Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Investigation on hydroplaning of vehicle tire on a wet road

Master's Final Degree Project

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Kaunas, 2019

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Vehicle Engineering (6211EX021)

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Kaunas, 2019

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Declaration of Academic Integrity

I confirm that the final project of mine, Saravanan Krishnasamy, on the topic „Investigation on hydroplaning of vehicle tire on a wet road" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

I fully and completely understand that any discovery of any manifestations/case/facts of dishonesty inevitably results in me incurring a penalty according to the procedure(s) effective at Kaunas University of Technology.

______________________________ ________________

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Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Study Programme – Vehicle Engineering 6211EX021

Task Assignment for Final Degree Project of Master Studies

Student – Saravanan Krishnasamy

1. Title of the Final Project:

Investigation on hydroplaning of the vehicle tire on a wet road

Transporto priemonės padangos akvaplanavimo tyrimas

2. Aim of the Final Project:

The main aim of the project is to analyse of the factors influencing hydroplaning of tire on the road filled with a thin film of water, and to determine the hydroplaning speed using computer-aided tools and comparing it with the numerically identified one using MSC patran and MSC dytran.

3. Tasks of the Final Project:

- Loss of traction in the tire when moving over a thin film of water.
- Prediction of hydroplaning speed helps in preventing hydroplaning.
- Identifying the factors that influences hydroplaning.
- Occurrence of hydroplaning at various vehicle speed.
- Influence of tire inflation pressure for the occurrence of hydroplaning
- CAD software – MSC Patran (Requirements)
- CAE software – MSC Dytran (Explicit analysis)
- Visualization application – Paraview 5.6.0

4. Structure of the Text Part:

- Indentified the factors that influences hydroplaning with the help of literature review by previous authors.
- Designed the model and analysed based on the factors that influence the hydroplaning and verified the results.

5. Consultants of the Final Project:

Author of the Final Project	Saravanan Krishnasamy	2017/11/02
	(Name, Surname, Signature, date)	
Supervisor of the Final Project	Vaidas Lukoševičius	2017/11/02
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Krishnasamy, Saravanan. Investigation on hydroplaning of vehicle tire on a wet road. Master's Final Degree Project supervisor Prof.Dr.Vaidas Lukoševičius; Faculty of mechanical engineering and design, Kaunas University of Technology.

Study field and area (study field group): Transport Engineering (E12), Engineering Science.

Keywords: Hydroplaning, Fluid-Structure interaction, Tire, Traffic safety, MSc Patran, MSc Dytran.

Kaunas, 2019. Number of pages.53

Summary

Prevention from the occurrence or cause of the accident is important in vehicle safety. In Lithuania every year thousands of people have impaired or loss their life on road crashes. Among the various causes of accidents hydroplaning is an important factor to be considered. The number of accidents caused due to hydroplaning has been increasing which is evident from the report (National Highway Safety Administration). Vehicles going on the wet road are agonized from hydroplaning due to loss of control over steering and braking. At the moment of travel, the vehicle tire on a wet road completely loss contact over the road and separated from it by a film of water are called hydroplaning. By the loss of contact of the tire, vehicle steering ability and braking capability is completely lost.

Computational models of hydroplaning tire on a wet road are prepared and evaluated to determine the critical hydroplaning speed and other factors through 3D models. The computational model is prepared, analyzed and visualized for better understanding of the phenomenon hydroplaning.

Krishnasamy, Saravanan. Transporto priemonės padangos akvaplanavimo tyrimas. Baigiamasis magistro laipsnis Projekto vadovas Prof.r.Vaidas Lukoševičius; Kauno technologijos universiteto Mechanikos inžinerijos ir dizaino fakultetas.

Studijų kryptis ir sritis (studijų krypčių grupė): Transporto inžinerija (E12), inžinerijos mokslai.

Reikšminiai žodžiai:Hidroplanavimas, skysčių struktūros sąveika, padanga, eismo saugumas, magistro studijos Patran, MSc Dytran.

Kaunas, 2019. Number of pages.53

Santrauka

Transporto priemonėse labai svarbi aktyvi sauga. Lietuvoje kasmet tūkstančiai žmonių žūsta ar susižaloja dėl avarijų keliuose. Tarp įvairių nelaimingų atsitikimų priežasčių, būtina atsižvelgti į padangų akvaplanavimą. Daug nelaimingų atsitikimų įvyksta būtent dėl akvaplanavimo. Važiuojančios drėgnu keliu, dėl agresyvaus vairavimo, transporto priemonės praranda stabdymo kontrolę. Važiavimo šlapiu keliu metu transporto priemonės padanga visiškai praranda kontaktą su keliu ir atskiriama nuo kelio vandens plėvele. Praradus padangos kontaktą, transporto priemonės valdymas ir stabdymas prarandamas visiškai.
Darbe sukurti ir skaičiuojami 3D padangų akpalanavimo modeliai, riedant padangai šlapiu keliu, siekiant nustatyti kritinį akvaplanavimo greitį ir kitus veiksnius, įtakojančius akvaplanavimo reiškinį.

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Abbreviations:

FSI- Fluid structure Interaction

ASD- Anti Skid depth

SPH- Smooth Particle Hydrodynamics

MSC – MacNeal-Schwendler Corporation

ALE – Arbitrary Lagrangian and Eulerian

Introduction

The hydroplaning collision of vehicles happens due to loss of friction of tire when the vehicle travels on a wet road. The vehicle that travels on a wet surface, losses friction due to a minimal level of contact over it which causes accidents. Hydroplaning collision is a important causes of traffic accidents. Weather condition mostly affects the conditions of the roads which has become a great potential to cause accidents with more damages and injuries. Inappropriately, the majority of driver's are unaware of hydroplaning and are very incautious about the weather. (1)From the National Highway Safety Administration report it is evident that the month at end of summer, autumn & winter season's high number of accidents occur due to stagnation of water on the road. (2)

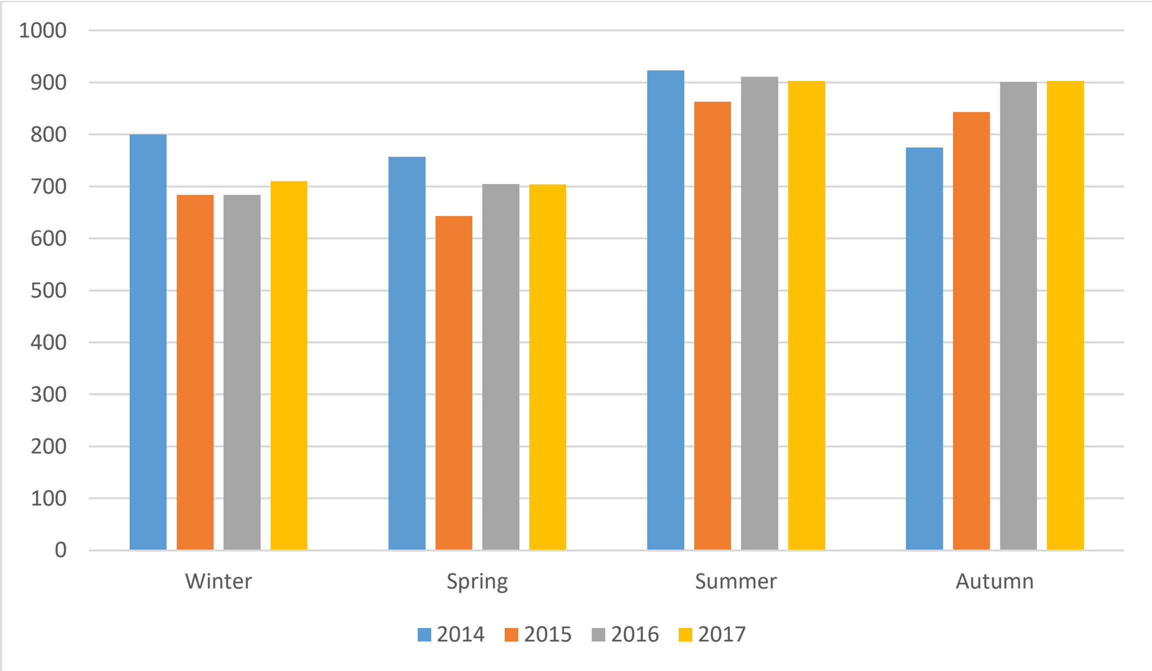


Fig. 1. Average no of accidents happened in Lithuania (3)

The graph (Fig.1) helps us to understand the average number of accidents happened at four different weather seasons on an account of four years. The thin layer of rainwater formed at the beginning of rain is dangerous because of the slippery environment. In the United States a year 6 million automobile accidents are happened, among that approximately around 1.5 million accidents are due to poor weather conditions. In that 1.6 million accidents, many of the accidents were happened due to hydroplaning. (4)

The road accident statistics show that 10 per cent of fatal crashes occurred due to the wet road during rainfall. In Texas, 28% of all accidents are categorized as occurred during rainfall or on a wet road. (5) Most people are not prepared for it, is the main reason behind not capable of controlling the occurrence of accidents. When the hydroplaning accidents happen at a mountain bends the situation is uncontrollable to avoid the huge damages.

