Evaluation of Dynamic Behavior of Tire on Concrete Pavement: A Case Study of Yamuna Expressway

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Abstract

The rigid pavement design has given higher speed but has somehow compromised in the surface friction part too and to balance this part, there hasbeenaprovisionofhighertexturedepthswhichhasgivenbettergripingvalueboth in dry and wet conditions. But now it has come into notice that there is a tirebursting phenomenon that is occurring in the rigid pavement, hence this paper has analyzed the amount of energy that is contributed by the higher texture depths into the rollingtires. This essay aims to assess the energy generated when a tyre rolls on a firm pavement surface, how it is transferred into the environment, and how some of it is absorbed by the tyre itself. This paper will place more attention on the energy generated as a result of the pavement's textures, leaving out any energy lost as a result of other factors.Textureprovidedonthepavementisbasicallya series of repeating figures drawn transverse to the moving direction in order to attain adesiredvalueofskidresistanceandfrictionsoastoavoidskiddinginanycondition. Butinviewofthisthereisanabruptincreaseintheamountof energybeingproduced andthisiscausingtheproblemoftirebursting.Sofortheanalysistestswereconducted atthesiteandtheinitialandthefinalpressureofthetireswerenoteddown.Thekinetic theory of gases has given the kinetic energy of the enclosed gas before the test and after the test. Since there is an increase in the pressure of the tires hence using Gay Lussac's law we concluded there will be an increase in the temperature also hence final temperature was calculated. Friction analysis and the contact area patch analysis has also given the reasons why low inflation pressure and the poor quality of the tires can lead to the tire bursting phenomenon .There has not been a lot of research going on regarding this issue but research paper related to few key problems involved in this study on combining will pave the foundation for the advance research on this issue.

Key word : Texture , Skid resistance, Inflation ,Tire dynamic , Energy distribution

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1.INTRODUCTION

In India, The two types of pavement that are installed are rigid pavement and flexible pavement. A flexible pavement is just a pavement layer that has been laid and compacted over a bed of granular layer and is composed of heated, properly mixed aggregates and bitumen. On the other hand, rigid pavements are constructed from slabs of cement concrete or reinforced concrete that are either set over a layer of low strength concrete (dry lean concrete, or DLC), or on top of a layer of compacted aggregates, or both.

Till now, Because of the lower starting expenses, flexible pavement has become more popular than rigid pavement. However, the government's choice of stiff pavement is being seen as a wise one given the country's expanding cement availability and the rising prices of bitumen. Limestone is a plentiful source of raw materials for the cement industry in India, hence no foreign exchange is needed. Main ingredient of flexible pavement mix is bitumen which is a byproduct of refinery. Raw material for refinery is crude oil, majority of which have been imported from oil exporting countries and no huge amount of foreign currency are required.

The decision of rigid pavement, taken after considering factors related to service life, fuel consumption, weather conditions, maintenance costs and natural resources, primarily aims to promote environment friendly construction practices in execution of road projects.

Without a doubt, hard pavement is more expensive up front than flexible pavement. However, rigid pavement has proven to be more cost-effective than flexible pavement in terms of lifecycle costs.

For areas with frequent downpours, flooded areas, and subgrade soil with low CBR (California Bearing Ratio) values, rigid pavement is typically selected.The stability of the roadway surface is very important aspect in the design of the pavementandshouldbenon-yieldingtoallowtheheavywheelloadsoftraffictomove with minimum possible rolling resistance. The surface of road should also beuniform along the longitudinal profile so as to provide the fast moving vehicles move safely and comfortably at the design speed. The primary goal of a well-designed and built pavement is to have elastic deformation that is within allowable bounds so that the road can withstand several repetitive load applications throughout the course of its design life.

1.2 BURSTING OFTIRES

This is one of the frequent contributing factors in accidents on the main highway and expressway networks. A tire often bursts when there is a sudden loss of pressured air from inside the tyre.When there is a compromise with respecttothestructuralintegrityofthetire,thetireisunabletoholdallthatairinside. Due to this situation, the pressurized air escapes out tearing apart the tire and rapidly causing an explosion and severe damage to the tire surface. The major causes of the tire burst are listedbelow:

1.2.1 DIRECT IMPACT- Due to the poor condition of the pavement surface there is a high possibility of a direct impact of the tire resulting in slashing of the tire surface at some point which becomes an open invitation for all the pressurized air to escape out thus leading to tireburst.

1.2.2 HIGH TEMPERATURE- Since most of India lies in the tropical or a subtropical region so it is prone to hot weather resulting in high temperatures and in general heat is the enemy for different parts of the vehicle especially the tire. Due to high temperature there is an excessive build-up of heat in the tires and this increase in temperature inside the moving tire results in an increase in the pressure within the tire. The friction between thepavement surface and the moving tire helps this process and weakens the tirewhich may result in bursting of tires due to this heatbuild-up.

1.2.3 UNDER INFLATION- Another one of the major causes of the bursting of the tires, Over inflation is not of a major concern under inflation is the reason behind more than 75 % of tire burst induced accidents. Such under-inflation tires suffer from excessive flexing and that increases the contact patch with the pavement surface which leads to the accumulation of excessivefrictionalforceandinturnbuildsuptheheatinsidethetire.The building up of heat is much higher than those induced during the hot summer.

1.2.4 HIGH SPEED- Every tire is meant to function best at a particular speed and there is a maximum speed that the tire can hold. Beyond the particular speedwillincreasethefrictionlevelsandwearquicklysointhiscasemore than one factors are responsible for the bursting oftires.

1.2.5 Concrete pavement have two engineering parameters which govern movement of vehicles on the road.

1.2.5.1 SKIDDING-Accidents occur on concrete pavement due to smoothness of travelling surface.Rear vehicle collides front vehicle specially in wet season when breake is applied and water over surface acts as lubricant between wheel and pavement surface.To make pavement surface skid resistance,textures are provided over surface. Though travelling surface become skid resistance by providing texturing and accident has been avoided.

