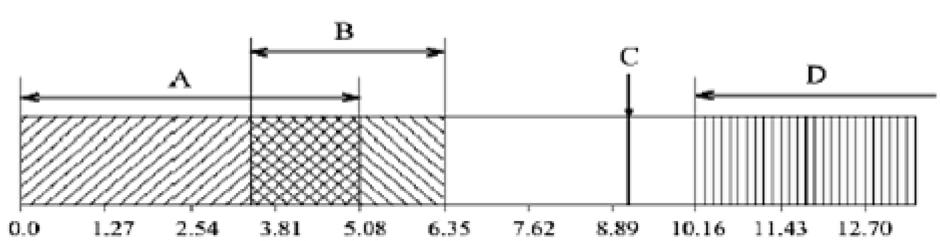


Figure 3.7: Vertical track deflection range

Domains indicated in figure 3.7: are described as follows:

- ✓ A: Deflection range for track which will last indefinitely.
- ✓ B: Normal maximum desirable deflection for heavy track to give requisite combination of Flexibility and stiffness.
- ✓ C: Limit of desirable deflection for track of light construction (with rails weigh < 50 kg/m)
- ✓ D: Weak or poorly maintained track which will deteriorate quickly.

It should also be noted that values of deflection in fig.3.7 do not include any looseness or play between rail and pad or pad and sleeper. In addition, these values represent deflections directly under the wheel load. According to AREM, the present design rail section track can be categorized under domain-A, which has between the ranges of 0.00mm up to 3.00 mm.

$$y_{max} = \frac{\text{Pd}K}{2u}$$

$$y_{max} = \frac{78.87\ \text{KN} * \frac{1.2}{m}}{2 * \frac{35490kN}{m2}}$$

$$y_{max} = \underline{\underline{1.34\ \ \text{mm}}}$$ (see in table 3.5:above)

Therefore the calculated maximum deflection y_{max} = 1.34 mm< 6.35 mm (AREMA max. Deflection)..ok! Hence, the given track stiffness and rail section is adequate for the design maximum load

3.3. EXISTING RAILWAY SWITCH DESIGN

3.3.1. Design parameter of existing railway switch

In this paper, for design of the present railway switch, we use maximum deflection and maximum Moment parameters, these parameters here determined by using AALRT data and by making the cross-section of the switch (shown in figure 3.8: below) from irregular shape to determined and simplified regular shape, for the purpose of second moment of inertia calculation otherwise it is very difficult to know the centroids of the irregular cross-section switch, for this mater, take almost equivalent simple cross-section geometry.[9,18,31, 32,]

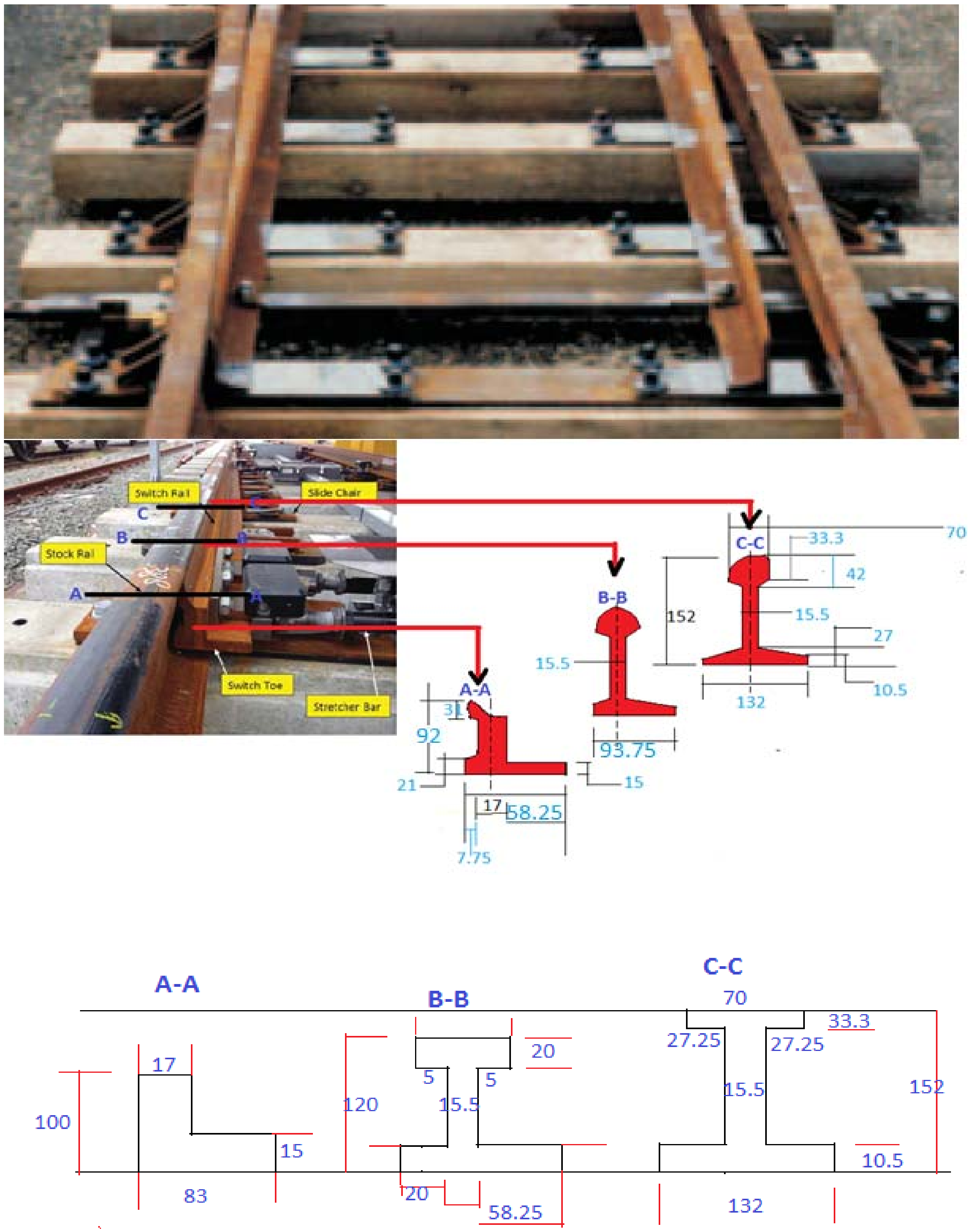


Figure 3.8: Different cross section of switch blade within three sleepers

From A.A.L.R.T data

- ✓ The amplified wheel dynamic load from the given value of design load (i.e. 55KN wheel load , source: ERC) become P^d=78.87 KN
- ✓ The rail fundation stiffnes = u=35.45 e6N/m2 (calculated value) this taken From classic ballasted track support stiffness and sleeper spacing (i.e. Rail pads 100E3kN/m ,Ballast bad 27E3kN/m and concrete sleeper infinity) [27]
- ✓ for 50kg/m rail section the modulus of elasticity from table 3.2: become E= 207Gpa

The second moment of inertia calculated using simple switch cross-section geometry

- The centroids of the composite geometry for section AA-CC

Table 3.9: Centroids of composite switch geometry for section AA-CC

- ➢ A-A

Part	A(mm2)	x(mm)	y(mm)	xA(mm3)	yA(mm)
A	1,245.00	41.50	7.50	51,667.50	9,337.50
B	1,445.00	8.50	57.50	12,282.50	83,087.50
Total	2,690.00			63,950.00	92,425.00
X	23.7732342				
Y	34.35873606				

- ➢ B-B

Part	A(mm2)	x(mm)	y(mm)	xA(mm3)	yA(mm)
A	510.00	27.75	110.00	14,152.50	56,100.00
B	1,387.25	27.75	55.25	38,496.19	76,645.56
C	984.38	46.88	5.25	46,142.58	5,167.97
Total	2,881.63			98,791.27	137,913.53
X	34.28317898				
Y	47.85963866				

➢ C-C

Part	A(mm2)	x(mm)	y(mm)	xA(mm3)	yA(mm)
A	2,331.00	66.00	135.35	153,846.00	315,500.85
B	1,677.10	66.00	64.60	110,688.60	108,340.66
C	1,386.00	66.00	5.25	91,476.00	7,276.50
Total	5,394.10			356,010.60	431,118.01
X	66				
Y	79.92399288				

- The Moment of inertia of the composite geometry I= $\sum$ I(centroidal) + $\sum A\, d2$ tabulated shown below [30]

Table 3.10: Moment of inertia for section AA-CC

a) A-A

part	area	Ix(centroidal)	Iy(centroidal)	dx2	dy2	Ix	Iy
A	1,245.00	23,343.75	714,733.75	721.39	314.24	921,476.42	1,105,960.3
B	1,445.00	870,010.42	34,800.42	535.52	233.27	1,643,834.07	371,878.00
IX	2,565,310.49	2.57E-06					
IY	1,477,838.34	1.48E-06					

b) B-B

part	area	Ix(centroidal)	Iy(centroidal)	dx2	dy2	Ix	Iy
A	510.00	17,000.00	27,635.63	3,861.42	42.68	1,986,326.50	49,403.66
B	1,387.25	926,018.28	27,773.90	54.62	133.01	1,001,786.32	212,297.87
C							

	984.38	9,043.95	720,977.78	27.56	158.55	36,175.78	877,054.33
IX	3,024,288.60	3.02E-06					
IY	1,138,755.87	1.14E-06					

c) C-C

part	area	Ix(centroidal)	Iy(centroidal)	dx2	dy2	Ix	Iy
A	2,331.00	215,401.88	951,825.00	3,072.04	0.00	7,376,332.40	951,825.00
B	1,677.10	1,636,184.35	33,576.94	234.82	0.00	2,030,008.95	33,576.94
C	1,386.00	12,733.88	2,012,472.00	5,576.21	0.00	7,741,354.30	2,012,472.0
IX	17,147,695.65	1.71E-05					
IY	2,997,873.94	3.00E-06					

- Stiffness ratio coefficient K $=\sqrt[4]{\mu/4EI}$
- Maximum deflection of railway switch become

$y(x)_{max} = \frac{P}{2Lu} = \frac{Pk}{2u}$

- Maximum Moment of railway switch

$M\ (x)_{max} = \frac{P}{4K}$`

- Maximum bending stress of railway switch

$$\sigma_{max} = \frac{\text{M (x)max } * c}{I} = \frac{\text{M (x)max}}{Z_b}$$

Table 3.11: Maximum deflection, maximum moment and maximum bending stress for section AA-CC

IX-A-C	I	P	U	E	K	Y(x)max [mm]	M(x)max [KNm]	Zb [m3]	σmax [Mpa]
A-A	2.57E-06	78870	3.55E+07	2E+11	2.021	2.248	9.755293898	7.08E-05	137.826
B-B	3.02E-06	78870	3.55E+07	2E+11	1.94	2.158	10.16508892	1.46E-04	69.468
C-C	1.71E-05	78870	3.55E+07	2E+11	1.257	1.398	15.68580514	3.44E-04	45.603

- Maximum shear on existing switch become:-

$\tau_{max} = 412\sqrt{\frac{Q}{r}}$ Where: - Q=55 KN, r=420.

$$= 412\sqrt{\frac{125KN}{420mm}}$$

τ_{max}= 149.09 MPa.

3.4. ISW ANSYS SOFTWARE RESULT OUTPUT

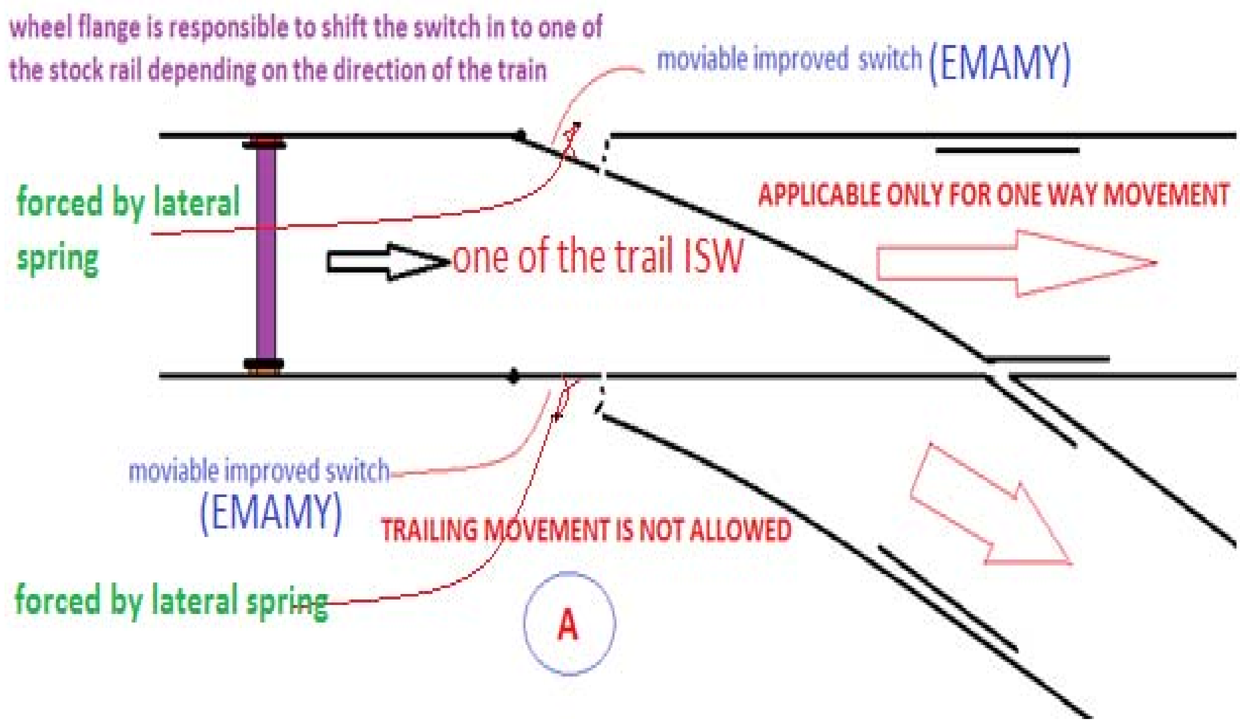
Table 3.12: ANSYS result of ISW

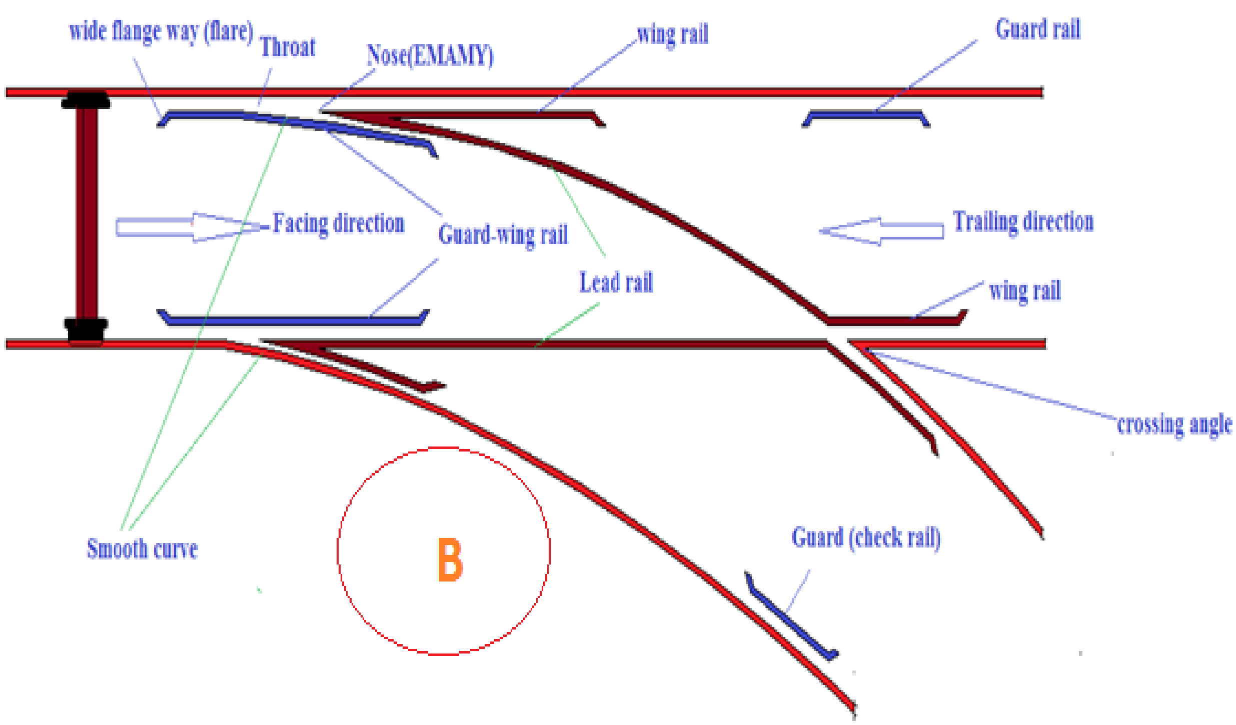
ANSYS Result Output (The Detail Is In The Appendix B :)				
No	**3D track Model**	**Maximum deflection [mm]**	**Maximum equivalent stress [MPa]**	**Maximum shear [MPa]**
For straight lock rail used	ISW	0.12097	3.2136	1.6802
For curved lock rail used	ISW	0.12306	4.0578	2.0779