Aim:

To analyse the factors influencing hydroplaning of tire on the road filled with a thin film of water and to determine the hydroplaning speed using computer-aided tools and comparing it with the numerically identified one.

Task:

- Loss of traction in the tire when moving over a thin film of water.
- Prediction of hydroplaning speed helps in preventing hydroplaning.
- Identifying the factors that influences hydroplaning.
- Occurrence of hydroplaning at various vehicle speed.
- Influence of tire inflation pressure for the occurrence of hydroplaning.

1. Hydroplaning

This phenomenon happens when a vehicle moves over a little profundity of water at a specific speed which is higher than the critical speed and the penetration of water between the tire and the road is called Hydroplaning. Amid the penetration of water between the tire and road, pressure on the water is made. This water pressure increments with an expansion in the speed of a vehicle. Hydroplaning happens with a couple of criteria like the speed of the vehicle, state of the road surface, water profundity out and about, tire inflation pressure, the tread pattern of the tire which are all the important purposes behind the reduce contact of tire on road. (5) When talking about it a microstructural view, under wet road conditions a hydrodynamic pressure is created on the main edges of road severities which prompt slipping activity of tire elastic thread in zones of gross slip. The expansion in hydrodynamic pressure lifts up the tire and the contact zone between smaller scale harshness of the road and the tire is decreased. This loss of contact region between the tire and the road makes the vehicle a low coefficient of friction and uplift forces which results in loss of braking capacity and control of the vehicle. (6)

1.1. Hydroplaning speed

At the point when a vehicle goes over a dainty film of water out and about, at a specific speed, the vehicle loss complete friction for braking or steering is called Hydroplaning speed or velocity. The hydroplaning speed isolates the tire from the road with the liquid uplift progressed underneath the tire that is same to wheel load. At that factor in time, there is no touch between the tire and the road surface, the tire-road contact force is decreased. Hydroplaning speed additionally can be expressed due to the proportion of hydroplaning capability of a wet road with a perceived water film thickness. The better the hydroplaning velocity brings down the hydroplaning ability. The hydroplaning speed depends both on vehicle qualities and characteristics, for example, the thickness of the water film out and about, road surface, tire pressure, tire pressure, load at the vehicle. (6) The hydroplaning velocity will increment with development in tire strain, expanding load and water film thickness.

1.2. Water depth on the road

When rainfall occurs the accumulation of water on road surfaces are due to the local rain and water flow. Moreover, water flows from a high slope to the lower surface. Numerous experimental studies have been done to indicate the water depth of the road surface which affects the skid resistance & hydroplaning speed. The essential water depth for the occurrence of hydroplaning depends on the size, number of escape channels provided by the road surface through surface unevenness and grooves or by an effective tire pattern which is present beneath the tire and delays the buildup of water pressure. (5)

1.3. Road texture

Hydroplaning is a physical phenomenon which happens on a wet road conditions and the safety data record reveals that the majority of accidents happens on the wet road whereas the accidents do not happen only in the rainy weather seasons in a year. So it is clear that the occurrence of accidents depends on a wet road, road characteristics & structure. A road characteristic consists of micro texture, macrotexture, the radius of curvature, longitudinal slope, cross fall, skid resistance etc. (6)

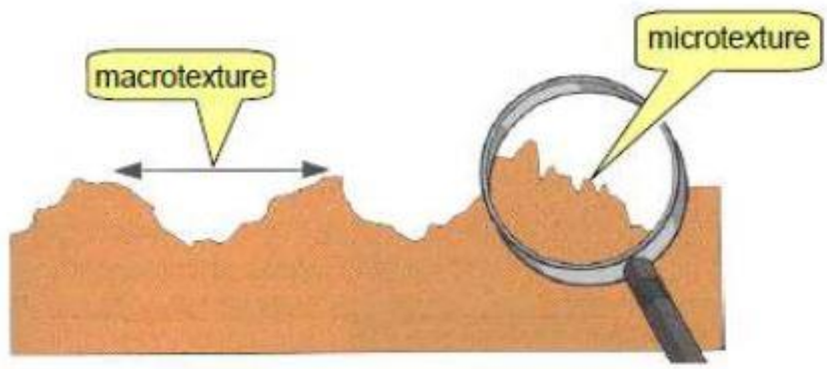


Fig. 2. Road pavement surface textures [6]

- **Microtexture**

Microtexture is a key element for the road surface with surface irregularities which include road profile not as good as 0.5 mm and vertical amplitude to 1 mm. It can be defined because of the choppy surfaces aggregates of gravel, sand, mortar that's in contact with tires rubber. (6) Microtexture is fashioned of diverse elements mixture from polish to harsh that's crucial for the development of frictional forces between the tire & road on wet surfaces. When a microtexture is loose from water, the value of the frictional forces increases with extended microtexture and it's miles elevated with the aid of a car travelling at low speeds. So when a thin layer of water is present over the road, the asperities on the road try to break through the film to make contact between the tire and the road. The asperities are the thousands of small peaks with pointed projections are combined to form microtexture. High local bearing pressure is created between the tire and the road by contact of it, thereby allowing the tire to establish dry contact with the road. (9)

- **Macrotexture**

The extent of large scale sized projections at the surface of the road varying from clean to difficult with a wavelength of road profile lying among 0.5 mm and 50 mm, vertical amplitude inferior to 10 mm. It may be described as the kind of wearing direction and to the manner in which it becomes applied, to damage and to periodic treatments made to the road surface. (8) The function of mixture gradation, road production approach, and unique road treatment, including grooving & chipping is macrotexture. Whereas micro texture will increase moist friction with low vehicle speed, macrotexture is the critical component for high vehicle speed. For a bad macrotexture, the frictional stages decrease for roads than for precise macro texture when the car speed is excessive and flooded conditions succeed. By lowering the hydrodynamic pressure current among the tire and the road surface whilst water is gift macro texture presents the channels for drainage. When a thin layer of water is present the macrotexture offers contact among the tire and the road surface.But in a flooded road, it acts as an escape channel for the bulk water drainage from beneath the tire footprint. (9)

1.4. Dynamic Hydroplaning

Dynamic hydroplaning occurs in a flooded road when driving a car in it, where the fluid film is capable of separating the vehicle tire from the road. During driving a car over the wet road with sufficiently high velocity, the inertial force developed is comparable to the inflation pressure, where the depth of fluid film exceeds the drainage capacity of the tread pattern of the tire. In this situation due to high inertial force developed & unacquainted fluid depth with a disadvantage of high vehicle speed results in hydroplaning. The dynamic hydroplaning result from the uplift force generated by the water wedge driven between a moving tire and the road surface. The risk of dynamic hydroplaning high with increased inertial forces and thick water film found on a flooded road. The dynamic hydroplaning can occur when the water encountered the tire exceeds the drainage conditions of the tire and road macrostructure. (7)

A tire can experience hydroplaning either partial or full dynamic hydroplaning. In a partial dynamic hydroplaning only a part of the tire actually rides over the surface of water film where the contact between the tire footprint and the road surface is at a least portion and it is maintained. Whereas in full dynamic hydroplaning the part of tire rides over the surface of water film has complete separation of the tire from the road surface. The full dynamic hydroplaning is a very dangerous situation than partial dynamic hydroplaning because the driver is totally unable to control the vehicle steering and braking due to complete loss of contact between the tire and the road surface. Speed and water film are major governing conditions for the partial and dynamic hydroplaning but it is difficult to identify the exact speed terms at which it can occur because the variables such as road surface, tire conditions, and driving environment should also be considered. Mostly the partial dynamic hydroplaning occurs with normal speed and water depth whereas the full dynamic hydroplaning occur with high speed and a thick film of water. Dynamic hydroplaning is a complex function between two variable while the probability of full dynamic hydroplaning is low. (9)

1.5. Viscous Hydroplaning

Viscous hydroplaning occurs in a thin film of water at low speed where little water become cohesively with tire and the road surface. It is a problem accompanying with low-speed operation on road with little or no microtexture. Form a result of an extremely thin film of water existing cohesively between the tire and road surface due to insufficient microtexture to penetrate and diffuse the fluid layer. From this, it is clear that why the viscous hydroplaning is referred to as thin film hydroplaning to differentiate it from dynamic hydroplaning which requires comparatively thick fluid layer. Opinions on the importance of vehicle speed to viscous hydroplaning may vary from journals to journal but the fact is it may occur when driving a vehicle with a very low speed such as with speeds typical on road driving. And some important factors that determine viscous hydroplaning are the viscosity of the fluid, tire condition, quality road surface. (9)

1.6. Thread rubber reversion hydroplaning

This type of hydroplaning occurs in a thin film of water where heavy braking leads to an increase in the pressure of water beneath the tire. The pressure of water increases with increase in speed. Thread rubber reversion hydroplaning happens when a tire with high inflation pressure slides over the melted tire rubber and water covered on the road surface, it usually happens in the aircraft where tire melts during landing due to high friction. In the thread, rubber reversion hydroplaning a large amount of heat is generated on the tire due to heavy braking while landing the flight. Between the tire and the runway where the reverted rubber acts as a seal which delays water drain from the tire footprint area. Usually, this type of hydroplaning does not occur in ground vehicles with tire pressure lower than 165 kPa. (8)

1.7. Preventive measures to overcome Hydroplaning

- Drivers can reduce the occurrence of the incident hydroplaning by maintaining tires at good conditions, at rated inflation pressure and by slowing down during rainstorms or on the wet road surface.