1.2.5.2 ENERGY PRODUCED- Huge quantity of extra energy are produced due to texturing on the surface in form of heat.Major part of heat are diffused in environment which causes some environmental impact.some part of heat are transmitted inside tire through wheel of the vehicle and increased temperature of the air inside tire. The increase in temperature in tire increases pressure of air inside tire.Finally,tire bursts causes a vital accident when travelling time is more.

2.LITRATURE REVIEW

2.1 TIRE DYNAMIC:

Thetireisthemaincomponentofavehicleinteractingwiththeroad.The performance of a vehicle is mainly influenced by the characteristicsof its tires. Tires affect a vehicle's handling, traction, ride comfort, andfuelconsumption.Tounderstanditsimportance,itisenoughtorememberthatavehiclecan maneuveronlybylongitudinal,vertical,andlateralforcesystemsgeneratedunderthetires. systemsgeneratedunderthetires.

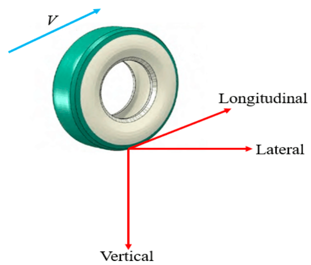


Figure1. Threeorthogonaldirectionsofcontactstresses.

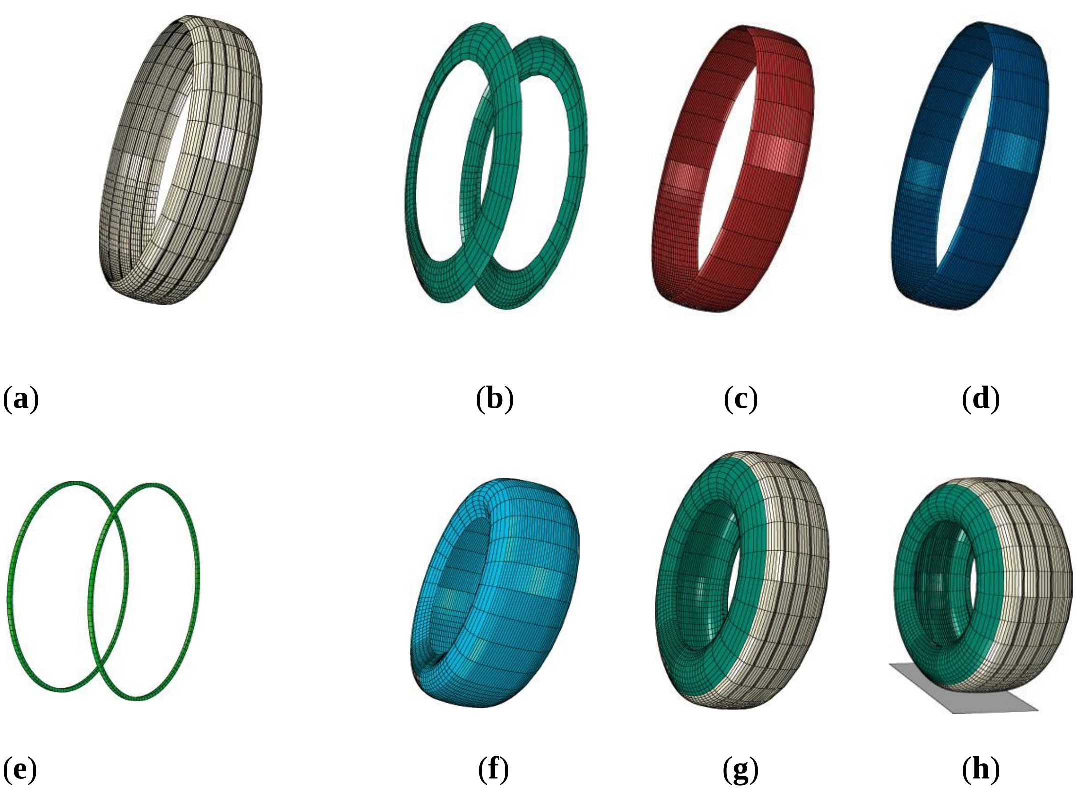


Figure 2. Meshesoftirecomponents. (**a**)Treadwithfourlongitudinalgrooves;(**b**)sidewall;(**c**)steel-belt-1;(**d**)steel-belt-2;(**e**)bead;(**f**)carcass;(**g**)fulltire;(**h**)thecontactmodeloftire–pavement.

Loadedtire *Tire axis*

Groundsurface

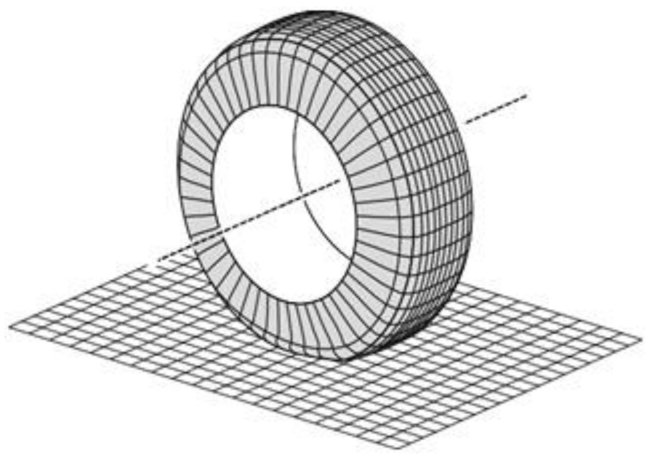


Figure3Averticallyloadedstationarytire.