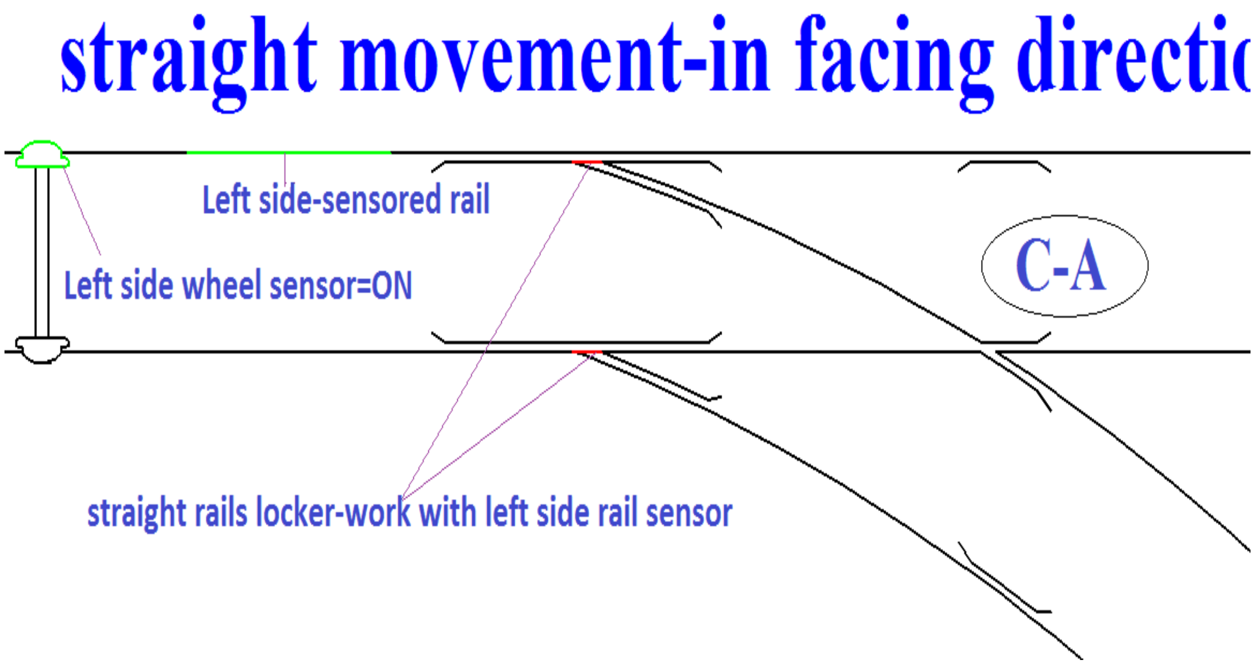
4. GEOMETRICAL DESIGN OF IMPROVED RAILWAY SWITCH

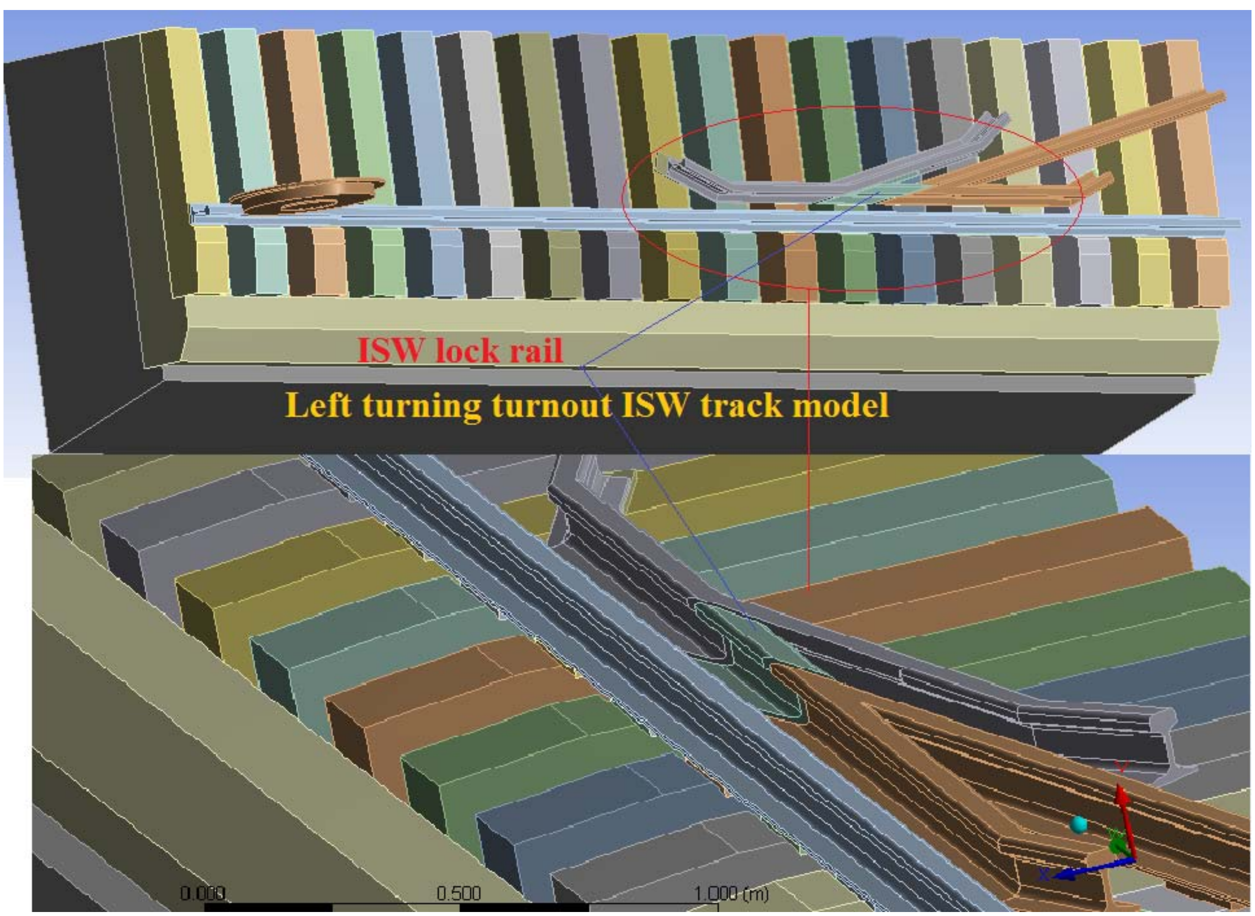
4.1. BACKGROUND OF ISW (IMPROVED SWITCH) GEOMETRY

After many trail of geometrical change of switch including the existing one (see in figure 4.1-A, 4.1-B and 4.1-C) we come up such type of improved geometry of switch shown in figure 4.1-C: below, so this geometry of improved switch is an arrangement of special track structure which connects different routes, either parallel or diverging routes to facilitate the movement of train from one track to another track. on this way, first the train passé the ISW and negotiate the crossing in the facing direction, in this case, the first pint of change direction is at the ISW point but the actual change of direction is on crossing (throat and around nose part), and when the train coming on the trailing direction, the vehicle first pass the crossing and negotiate the ISW, hear what we understand is that, vehicle first negotiate the crossing so this one is the first point of change direction of vehicle and the vehicle negotiate the ISW, this indicate that, for trailing direction switch point is the actual change of direction. The existing whole switching parts including the switch machine are replaced by the new ISW structure shown in figure 4.1: below, as shown in the figure, both pair of ISW track not move any side of the stock rail in both facing direction and trailing direction but, there are two types of rail lockers, which are work with sensed rails, as a result of this, if the vehicle want to move in the straight track, the deriver should be first press the left side wheel sensor than, after same time interval, the sensed left side wheel and left side sensed rail connect each other, as a result of this connection, the straight rail locker, raise and become level with the straight rail track shown in figure: 4.1: C-A, this allow straight forward movement and lock's the curved movement. Therefore, the same is true for the rest directions shown in figure: group-C below. This consist of mainly; a pair of wide flange way entrance (flare), a pair of guard-wing rails , a pair of locker rails, pair of throat, a pair of nose (EMAMY), a pair of stock rails, a pair of lead rails, bolt and fishplate.


wheel flange is responsible to shift the switch in to one of the stock rail depending on the direction of the train
moviable improved switch (EMAMY)
forced by lateral spring
one of the trail ISW
APPLICABLE ONLY FOR ONE WAY MOVEMENT
moviable improved switch (EMAMY)
TRAILING MOVEMENT IS NOT ALLOWED
forced by lateral spring
A


wide flange way (flare)
Throat
Nose(EMAMY)
wing rail
Guard rail
Facing direction
Guard-wing rail
Trailing direction
Lead rail
wing rail
crossing angle
Smooth curve
B
Guard (check rail)


straight movement-in facing directi
Left side-sensored rail
Left side wheel sensor=ON
C-A
straight rails locker-work with left side rail sensor


ISW lock rail
Left turning turnout ISW track model
0.000
0.500
1.000 (m)

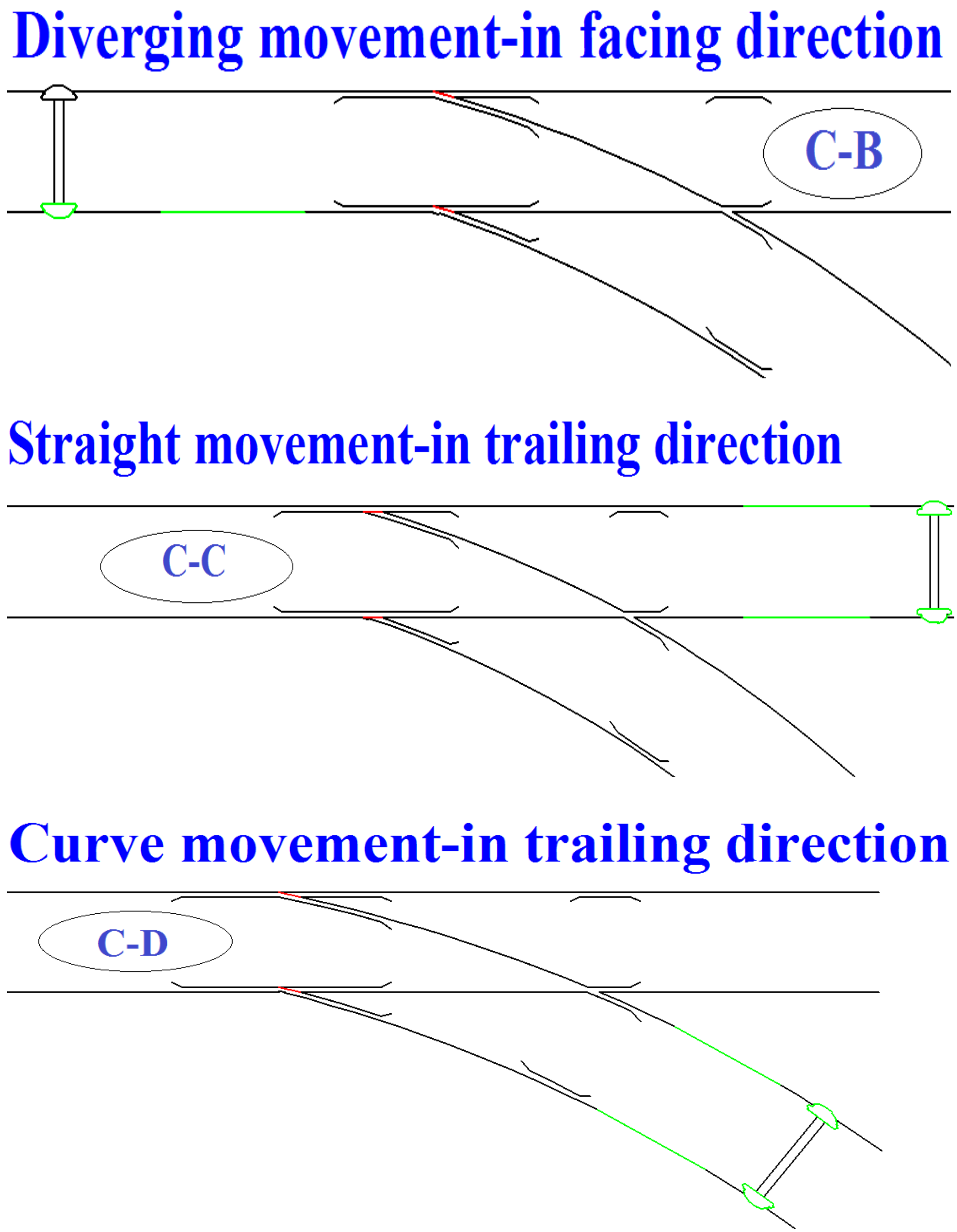


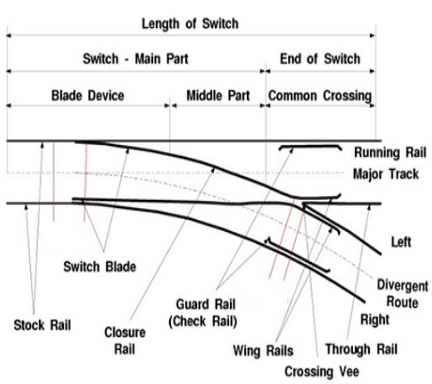
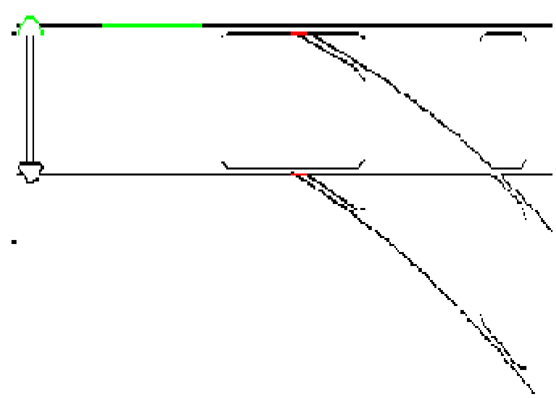
Figure 4.1: Right turning, improved railway switch turnout

4.2. THE BASIC DIFFERENCE BETWEEN THE EXISTING RAILWAY SWITCH AND THE IMPROVED ONE

The main difference between the existing railway switch and the improved switch one is discuses below in table 4.1: in detail

Table 4.1: Basic differences between existing railways switch and improved switch

EXISTING RAILWAY SWITCH (NOW WE USED)	IMPROVED RAILWAY SWITCH
✓ Use a movable pair of switch (tongue rail)for couching the vehicle wheel	✓ Use fixed switch rail but, there are two types of locker rails, for guarding vehicle wheel for proper position.
✓ For the purpose of moving the switch forth and back uses the listed materials: switch machine, stretcher bar , Heel blocks or distance blocks , gauge tie plate ,Sliding plate ,Point rod …….so on	✓ No need of movable tongue rail used and it's supportive material used to facilitate the movement are: Nose(EMAMY), guard-wing rail, locker rail, gauge tie- plate ,heel block ,bolt, nut and fishplate
✓ Use mechanical system(due to moving tongue rail) the analysis is done dynamically	✓ Use static structure (use fixed structure) and mechanical locker rails due to this, the analysis include the dynamic load because of the nature loading (i.e. moving wheel load) and presence of locker rail
✓ Guide the vehicle wheel by moving to either direction of the stock rail: if the tongue rail connects to the left stock rail, the left vehicle wheel will be guided and changed its direction to the right. the reverse is true for the right one	✓ The structural system are designed according to the flange way clearance ,that keeps the fixed passing flange distance so, this makes the wheel flange move on either direction depending on the driver interest

✓ The mechanical structural system working with the combination of materials that are list in the above and if, from this, one of the materials damaged, the whole system is stopped.	✓ The structural system of improved railway switch is work by the help of different sensors which are assembled in vehicle wheel and track rails.
✓ The frog (nose) used in the crossing part and the two side of the frog design for loading.	✓ But in this case, switch nose (EMAMY) used in switching part, design as, one of the side only for loading and the other side act as wing rail.
✓ Each components of the crossing has a single function. for example guard(check) rail –only guarding	✓ Guard-wing rail --has multi function, as like the name, continuously (guarding and facilitating the movement of wheel entering and leaving through ISW)
✓ Most of the time the switch rail manufacture in the industries, by pre casted form	✓ It is possible, to assemble the switch on site by using welding and grinder machine
✓ See the Model difference 	✓ 

4.3. IMPROVED SWITCH TRACK LAYOUT COMPATIBILITY WITH TRACK JUNCTION

Track junctions are formed by the combination of improved switch and crossings. Their main objective is to transfer rail vehicles from one track to another or to enable them to cross from one track to another smoothly. Depending upon the requirements of traffic, there are several types of track junctions with simple track layouts. The most commonly used layouts and their compatibility with improved switch are discussed in the following sections.

4.3.1. Symmetrical Split

When a straight track splits up in two different directions with equal radii, the layout is known as a symmetrical split (Fig. 4.2). In other words, a symmetrical split is a similar flexure in which the radii of the two curves are the same. The significant features of a symmetrical split are the following.

- ✓ The layout consists of a pair of improved points, one acute angle crossing, four curved lead rails, two check rails and two different locker rails and two guard-wing rail
- ✓ The layout is symmetrical about the centre line. This means that the radii of the main track as well as of the branching track are equal.
- ✓ The layout provides facilities for diverting vehicles both towards the left and the right.
- ✓ It is suitable for locations with space constraints, as it occupies comparatively much less space than a turnout from the straight track.