- Checking of inflation pressure of tire prevents from hydroplaning because while hydroplaning happens the hydroplaning speed increases with an increase in inflation pressure.

- Using seasonal tires like summer tires & winter tires prevents from hydroplaning, the summer tire is recommended during warmer climatic conditions of 7degree Celsius and above, which would give excellent friction and handling during warmer conditions. Where else the winter tire delivers good friction in snow and ice.

- Reduction in the speed level of the vehicle helps to avoid hydroplaning, where an increase in vehicle speed leads to increases the pressure of the water beneath the tire. Reduction in speed over a thin film of water helps to regain the friction of tire.

- Formation of ruts on roads is a major cause of hydroplaning. Hydroplaning happens due to the stagnation of water on the roads. So by proper maintenance of the road from the formation of ruts prevents from hydroplaning.

- To avoid hydroplaning in aircraft while landing by releasing the brake and allowing the wheels to spin up because heavy brake on the wet surface leads to thread reverted hydroplaning and generates more heat, so moderate braking may prevent from hydroplaning.

- Maximizing the landing distance by making use of the available distance for avoiding the hydroplaning on the wet run because by the use of the long distance runway the heavy braking of the aircraft while landing can be avoided.

- Calculation of the critical speed before landing helps to avoid heavy breaking. Landing the aircraft with the calculated critical speed by using the long distance runway allows using moderated braking.

2. Literature Review

The car safety era has started in the 18^{th} century by the automobile industry due to stimulation was given by legislators, who were working towards reducing road accidents. The preliminary safety capabilities are safety glass, four-wheel hydraulic brakes, seat belts, and padded dashboards. Among that hydroplaning is an important problem to maintain the vehicle the stability on different climatic conditions and environment.

According to the journal (10) have attempted to brief two extreme conditions i.e., while the tire is absolutely rolling and a very locked tire. The modelling and analysis of the tire are carried out in ABAQUS. The pressure range among a hundred and ten to one hundred fifty-five kpa observed with an underneath swelled tire condition that is through all bills steadily inclined to the hydroplaning threat. With admire to the incidence, hydroplaning speed obtained at 110 kPa is decreased with the aid of 1.25 occasions the standard accelerated example of a hundred sixty-five kPa for moving tires. While the hydroplaning velocity noticed at a hundred and ten kPa is reduced via 1.18 occasions the usual accelerated example of a hundred sixty-five kPa for sliding tires, at a constant water profundity of seven millimetres. It was seen that for an unfastened moving case, the hydroplaning velocity is around 4 km/h to sixteen km/h better than the completely braked tire contingent at the enlargement weight taken into consideration. From special exam made it's far clearer that the hydroplaning speed diminishes with increment in water profundity whilst the hydroplaning pace increments with a decline in water profundity. From these studies, it may be concluded that the hydroplaning velocity decreases with growth in water depth and additionally hydroplaning velocity will increase with a lower in water intensity. For future, the advanced version can effectively be prolonged for utilization underneath the determination of hydroplaning velocity and skid resistance for tires rolling/skidding over actual pavement surface meshes.

The Journal (11) an advanced variant to discover the importance and course of the momentum switch speed in water film based at the comparability of the strips and kinematic attributes of the particle, which fits perfectly for the cases with small tire load and thick water layers. At the point when the thickness of the water layer is 3 millimetres deep over a runway is considered as defined by the standing water because of a couple of serious issues experienced with the guide of the plane. So while the tire goes over the layer of water it creates a water splash that is a complex substantial technique might be isolated into three degrees. The distortion and fracture of the water layer, the separation of stream, and the final movement of the beads in the wind current field. All together dispensed with the peril of plane water splash, numerous measures to lighten or perhaps control the tire spray were explored and the utilization of sweeper, chine tires are examined. The attributes of the starter shower in view of a moving plane are sure and the tire splash has been isolated into 4 sorts: bow wave, rooster tail, the impact created face crest and wave produced perspective tuft. From the specific examination of the model, it's far clean that the way of energy switch is along the course opposite to the tire velocity course and the significance of the force exchange speed can be acquired from the form. The tire spray methods with one of the kind tire speeds, water profundity and tire burden have been mimicked to approve the precision of the model. The model can anticipate the force exchange system very well inside the conditions in which the tiring burden is eminently little and the water layer is somewhat thick. The principal phase of the shower procedure is the significant thing to investigate the entire framework, and the exchange between the water film and the tire chine especially happens on this stage. Along these lines, it's far trusted this examines should improve the mastery of the tire shower strategy and make a commitment to the cine tires structure. What's more, it's far basic to direct the further examination at the enhancement plan of the chine profile in future.

From the journal (12) describes the friction of rubber on the ice and introduces a brand new linear tribometer. The frictional behaviour of rubber on ice is especially because of the lubricating layer over the ice at some point of sliding. By investigating the friction of rubber over numerous sliders consequences that the lubricating liquid thickness, frictional pressure, dynamic frictional coefficient, the speed of the slider, temperature & load are the primary elements that decide it. A test is carried out to determine the friction of rubber on ice. The experiment consists of the synthetic ice surface, rubber tires. The artificial ice is prepared in an aluminium tray via freezing more number of water layers to keep away from floor irregularities caused by water enlargement for the duration of freezing. The rubber samples had been supplied by way of Michelin include three samples of -50,-25,-9 diploma Celsius. The test is by way of making contact between the ice & the rubber surfaces. The records are obtained by way of dividing the issue of the pressure inside the x-axis with the element of the force inside the z-direction (normal load).

The journal (13) states that a tire tread is a complex structure with threads & groves, the analysis of 3D tire by neglecting threads & groves would lead to poor numerical expectations. So a powerful mesh creation strategy for 3D car tires in which the exact track blocks with against slip force is completely mulled over. A tire, as a rule, has direct contact onside the road with a huge length of the contact place, the tire string portrays greatest tire in general execution comprising of contact force, put on clamour, slip and hydroplaning. The profundity of the notch is called hostile to slip profundity isn't constantly uniform yet factor and which upgrades the tire put on execution as indicated by the modification of the track solidness. A successful and efficiently created 3-d limited component lattices of tire considering the careful track squares of variable ASD in uneven on the whole become produced. Track work is amassed into the tire casing of surface running self-assertively zero to 360 confirmation by methods for the surface to surface contact duplicity strategy. The developed modernized work innovation application that is incorporated with the I-DEAS and ABAQUS can run the static tire contact investigation. It is affirmed that the system proposed for lattice does not reason any mistake inside the limited component assessment.

The journal (14) briefs about various factors that contribute to the complicated frictional mechanism at the Tire interface which is important for high passenger safety. The advancement in vehicle safety has led to the avoidance of the accidence through various safety measures but still driving on ice is considered as low safety. The frictional mechanism on the tire’s interface is complicated with numerous factors affecting it. The tires in flip dependent on the ambient temperature, tire specification, car specification & car type. The notice of all trying out conditions are taken however the performance consequences are legitimate only for specific situations. Ice surface with equal texture, surface roughness, strength & floor temperature are the vital testing situations to be reproduced on the experimental have a look at. The contrast of the take a look at with a different state of affairs consisting of varying inflation pressures, loads & ice surfaces enables to assess the braking performances successfully. The friction coefficient predicted during tire braking with various models helps tire manufacturer by regulating to a new rate of braking performance.

According to the journal (15) explains about the hydroplaning traits of the patterned tire on a watery road are experimented by finite volume & finite element technique. A 3-dimensional model of the tire is created & general coupling technique is used inside the fluid-structure interaction among the surprisingly convoluted tire track and water stream. The solid and dependable numerical framework to invigorate and research the tire hydroplaning factor been offered through regularly coupling the limited amount approach and the expressly limited component strategy. The orthotropic shell components and punished Moonley-Rivin model was utilized effectively for the complex texture arrangement. The numerical analyses experiment that a little hydrodynamic pressure is delivered than the three grooved tire model, because of the additional water stream by means of sidelong tire results inside the contact pressure affirming that the wet footing of the designed tire is higher. From the outcome, it has been cleared that the hydrodynamic weight will increment in corresponding to the rectangular of the tire moving speed and that is very customary with the diagnostic hydrodynamic answer.