3.2 TIRECOORDINATEFRAMEANDTIREFORCESYSTEM

To describe the tire-road interaction and its force system, we assume aflat ground and attach a Cartesian coordinate frame at the center of thetireprint as shown in Figure 3. The x-axis is along the intersection lineof the tire-plane and the ground. The tire plane is the plane made bynarrowing the tire to a flat disk. The x-axis is perpendicular to the groundandupward,andthex-axismakesthecoordinatesystemaright-handtriad.

To show the tire orientation, we use two angles: camber angle ç andsideslipangle .Thecamberangleistheanglebetweenthetire-planeand theverticalplanemeasuredaboutthex-axis.Thecamberanglecanberecognized better in a front view as shown in Figure 2.(d). The sideslipangle , or simply sideslip, is the angle between the velocity vector v andthex-axismeasuredaboutthex-axis.Thesideslipcanberecognizedbetterinatopview,asshowninFigure2.(e).

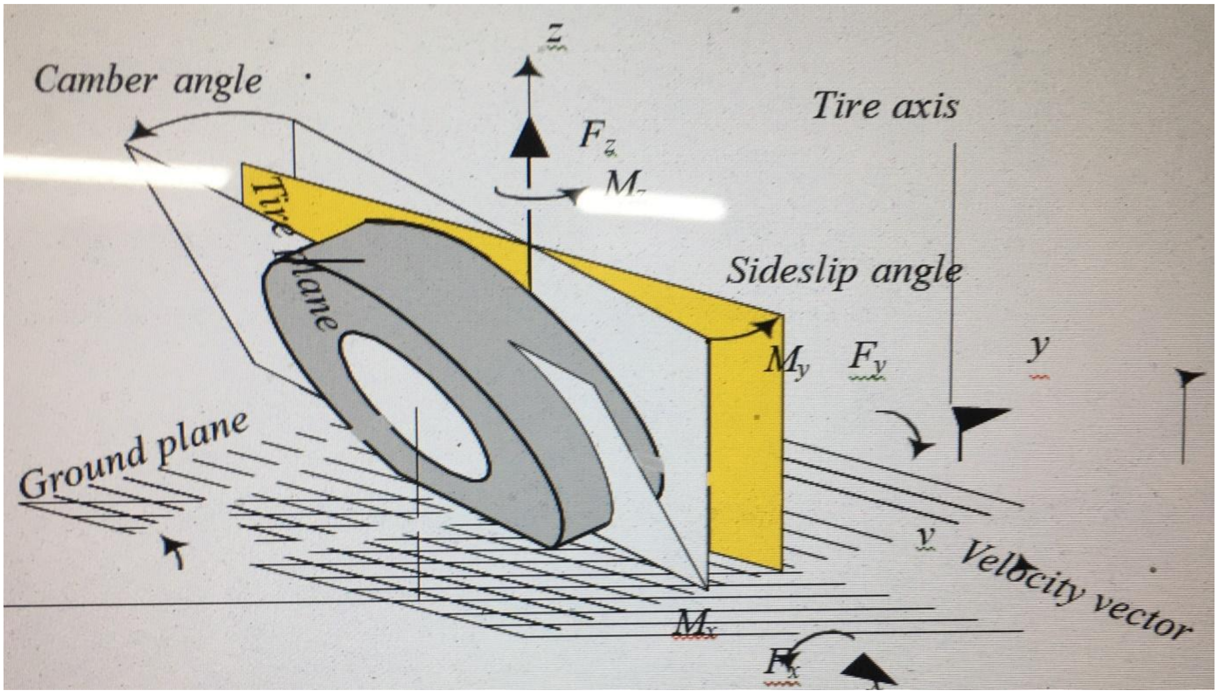


Figure4Tirecoordinatesystem.

It is considered that the resultant force system a tyre experiences from the ground is situated in the middle of the tyre print and can be divided along the x, y, and z axes. As a result, Figure 4 illustrates the three-dimensional (3D) force system created by a tire's interaction with the road. This system consists of three forces and three moments.

1. Longitudinal force -Itistheforceactingalongthex-axis.The resultantlongitudinalforce comes in both cases accelerating or breaking Longitudinal force is also called forwardforce.

2. Normal force-Itistheverticalforceacting alongthex-axisnormaltothegroundplane. Theresultantnormalforce
a c t s inupward.Thetraditionaltiresandpavementsareunabletoprovidethis
force.Normalforceisalsocalledverticalforceorwheelload.

3. Lateral force-.Itistheforce,tangenttothegroundandorthogonal toboth forces acting in x-and y-direction.Theresultantlateralforce actswhenitisin they-and z- direction.

4. Rollmoment -It is a longitudinal moment about x-axix.The resultant roll moment acts when it tends to turn the

tire.Therollmomentisalsocalledthebankmoment,tiltingtorque,oroverturningmoment.

5. Pitch momentP_y -. The lateral moment about the y-axis is what it is. The tire is moved forward and turned about the y-axis by the resulting pitch moment. The rolling resistance torque is another name for the pitch moment.

6. Yaw moment-. It is the z-upward axis's moment. When it tends to rotate the tire about the z-axis, the resulting yaw moment acts. The aligning moment, self-aligning moment, and bore torque are other names for the yaw moment.

These are the systems of force that the ground applies to the tire. The wheel axle is the location of all additional forces on a wheel. Wheel torque is the driving or braking force applied to the tire by the vehicle around the tire axis.

3.3 ENERGY DISTRIBUTION:Forcarspoweredbyclassicalcombustionengines,onlyabout10%to20%ofthechemicalenergystoredinthefuelisavailableasmechanicalenergyattheaxlestodrivethewheels,theremainderbeingconsumedby engine inefficiency, friction in the driveline, standby operation or auxiliary appliances (e.g.the A/Csystem) . Ultimately, these 10 % to 20 % are consumed by aerodynamic drag, rolling resistance and braking/acceleration. Depending on the driving conditions, approximately 4 % to 7 % of the fuel consumption are based on rolling losses in the tires, see . For trucks and other heavy vehicles, the influence is evenhigher.