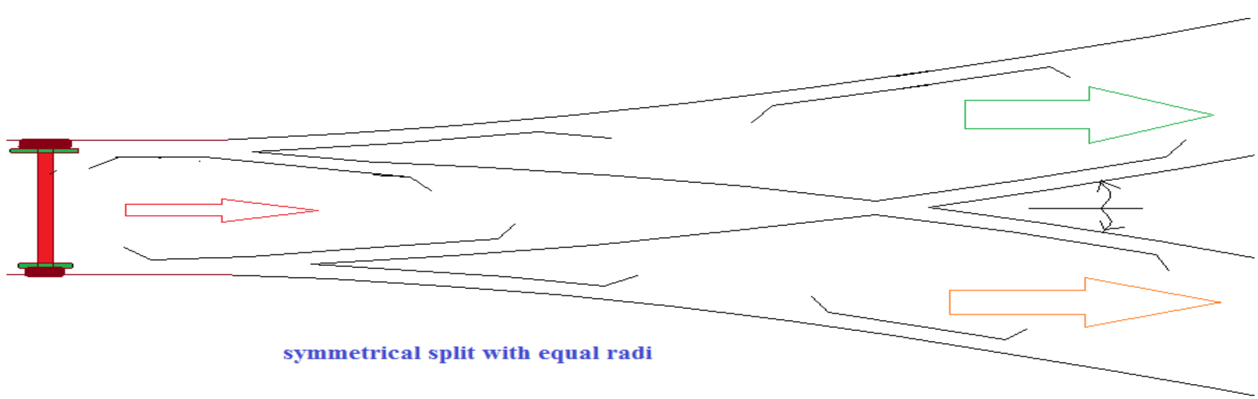


Figure 4.2: Symmetrical spilt improved switch

4.3.2. Three-throw improved Switch

In a three-throw arrangement, two turnouts take off from the same point of a main line track. A three-throw switch can have similar flexure, as shown in Figs 4.3: respectively. Three-throw switches are used in congested yards and at entry points to locomotive yards, where there is a great limitation of space. A three-throw switch has two improved switches and each switch has two nose rails placed side by side. The switches can be operated in such a way that, a vehicle at a time has two options, to the right and straight forward, then next straight and to the left; generally the movement is possible in three different directions by the help of four different types of sensed locker rails and four guard-wing rails i.e., straight, to the right, and to the left

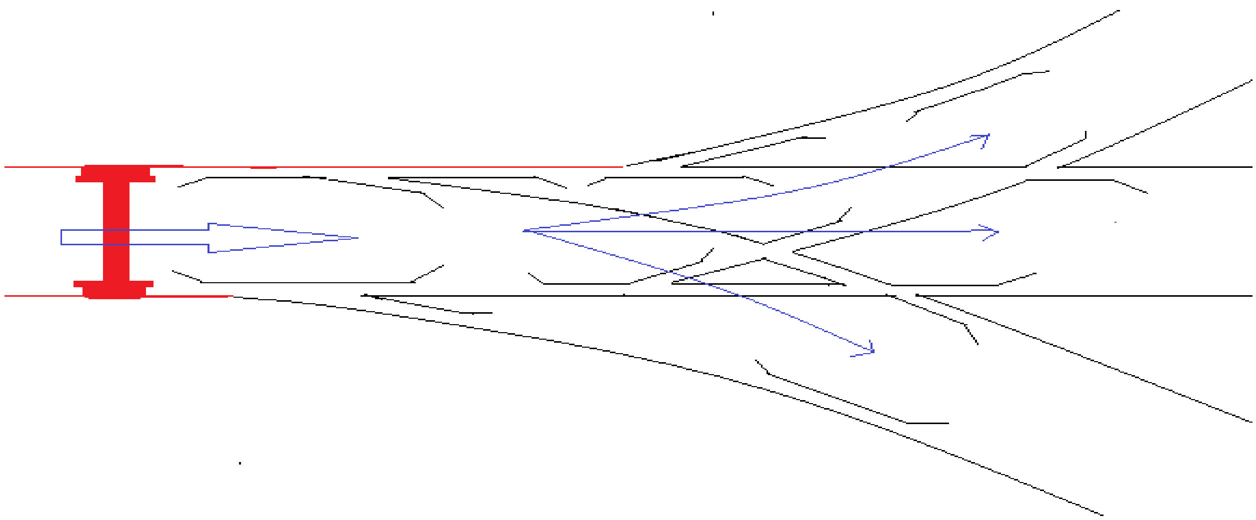


Figure 4.3: Three-throw improved Switch

4.3.3. Double Turnout

A double turnout or tandem is an improvement over a three-throw switch. In a double turnout, turnouts are taken off from the main line at two different places. The distance between the two sets of longitudinal improved switch should be adequate to allow or flexible movement of vehicle. Double turnouts can be of similar flexure, when the two turnouts take off on the same side of track (Fig 4.4 :), Double turnouts are mostly used in congested areas, particularly where traffic is heavy, so as to economize on space.

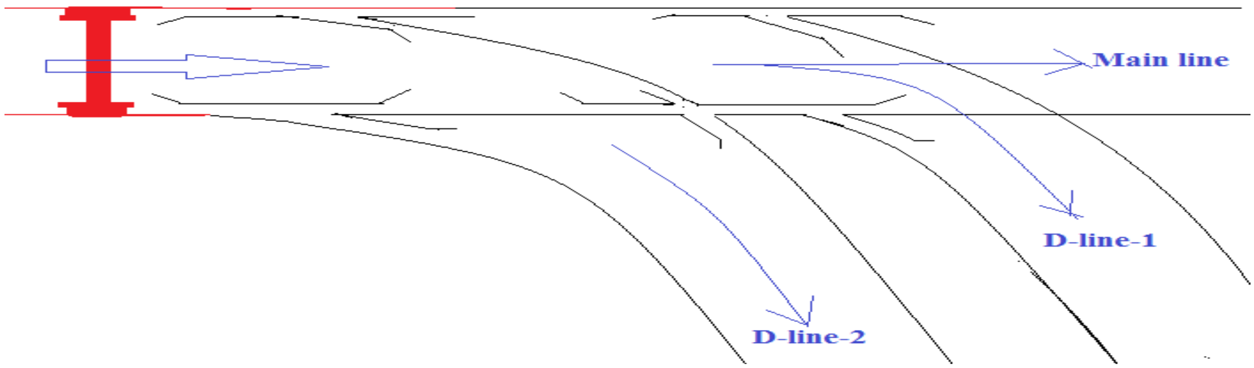


Figure 4.4: Double Turnout

4.3.4. Scissor Cross-over or double cross-over

It is a combination of one cross –over over another cross-over in the opposite direction, to enable the trains to change the track from either direction along the main track see in figure 4.5: below. The arrangement is useful where enough space for two separate cross-over is available or it is provided where lack of space does not permit and shunting operation are frequent. It consists of four pairs of improved switches, six acute crossings, two obtuse crossings, check rails and eight different sensed locker rails and eight guard-wing rails etc. This arrangement is very munch expensive in initial cost and more over requires careful maintenance

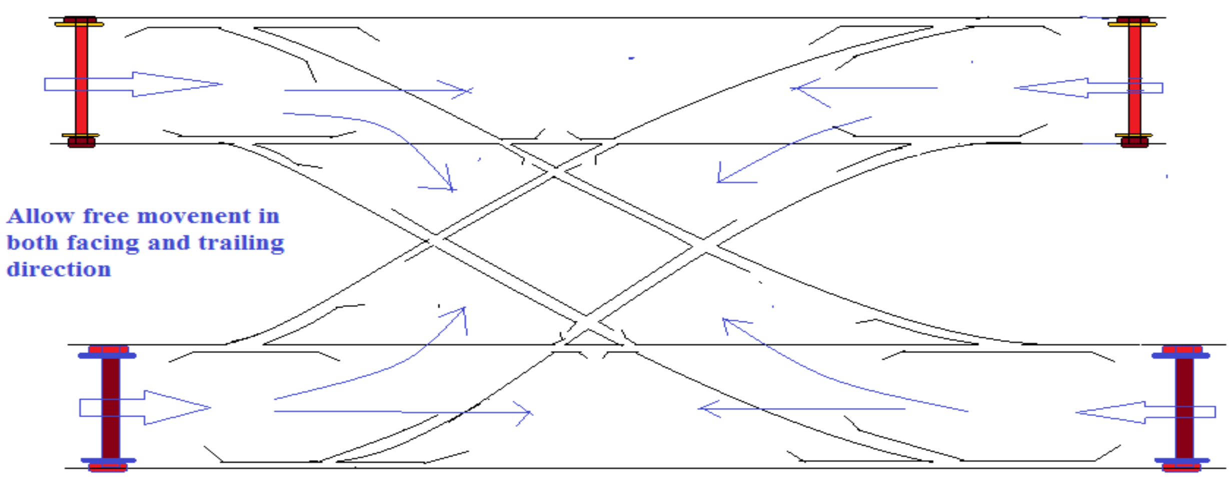


Figure 4.5: Scissor Cross-over or double cross-over

4.4. GENERAL VIEW OF DESIGN OF ISW

In general the design of improved railway switch includes two main switch design parts; these are the ISW and guard-wing rail. According to crossing the nose part is known as frog but in case of ISW call as EMAMY, the difference of the two is that, frog nose beer load on both side, but in the case of improved nose switch, one of the side part only loads , the other side use as like wing rail and the second one is guard or check-wing rail or in crossing we call also guard rail or check rail because the function is only guarding or keeping but in case of guard-wing or check-wing rail the function is multi, that means both guarding and makes the vehicle wheel enter and leave the track smoothly.

Therefore, in ISW there is no, new formula developed for geometrical design because it's geometry adopted from the crossing frog structure due to this it is possible to use the crossing formulas and ideas in the geometrical design of improved switches and guard–wing rail, but there is slight deference, this deference always is kept by restricting or by adding same point change.

One of the key designs out puts for a model of ISW is that, it provides a smooth curve set of rails along the diverging (reverse) route. This means reduce the angular discontinuities (kinks) a minimum by one rails, further, there is no angular discontinuities where the ISW rail meets the curved closure rail and where the curved closure rail meets the frog toe.

4.5. NUMBER AND ANGLE OF IMPROVED SWITCH

Angle of improved switch is an angle between the loading side of switch rail and the unloading side wing switch rail or splice switch rail. It is also known as angle of nose (EMAMY) switch divergence or angle between vee improved switch rails. For smooth entry and movement of trains, it is desirable to have a small improved switch angles on the track, which is going to be used for fast moving trains. The important point in number and angle of improved switch (ISW) is, theoretical and actual nose of improved switch (TNOISW and ANOISW) see in figure 4.12: below, the nose of ISW is never manufactured to a well defined sharp point as it would break off under the dynamic load of moving vehicle and it is not practical. Therefore, to fit the locker rail between ISW nose rail and guard-wing rail, to facilitate the movement for smooth entry and out and to make smooth, flat and continuous rail surface, blunt nose should be provided to become safe. This has increase strength of the ISW, punching resistance and makes stationary in place or fixed whenever applying any different load. The thickness of blunt nose according to IRS is usually equals to the thickness of the web of the rail, according to NMRA 1:2 inch and in U.S.A or according to AREA standard the thickness of blunt nose is kept 1.25 cm for all the section. In this case, the value used for thickness of nose is nearly similar in all standards, Therefore for our study, the thickness of the nose of ISW taken from AREA or NMRA standard almost similar thickness are used that means 1:2 in (1.25cm) The sharp imaginary point nose of ISW would meet is known as true or theoretical nose of ISW (TNOISW) and the blunt one is the actual (ANOISW). A ISW is designated either by the angle the inner faces of vee rails make with each other or, by the number of the ISW, represented by Ns. There are three methods of measuring the number of ISW, and the value of Ns also depends upon the method adopted. All these methods are illustrated below.

The number of ISW (NS) is defined as the ratio of $= \frac{\text{the spread at the vee of ISW}}{\text{The length of the ISW from TNOISW}}$

There are three methods of calculating the number of ISW and the value of “Ns” depends upon the method adapted.

4.5.1. Right angle or Cole’s method

In this method, Ns are measured along the base of a right-angled triangle; used in one of the right turning ISW or the left turning ISW. This method is used on Indian Railways according to crossing .see in figure 4.6: the right turning ISW below

From figure

$$\text{Tan } \boldsymbol{\beta} = \frac{1}{\text{Ns}}$$

$$\text{Ns} = \cot \boldsymbol{\beta} \quad \text{.......} 4.1$$

Where NS= number of ISW

$\boldsymbol{\beta}$ =angle of ISW

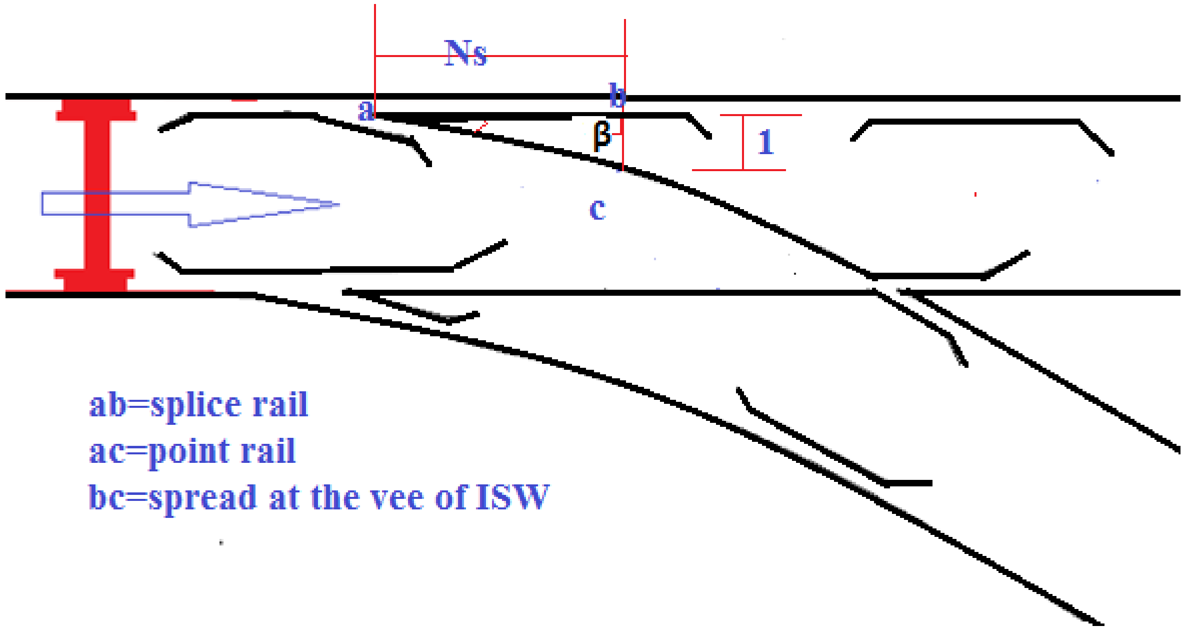


Figure 4.6: Right angle methods for numbering the ISW

4.5.2. Center line method

According to center line method Ns is measured along the centre line of the ISW or from the TNOISW to the spread at the vee of ISW. This method is used in Britain and the US in case of crossing. For this method take an example of symmetrical split track junction shown in figure 4.2:

From figure

$$\text{Tan}\,\frac{\beta}{2} = \frac{1/2}{Ns} = \frac{1}{2Ns}$$

Cot β/2=2 Ns (angle of ISW)

Ns=1/2 cot β/2 (number of ISW)……………………………4.2

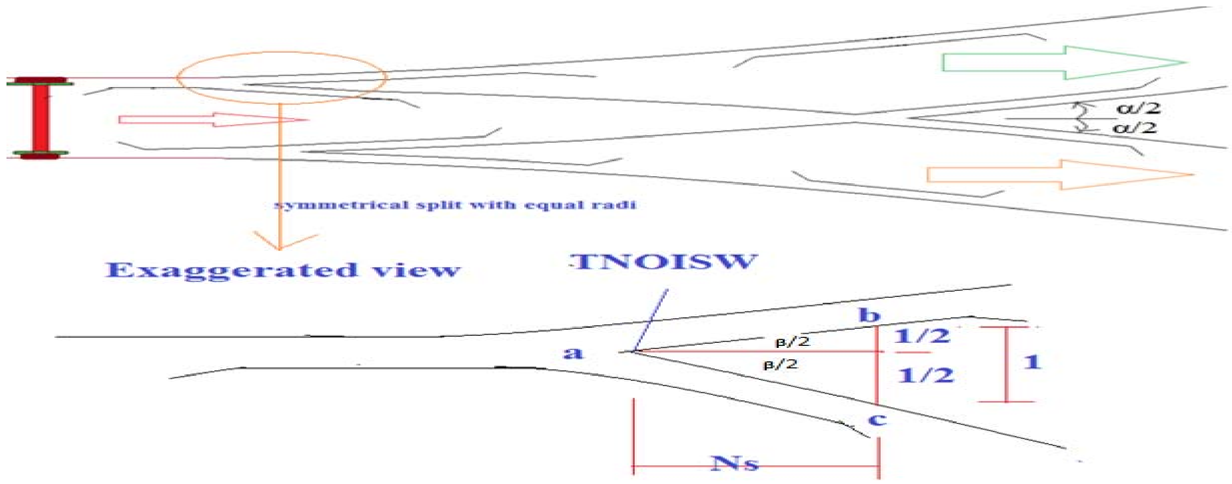


Figure 4.7: Center line method of numbering the ISW

4.5.3. Isosceles triangle method

In this method, the measurement of "Ns" is taken as one of the equal sides of an isosceles triangle.

From figure

Sin **β**/2 = ½ /Ns = 1/2Ns

Cosec **β**/2 = 2Ns

Ns = ½ Cosec **β**/2………………………………………………..4.3

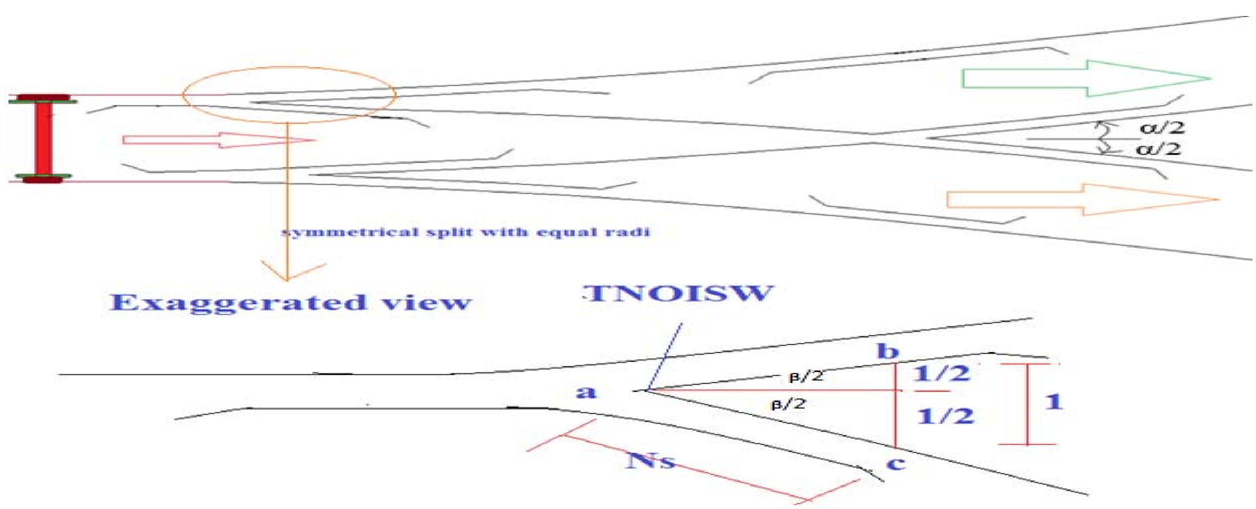


Figure 4.8: Isosceles triangle method of numbering the ISW

4.6. GEOMETRICAL DESIGN OF IMPROVED SWITCH

The geometrical design improved switch included in design of turnout (switch and crossing design), thetas why, because of they are connected each other by lead curve so, their main function is diverting train in different direction with respect to the main track, individually:-

A crossing or a frog is advice which provides two flange way through which the wheel of the flanges may move when the two rails intersect each other at an angle "α" the flanged wheels of the train jump over the gap from throat to nose of crossing and to check the wheel flanges from striking the nose, the opposite wheel flanges are guided by use of check rail inside the running rail and

An improved switch is also advice which provides one flange way through which the wheels of the flange are diverted from one route to another. It is the first point of turning or changing direction but not actual change. The actual change of direction is at the crossing.