(16) is a journal on the comparison of the dynamic powers applied at the tire hub between numerically anticipated and trial impacts, the tire moving speed and the expansion load on the transient dynamic evaluation. The transient dynamic response of a moving tire affecting with little fitting is tried through building up a 3-dimensional model tire exact with the tire track is utilized to reenact correctly the close-by tire-projection sway way by an expressly limited detail strategy. At the point when the vehicle activities in the road, the tire move over various constraints which applies effect powers on it. These impact powers are consumed by method for the tire pad sway, yet the last component is transmitted to vehicle through the tire belts. With the express, a limited component system using the mass lumping and the fake mass relative damping effectively and steadily reenacted the somewhat tedious frictional unique contact bother of the 3-dimensional designed tire. The time-records and the recurrence response of the dynamic powers applied on the tire are numerically examined and in correlation with fair exploratory outcomes. The tire moving speed has impacted over the short powerful powers on both level and vertical powers applied on the hub. With the impact of tire speed, every unique power display the varieties on the other hand inverse to each extraordinary. The sufficiency of the vertical unique powers in time and recurrence will increment in relative to tire moving speed and the other way around in the even unique power. While the expansion inside the tire moving speed, the vertical powerful power lower in resounding recurrence and the even power scarcely increments. In spite of the fact that making a distinction in the expanding pressure and tire moving speed does now not make any broad fluctuations in transient dynamic powers.

The Journal (17) is to measure the tire sidelong powers versus slip edge realities on ice and snow at various temperature conditions. The Cold Region Research and Engineering Laboratory's Instrumented vehicle to report longitudinal, horizontal and vertical powers at tire contact way of each wheel notwithstanding car speed, tire speed, the front tire slip angle. The records of tire parallel pressure certainties with considerably changing over climate conditions with customary research centre system of an instrumented tire on a moving tire belt isn't conceivable. The tire slip angle is the point between the way of the car and the heading of the tire itself or edges among the vehicle longitudinal pivot and the tire heading. From the records, it can delineate that the slip point of view versus the parallel powers is confounded with fluctuates physical properties of snow alongside temperature, thickness and dampness content. In any case, in certain methodologies, the records are relating to the variation in the longitudinal erosion rather than slipping point of view on winter surfaces. The cold conditions are marked on changes classes alongside the Fresh dry snow conditions

(FS), Wet Snow (WS) surface, Remixed Snow (RS). In the FS circumstances, there's a precise lower of the parallel coefficient of grating and height in the snow profundity with a greater slip edge. In WS conditions the coefficient horizontal rubbing achieves a base cost and the slip frame of mind shifts with a charge close to the slip point in FS conditions. Fascinatingly the RS circumstance accomplishes a greatest sidelong coefficient of rubbing with the most slip point of view. The adjustments inside the estimations of the horizontal coefficient of erosion and the slip edge as a result of the fluctuates snow conditions with changes inside the thickness, temperature and dampness content.

In the paper (18) reported that the asphalt slide opposition is viewed as the main thing to limit traffic wounds. In spite of the fact that asphalt slip obstruction can be stricken by a gigantic assortment of things, street surfaces and water layer advancement are two noteworthy components. The asphalt is a story that is considered as an inflexible and relentless where it is redirected from the genuine planar surface because of inconsistencies found in it. The elastic tire surface gets infiltrated with the guide of the miniaturized scale ill tempers of the asphalt surface to give tire-asphalt contact. The asphalt surfaces can be named basically dependent on the incentive as smaller scale surface and full-scale surface. The surface inconsistencies that are estimated at the miniaturized scale stage size with a component of totalled molecule mineralogy for given climate circumstances, traffic circumstance and asphalt age is known as smaller scale surface. The principal groups of smaller scale surface are to enter by means of the dainty water film for tire asphalt grindings. The full-scale surface is estimated in millimetres and specifically ascribed to the size, shape, rakishness, separating, and appropriation of course totals. The real highlights of the full-scale surface are to offer seepage. At the point when the downpour starts the asphalt will wind up wet with a water motion picture of thickness fluctuating from a couple of microns to a couple of millimetres. With ale thickness, the motion picture of water goes about as grease between the tire and the asphalt which results inside the decline of slip opposition. The wet or states of the asphalt is an indispensable parameter instigating asphalt slide obstruction. In the wet contact speed relationship, there are significant major standards which are the level of grating for a given speed is a component of the surface miniaturized scale surface and the charge of fall of grinding is an element of the surface full-scale surface. The fractal outline of asphalt surface slide opposition esteem and the fractal size of the asphalt floor charge rely upon one another. The fractal size of the asphalt surface in dried circumstances is bigger than in wetted asphalt conditions.

(19) intends that the vehicle safety depends on two factors like directional stability and the safe speed limit in case of hydroplaning to guarantee more noteworthy traffic wellbeing and decrease the likelihood of a mishap. The test testing and numerical demonstrating help to take care of the issue in a touchy structure where the dynamic and aloof wellbeing issues have all the earmarks of being increasingly more perplexing with continually improved. The act of spontaneity of the tire is finished with dynamic definitions of Lagrange – Euler and models are created utilizing MSC Patran and MSC Dytran. The primary target of this examination is to build up a vehicle tire with hydroplaning safe which would be quicker and fundamentally less expensive. The test examines techniques for an intricate situation like hydroplaning are considerably more costly and tedious than numerical ones which additionally predictable. The improved model of tire created in MSC Patran and incitement tire liquid communications are completed in MSC Dytran. With this model and reproductions, an of a disentangled model of tire on the wet asphalt an immediate impact on directional strength and dynamic security of the vehicle was resolved. To decide the accurate and exact qualities a various number of tire water connection were finished with various film thickness and tire speeds.

According to the journal (20) hydroplaning is the phenomenon which occurs due to the reduction in the friction between the tire and road by a thin film of fluid. It is stated as an important factor that determines the safe driving of the vehicle on a wet road. The hydroplaning interaction between tire and road are explained with the help of three-zone concept in which the complete hydroplaning region is the Region A where dynamic pressure is created due to the interaction of tire and water is also called as a Bulk zone. The next zone is Region B where the partially hydroplaning occurs & due to the influence of viscous lubrication of water is also called thin film zone. The region C is the last zone where complete adhesion occurs which is also called Dry zone. A tire is modelled with the smallest element length it determines the stable time increment. A thin film of water is modelled where the film contains a vacant space on the surface is called void which enables scattering of water. MSC Dytran comprises two functions of coupling such as Arbitrary Lagrangian – Euler and General Coupling function. But ALE is not suitable for the hydroplaning stimulation with complex thread pattern due to complex node elements and shapes. So General coupling can be used for fluid-structure interaction between the tire, road and thin film of water. The modelling and experiments are done with four different simplified tread pattern with a specification such as 195/65R15, a vertical load of 4kN, the inflation pressure of 200kPa and are compared. The four patterns are smooth tire, two longitudinal grove tires and V-shaped grooved tires. The results of the numerical method and the results of computation methods are compared and verified with each other. From results, the hydroplaning performance of the tire shows that it depends on the tread pattern and its geometry quantitatively.

(21) is a journal of computational physics wherein the interaction between unfastened surface flow and a moving impediment is simulated numerically and is considered for the evaluation of hydroplaning flows. The article stated that the hydroplaning is the end result of the lack of friction among a tire and the road when an automobile is moving at a certain speed on a wet road. The hyperlink among the automobile velocity and the hydroplaning strain is defined because the made from vehicle speed and a regular that is equal to half the density of water from the Bernoulli assumption of ideal fluid behaviour. The investigation of the 2-phase go with the flow interplay with an impediment is determined with the aid of unstructured and based grid numerical strategies. Based at the formalization of Navier Stokes equation for unsteady loose floor float a -section version is created and the stimulation of hydroplaning turned into generated. The artificial subdomains are merged with the constant grids for the duration of fluid-structure interactions. For correct treatment of the speed-pressure coupling which is 2nd-order in space, an algebraic augmented Lagrangian technique has been recommended even as the primary order has been measured inside the framework of the two-segment flows. The frameworks are explained with a phase monitoring method and are confirmed with the ALE technique or time splitting method by using validating it on a water column in a square tank. By evaluating the experimental measurements with the augmented Lagrangian approach and algebraic adaptive augmented Lagrangian approach the prevalence of the algebraic adaptive augmented Lagrangian is determined.