Hence, a decrease in the energy losses caused by rolling resistance has a significant chance of decreasing a vehicle's overall fuel usage. A 10% decrease in average rolling resistance, for instance, "promises a 1 to 2 percent boost in fuel economy," according to the Transportation Research Board of the United States. This translates to a 3.7 109 l to 7.5 109 l decrease in overall annual fuel usage for the United States.About 80 % to 95 % percent of rolling losses can be attributed to hysteretic losses in the tires , i.e.The viscoelastic characteristics of the tyre material are the foundation for the dissipation. Changing the tread geometry, the rubber compound, or reducing the thread thickness are all potential strategies to reduce rolling resistance because the majority of dissipation is connected to deformation of the tread's rubber material. However, any modification to a single tyre parameter affects not only rolling losses but also vital elements like wear, traction, and noise production.

Thisisaproblemwhichisevenintensifiedbythecomplextirestructurewith inhomogenous and anisotropic material properties.Knowledge about how the hysteretic losses aredistributedinthestructureofatirerollingonanactualroadandwhichvibrationalmodescontributemostlytotheselossescanhelptomakedesigndecisionsfortireswithalowrollingresistance.

3.4 FUNDAMENTALSOFROLLINGRESISTANCEANDPREDICTIONMETHODS

1. Generally, rolling resistance is defined as the mechanical energy converted into heat for a unit distancetravelled,withaunitofJ/m.Traditionally,This has been connected to an N-unit drag force that opposes the motion. The more inclusive energy-based definition will be utilized in the

2. following because it appears more relevant for the context of this investigation. This also permits the expression "rolling loss" to be used as a synonym for "rolling resistance."As mentioned before, the majority of the rolling loss can be attributed to hysteresis.

During rolling, the tire material is periodically deformed. Due to the viscoelastic properties of the rubber compound, in each cycle not all of the stored elastic energy can be regained, instead a part of it is dissipated. The primary reason a rolling tyre deforms is the flattening of the contact patch, which causes the crown, sidewalls, and bead area to bend, the tread to be compressed, and the sidewall and tread to be sheared.The viscoelastic properties of the rubber compound are highly temperature and frequent dependent .Additionally,therollingresistanceshowsamoreorlessprominentdependenceonavarietyoffeaturessuchastireload,tiregeometry,tirepressure,drivingspeed,(road)surfacegeometry, conditionandroughness,etc.

3. The technique is based on the idea that local potential energy plus local loss factors combine to determine how much energy is dissipated within a structure. Thus, rolling loss and potential energy are mutually exclusive. The approach does not currently attempt to calculate precise numbers for the energy dissipated.

4. Thisisduetothefactthatthiswouldrequirefullknowledgeaboutthelossfactorinspecificregions of the tire, which is not available in the necessary detail level.Although almost all tyre models

include some assumptions about the tire's loss factor characteristics, these values differ significantly between models, and it is thought that successful simulation results for some cases (such as calculations of point and transfer mobility) do not necessarily indicate exact loss factor assumptions, especially not on a more local level.

5. A notable effort at estimating viscoelastic details for a tire structure is made in , howeverthe employed process is quite tedious and requires dedicated measurements of the specific
tire.Hence,dissipationwillbeassumedtobebasedonasetofrathergloballossfactorassumptionsforthetimebeing.

4.DATA COLLECTION :

4.1 TIRE THICKNESS AND TEMPERATURE DIFFERENCE

Sr N	Type of tire	Tire Thickness	Temperature at outer face	Temperature at inner face	Temperature difference
1	Bus	8mm	21	23.50	2.50
2	Truck	9mm	25	29.50	4.50
3	Truck	8mm	22	26.00	4.00
4	Bus	9mm	32	36.60	4.60
5	Car	6mm	24	26.20	4.20
6	Car	6mm	36	41.00	5.00
7	Car	5mm	40	44.50	4.50

4.2 MEASUREMENT OF TEXTURE

SN	CHAINAGE	Distance from base line	Greater Noida to Etmadpur	Etmadpur to Greater Noida
			Texture deoth in mm	Texture deoth in mm

			Right	Center	Left	Right	Center	Left
1.	14.400	0	4	3	3	4	3	3
		12	3	2	4	3	3	2
		16	3	3	3	3	3	2
		14	5	4	3	4	2	4
		16	3	2	4	2	4	3
		13	4	3	3	3	3	4
		15	2	3	4	3	2	3
		17	3	3	2	4	4	4
		11	3	4	3	3	3	3
		16	3	4	3	3	3	2
		13	2	3	4	2	3	4
		14	4	2	4	4	4	3
		15	3	3	3	3	2	2
		14	2	3	4	2	3	3
		12	3	3	3	4	3	4

4.2. MEASUREMENT OF PRESSUE:

Date – 25/05/2021

Day time Temperature – 36 0

S N	**TIRE COMPANY**	**JOURNEY**	**JOURNEY**	**Average Speed**	**TYPE OF**		**FRONT**	**REAR**	**INITIAL Tire Pressure**		**Final Tire Pressure**	
									Front axle	**Rear axle**	**Front axle**	**Rear axle**

								Right	Left	Right inner	Right outer	Left inner	Left outer	Right	Left	Right inner	Right outer	Left inner	Left outer
1	GOODYEAR	10.30	12.20	90	car	1	1	33	34	34	33	33	33	48	47	44	45	44	44
2	GOODYEAR	10.35	12.25	82.5	jeep	1	1	32	34	33	33	33	34	46	44	45	47	44	45
3	GOODYEAR	10.40	12.55	73.33	Mini Truck	1	1	-	-	-	-	-	-	-	-	-	-	-	-
4	GOODYEAR	10.45	12.45	82.5	Truck	1	1	33	33	35	34	35	33	47	44	47	45	45	46