Therefore the two main part of turnout, that is switch and crossing are not give function separately, in case of this, the geometrical design of improved switch include the crossing part for the design purpose, meaning for design ISW, whole turnout section should be considered hear.

4.6.1. IMPROVED SWITCH TURNOUT DESIGN

To do the sample of improved switch turnout design, it should be better fixing the value of heel divergence, because of including heel divergent the unknown variable become three (d, SL and CL) for this reason, it should be better developing one equation from the relation of crossing angle and switch angle by given value of heel divergent and to simplify this calculation it should be better following the excel template. Therefore from this relation of excl template, one of the unknown variables is identified from the three unknown variable, this manse that it simplifies the equations from indeterminate to determinate equation, which are two equations with two unknown's remains. After that it is possible to do such sample design turnout by only following the design procedures

4.6.1.1. Switch angle and crossing angle relation

Given data

- ✓ Cole's method -1 formula that is taken from the above literature reviews section.
- ✓ For standard gauge 1435 mm from china standard(G=1.435m)
- ✓ 50kg/m rail section
- ✓ Number of crossing calculated by right angle method (cole's method)
- ✓ d= tolerance for the wear + flange way clearance + rail head width (IRS standard)

  d=0.3cm+6.7cm+7cm

  d=0.14m
- ✓ the listed formulas are used for table 4.2: below :-
  - $\alpha = \tan^{-1}(1/N)$
  - $CL = 2GN$
  - $Ro = 1.5\,G + 2GN^2$
  - $R = Ro - G/2$
  - $SL = \sqrt{2Rod}$
  - $L = CL - SL$
  - $\beta = \tan^{-1}(d/SL)$
  - $LC = SL/\cos\beta$

Table 4.2: Method -1 design turnout

frog number (N)	crossing angle (α)	curve lead(CL) [m]	radius of outer curve(Ro) [m]	radius of C.L of turnout (R) [m]	switch lead (SL) [m]	lead (L) [m]	switch angle (β)	switch length (LC) [m]
4	14.036	11.480	48.073	47.355	3.669	7.811	2.185	3.671
5	11.310	14.350	73.903	73.185	4.549	9.801	1.763	4.551
6	9.462	17.220	105.473	104.755	5.434	11.786	1.476	5.436
7	8.130	20.090	142.783	142.065	6.323	13.767	1.268	6.324
8	7.125	22.960	185.833	185.115	7.213	15.747	1.112	7.215
9	6.340	25.830	234.623	233.905	8.105	17.725	0.990	8.106
10	5.711	28.700	289.153	288.435	8.998	19.702	0.891	8.999

11	5.194	31.570	349.423	348.705	9.891	21.679	0.811	9.892
12	4.764	34.440	415.433	414.715	10.785	23.655	0.744	10.786
13	4.399	37.310	487.183	486.465	11.680	25.630	0.687	11.680
14	4.086	40.180	564.673	563.955	12.574	27.606	0.638	12.575
15	3.814	43.050	647.903	647.185	13.469	29.581	0.596	13.470
16	3.576	45.920	736.873	736.155	14.364	31.556	0.558	14.365
17	3.366	48.790	831.583	830.865	15.259	33.531	0.526	15.260
18	3.180	51.660	932.033	931.315	16.155	35.505	0.497	16.155
19	3.013	54.530	1038.223	1037.505	17.050	37.480	0.470	17.051
20	2.862	57.400	1150.153	1149.435	17.946	39.454	0.447	17.946

The crossing angle and the switch angle are taken from table 4.2: above and this values described clearly in a table 4.3: and in figure 4.9: below. therefore from this two angle relation it is possible to drive one constant value for the purpose of knowing the unknown third equations, see this relation in a table 4.3: below

Table 4.3: Relation of angle constant between crossing angle and switch angle

frog number (N)	crossing angle (α)	switch angle (β)	relation of angles(k=α/β)
4	14.036	2.185	6.423
5	11.310	1.763	6.416
6	9.462	1.476	6.412
7	8.130	1.268	6.410
8	7.125	1.112	6.408
9	6.340	0.990	6.407
10	5.711	0.891	6.406
11	5.194	0.811	6.406
12	4.764	0.744	6.405
13	4.399	0.687	6.405
14	4.086	0.638	6.405
15	3.814	0.596	6.405
16	3.576	0.558	6.404
17	3.366	0.526	6.404
18	3.180	0.497	6.404
19	3.013	0.470	6.404
20	2.862	0.447	6.404

From table 4.3: the average value of crossing angle and switch angle is constant therefore the switch angle become approximately 1/6.4 of the crossing angle (K= α/β=6.4) and the clarification of this relation is clearly described in figure 4.9: below

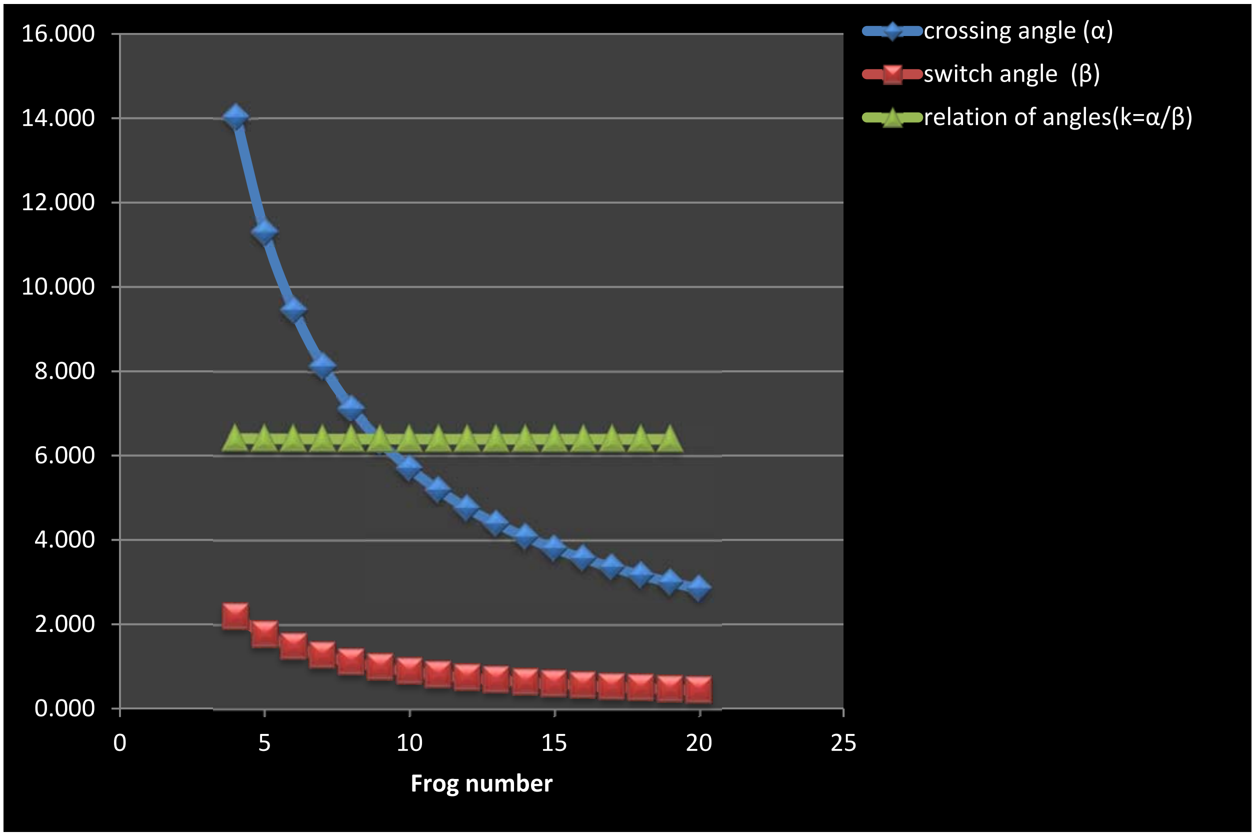


Figure 4.9: Relation of angle constant between crossing angle and switch angle

4.6.1.2. Sample of improved switch turnout design

From Addis Ababa light rail transit (AA-LRT) east-west and north-south phase, take one of the project for sample calculation so that, take turnout number seven or 7# (1 in 7 turnout) for 50kg/m steel track with standards gauge of 1435mm from north-south rail project and the rails set of this turnout is concrete sleeper, from this sleepers same switch sleepers up to frog perpendicular to internal bisector and the rest perpendicular to rail track. Rail switch track with its curve starts from the nose of improved switch and tangential to the gauge face of the outer main rail than passes through theoretical nose crossing (T.N.C). For this sample calculation we follow col's method-1 formula because of, switch lead existed on this method but, on the other two methods, switch lead not considered at all because, the curve springs from the heel of the switch rail due to this, it missed the switch length.

Given data

- ✓ N=7(ERC...north-south phase-1 project)
- ✓ G=1.435m
- ✓ For AALRT 50kg/m rail section =the width of head rail=70mm
- ✓ For flange way clearance =6.7cm from IRS and
- ✓ consider 0.3 cm for wear according to IRS

1) Curve lead
   - ✓ CL= 2GN……………………from equation (2.3)(method-1)
   - ✓ CL=2*1.435m*7
   - ✓ CL=20.09m
2) Radius –R
   - ✓ Ro=1.5 G + $2GN^2$ ……….. from equation (2.4) (method-1)
   - ✓ Ro=1.5*1.435 + $2*1.435*7^2$
   - ✓ Ro=142.78m
   - ✓ R= Ro-G/2………………..… from equation (2.5) (method-1)
   - ✓ R=142.78-(1.435/2)
   - ✓ R=142.065m
3) Heel divergence (d)

   Heel divergent is equal to flange way clearance plus tolerance for the wear plus switch heel (x distance) plus two times the width of head of rail see in figure: 4.10: below

   Heel divergence becomes:
   - ✓ d=Fc + w + 2Wh + x
   - ✓ d=6.7cm+0.3cm+(2*7cm)+x
   - ✓ d=21cm+x
   - ✓ d=0.21m+x

Therefore the heel of the switch is located at the point where the offset of the curve is equal to the heel divergence

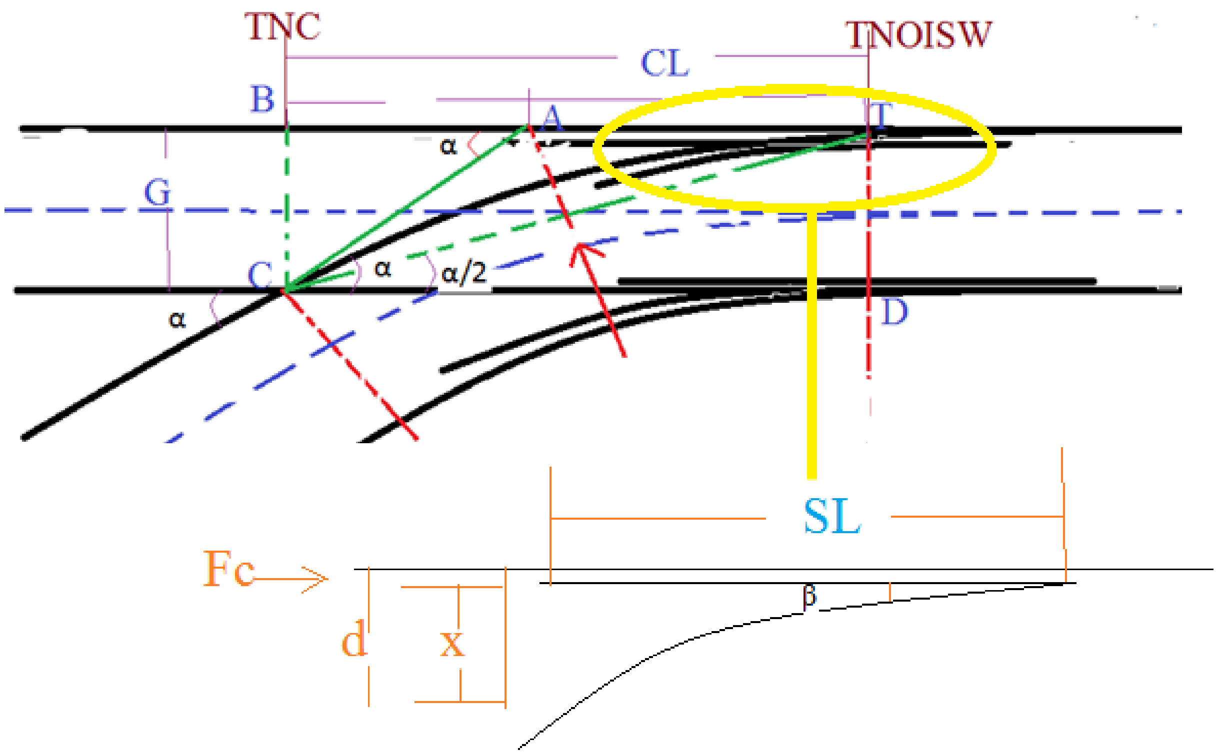


Figure 4.10: Improved switch heel divergent

4) switch lead (SL)

$SL = \sqrt{2Rod}$ ……………… from equation (2.6) (method-1)

$SL = \sqrt{2 * 142.78m * (0.21m + x)}$

$SL^2 = 59.97 + 285.56x$…………………………..equation (*)

5) Angle relation constant (K)

From table 4.3 and from figure 4.9: the average value of K= α/β=6.4

- ✓ N=7…………(given sample turnout number)
- ✓ N=cot α

  α= 8.130
- ✓ β=1/6.4(8.130)

  β=1.270
- ✓ $\tan \beta = \frac{x}{SL}$ ……………………………….from fig 4.10

  $Tan\ 1.270 = \frac{x}{SL} = 0.0222$

SL=45X…………………………………equation (**)

Finally insert equation (**) in to equation (*), than you will get

$2025x^2 - 285.56x - 59.97=0$

- ✓ X2 – 0.141x – 0.03 =0…..….by using quadratic function $\frac{-b\pm\sqrt{b^2-4ac}}{2a}$

  X=0.26m ……………………….approximate positive value
- ✓ SL2=59.97+285.56(0.26m)

  SL=11.58m
- ✓ d=0.21m+x

  d=0.21m +0.26m

  d=0.47m

6) lead (L)

   L= 2GN-$\sqrt{2Rod}$ ………….… from equation (2.7) (literature method-1)

   L=CL-SL

   L=20.09m – 11.58m

   L=8.51m

Generally by using of fixed value of " x " taken from the above section that is x=0.26m and for standard gauge 1435mm with 50kg/m rail section, it is possible to develop excl template for design of improved switch length for all turnout number.

Given data for preparing excl template:

d=Fc + w + 2Wh + x

d=6.7cm +0.3cm +2*7cm +26cm

d=47cm

d=0.47m

G=1.435m

The listed formulas are used for table 4.4: below:-

- α =tan-1(1/N)
- CL= 2GN
- Ro=1.5 G + 2GN2

- $R = Ro - G/2$
- $SL = \sqrt{2Rod}$
- L=CL-SL
- α =tan-1(d/ SL)
- LC= SL/Cos β

Table 4.4: Improved switch length for all turnout number

frog number (N)	crossing angle (α)	curve lead (CL)m	radius of outer curve (Ro)	radius of C.L of turnout R	switch lead (SL)	lead (L)	switch angle (β)	switch length (LC)
4	14.036	11.480	48.073	47.355	6.722	4.758	3.999	6.739
5	11.310	14.350	73.903	73.185	8.335	6.015	3.228	8.348
6	9.462	17.220	105.473	104.755	9.957	7.263	2.702	9.968
7	**8.130**	**20.090**	**142.783**	**142.065**	**11.585**	**8.505**	**2.323**	**11.595**
8	7.125	22.960	185.833	185.115	13.217	9.743	2.037	13.225
9	6.340	25.830	234.623	233.905	14.851	10.979	1.813	14.858
10	5.711	28.700	289.153	288.435	16.486	12.214	1.633	16.493
11	5.194	31.570	349.423	348.705	18.123	13.447	1.486	18.129
12	4.764	34.440	415.433	414.715	19.761	14.679	1.362	19.767
13	4.399	37.310	487.183	486.465	21.400	15.910	1.258	21.405
14	4.086	40.180	564.673	563.955	23.039	17.141	1.169	23.044
15	3.814	43.050	647.903	647.185	24.678	18.372	1.091	24.683
16	3.576	45.920	736.873	736.155	26.318	19.602	1.023	26.323
17	3.366	48.790	831.583	830.865	27.959	20.831	0.963	27.963
18	3.180	51.660	932.033	931.315	29.599	22.061	0.910	29.603
19	3.013	54.530	1038.223	1037.505	31.240	23.290	0.862	31.243
20	2.862	57.400	1150.153	1149.435	32.881	24.519	0.819	32.884

From table 4.4: the straight switch lead length and the curve switch rail length relation is shown in figure 4.11: in detail, so from this relation what we understand is that, the theoretical and the practical consideration is true that means, theoretically curved switch rail length is greater than straight switch lead length practically from figure 4.11: shows you curved switch rail length always greater than straight switch lead length for all turnout number.