This journal (7) describes dynamic hydroplaning which takes place while an automobile travels over a puddle in which inertial forces inside the fluid layer absolutely separate the tire from the road. The hydroplaning can’t be controlled while the amount of water exceeds the drainage potential of the tread sample of the tire and the road texture. The factors that have an effect on hydroplaning are hydroplaning velocity, water depth, the density of the fluid, tread pattern and so on. Hydroplaning velocity may be defined because the specific speed of the automobile at which the automobile is completely separated from the street. This hydroplaning velocity can be decided analytically by the equation evolved through NASA. The hydroplaning speed is identical to the made from 6.36 and the square root of the tire inflation stress. Utilizing the computer stimulation form it is found that the hydroplaning speed increments with developing tire weight, burden and diminishing water layer thickness. It has been dictated by method for the computer reenactment model of a bolted wheel sliding on an overflowed flying machine road surface. The parts envelop a pneumatic tire model, liquid float model, and the street surface model. Also, the results are resolved with the help of liquid tire association and tire street communication being developed. From the watched outcomes, it's seen that the tire expansion stress is the overwhelming component, wheel burden and water film thickness are the optional elements that influencing the hydroplaning speed.

From research over these journals, helps to understand about hydroplaning and the factors that influencing hydroplaning. When an automobile at a particular velocity travels over a film of fluid, hydrodynamic pressure is created over the fluid. Due to this pressure created between the tire and surface of the road a hydrodynamic lift is evolved which results in the loss of friction. The vehicle with high speed results in high hydroplaning speed where the vehicle is uncontrolled due to the complete loss of friction. From this situation, it can be stated that hydroplaning is a dangerous phenomenon which leads to the uncontrolled situation over the vehicle on a wet road.

It is clear from the research study that the hydroplaning of vehicle tire depends on and are influenced by many factors like from tread pattern, groove depth, the surface of the road, and thickness of the fluid film, vehicle speed, and tire inflation pressure.

3. Theoretical background

Vehicle hydroplaning road accidents is one among the harmful issues being faced by automobile drivers due to the thin film of water on the road. Hydroplaning accidents on vehicles are caused due to loss of traction on the tire but the factors that play a key role are roads & ruts. Since with proper maintenance of the road, the ruts and stagnation of water can be avoided which causes hydroplaning. The accidents happened due to hydroplaning may affect severely or may not cause huge damages. But mostly the hydroplaning vehicle accidents cause massive damages due to the uncontrolled situation over the vehicle. The incident starts when the loss traction between the tire and the road which makes the vehicle slides over it freely. The water pressure generated over the thin layer of water film leads to the formation of a gap, which results in slipping of vehicle.

3.1. Analytical approaches to hydroplaning speed

The approaches to calculate hydroplaning speed in an analytical way can be,

According to Agarwal and Hendry (1977) when hydroplaning happens for an immovable wheel sliding on the road surface with a water layer thickness of 2.4 mm then the hydroplaning velocity is as follows:

$V_p = 33.7+5.28\ (t_w)^{-0.5}$ (8)

Where V_p is the hydroplaning velocity in mph and t_w is the thickness of water layer.

From Huebner et al (1986) proposed this hydroplaning velocity formula for the situation which would be the same as the experiment conditions of Anderson et al, 1988 from which they were derived.

$V_p= 26.04(t_w)^{0.259}$

Horne and Dreher derived the formula from hydroplaning velocity from their research which is held at Langley Center. And the equation is called the NASA hydroplaning equation:

$V_p= 6.36\sqrt{p_t}$ (8)

Where p_t is tire inflation pressure in kPa and V_p is the hydroplaning velocity in km/h. They have pointed out that the inflation pressure is an important parameter related to hydroplaning speed.

The tire total dynamic hydroplaning speed is:

$$v_p = \sqrt{\frac{2p}{\rho CLh}} \quad (19)$$

Where p is the tire inflation pressure, ρ is the density of fluid on the pavement, C_{Lh} is the hydrodynamic lift coefficient. The value of hydrodynamic coefficient varies, for free rolling is about 0.7 and for a sliding tire is about 0.95.

With,

Thickness of the water film= 10 mm

Inflation pressure= 2 bar or 200000 Pa or 29.0075psi or 200kpa

Density of the fluid = 1000 kg/m^3

Table 1. The analytical approaches for Hydroplaning speed

S.No	Formula	Numerically calculated result V_p (kmph)
1.	$V_p = 33.7+5.28\,(t_w)^{-0.5}$	37.43
2.	$V_p= 26.04(t_w)^{0.259}$	31.16
3.	$V_p= 6.36\sqrt{p_t}$	89,94
4.	$V_p= 5.43 \times \sqrt[2]{p}$	76,79
5.	$v_p = \sqrt{\dfrac{2p}{\rho C^{Lh}}}$	52,91
6.	Horne's $V= 9\times \sqrt[2]{p}$	127,2
7.	$V_p=10.35\times \sqrt[2]{p}$	146.3

3.2. Analytical approached of Skid resistance

The force that decelerates which is developed in the tire-pavement interface when the tire of the vehicle sliding on the pavement surface is called skid resistance of the surface of the pavement. The pavement and the skid resistance are difficult phenomena which depend on and affected by various factors. The most extreme frictional power created between the asphalt and the feel burnt out on the vehicle which slides over the asphalt at a given sliding rate is called slip opposition. The measure of grating required for a vehicle to stop securely can be achieved in the perfect dry asphalt. In any case, in wet asphalt, the contact basic to stop the vehicle securely diminishes radically. The skid resistance can be found by the three different methods on wet pavement such as locked wheel skidding, impending skidding, and sideways skidding. (8)

In the locked wheel method, the wheel of the vehicle is completely locked while braking with this the resistance force developed at the tire-pavement interface can be measured. It is the most usually used strategy to gauge the slip opposition. In the slip technique, there are two methodologies alongside a fixed and variable slip. In the fixed strategy, the braked wheel with a fixed slip and the variable slip plays with a number of slip proportions. In the sideways weight method, the wheel is at a positive yaw point to the heading of the development and estimated with angle rubbing weight opposite to the wheel plane. (8)

Table 2. The analytical approaches for Hydroplaning skid resistance (8)

S.No	Researched by	Formula	Explanation
1.	Rose and Gallaway	$SN_v=\frac{154}{mph^{0.77}}[(TD)^{0.05}+\frac{4.71(TXD)^{0.09}}{(25.4WD+2.5)^{0.09}}]$	For the car with 165.5kPa inflation pressure: SN_v=Skid number at corresponding speed; Mph =vehicle speed; TD= tread depth in inches; TXD= average surface texture depth in inches; WD= water depth;
2.	Gallaway et al	$SN_v=\left(\frac{239}{V^{1.15}}\right)\times 26.65(TD+1)^{0.18}\times TDX^{0.49}+\frac{1}{(WD+0.1)^{0.53}}$ $SN_v=\left(\frac{909}{V^{1.37}}\right)\times 3.32(TD+1)^{0.14}\times TDX^{0.06}+\frac{1}{(WD+0.1)^{0.31}}$	Where SN_v = calculated skid number ; V= vehicle speed in mph; TD= skid tire tread depth in 32^{nds} inch; TXD = pavement texture depth in inches based on putty impression values;
3.	Pennsylvania Institute	The equation for smooth tire SN_B=16.87+0.54BPN+0.50MTD $SN_v= SN_o e^{-(PNG/100)v}$ $PNG= a_3 MTD^{a4}$ SN_o= 1.32(BPN)-34.9, PNG= $0.45(MTD)^{-0.47}$ $FR(60) = FRS \times e^{(S-60)Sp}$	Where SN_B= SN_{65} for smooth tire; BPN= British Pendulum skid test; MTD = Mean texture; SN_0= fictitious skid number at zero vehicle speed; PNG = the percentage normalized gradient of SN versus v curve; a_1, a_2, a_3, regression coefficients; S_p= Speed constant;
4.	Meegoda et al	MTD = 0.7796 MPD -0.379 SN_{40}=-202.64MPD^2+ 306.66 MPD – 61.508 (MTD<0.21mm) SN_{40}=-841.47MPD^2+1343MPD-481.46 (0.21mm≤MTD≤0.32mm) SN_{40}=-7.1616MPD^2+(18.914)MPD+76.973 (0.32mm<MTD<0.52mm)	

3.3. Road and its maintenance

A road is a thoroughfare route made of four or five layers of mineral aggregate stabilized for the better movement of humans, vehicle etc which is a flexible one. A road commonly consists of four layers mineral aggregate namely Asphalt, base layer, sub-base layer, and sub-grade. Asphalt is a blend of mineral total and bitumen which is the top layer of the street. The exceedingly thick, dark, sticky, dissolvable in carbon disulfide balanced with very consolidated polycyclic sweet-smelling hydrocarbon blend of natural fluid all joined to be known as bitumen. The second layer is the base layer comprises of a blend of uneven and unstabilized minerals. The unstabilized blend is balanced out by the black-top layer, Portland bond or some other settling specialist. Basically, black-top is the heaviest layer gotten by the partial refining of bitumen in unrefined petroleum at the greatest breaking point. And the subbase layer would always the local mineral or sand available which is stabilized by the cement or lime. The life of the flexible road would be 10-20 years. (22)