4.3.MEASUREMENT OF PRESSUE :

Date – 26/05/2021

Day time Temperature – 36 0

2	**FIRESTONE**	**10.35**	**12.25**	**82.5**	**jeep**	**1**	**1**	**33**	**35**	**33**	**34**	**33**	**34**	**46**	**44**	**45**	**47**	**44**	**45**
3	**FIRESTONE**	**10.40**	**12.55**	**73.33**	**Mini Truck**	**1**	**1**	**34**	**35**	**34**	**33**	**33**	**33**	**45**	**48**	**47**	**46**	**45**	**46**
4	**FIRESTONE**	**10.45**	**12.45**	**82.5**	**Truck**	**1**	**1**	**36**	**33**	**35**	**34**	**32**	**33**	**43**	**46**	**47**	**45**	**46**	**47**

4.4 LUCKNOW PRAYAGRAJ ROAD (FLEXIBLE PAVEMENT)

Date – 29/05/2021

Day time Temperature – 36 0

Length covered : 165 km

SN	**TIRE COMPANY**	**JOURNEY START TIME**	**JOURNEY FINISH TIME**	**Average Speed**	**TYPE OF VEHICLE**	**FRONT AXLE**	**REAR AXLE**	**Initial Tire Pressure**		**Final Tire Pressure**	
								Front axle	**Rear axle**	**Front axle**	**Rear axle**

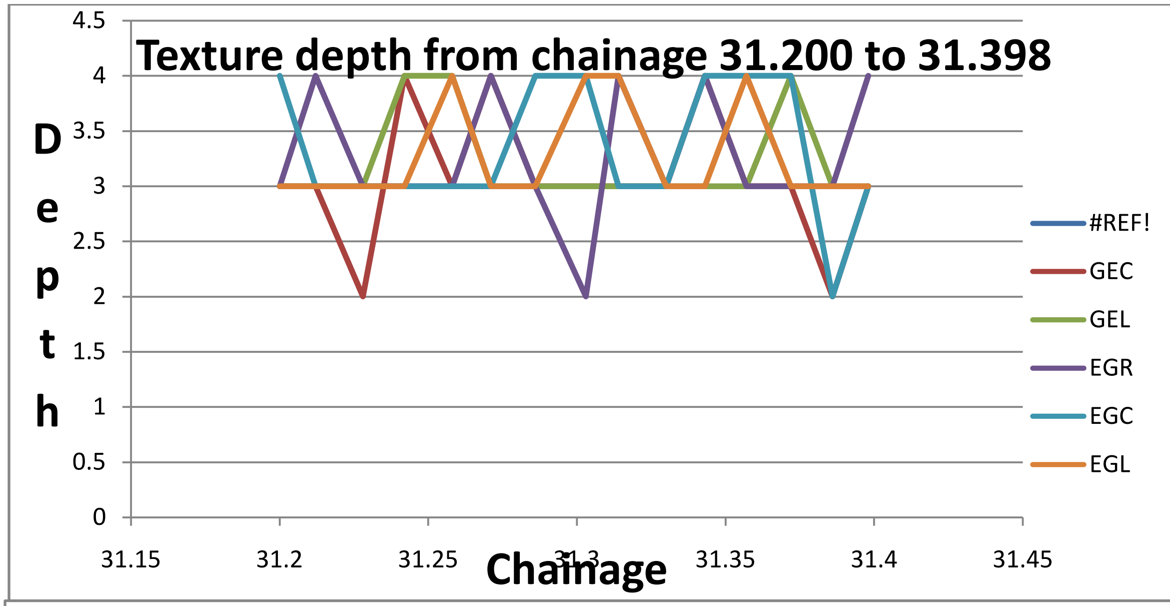
								Right	Left	Right	Right	Left	Left	Right	Left	Right	Right	Left	Left
1	**MRF**	**8.30**	**10.50**	**71**	**car**	**1**	**1**	**32**	**33**	**33**	**34**	**31**	**32**	**39**	**41**	**40**	**40**	**39**	**40**
4	**APOLLO**	**8.25**	**12.10**	**44**	**Truck**	**1**	**1**	**31**	**34**	**32**	**33**	**32**	**31**	**38**	**40**	**38**	**39**	**38**	**40**