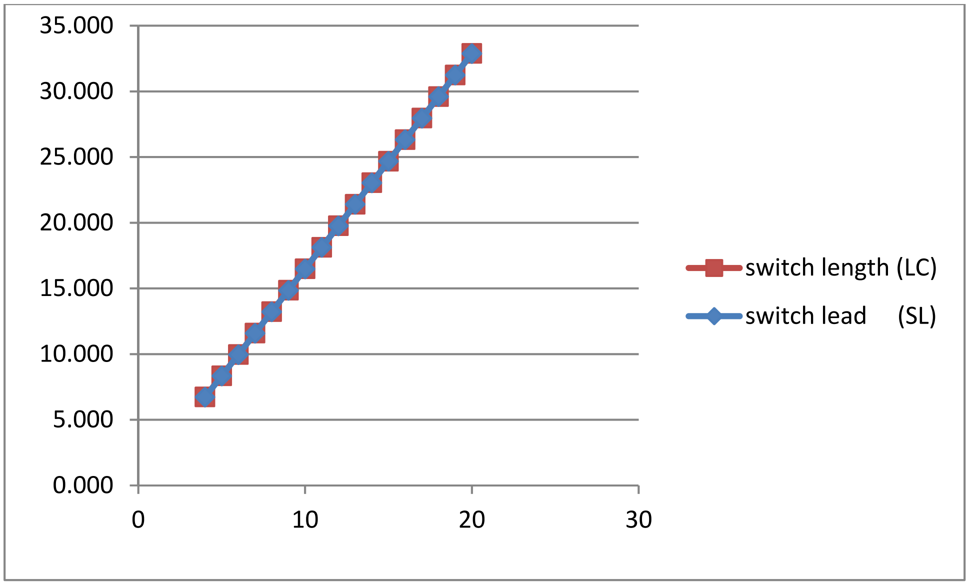


Figure 4.11: Switch length and switch lead curve relation

4.7. IMPROVED GUARD-WING RAIL DESIGN

Guard-wing rail laid parallel to the running stock rail and the switch rail, placed opposite one each other from the ISW within inside of stock rail, that's ensure the vehicle wheel flange follow the appropriate flange way and keeps the nose of ISW as well as the wing rail and related running rails, from an necessary wear, hitting(picking).

Depending on the AREA tee rail guard rail standard, it is possible to set out the minimum length of guard-wing rail by cutting from the given standard stock rail length that have (25m and 12.5 m) therefore it become four guard-wing rail length. These are:-12.5m, 6.25m 3.125m and 1.5625m

The design of guard-wing rail have three parts this are: left side bevel and plane part, straight part and right side bevel and plane part, from this three parts two of them the right one and the left side one are similar in both length and design procedure so, this length one start from throat of ISW along the running stock rail and the other one is, from the ANOISW minus set back distance along the lead direction so that, this two guard-wing rail are included according to AREA tee guard rail design on plane portion and bevel section. The intermediate part of guard-wing rail is between a setback distances from back of ANOISW to throat of improved switch called, parallel or straight section of guard-wing rail.

4.7.1. Guard-wing rail given data and requirements

- ✓ crossing number:-for this sample geometrical design of guard-wing rail as like above follow cole's right angle method
- ✓ switch angle :-is taken from table 4.4: above and by using this angle ,calculate both distance, one from TNOISW to ANOISW and the other from TNOISW to the throat of ISW
- ✓ half inch switch(blunt thickness of ANOISW):- take this value as it is, according to AREA tee rail guard rail design standard
- ✓ Flange way width:-to become safe guard rail geometrical design, take flange way width according to Indian railway standard (IRS) because it is grater flange way width used than AREA tee rail guard rail design.
  - According to IRS flange way width=6.7cm (including wear)
  - According to AREA flange way width=1.875 in=4.76cm
- ✓ Set back distance:-this is an additional distance that we are consider at the back side of ANOISW for safe protection of switch nose, so take this dimension from AREA tee guard rail design standard that is six inches, but this value is determined by using cole's right angle method and by taking the average, look the procedure below.

  - From similarity of triangle (see in figure 4.12: below)

$$n/1 = ds /1/2$$

$$ds=n/2 \qquad \ldots\ldots 4.4$$

  - By using ds=n/2 formula the set back distance seated below in table 4.5:

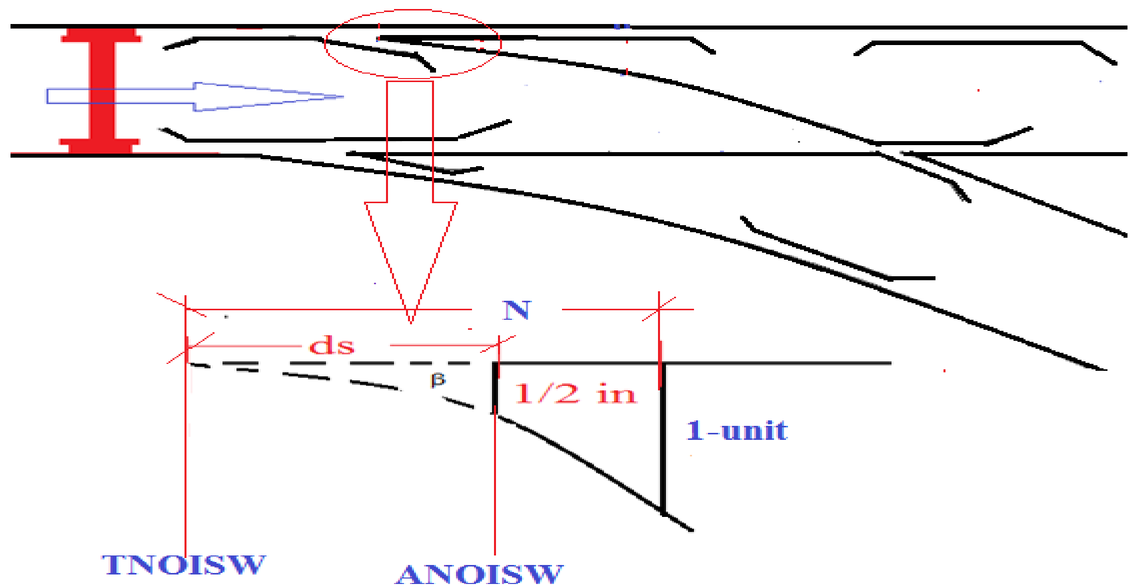


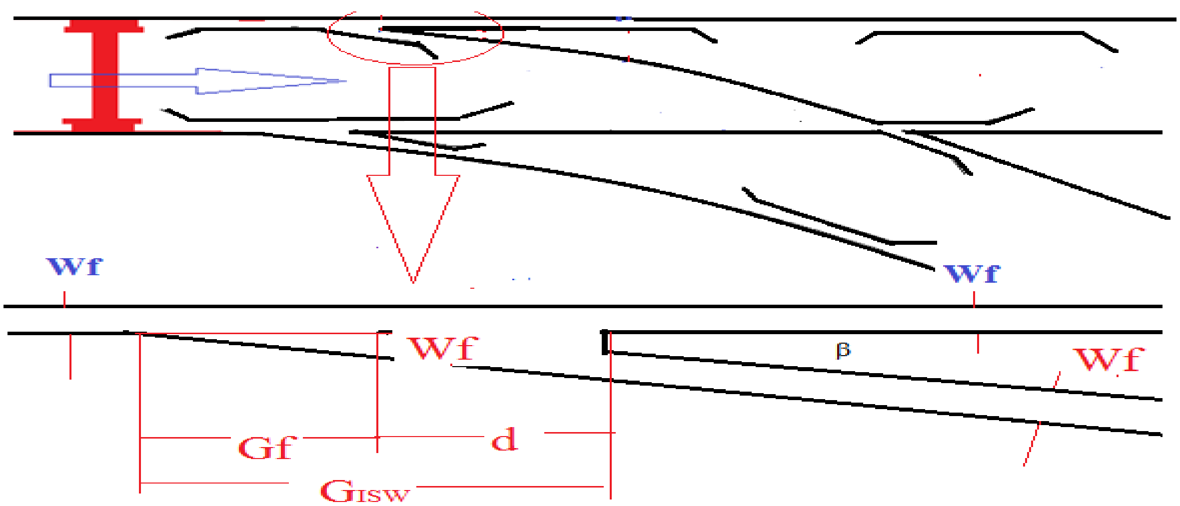
Figure 4.12: Setback distance

Table 4.5: Area tee guard rail set back distance

N	A	set back (in) ds=N/2	Ave. set back (in)
4	14.036	2	
5	11.310	2.5	
6	9.462	3	
7	8.130	3.5	
8	7.125	4	
9	6.340	4.5	6
10	5.711	5	
11	5.194	5.5	
12	4.764	6	
13	4.399	6.5	
14	4.086	7	
15	3.814	7.5	
16	3.576	8	
17	3.366	8.5	
18	3.180	9	
19	3.013	9.5	
20	2.862	10	

4.7.2. Straight (parallel) portion of guard-wing rail design

The straight (parallel) portion of guard-wing rail must be design and placed in proper position relative to the ½-inch point of the improved switch, to ensure that the wheels follow the appropriate flange way through the ISW and keeps the nose of ISW from strike by wheel flange.(in other way your design prevent any derailment in switch area)



Where:

GISW…..gap of improved switch

Gf…….gap of flange way

Wf….flange way

Figure 4.13: Gap of improved switch

1/2in=12.7mm

Wf=6.7cm=67mm

ds =6in=152.4mm

$\tan\beta = 12.7/d$

$$d = 12.7\cot\beta \text{ (mm)} \qquad (4.5)$$

$\tan\beta = Wf/Gf$

$$Gf = 67\cot\beta \text{ (mm)} \qquad (4.6)$$

$$G_{ISW} = Gf + d + ds \qquad (4.7)$$

$$G_{ISW} = 67\cot\beta + 12.7\cot\beta + 152.4 \text{ (mm)}$$

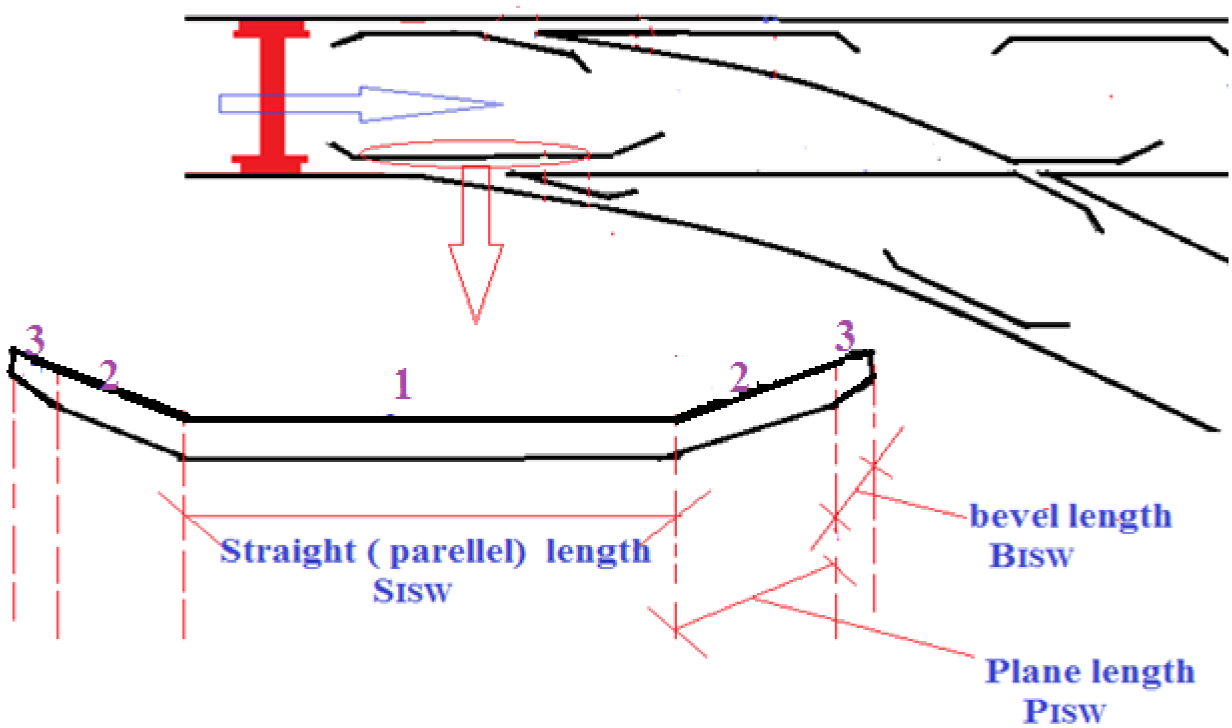


Figure 4.14: Guard-wing rail length

For our sample turnout #7 (1 in 7 turnout) 50kg/m by using the above formula we can easily set the straight (parallel) length of guard-wing rail. Take switch angle β from table 4.4:

$\beta = 2.323^0$

GISW = Gf + d + ds

GISW = 67 cot β + 12.7cot β + 152.4 (mm)

GISW = 67 *cot 2.323^0+ 12.7*cot 2.323^0+ 152.4 (mm)

GISW =1651.499+ 313.045+ 152.4 (mm)

GISW=2116.945mm

GISW=2.117m (minimum straight length)

To become safe, the straight length should be grater then the minimum value of GISW =2.116m so add 10 % of the minimum length additionally to the straight part and become GISW=2.328m .this is, for only this sample geometric design of straight guard-wing rail length. Therefore By this manner it can tabulate the rest crossing number from turnout #4 up to turnout #20

Table 4.6: Straight (parallel) length of guard-wing rail

frog number	switch angle (β)	d=12.7cot β (mm)	Gf=67 cot β (mm)	GISW= 67 cot β + 12.7cot β + 152.4 (mm)	GISW (m)	GISW= (GISW+10%*GISW) (m)
4	3.999	181.643	958.273	1292.316	1.292	1.422
5	3.228	225.216	1188.148	1565.764	1.566	1.722
6	2.702	269.054	1419.419	1840.873	1.841	2.025
7	2.323	313.045	1651.499	2116.945	2.117	2.329
8	2.037	357.134	1884.090	2393.624	2.394	2.633
9	1.813	401.287	2117.024	2670.710	2.671	2.938
10	1.633	445.485	2350.197	2948.083	2.948	3.243
11	1.486	489.717	2583.547	3225.664	3.226	3.548
12	1.362	533.974	2817.028	3503.402	3.503	3.854
13	1.258	578.250	3050.610	3781.260	3.781	4.159
14	1.169	622.541	3284.273	4059.214	4.059	4.465
15	1.091	666.845	3517.999	4337.243	4.337	4.771
16	1.023	711.158	3751.777	4615.335	4.615	5.077
17	0.963	755.479	3985.598	4893.478	4.893	5.383
18	0.910	799.807	4219.455	5171.663	5.172	5.689
19	0.862	844.141	4453.342	5449.883	5.450	5.995
20	0.819	888.480	4687.255	5728.135	5.728	6.301

NOTE ………..Straight (parallel) length SISWG=GISW (m)

4.7.3. Plane and bevel length of guard-wing rail design

Depending on the AREA tee rail guard rail standard, it is possible to set out the minimum guard-wing rail length by cutting from the given standard stock rail length that have (25m and 12.5 m)

Straight (parallel) length and plane length Vary linearly with guard-wing length but bevel length is taken as constant length, which is equal to 13in (330.2mm) according to AREMA. The guard-wing rail length obtained from standard rail length 25m and 12.5m, so from this standard length it is possible to obtain four guar-wing lengths by cutting 12.5m.

This are:

1) 12.5 m

2) 6.25m

3)3.125 and

4)1.5625m

the last cutting length of guard-wing rail is 1.5625m this is because our minimum straight guard-wing rail length is 1.422m as a case of this, four length only used and stop cutting standard rail at this length, then After cutting the guard rail to its full overall length, the manufacturer makes a 3-inch. 45-degree end bevel cut and makes the final bevel cut, at an angle of 25 degrees to the vertical, over the distance L_{BV}

$$WFL= \frac{LBV}{LBV-3} + 0.625(in)\ldots\ldots 4.8$$

Because the bevel length is 13 inches (330.2mm) for all Tees rail guard rails according to AREA standard so the flare is also the same shown in figure 2.18: above. Thus, equation...* produces a constant width flare value of WFL= 1.925 inches = 48.895mm, with this reason take the bevel length for this sample geometric design as it is and for the design of plane length from the total standard guard-wing rail length deduct the bevel length and the straight length from the four standard cute guard-wing rail length

- ✓ The general guard-wing rail formula
- ✓ $L_{ISWG}=S_{ISWG} + 2 (P_{ISG} + B_{ISG})$

Where:

- L_{ISWG}-total length of guard-wing rail
- S_{ISWG}-straight length
- P_{ISWG}-plane length
- B_{ISW}-bevel length

- ✓ According to AREA, plane length is always greater than bevel length

Table 4.7: Plane length (from the given guard-wing rail length)

N-crossing	straight (parallel)length SISWG=GISW (M)	bevel length (m)	2*BISW(m)+SISG (m)	given guard length (m)	plane length (m)
4	1.422	0.3302	2.082	3.125	0.522
5	1.722	0.3302	2.383	3.125	0.371
6	2.025	0.3302	2.685	6.25	1.782
7	2.329	0.3302	2.989	6.25	1.630
8	2.633	0.3302	3.293	6.25	1.478
9	2.938	0.3302	3.598	6.25	1.326
10	3.243	0.3302	3.903	6.25	1.173
11	3.548	0.3302	4.209	6.25	1.021
12	3.854	0.3302	4.514	6.25	0.868
13	4.159	0.3302	4.820	6.25	0.715
14	4.465	0.3302	5.126	6.25	0.562
15	4.771	0.3302	5.431	6.25	0.409
16	5.077	0.3302	5.737	12.5	3.381
17	5.383	0.3302	6.043	12.5	3.228
18	5.689	0.3302	6.349	12.5	3.075
19	5.995	0.3302	6.655	12.5	2.922
20	6.301	0.3302	6.961	12.5	2.769

Table 4.8: Guard-wing rail length relation

N-crossing	LISG(m)	SISG(m)	PISWG(m)	BISW(m)
	1.5625	-	-	0.3302
#4-#5	3.125	1.422-1.722	0.371-0.522	0.3302
#6-#15	6.25	2.025-4.711	0.409-1.782	0.3302
#16-#20	12.5	5.077-6.301	2.769-3.381	0.3302

4.8. IMPROVED SWITCH LOCK RAIL DESIGN

An ISW lock rail are locks or closes the gap between ISW blunt nose to guard-wing rails and blunt nose to stock rail in both right side and left side stock rail depending on the driver interest direction. For straight movement for left turning turnout shown in model below, the right stock rail sensor should be first sensed then, this leads rise of straight lock rails in right and left side stock rail i.e. close the curved movement and allows the straight forward movement this shown in detail in figure:11252 below. Therefore the design length of ISW lock rails are two types the straight lock rail length and the curved lock rail length, which keeps vehicle wheel in proper position with respect to the direction.