Rigid roads are mostly designed to endure all weather conditions with long-lasting lifespan to the server the high-speed traffic which is similar to the flexible road found in airport and highways. The top layer of the rigid road is made of a concrete slab with a thickness of 10-30 cm. Due to the concrete slab, there will be a difference in the load transmission mechanism in the two road types. In the flexible road when traffic load is applied a localized deformation occurs under the load on the top layer of the surface whereas in the rigid road the load is distributed over a long area. At the point when a traffic burden is connected over a little zone at the surface, the heap is conveyed over a bigger region because of expansion inside and out. In this way when the most elevated pressure happens at the street surface, the pressure diminishes with increment top to bottom. Consequently, the nature of the material on the top surface of the street relies upon the profundity increment. When a frequent deformation occurs over the small area in small value leads to the formation of ruts. The lifespan of the concrete road would be 35-40 years. (22)

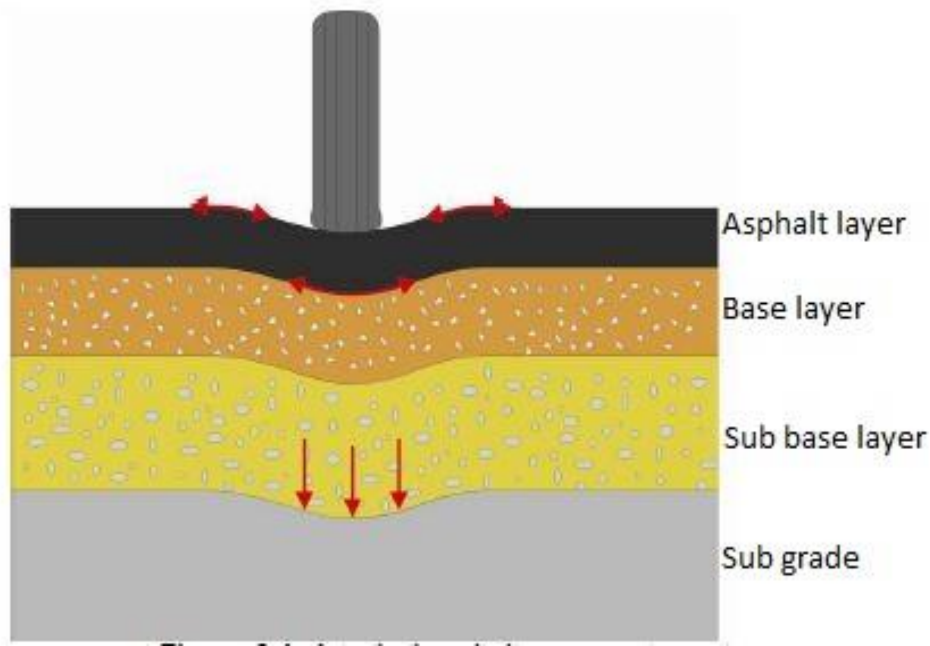


Fig. 3. Layers of road construction (22)

3.4. Road wear and sustainability

The road wear is caused due to the vehicle loading, actual wear relies upon the stacking level of vehicle and kinds of the heap conveyed by the vehicle. The street wears are uncovered from the asphalt by the traffic, it very well may be found by stacking Lorries, transports and semi-trailers and so forth. Because of shifting vehicle elements, the genuine loads on the streets or not rise to the static hub stacks likewise the impacts of the pivot are affected by the adjacent hub loads. There two sorts of pivot burden, for example, static hub burden and dynamic hub load. In static pivot load, the vehicle is at rest or not in motion so the total load of the vehicle acts on the road due to the force of gravity. In dynamic axle load, the vehicle is in motion where the vehicle load is varied due to the unevenness of the road and the vehicle moves ups and downs. This results in variation in the dynamic loading with their constant static values. The road wear varies from rural to urban moreover the wear caused due to varies types of vehicle. And the traffic flow is exposed by road wear which depends on traffic composition. (22)

Depending at the potential of the road cloth and design, the road put on is exposed to the visitors float with the intention to increase distresses through the years. Until the road attains the unacceptable condition, the road can be recreated by surfacing and strengthening it again. Therefore design and maintenance are two important parameters to be focused on preventing road wear. The unacceptable conditions are normally caused due to the defects related to the functional and structural properties of the road. The formation ruts, uneven surface and cracked surfaces are related to the bound road materials. (22)

In Europe, mostly the tires used in automobile vehicle are smaller in size with high tire pressure. The smaller tire will increase the quantity that is feasible to transport while in large tire enables within the fuel consumption of the car. The contact vicinity between the road and tire is called footprint that is an essential aspect for road put on. When the footprint of the tire is bigger the weight allotted on the street is smaller at the same time as the footprint of the tire is smaller the burden distributed on the street is bigger. The road wear is caused not only by the single tire and dual tire but also by the smaller tire and larger tire.

3.5. Road distress and its types

Road distress or road wear is the degradation of the road surface caused due to the vehicle loading vehicle load carriers and climate. The road distress varies for different types of road, design and maintenance. Road distress leads to the formation of ruts, cracks, and other distress modes. (22)

3.5.1. Road cracking

Road cracking is caused due to imperfections of the materials of the road where the cracking formed from the bottom to surface by various effects form the environment. There four types of cracking they are fatigue cracking, thermal cracking, surface cracking, and reflective cracking. (22)

- **Fatigue cracking:** This type of cracking formed from the bottom layers of the road to the surface bituminous or asphalt layer of the road due to fatigue of the materials by a great number of bending's due to the vehicle loads. Fatigue cracking is caused due to repeated stress cycles.

- **Thermal cracking:** The cracking that is formed due to the tensile stress caused by the temperature changes on the bituminous layer of the road is called thermal cracking.
- **Surface cracking**: The cracking which is formed due to the fatigue of the material caused by the shear loading of the tire on the road surface. It is usually formed on the bituminous material from the surface of the road.
- **Reflective cracking:** These types of cracks are found on the top surface of the road due to cracks or joint breaks formed in the bottom of the road.

3.5.2. Road rutting

The development of depressions of width several decimeters and of length ten to thousand meters on the top surface of the road along the wheel paths are called rutting. Rutting is of three types: (22)

- **Primary rutting:** The rutting is formed due to the deformation caused by the shearing stress on the bituminous layers. These are permanent deformation due to compaction.
- **Secondary rutting:** The everlasting deformation that is formed at the subgrade or in the granular layer below the asphalt layer because of various factors are called secondary rutting.
- **Tertiary rutting:** This type of rutting is formed due to the abrasion of the road surface by the studded tires.

There some other types of road distress are present some of them are ravelling roughness and potholes. Road distress is not only caused by loading but also by the poor quality of the material. (22)

- **Ravelling:** This type of road distress are caused by the loss of stones on the surface of the road due to continuous traffic flow. The loss of stone result in the failure of the bond between the aggregate and the base layers due to a large number of shear loading combined with the ageing of the material.
- **Roughness:** It is caused due to the several factors such as rutting, cracking, potholes, and uneven settlements, etc., results in the unevenness of the road.
- **Potholes:** Formed from the collapse of the road layer by the effect of structural defects or from the action of water ingress. (22)

3.6. Tire and its components

A tire is a rubber tube which is circular in shape made of rubber and plastic components. The tire is an important part of a vehicle that is made, to withstand the weight, vibrations and to provide grip, smooth driving conditions for the vehicle on road. Essentially a wheel consists of rim and rubber tire joint together for transmission of load and delivers better performance for the vehicle. Tries are the only component that makes contact between the vehicle and the road. The contact area of the tire on the surface of the road usually in the size of a postcard or human hand. (23)The first pneumatic tire was patent in 1845. During the invention of the tire, the potential risk of loss of air from it made delay for publishing. The tire is not only made of rubber but also there are other components in it. The other components of the tire are an inner liner, carcass, bead, apex, sidewall, belt, cap-ply, tread. The tires can be classified based on the structure as pneumatic tire, semi-pneumatic tire, solid tire, and cushion tire. (24)

Pneumatic tires are air inflation tire that is these type of tires consists of an inflated hollow chamber inside it. The tire attains its shape due to air pressure and when the air pressure is released it is unshaped. The air chamber of the pneumatic tires consists of a tube or tubeless. Semi-pneumatic tires are used by lawn mowers, shopping carts and wheelbarrows as the tires are a good shock absorber and light weighted. The semi-pneumatic tires are commonly hollow tire which is not pressurized. Solid tires consist of several layers of different thickness and compound which are composed to form a composite structure. Among the several layers of the solid tire, the steel ring is the most important layer which is used for reinforcement. Solid tires are important components in heavy industries where they are used in forklifts and in various types of industrial vehicles but also on karts, scooters and lawn mowers. Cushion tire is one type of solid tires which are equipped with sealed internal air pressure to maintain its shape. (24)