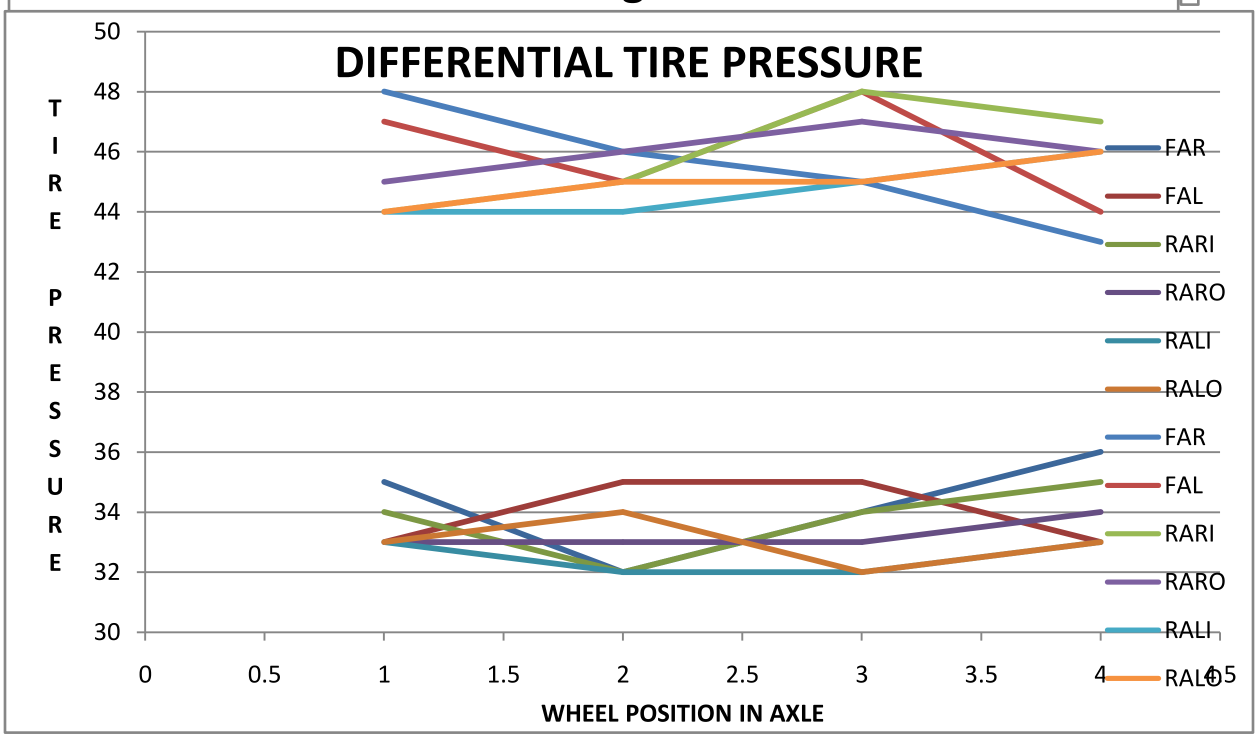
5. DATA ANALYSIS :

This graph has been prepared between type of pavement and pressure in tire after travelling of equal distance of 165km.

5.1 DATA FOR TIRE AGE,TREAD THICKNESS,PRESSURE DIFFERENCE AND DISTANCE TRAVEL

	Age	Temperatu	Thickne	Initial	Final	Dista	Remarks
1	3 ± 0.5	20 ± 0.5	6	28	37	165	Safely cross entire length of road
2	3 ± 0.5	20 ± 0.5	6	30	40	165	Safely cross entire length of road
3	3 ± 0.5	20 ± 0.5	7	32	43	165	Safely cross entire length of road
4	3 ± 0.5	20 ± 0.5	7	34	45	165	Safely cross entire length of road
5	3 ± 0.5	20 ± 0.5	6	36	48	165	Safely cross entire length of road
6	3 ± 0.5	50 ± 0.5	7	28	39	165	Safely cross entire length of road
7	3 ± 0.5	50 ± 0.5	6	30	44	165	Safely cross entire length of road
8	3 ± 0.5	50 ± 0.5	7	32	47	165	Safely cross entire length of road
9	3 ± 0.5	50 ± 0.5	7	34	49	165	Safely cross entire length of road
10	3 ± 0.5	50 ± 0.5	6	36	52	165	Safely cross entire length of road
11	3 ± 0.5	50 ± 0.5	6	38	55	165	Safely cross entire length of road
12	3 ± 0.5	50 ± 0.5	6	40	58	165	Safely cross entire length of road


Texture depth from chainage 31.200 to 31.398
Depth
Chainage
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
31.15
31.2
31.25
31.3
31.35
31.4
31.45
#REF!
GEC
GEL
EGR
EGC
EGL