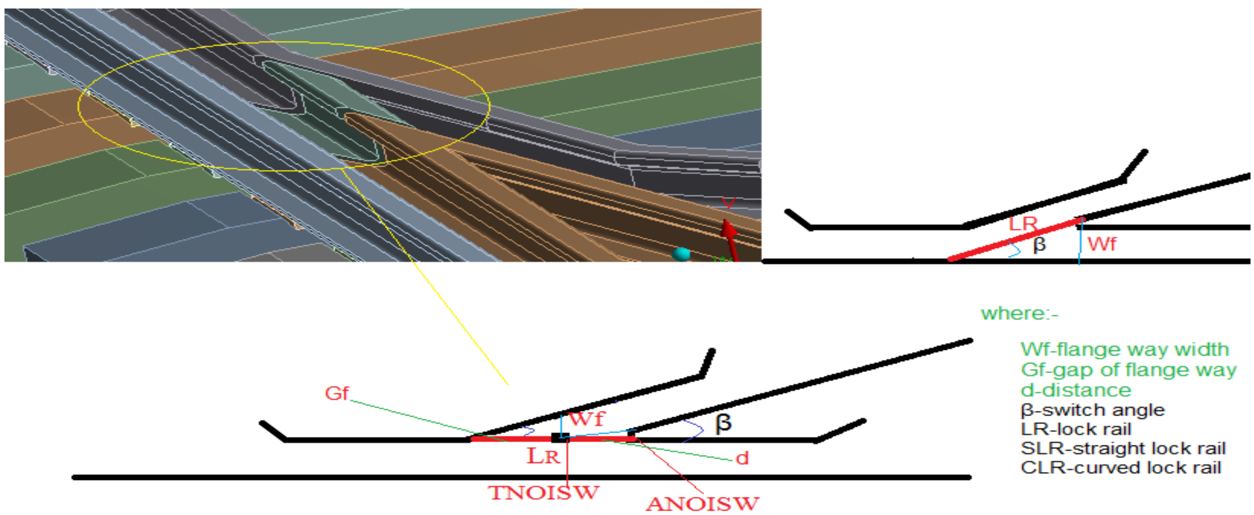


Figure 4.15: Straight and curved lock rail

Given data

- ✓ 1/2in=12.7mm
- ✓ Wf=6.7cm=67mm
- ✓ Tan β=12.7/d
- ✓ d=12.7cot β (mm)
- ✓ Tan β=Wf/Gf
- ✓ Gf=67 cot β (mm)
- ✓ SLR= Gf + d
- ✓ SLR = 67 cot β + 12.7cot β where β =2.323 for turnout#7
- ✓ SLR = 67 cot 2.323+ 12.7cot 2.323
- ✓ SLR = 313.045 + 1651.499 mm
- ✓ **SLR = 1964.544 mm**
- ✓ CLR= (12.7 + 67) *1/ sin β
- ✓ CLR =79.7 * (1/sin 2.323)
- ✓ **CLR = 1966.304 mm** ......similar procedure for the rest turnout number.

4.9. LIMITATION OF EXISTING SWITCH AND THEIR SOLUTIONS ACCORDING TO IMPROVED SWITCH

The flange of vehicle wheel need same special railway structure to pass from one track to another track due to this flange, the system of existing switch rail face for lot of limitation, the following are the most one:

- ✓ Speed limitation (depending on the turnout number), when the train entering or leaving the switches at a speed, results a wheel climb derailment.
- ✓ Due to discontinuity rather than, standard rail connection point, passenger comfort disturbed
- ✓ Same time wrong movement of flange happen specially on trailing direction which leads the train to an proper position this also need attention, according to safety of the passenger
- ✓ Comparing the switch section area from other section area it is high derailment area due to moving part. The switch related derailment risks defined as;
    - o improper flange contact between the wheel flange and the switch point,
    - o excessive or unusual wear of the switch point,
    - o excessive switch rail damage and
    - o improper switch rail profile
- ✓ when the train ride from trailing to facing direction or from crossing to switch, the switch should be open otherwise the vehicle wheel have responsible to force the switch to other side this also another limitation of switch rail.

According to inspection , the structure of ISW are fixed structure but, there are two types of different rail locker which are an additional gap filler or guarder for proper position of wheel. So that, it need relatively managed inspection due to discontinuity like normal standard track. when we see the assembling of improved railway switch, the rails are set uniformly not double track connected as like the existing one , this makes flexible for riding of vehicle, as result of uniformity of rail ,the passenger attend good comfort ,minimizes the derailment and fully free movement in both direction, no locking of the switch hear ,in both trailing and facing direction.

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The design and analysis of improved switch rail from the geometry and ANSYS result as well as existing switch rail from literature review are used for the following conclusion. For the same structural support stiffness, the existing railway switch shows 2.248 mm at section A-A, 2.158 mm at section B-B and 1.398 mm at section C-C vertical deflection, which are relatively smaller than 3.14mm ISW rail deformation. Hence, the results are within the range of AREMA maximum vertical rail deflection limit which is 6.35mm.This mean that, both rail sections are sufficient enough for the maximum design load. According to the shear parameter, the existing railway switch, for the same radius of wheel and for the same steel structure with equal sleeper spacing shows 149.09 MPa Maximum shears which is greater than 140MPa allowable maximum shear stress. For this reason, the sections are less resistance for high force and vibration than the ISW rail one, which is 8.8 MPa. In case of stress, the current switch shows 137.826MPa at section A-A, 69.468 at section B-B and 45.603 at section c-c maximum stress which is very high comparing to the improved one, switch is 16.277 MPa, this is due to section modulus variation.

According to the sample from Addis Ababa light rail transit north-south phase 1 project for turnout number seven and for 50kg/m steel rail track with standards gauge of 1435mm, the geometrical design of improved switch rail length shows 11.595m, which is longer than the existing rail length 6.324m , this makes the transition smooth and increases the speed from the previous one and The total guard-wing rail length for turnout number seven is 6.25m from this total length the minimum straight guard-wing rail length is 2.329m which are placed proportional with respect to improved switch gap, the bevel length is 0.3302m which is constant and the plane guard-wing rail length is 1.63m

Finally, improved railway switches minimize the drawback of the existing railway switch, like movement restriction in trailing direction, speed limitation especially from result of switch component interactions with stock rail (discontinuity), high derailment due to improper flange contact between the wheel flange and the switch point and excessive wear. Whereas, the ISW structurally differ from the existing railway switch due to this, it allows free movement in both direction and adds an additional directional change system with respect to driver interest. The assembling of improved railway switch is set uniformly (not double track connected) this makes, smooth transition throughout the track and the passenger attend good comfort.

5.2. RECOMMENDATION

For future Ethiopian railway development and maintenance activities**:** new idea, new model rail track, new vehicle model and periodic maintenance are an option to reduce the railway initial investment cost and maintenance cost so that, in this paper the movable existent switch mechanics converted to fixed static ISW track structure. Therefore, it would be better recommending Improved switch should be inspected and maintained frequently according to the traffic flow because of, the quality of train ride greatly depends on the maintenance like that of the existing railway switch and crossing but in case of improved switch structure it is used a fixed track system (without ISW lock rail), that are organized by fixed materials, due this fixity of track structures, the geometry by itself avoids lubricant and other un necessary oiling, this is a great relief according to inspection and maintenance but it need relative managed and inspection due to discontinuity like normal standard track, this results increasing the life time.

5.2.1. RECOMMENDATION FOR FUTURE WORK

Railway train is responsible for changing its own direction without the help of rail guidance, which is from the train wheel mechanics it's expected to change the direction at the improved switch turning point rather than switch devices therefore, the following recommendation are proposed for further researches:

1) Further detail investigation on the railway vehicle mechanics
2) Detail investigations on ISW lock rail mechanics in relation to inter locking system with respect to sensors which are installed in vehicle wheel and in rail track.
3) Switch and crossing track structure provided because of, the existence of railway vehicle wheel flange therefore, there should be detail study on model of vehicle wheel with flange and without flange (remember avoid wheel flange means avoid switch and crossing and investigate new railway track model)
4) Considering the whole railway track maintenance cost, more than half of this cost is expended for switches and crossing. Since the materials and the spare parts are imported and require high foreign currency due to this, switch maintenance cost is the great problem for future Ethiopian railway corporation therefore, studying in detail in maintenance of switch and crossing in Ethiopian new railway line helps future maintenance cost, increase the life time and smooth transition will exist throughout the track.

6. APPENDIX

APPENDIX A: ABBRVATION

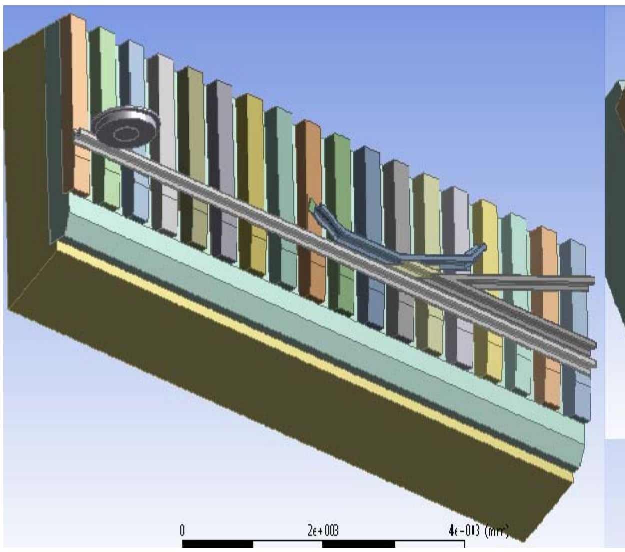
- ✓ NMRA…………………………...……… NATIONAL MODELING RAILROAD ASSOCIATION
- ✓ AREA……………………………….... AMERICAN RAILWAY ENGINERING ASSOCATION
- ✓ AREMA……………………...AMERICAN RAILWAY ENGINERING AND MENITENANCE WAY ASSOCATION
- ✓ IRS ………………………………………………………..…. INDIAN RAILWAY STANDARD
- ✓ GB…………………………………………………………...……..…CHINESE STANDARD
- ✓ BG……………………………………………………………….………...BROADER GAUGE
- ✓ MG……………………………………………………………………....……...METER GAUGE
- ✓ ISW……………………………………………………………..…………..IMPROVED SWITCH
- ✓ TNOISW…………………….....……………..THEOROTICAL NOSE OF IMPROVED SWITCH
- ✓ ANOISW…………………………………………….ACTUAL NOSE OF IMPROVED SWITCH
- ✓ TNC……………………………………………....……..THEORTICAL NOSE OF CROSSING
- ✓ ANC…………………………………………………………..ACTUAL NOSE OF CROSSING
- ✓ NS……………………………..…………………………NUMBER OF IMPROVED SWITCH
- ✓ HS…………………………………………………………………………..HEAL OF SWITCH
- ✓ UIC…………………………………....……………INTERNATIONAL UNION OF RAILWAY
- ✓ RP……………………………………………………………....RECOMMENDED PRACTICE
- ✓ USADOD ………………....…….UNITED STATE OF AMERICA DEPARTMENT OF DEFENSE
- ✓ AALRT…………………………………………ADDIS ABABA LIGHT RAILWAY TRANSIT
- ✓ EI..BENDING STIFFENS
- ✓ CWR...CONTINUOUS WELDED RAIL
- ✓ ERC……………………………..…………………ETHIOPIAN RAILWAY CORPORATION
- ✓ IRW…………………………………………....……..INDEPENDENT ROTATING WHEEL
- ✓ S……………………………………………………………………………………….SWITCH
- ✓ C……………………..…………………………………………………………..…..CROSSING
- ✓ FPL…………………………………………………………………..A FACING POINT LOCK
- ✓ DAF………………………………………………… DYNAMIC AMPLIFICATION FACTOR
- ✓ LR………………………………………………………………………………..LOCK RAIL
- ✓ SLR………………………………………………...………………STRAIGHT LOCK RAIL
- ✓ CLR…………………………………………………………………..CURVED LOCK RAIL

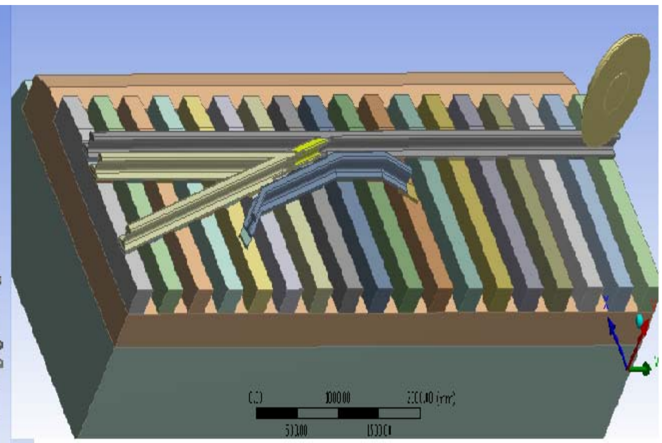
APPENDIX B: 3D ISW ANSIS MODEL AND RESULT

1) IMPROVED RAILWAY SWITCH (SYMMETRIC SECTION)

[1] 3D ISW solid geometry section

The left ISW model one is straight lock rail used and the right one is curved lock rail used



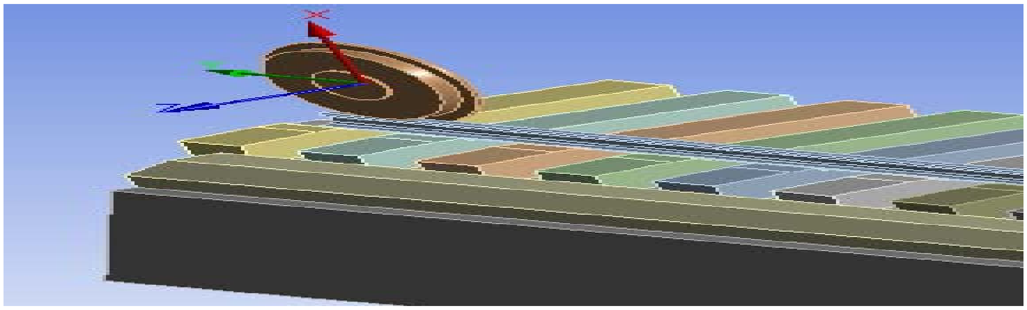


Material property for each element

Material	Stiffness (kN/m)	UNIT WIGHT (kg/m^3)	Density (kg/m^3)	Young's Modulus (GPa)	Poisson's Ratio
Rail =50Kg/m	886250	7850	7850	207	0.3
Railpad	100000	7850	7750	200	0.32
Sleeper	Infinity	2400	2300	150	0.27
Ballast	27000 (per sleeper)	2400	1800	170	0.28
Subgrade		2000	1600	30	0.21

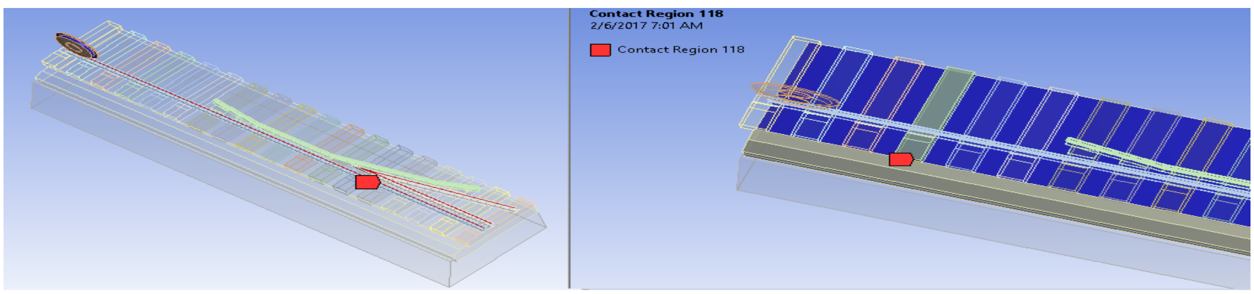
[2] Coordinate system

With the reference of the global coordinate system the transformed coordinate system is:-
X=496.22mm, Y=9687.1mm, Z=982.28mm



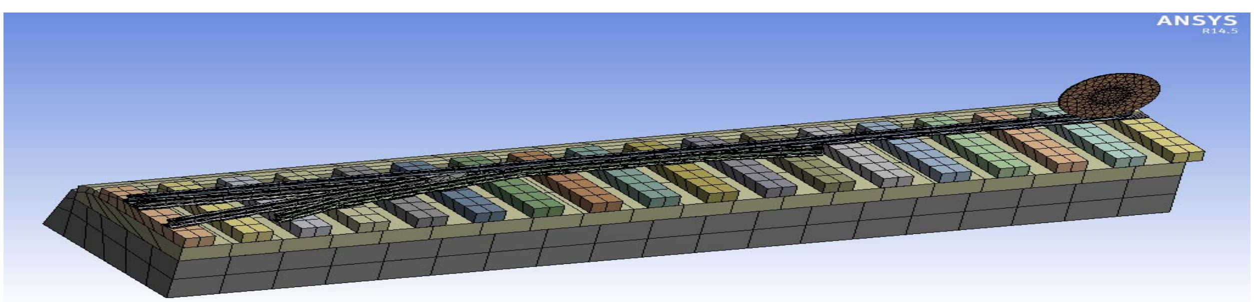
[3] Contact

The contact region between vehicle wheel head face with stock target rail head face is frictional, with friction coefficient of 0.21, the rest of contact solid bodies is bonded each other.



[4] Mesh

Default mesh, with minimum edge length 0.00050762 mm and The Static data becomes:-nodes=40117, Elements=14585 and for curved lock rail minimum edge length 0.000056411 mm and The Static data becomes:-nodes=44879, Elements=16590



[5] The static structural input data

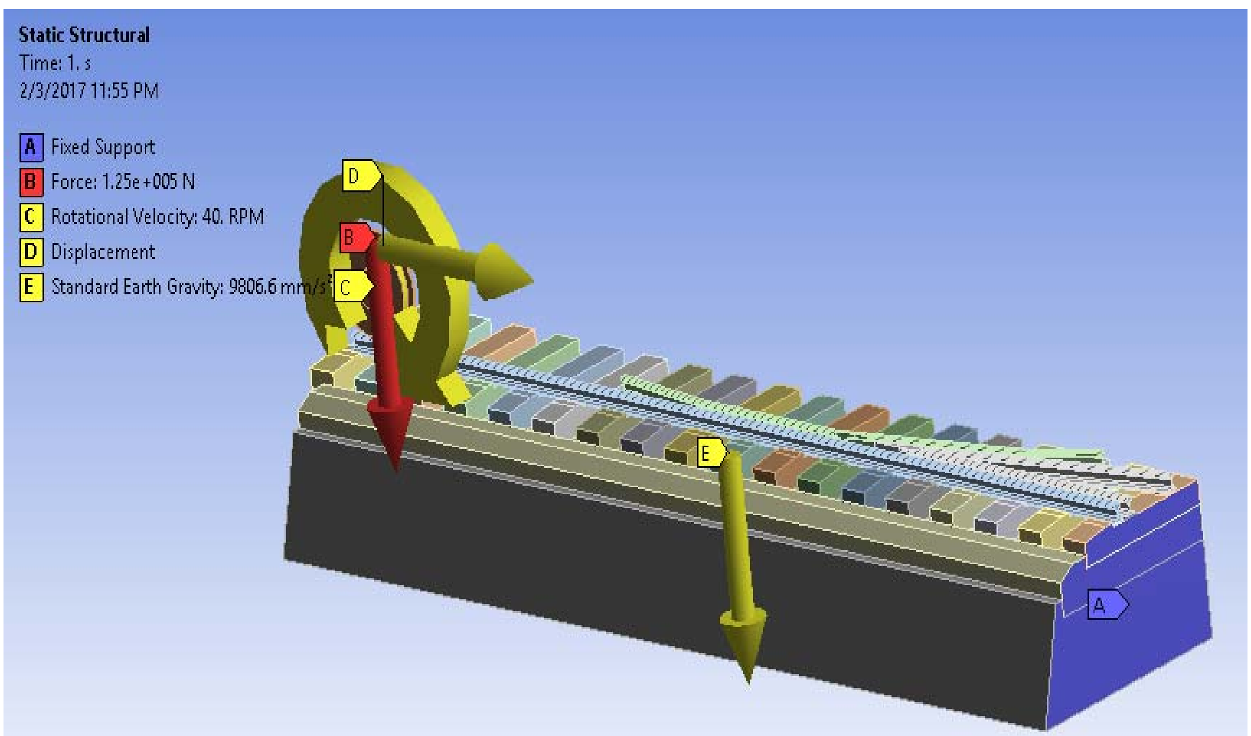
The analysis setting defined by sub steps:-

- ✓ Initial sub stapes -40
- ✓ Minimum sub stapes-30
- ✓ Maximum sub stapes-100

❖ Standard earth gravity

It is applied at the center of combined body, in the X-direction shown in table below

time[s]	X [mm/s2]	Y [mm/s2]	Z [mm/s2]
0	0	0	0
1	-9806.6	0	0



❖ Rotational velocity

Applied on vehicle wheel only (one body) and defined by components coordinate system (tabular data)

time[s]	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
X [rpm]	0	0	0	0	0	0	0	0	0	0	0
Y [rpm]	0	0	0	0	0	0	0	0	0	0	0
Z [rpm]	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40	-40

- Fixed support

Relative to the geometry a leaven faces are fixed supported

- Force

The force is applied on the face of vehicle wheel head and its defined by components coordinate system (tabular data)

time[s]	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
X [N]	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05	-1.25E+05
Y [N]	0	0	0	0	0	0	0	0	0	0	0
Z [N]	0	0	0	0	0	0	0	0	0	0	0

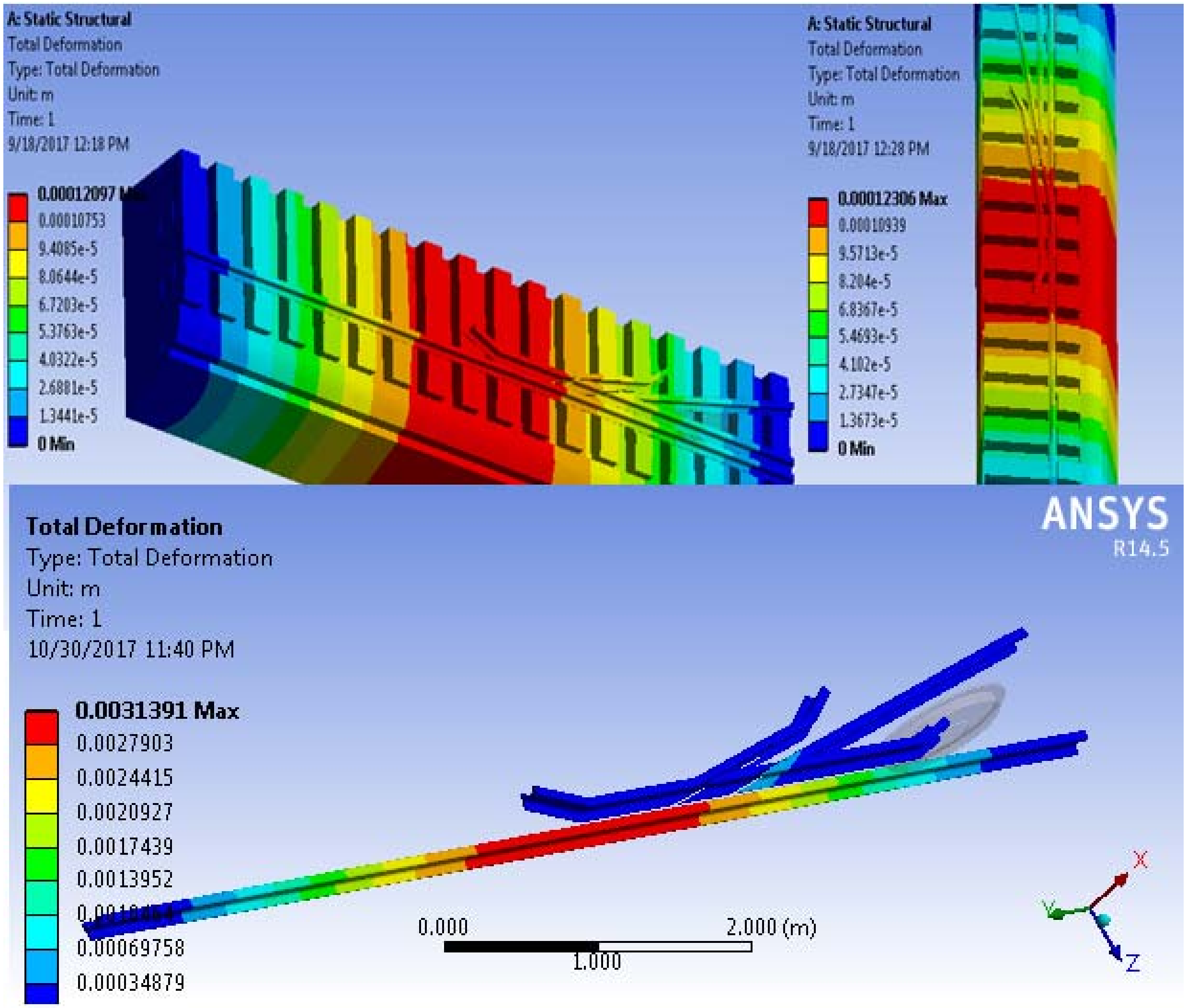
- Displacement

Defined by component coordinate system (tabular data)

Time [s]	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
X [mm]	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05	-1.00E-05
Y [mm]	0	-800	-1600	-2400	-3200	-4000	-4800	-5600	-6200	-7000	-7800
Z [mm]	0	0	0	0	0	0	0	0	0	0	0

[6] ANSYS result out put

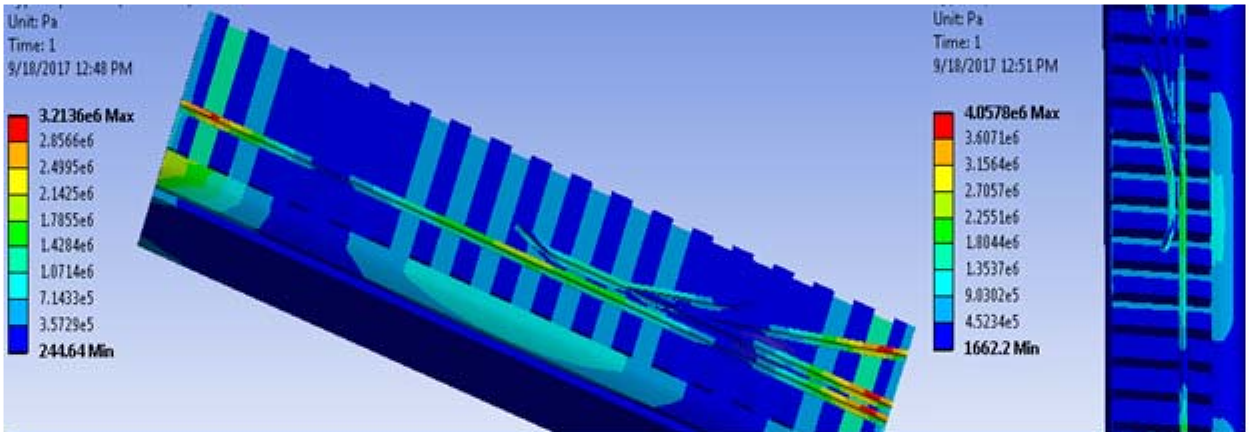
- ❖ Total deformation for all body track and for switch rail

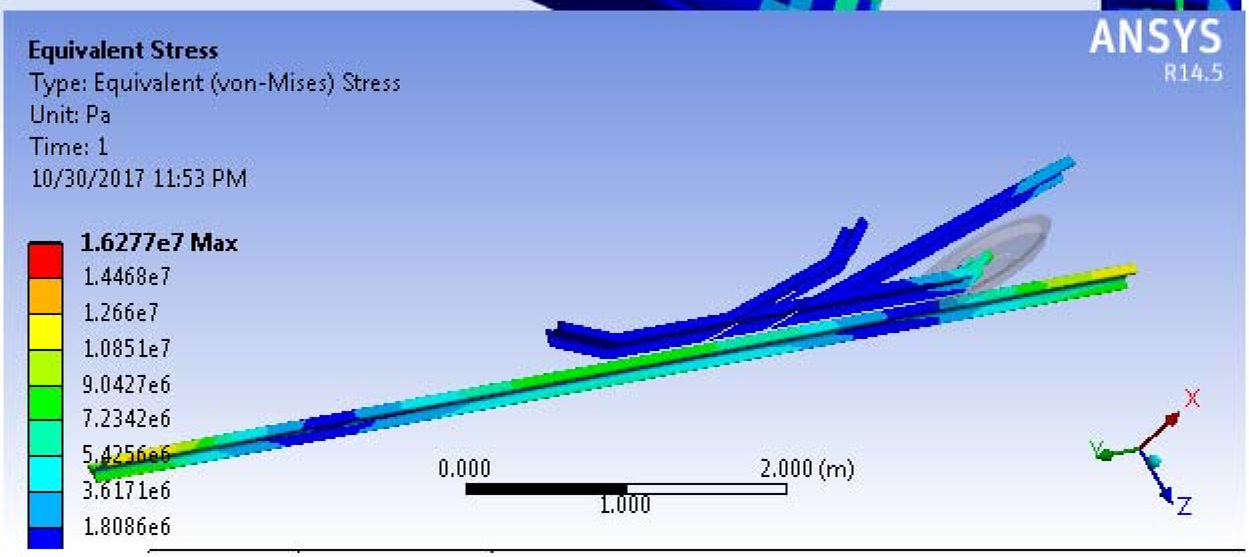


time [s]	Minimum [mm]	Maximum [mm] [straight lock rail]	Maximum [mm] [curved lock rail]	Maximum deformation [mm] [on ISW rail]
2.50E-02	0	3.02E-06	3.08E-06	7.85E-02
5.00E-02	0	6.05E-06	6.15E-06	1.57E-01
8.33E-02	0	1.01E-05	1.03E-05	2.62E-01
0.11667	0	1.41E-05	1.44E-05	3.66E-01
0.15	0	1.81E-05	1.85E-05	4.71E-01
0.18333	0	2.22E-05	2.26E-05	5.76E-01
0.21667	0	2.62E-05	2.67E-05	6.80E-01
0.25	0	3.02E-05	3.08E-05	7.85E-01

0.28333	0	3.43E-05	3.49E-05	8.89E-01
0.31667	0	3.83E-05	3.90E-05	9.94E-01
0.35	0	4.23E-05	4.31E-05	1.10E+00
0.38333	0	4.64E-05	4.72E-05	1.20E+00
0.41667	0	5.04E-05	5.13E-05	1.31E+00
0.45	0	5.44E-05	5.54E-05	1.41E+00
0.48333	0	5.85E-05	5.95E-05	1.52E+00
0.51667	0	6.25E-05	6.36E-05	1.62E+00
0.55	0	6.65E-05	6.77E-05	1.73E+00
0.58333	0	7.06E-05	7.18E-05	1.83E+00
0.61667	0	7.46E-05	7.59E-05	1.94E+00
0.65	0	7.86E-05	8.00E-05	2.04E+00
0.68333	0	8.27E-05	8.41E-05	2.15E+00
0.71667	0	8.67E-05	8.82E-05	2.25E+00
0.75	0	9.07E-05	9.23E-05	2.35E+00
0.78333	0	9.48E-05	9.64E-05	2.46E+00
0.81667	0	9.88E-05	1.01E-04	2.56E+00
0.85	0	1.03E-04	1.05E-04	2.67E+00
0.88333	0	1.07E-04	1.09E-04	2.77E+00
0.91667	0	1.11E-04	1.13E-04	2.88E+00
0.95	0	1.15E-04	1.17E-04	2.98E+00
0.98333	0	1.19E-04	1.21E-04	3.09E+00
1	0	1.21E-04	1.23E-04	3.14E+00