DIFFERENTIAL TIRE PRESSURE
TIRE PRESSURE
WHEEL POSITION IN AXLE
50
48
46
44
42
40
38
36
34
32
30
0
0.5
1
1.5
2
2.5
3
3.5
4
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FAR
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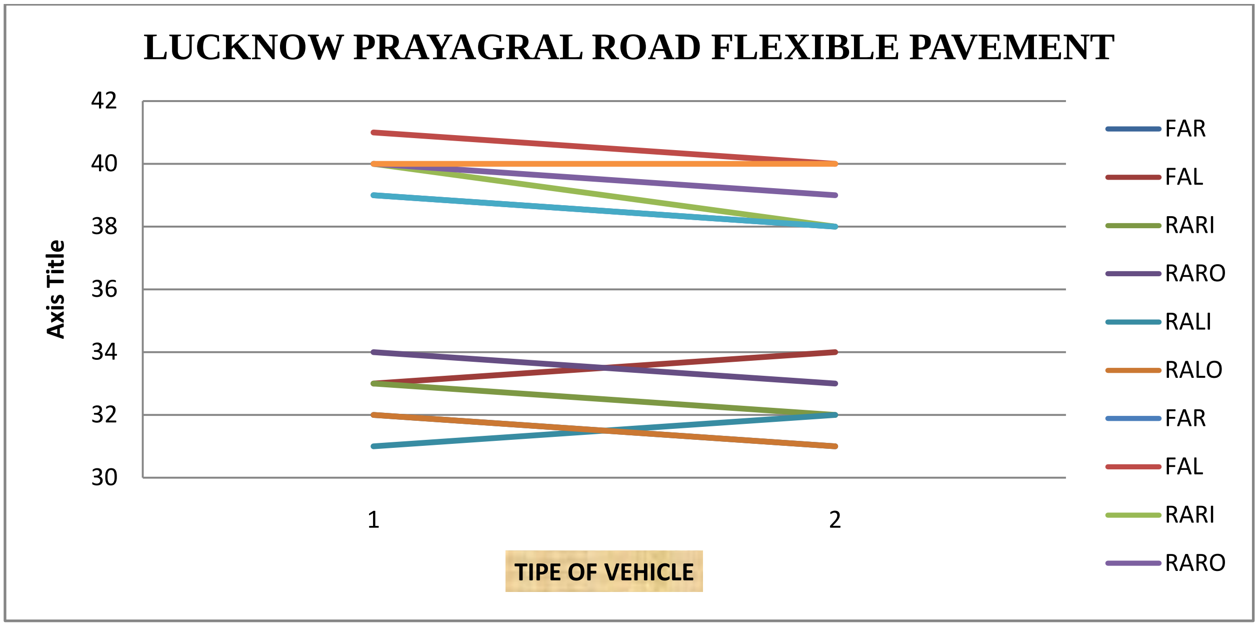
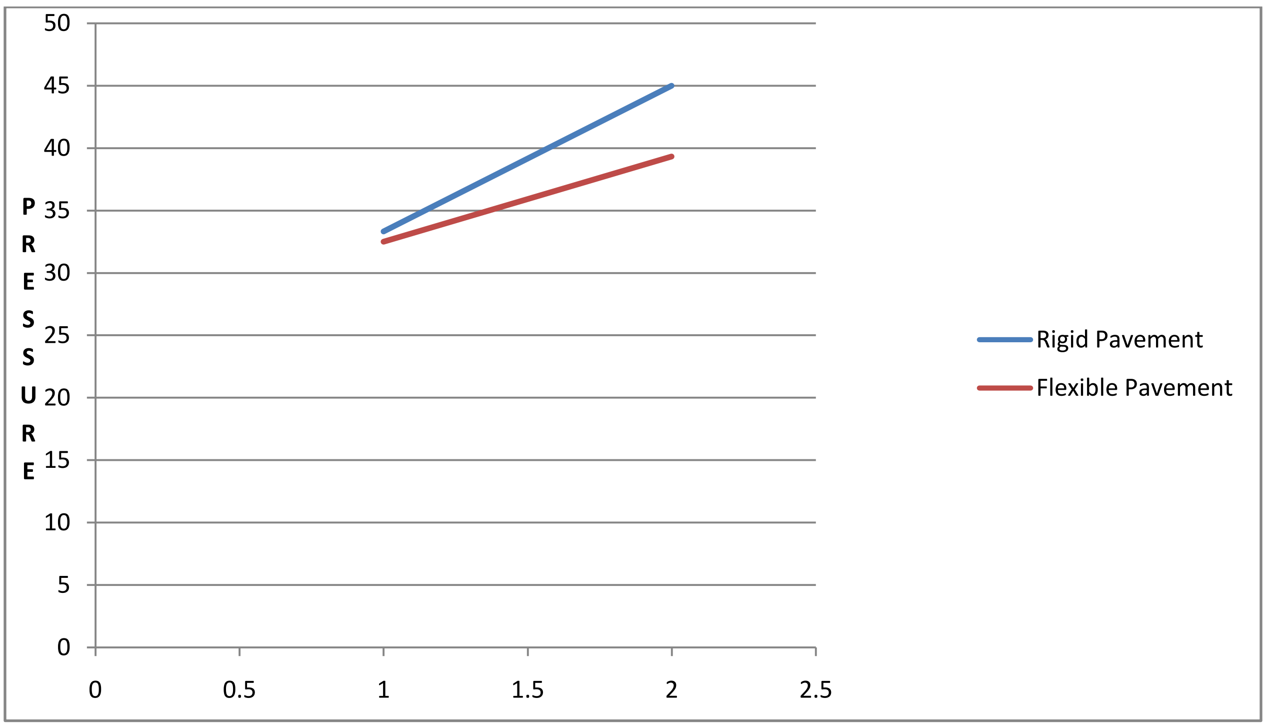
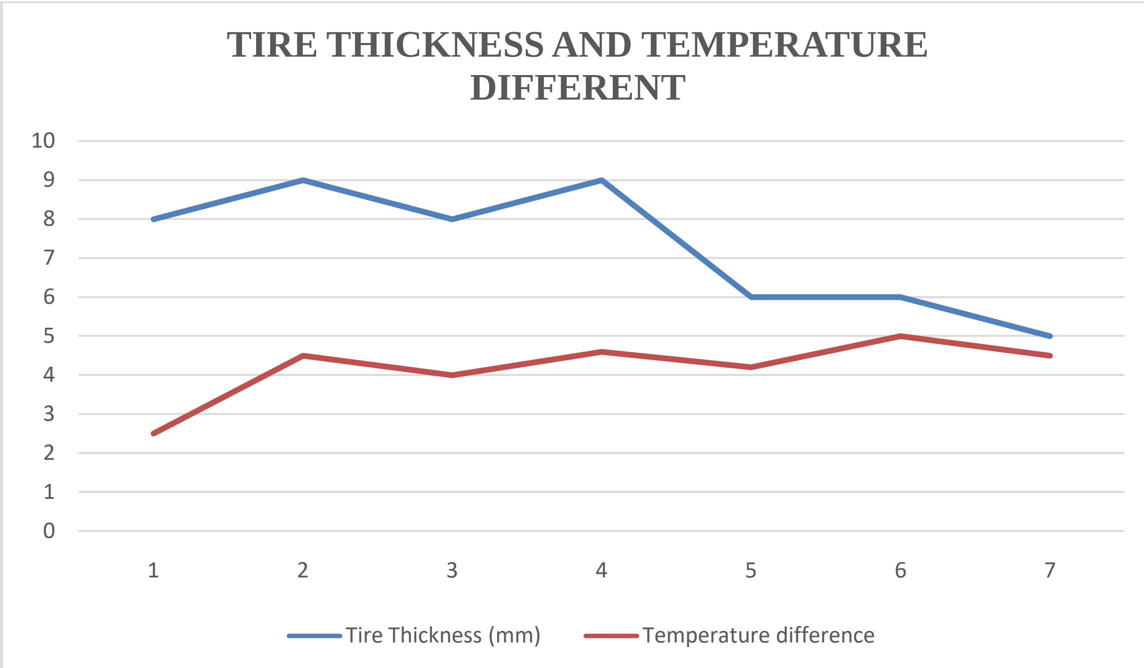