❖ Total Equivalent stresses for all body track and for switch rail

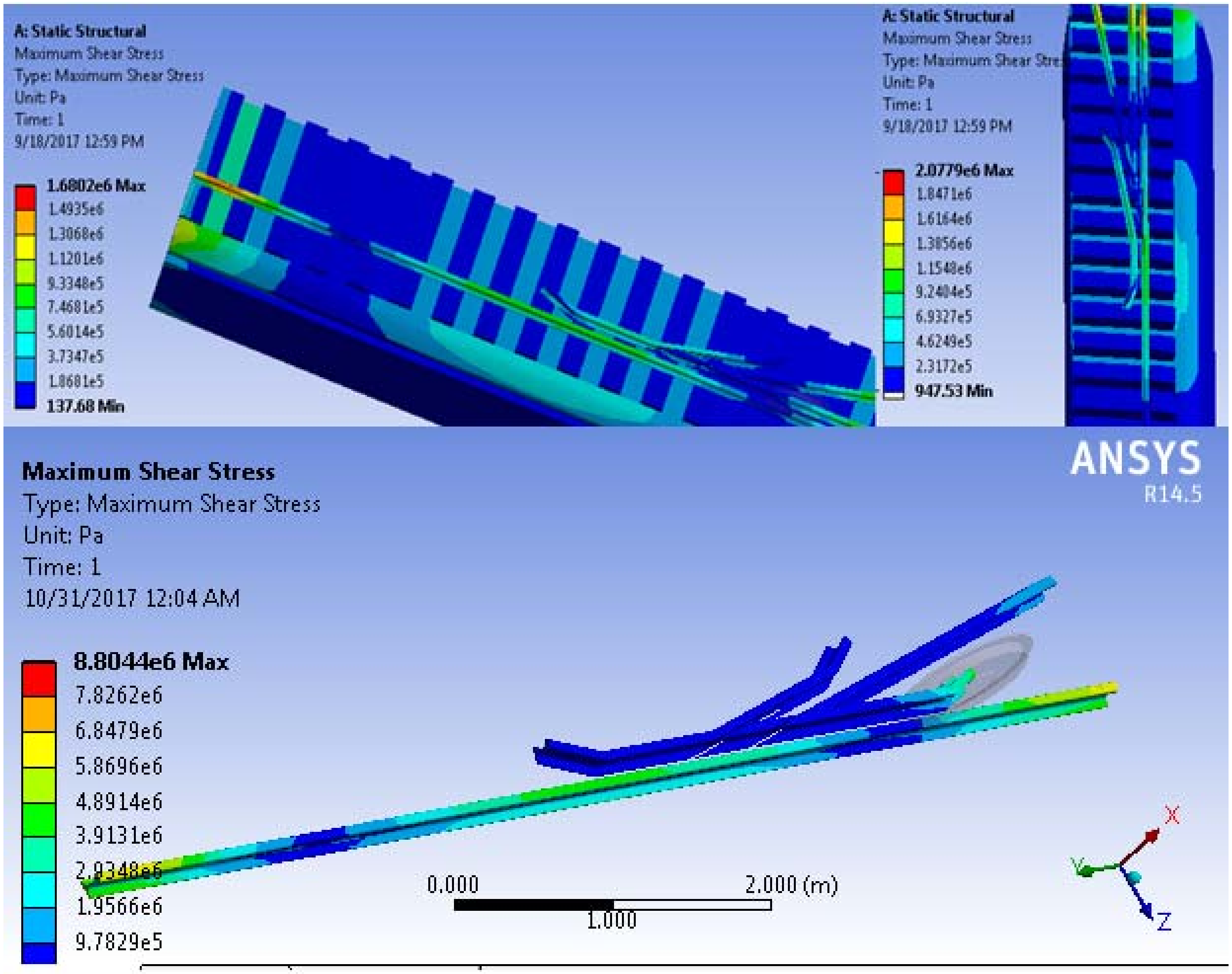




time [s]	Minimum [Pa] [straight lock rail]	Maximum [Pa] [straight lock rail]	Minimum [Pa] [curved lock rail]	Maximum [Pa] [curved lock rail]	Maximum stress [Pa] [on ISW rail]
2.50E-02	6.12E+00	80341	4.16E+01	1.01E+05	4.07E+05
5.00E-02	1.22E+01	1.61E+05	8.31E+01	2.03E+05	8.14E+05
8.33E-02	2.04E+01	2.68E+05	1.39E+02	3.38E+05	1.36E+06
0.11667	2.85E+01	3.75E+05	1.94E+02	4.73E+05	1.90E+06
0.15	3.67E+01	4.82E+05	2.49E+02	6.09E+05	2.44E+06
0.18333	4.49E+01	5.89E+05	3.05E+02	7.44E+05	2.98E+06
0.21667	5.30E+01	6.96E+05	3.60E+02	8.79E+05	3.53E+06
0.25	6.12E+01	8.03E+05	4.16E+02	1.01E+06	4.07E+06
0.28333	6.93E+01	9.11E+05	4.71E+02	1.15E+06	4.61E+06
0.31667	7.75E+01	1.02E+06	5.26E+02	1.29E+06	5.15E+06

0.35	8.56E+01	1.12E+06	5.82E+02	1.42E+06	5.70E+06
0.38333	9.38E+01	1.23E+06	6.37E+02	1.56E+06	6.24E+06
0.41667	1.02E+02	1.34E+06	6.93E+02	1.69E+06	6.78E+06
0.45	1.10E+02	1.45E+06	7.48E+02	1.83E+06	7.32E+06
0.48333	1.18E+02	1.55E+06	8.03E+02	1.96E+06	7.87E+06
0.51667	1.26E+02	1.66E+06	8.59E+02	2.10E+06	8.41E+06
0.55	1.35E+02	1.77E+06	9.14E+02	2.23E+06	8.95E+06
0.58333	1.43E+02	1.87E+06	9.70E+02	2.37E+06	9.49E+06
0.61667	1.51E+02	1.98E+06	1.03E+03	2.50E+06	1.00E+07
0.65	1.59E+02	2.09E+06	1.08E+03	2.64E+06	1.06E+07
0.68333	1.67E+02	2.20E+06	1.14E+03	2.77E+06	1.11E+07
0.71667	1.75E+02	2.30E+06	1.19E+03	2.91E+06	1.17E+07
0.75	1.83E+02	2.41E+06	1.25E+03	3.04E+06	1.22E+07
0.78333	1.92E+02	2.52E+06	1.30E+03	3.18E+06	1.28E+07
0.81667	2.00E+02	2.62E+06	1.36E+03	3.31E+06	1.33E+07
0.85	2.08E+02	2.73E+06	1.41E+03	3.45E+06	1.38E+07
0.88333	2.16E+02	2.84E+06	1.47E+03	3.58E+06	1.44E+07
0.91667	2.24E+02	2.95E+06	1.52E+03	3.72E+06	1.49E+07
0.95	2.32E+02	3.05E+06	1.58E+03	3.85E+06	1.55E+07
0.98333	2.41E+02	3.16E+06	1.63E+03	3.99E+06	1.60E+07
1	2.45E+02	3.21E+06	1.66E+03	4.06E+06	1.63E+07

❖ Total Maximum shear stresses for all body track and for switch rail



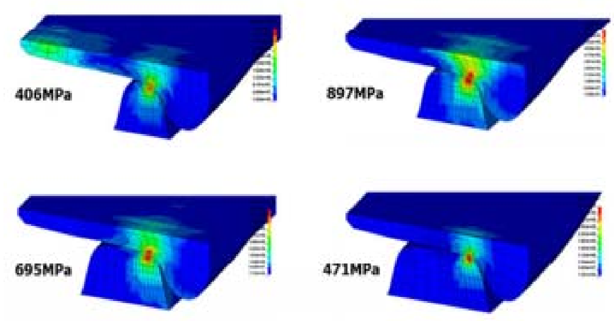
time [s]	Minimum [MPa] [straight lock rail]	Maximum [MPa] [straight lock rail]	Minimum [MPa] [curved lock rail]	Maximum [MPa] [curved lock rail]	Maximum shear [MPa] [on ISW rail]
2.50E-02	3.44E-06	4.20E-02	0.00E+00	5.19E-02	2.20E-01
5.00E-02	6.88E-06	8.40E-02	0.00E+00	1.04E-01	4.40E-01
8.33E-02	1.15E-05	1.40E-01	0.00E+00	1.73E-01	7.34E-01
0.11667	1.61E-05	1.96E-01	0.00E+00	2.42E-01	1.03E+00
0.15	2.07E-05	2.52E-01	0.00E+00	3.12E-01	1.32E+00
0.18333	2.52E-05	3.08E-01	0.00E+00	3.81E-01	1.61E+00
0.21667	2.98E-05	3.64E-01	0.00E+00	4.50E-01	1.91E+00
0.25	3.44E-05	4.20E-01	0.00E+00	5.19E-01	2.20E+00
0.28333	3.90E-05	4.76E-01	0.00E+00	5.89E-01	2.49E+00
0.31667	4.36E-05	5.32E-01	0.00E+00	6.58E-01	2.79E+00

0.35	4.82E-05	5.88E-01	0.00E+00	7.27E-01	3.08E+00
0.38333	5.28E-05	6.44E-01	0.00E+00	7.97E-01	3.38E+00
0.41667	5.74E-05	7.00E-01	0.00E+00	8.66E-01	3.67E+00
0.45	6.20E-05	7.56E-01	0.00E+00	9.35E-01	3.96E+00
0.48333	6.66E-05	8.12E-01	0.00E+00	1.00E+00	4.26E+00
0.51667	7.11E-05	8.68E-01	0.00E+00	1.07E+00	4.55E+00
0.55	7.57E-05	9.24E-01	1.00E-03	1.14E+00	4.84E+00
0.58333	8.03E-05	9.80E-01	1.00E-03	1.21E+00	5.14E+00
0.61667	8.49E-05	1.04E+00	1.00E-03	1.28E+00	5.43E+00
0.65	8.95E-05	1.09E+00	1.00E-03	1.35E+00	5.72E+00
0.68333	9.41E-05	1.15E+00	1.00E-03	1.42E+00	6.02E+00
0.71667	9.87E-05	1.20E+00	1.00E-03	1.49E+00	6.31E+00
0.75	1.03E-04	1.26E+00	1.00E-03	1.56E+00	6.60E+00
0.78333	1.08E-04	1.32E+00	1.00E-03	1.63E+00	6.90E+00
0.81667	1.12E-04	1.37E+00	1.00E-03	1.70E+00	7.19E+00
0.85	1.17E-04	1.43E+00	1.00E-03	1.77E+00	7.48E+00
0.88333	1.22E-04	1.48E+00	1.00E-03	1.84E+00	7.78E+00
0.91667	1.26E-04	1.54E+00	1.00E-03	1.90E+00	8.07E+00
0.95	1.31E-04	1.60E+00	1.00E-03	1.97E+00	8.36E+00
0.98333	1.35E-04	1.65E+00	1.00E-03	2.04E+00	8.66E+00
1	1.38E-04	1.68E+00	1.00E-03	2.08E+00	8.80E+00

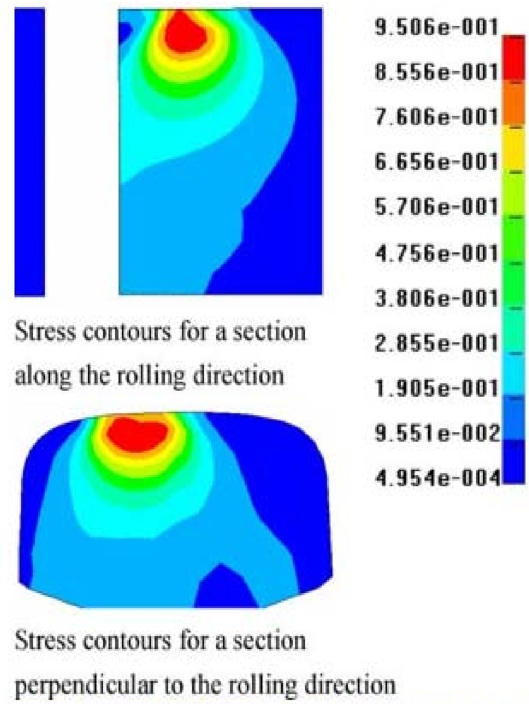
[7] VERIFICATION OF ISW RAIL

1) The total equivalent stresses of ISW rail model for straight and curved lock rail track from ANSYS software are 3.2136MPa and 4.058MPa in addition to this, on switch rail, the stress become 16.277MPa which are less than 222mpa of allowable bending stress shown in figure below[35,36]. These shows, ISW rail section is much adequate for the given stress value

c

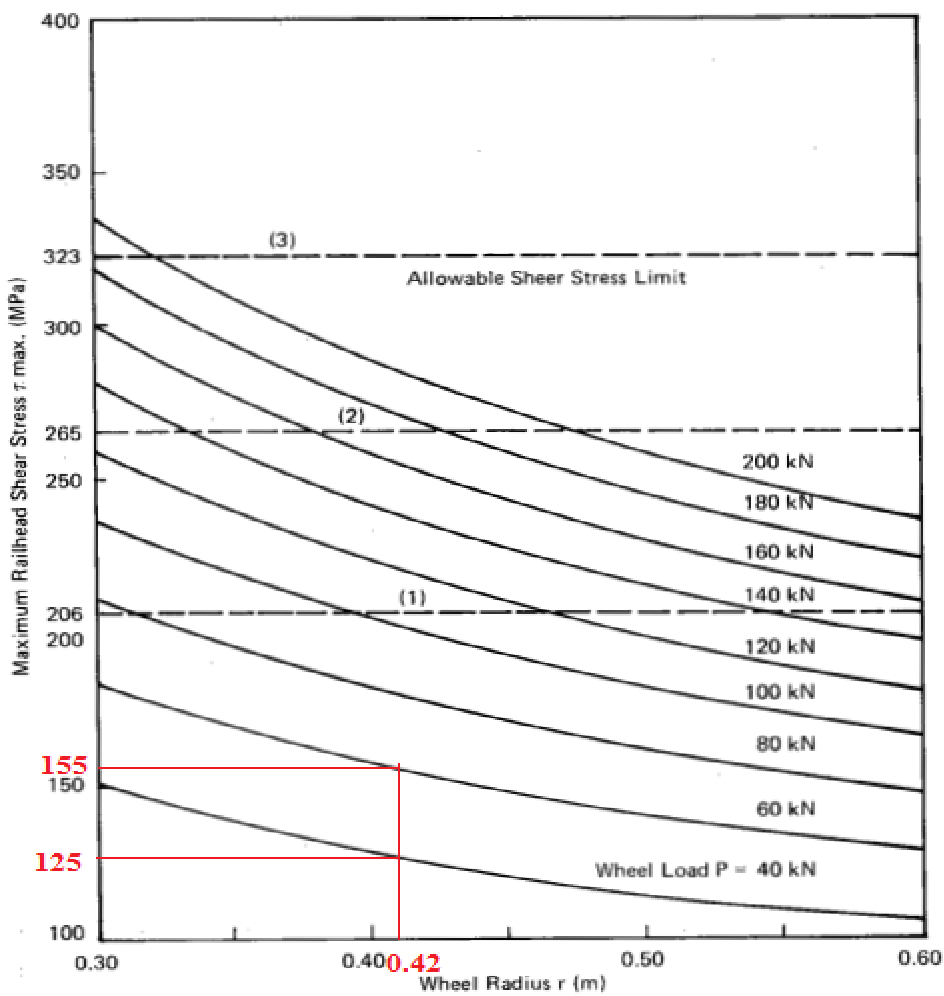


von mises stresses at diffrent location

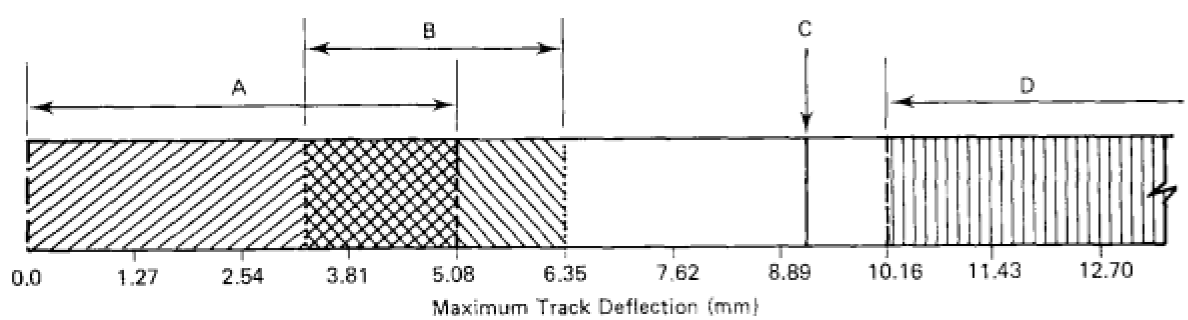


von mises effective stress contoures at the instant when the effective stress reaches the peak value (unit : GPa)

2) According to shear parameter, from the allowable Maximum shear stress graph, For given 0.42 wheel radius and for 55KN design wheel load, the allowable shear stress are 140MPa shown in graph below[34] and the maximum allowable shear limit from analytical one is 293.85MPa. But, in case of ISW rail model for straight and curved lock rail, the result are shows 1.6802MPa and 2.0779MPa shear stress in all inside track body and 8.8MPa on switch rail . These means that, ISW rail section adequate enough for the required shear stresses on the rail head.



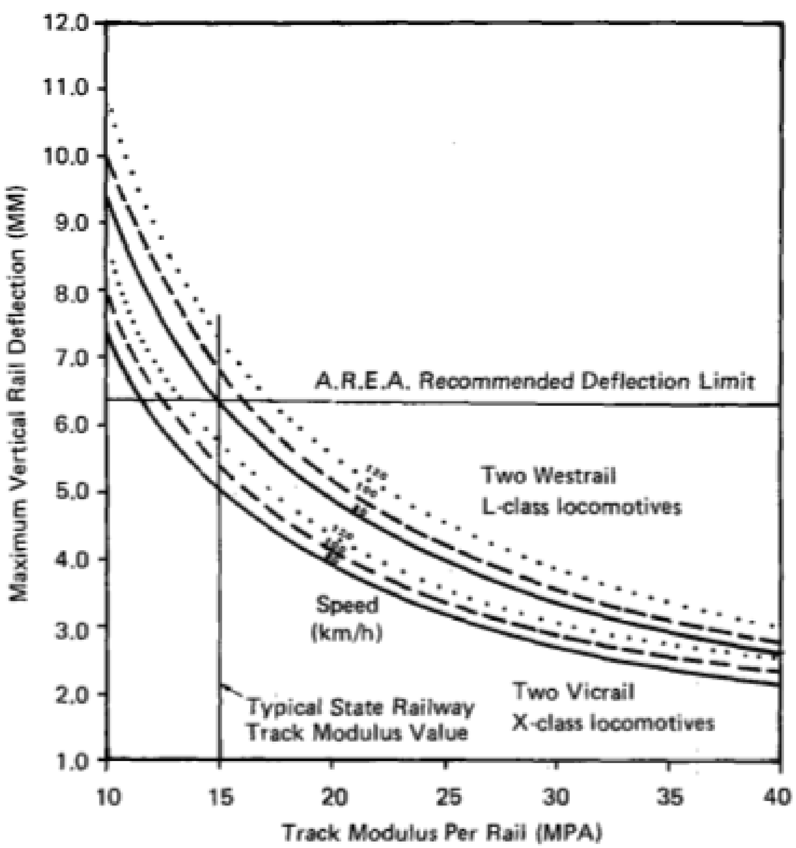
3) According to deformation, ISW rail shows 0.12mm and 0.123 mm vertical deflection in all inside track body model and 3.14mm on switch rail model , this value from Lundgren and his colleagues vertical rail deflection diagram mean that, in range A, shown in figure below. This indicate that, the given track stiffness and rail section are sufficient for the design maximum load. These result also less than form 6.35mm AREMA maximum vertical rail deflections.



- A: Deflection range for track which will last indefinitely.
- B: Normal maximum desirable deflection for heavy track to give requisite combination of Flexibility and stiffness.
- C: Limit of desirable deflection for track of light construction (with rails weigh < 50 kg/m)
- D: Weak or poorly maintained track which will deteriorate quickly.

Note: values of deflection are exclusive of any looseness or play between rail and plate or plate and sleeper and represent deflections under load.[34]

AREMA recommended deflection graph [34]



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