TEMPERATURE DIFFERENCE IN RIGID AND FLEXIBLE PAVEMENT



6.CONCLUSION:

The distribution of contact stresses and rolling resistance under various tyre operating situations, such as various tire loads, inflation pressures, and velocities, are predicted in this study using a three-dimensional tire-pavement model. In doing so, it is possible to examine how contact stresses at the tire-pavement interface change over time as well as the functional connection between rolling resistance and the circumstances in which truck- and bus-tires operate. Results indicate that rolling conditions affect the magnitude connection between transverse and longitudinal contact stresses, and that overload and low tire pressure are significant causes of tire shoulder
degradation.Inaddition,theproposedexponentialequationpresentsamethodthatcanbeusedtoforecastr ollingresistancerelatedtotheworkingconditionsofthetruck-
bustire,andasimilarmethodcanbeusedtopredicttherollingresistancesofothertypesoftires.

6.2.
Awayisshownhowtoassessrollinglossesbasedonthestrainenergydistributioninanexistingwaveguide finiteelementmodelofacartirewhichiscoupledwithaquasi-three-

dimensionalmodelforrollingcontact.PreliminaryresultsbasedonaspecificISOroadroughnessprofile areusedtoshowthegeneralapplicabilityofthisapproach.Theestimatedtotalrollinglossiscomparableto valuesfoundintheliteratureanddetailedexaminationofthefrequencyandwaveordercontentrevealthei mportanceofthecontactpatchsizeanda strong influence of a limited set of tire modes on the rolling resistance.In general, rolling resistanceseems to be a low-frequency, low wave order problem. The solid rubber elements seem to contribute lessto the dissipation as expected, which will be the topic of further investigations in the future.A necessaryimprovementisanaveragingoveralongersectionofroadroughnessprofilestoreducetheinflu enceofveryspecific local characteristics. This was only partly possible for this study due to time constraints. Furtherstudies will include evaluation of the influence of different conditions such as road profile, speed, loading,etc.ontherollinglossdistribution.

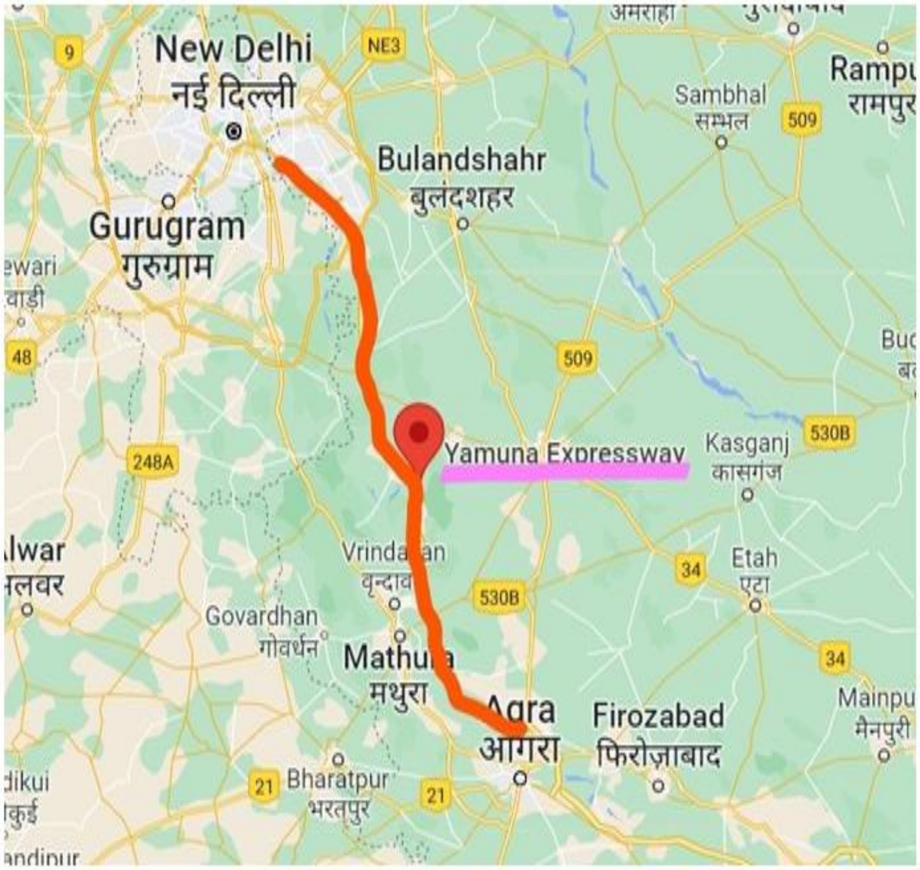
6.3. The tire-pavement contact model developed in this work shows the potential to predict contactstresses and rolling resistance under different rolling conditions.Based on the preceding analysis,thefollowingconclusionscanbemadeandprovidevaluablesuggestionsandviewpointsfortire –pavementcontactmechanicsandfuel-economictireproduction/design.

(1) The maximum value of the transverse contact stress is greater than the longitudinal contact stressunder the free-rolling condition. However, the situation under the full-braking condition istheopposite.

(2) Longitudinal contact stresses under the free-rolling and full-braking conditions were symmetricallydistributed in a longitudinal direction, while the lateral contact stress presented an almostantisymmetricdistributioninalongitudinaldirection.Underthefull-brakingcondition,longitudinalstressisthemaincomponentofthehorizontalcontactstresses.

(3) The tire load and inflation pressure have significant impacts on contact stresses. Overload andlow tire pressure are important contributors to the wear of the tire shoulder. Properly increasingtheinflationpressurecaneffectivelyrelievedamagetothetireshouldercausedbyoverloading.

YAMUNA EXPRESSWAY



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