So the importance of tire is huge wherein a car it can have a good engine with better mileage and horsepower but everything depends on the performance tie for the enhanced efficiency of the vehicle. Selection of suitable tire for better performance of the vehicle is more important. Selecting the right tire from good and bad, cheap and expensive, sizes of tires, seasons and conditions are some important factors. (23)

3.7. Classification of tires

The tires can be classified on a different basis such as air-enclosure type, carcass type, and based on their uses as:

1. Based on the air-enclosure type
    - Conventional tube tire
    - Tubeless tire
    - Run flat tire
2. Based on carcass type
    - Cross-ply or bias ply
    - Radial ply
    - Belted-bias
3. Based on the use
    - All-season tires
    - Summer tires
    - Wet-weather tires
    - Snow-ice tires
    - All terms tires

Conventional tube tires: The tube is in doughnut-shaped which consists of an inner tube present in between the tire and the rim and are made of rubber. The tube is filled with air and it holds the pressure during movement. The tire gets punctured by the puncture in the tube and it loses the air inside it. The tire is provided with a valve which protrudes through a hole in the rim and the valve helps to fill the air inside. When a nail is punctured tire tread, it creates the multiple punctures then tube gets deflated and as rotated within the tire. For repairing the tube, it has to be taken off from the tire and the rim completely.

Tubeless tires: Tubeless tires are airtight, it is manufactured by adding the rubber to the tire material or by fixing inside the casing with butyl rubber. These tire usually don't get punctures, it gets deflate slowly where it improves the safety and reliability of tires. The tires are manufactured by sealing the spoke well of the rim with a specially designed rim with butyl or plastic strip.

Run-flat tires: These tires are manufactured in a premium category and are designed to minimize the loss of handling of a vehicle when the tire gets punctured. The tire can be used after the punctured and used for a short distance of about 80 km/s under a speed limit of 80km/h.

Cross-ply or Bias ply tires: This types of tires have fabric cords from one bead to another at an angle with respect to the centerline of the tire.

Radial tires: Radial tires have parallel plies radiate from one bead to another, don't have belts that cross over each other. They provide a smooth and comfortable ride but the directional stability of the vehicle is poor due to the weak sidewall. The stiff belts of the steel or fabric run around the circumference of the tire between the plies and the tread.

All seasoned tires: The tire patterns of all-season tires are complex as these tires are suited for all seasons to use. It is not an ultimate performing tire in dry or wet weather conditions on ice but can be used the majority of years by saving costs of having to change the tire in line with all seasons. These tires have more sipes or small slits on the tread blocks of the tires. They provide good traction and stability by the deep tread bites over the surface for grips in the freezing conditions. But they are not recommended for very cold and icy conditions.

Summer tires: The tires are designed with soft tread component rubber as they provide maximum grip at high speeds during dry and wet weather conditions. The tire usually preferred for sports cars as they are the cheapest and most preferred way to cut down the lap timings. As they have aggressive tread patterns they provide more tractions.

Snow/winter tires: Tires have larger contact path and have larger and more tread patterns than standard tires. They are used in climatic conditions at a temperature below 7℃ as the normal tire get harden and reduces grip over the old, wet road, ice and snow. They provide maximum grips on snows and loose ice as they manufactured with metal studs. These tires cannot be used on the normal road as they produce more road noise, and gets wear out very quickly by damaging the roads. The winter tire provides better traction over snow and ice upto 60% better than other tires.

Wet-weather tires: During rainy seasons or on wet roads the normal tire get losses traction and increase in stopping distance. So wet-weather tires or rainy tires can be used as they can cope up well in rain and wet conditions, as they greater tread depth of atleast 1.6mm for the better ability to evacuate water. (24)

4. Research methodology

The methodology of this research is to design and analysis of the vehicle tire on a wet road in which the tire experiences hydroplaning and to prevent from hydroplaning collision. In the hydroplaning collision, the vehicle is out of control and it is very difficult to prevent. The main cause behind hydroplaning is the loss of friction among the tire and the road. The tire with profundity grooves and thread helps in hydroplaning.

- Design of tire consists of various parts in it. The parts of the tire are an inner liner, carcass, bead, apex, sidewall, belt, cap-ply, thread and rim. Among that the important parts that are essential to carry out the analysis of hydroplaning are designed and the modelled.

- The material properties are intended according to real tire such as material properties of the rubber such as thickness, density, Poisson ratio, elastic modulus, quality. The properties that are needed to get the maximum result close to real-time experience are made.

- The modelled tire is made to run on a wet road with varying thickness of water film. And the speed of the vehicle is also changed to measure the hydroplaning speed. From the comparison of the results with the different condition, the effect of hydroplaning speed can be calculated.

- The various speed levels, water film thickness and some factors influencing hydroplaning are obstacles with this the analysis of the tire in different conditions can be achieved.

- The explicit analysis is done so that the results are compared with the analytical results. The analytical result is found with the help of the formulations derived by Horne‘s, Huebner, Agrawal, Hendry, Dreher for hydroplaning speed.

- Comparison of results from the explicit analysis and numerical methods for the tire with particular speed and thickness of water film and finding the precious value.

4.1. Research methodology observation

The research methodology of the hydroplaning of vehicle tire on the wet road has been divided into four steps. In the first step, the theoretical study on the research has been done and thorough knowledge about tire, methodical background over has been observed. In the second step, the major parts of the tire are modelled. In the next step, various conditions and obstacles are listed. The results from software are compared with the numerical method of analysis in the final step.

Step 1:

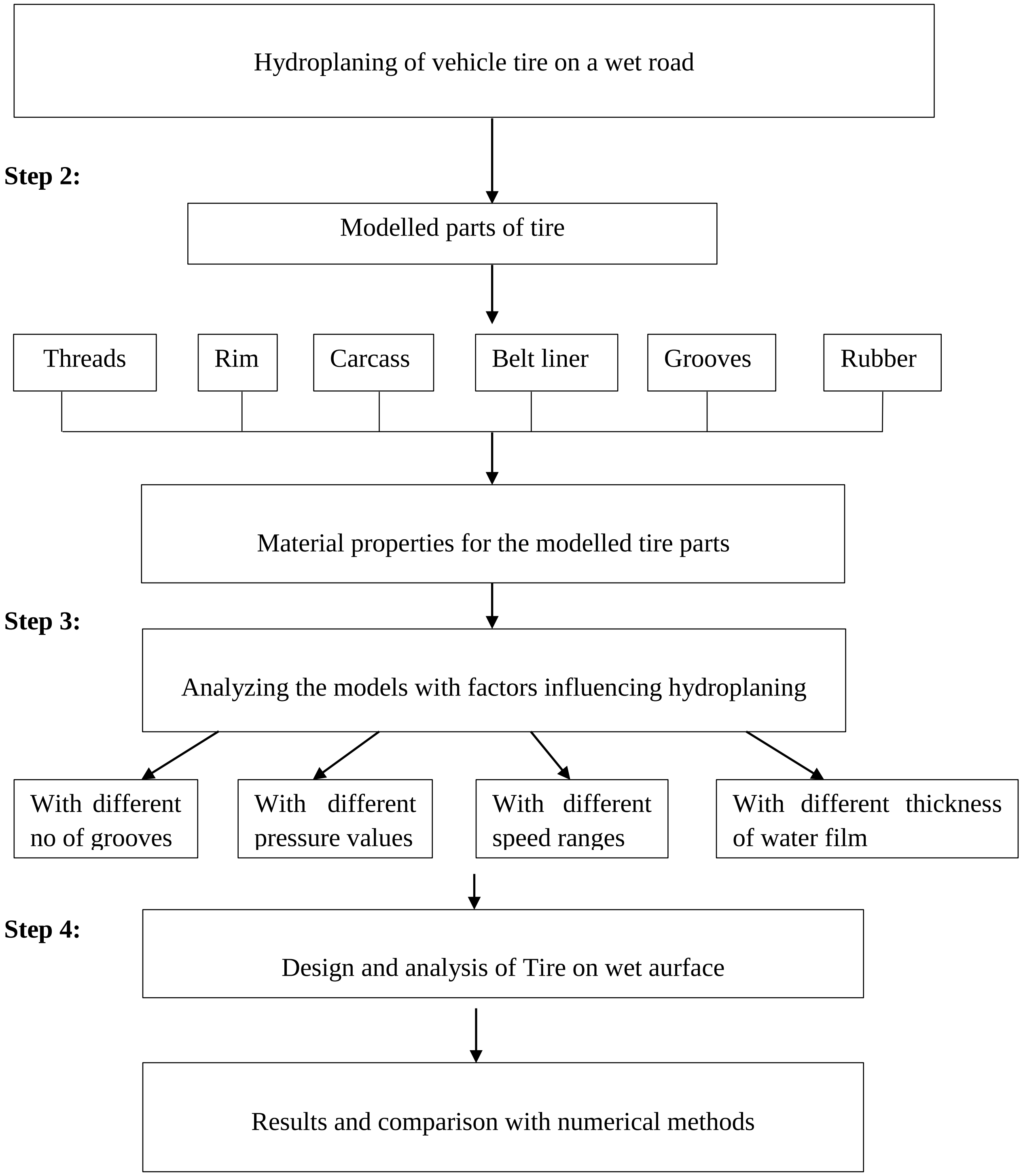


Fig. 4. Flow chart of research methodology

4.2. Problem identification

The problems identified are referred from the literature review about hydroplaning of vehicle tire on a wet road. With the help of a literature review, the obstacles and preventive measures that are needed to be taken are identified. So the identified problems are:

- A tire inflated with a required pressure of air of 110 to 165.5 kpa is allowed to move over the wet road, the hydroplaning velocity of the vehicle increases with decrease in depth of water layer on road. And hydroplaning velocity decreases with the increase in water depth.

- The hydroplaning is occurred by the unrated inflation pressure in the tire and unidentified speed to cross the water contaminated road. At particular speed on the wet road vehicle can cross over it but the range of speed varies for different depth of water stagnated.

- The hydroplaning speed is directly proportional to the inflation pressure of tire so an increase in inflation pressure will increase hydroplaning speed. The exact pressure of air in the tire is an important fact.

- The threads and grooves are important parts tire that gives friction and directional stability for the vehicle to move on the road. This thread and grooves without eroding may help the vehicle on the water contaminated road.

- The hydroplaning is an important phenomenon to be considered but the causes for hydroplaning does not always due to the flaws on the vehicle tire and driver, the road, ruts formation on road, and others. But it can be prevented with help tire.

- The formation ruts help to stag the water. The depth of the water may increase due to ruts formed on the road. The roads can be divided into three types based on quality. The higher end road is being laid on airports, even though the road degraded by continuous usage.

- With low speed over the thin wet surface, the vehicle is able to gain friction and retain its stability. Travelling at high speed over the wet surface increases the hydrodynamic pressure beneath the tire.

- The travelling of vehicle over ice is still considered as low safety and it is mainly avoided by the drivers. The loss friction over the ice is due to the lubricating liquid that is present over the surface. So the vehicle tire loss friction over it while travelling at a certain speed.

- Surface irregularities are some of the factors that are responsible for friction. The surface texture can be divided into macrotexture and microtexture. The macrotexture and microtexture are the two important factors which make contact between the tire and road. And in the flooded road, the macrotexture acts water escape channel or drainage system.

4.3. Computer-aided tools and modelling

Computer-aided tools and modelling is an activity that helps in the production and the process of a new product with which it can satisfy the need and desire of the society. The computer-aided tools and modelling processes can be placed under four steps such as problem identification, creative process, analytical process and development of prototype and testing. In the problem identification, the extraction of the need or identification of the defect of an engineering part is done by a collection of information through observation or detailed survey. The creative process is the process of synthesizing or design for the defects identified. The solution for the problem can be found through various forms like brainstorming where multiple solutions can be found through groups. The sizing, function, strength, reliability, feasibility, manufacturing, determination of cost, the environmental impact may all be analyzed in the analyzing process. The selection of best design that satisfies all or most of the requirements are done in this step. Development of prototype and testing provide a practical check and helps in improving. This provides an interchange between the design and manufacturing process.

A computer design software allows a designer to perform various tasks starting from design to manufacturing of an engineering factor with number one interactive, instructive, and person-pleasant manner. The computer software includes ends, the front end presents a graphical user interface whilst the returned quit incorporates computation and database management exercises. The graphical user interface includes two elements they're a visible manifestation or graphical window and the command window. In the graphical window, you possibly can manipulate the position of the design in relative to the fixed coordinate gadget, with the aid of offering the visible remarks the person can visualize the adjustments as a detailed preferred fact on the graphical window. The design instructions may be given through a command window, in which the commands appear in groups as an icon.

The graphical user interface comes under the computer design and engineering which provide interaction between the designer and computer by define, store, manipulate, interrogate and present pictorial output. It consists of three-dimensional modelling, shading, realism, natural scene, animation and virtual reality. The graphical data can also be converted into machining date and can be used for the machine manufacturing. The two important constituents of the graphical user interface are the hardware and the software. The computer-aided model can be converted into codes which can be used for production through CNC machines. (28)

4.3.1. MSC Patran

Patran is a computer-aided finite element modelling software which provides solid modelling, meshing, analysis setup and the results can be analyzed with various solvers like MSC Naastran, Marc, Abaqus, LS-DYNA, ANSYS, and Pam-crash. It is a broadly used pre/put up-processing software with a rich set of gear which can create the evaluation of equipped models for linear, nonlinear, specific dynamics, thermal, and different finite element solutions. Patran makes smooth for the engineers to address gaps and silver for finite detail models. Patran enables in imparting the results faster virtual prototype which could evaluate the product performance in opposition to requirements and optimize the layout. It provides management and options over the advent of mesh on both stable and surfaces. It has the functionality to get right of entry to the geometry from every other leading CAD gadget. This choice allows industries in assisting geometry exchange. It makes smooth for gaining access to the geometry by using presenting import/export option with Parasolid format that's supported with the aid of many different CAD software programs. And can benefit get right of entry to to all finite factors, loads, boundary conditions, and fabric houses. The introduction of models in Patran is straightforward because of the advanced set of geometry equipment and directly get admission to to the finite element geometry version from other systems. Some of the superior geometry tools are delete, edit, fillets and chambers and at the same time as uploading 3-dimensional models the present mesh and hundreds will be regenerated by way of itself. The aid from MSC Nastran and MSC Nastran helps to carry out the superior studying techniques with Nastran design optimization and topology optimization abilities. Patran is supported via the solvers like MSC Marc, MSC Dytran, MSC Sinda, Abaqus, Ansys, LS-Dyna and Pamcrash. It enables to live in a single graphical consumer wherein a couple of customers are critical.

The resultant values can be presented in association with its finite elements and nodes in structural, thermal, fatigue, fluid, and magnetic analysis. Patran is programmed through an excessive stage, a block-based language that gives many blessings in a traditional programming language which called as Patran command language. (29)

Capabilities:

- Direct accessing of CAD geometry with spontaneous graphical interface and automatic/cooperative recognition.
- Support of integrations with other MSC software’s analyzing solvers and third parties, solvers.
- The advantages such as robust automation and solid mesh with advanced mesh on mesh option.
- The creation of connectors and bolts option in access with preloads.
- The availability of the full three-dimensional contact for non-linear analysis.
- The support from Nastran design optimization and topology optimization capabilities helps to perform advanced analyzing techniques.
- Support from Nastran super elements and Marc’s coupled analyses helps in providing comprehensive results post-processing.
- The standardization and customization of results through result templates and Patran command languages. (30)

Benefits:

- By the advanced geometry tools and direct access to other geometry models, the productivity of the design and development process increases.
- The improved productivity and accuracy with multiple analysis, optimization and increased use of simulation technologies the reduction cost is developed. (30)

4.3.2. MSC Dytran

MSC dytran is a three-dimensional analyzing software helps to solve the nonlinear behaviour between the fluids and solids. Dytran plays explicit finite element evaluation solution for the short period and complicated nonlinear behaviours that structure undergoes for the duration of the occasions like impact and crash etc. The structural integrity of layout can be achieved via dytran in which the very last product can meet the patron with higher safety, reliability, and regulatory necessities. Dytran includes structural, material drift, fluid-shape interaction evaluation and precise coupling competencies with which will permit the incorporated Evaluation of structural components with fluids and exceedingly deformed substances in a single non-stop simulation. The engineers can predict the prototype with recognize to a spread of real-worldwide dynamic activities and examines its potential, causes of failure through dytran. It is likewise proved to be the correct software program with the aid of correlation with physical experiments. The application of dytran consists of aerospace, automotive, military and defence, and other industrial applications.

Some of the aerospace application are Plane ditching, fuel tank sloshing, chook strike simulation, engine blade containment, aircraft crashworthiness, seat layout, protection, plane and cargo containment hardening. Automotive programs are airbag layout. Occupant safety, dummy modelling, seat format, automobile effect, crashworthiness, crash checking out, hydroplaning, gas tank sloshing, and rupture. The industrial and military packages are fashioned charge simulation, perforation of goals, hydrodynamic ram, supply collision, underwater surprise explosion, blast resistance, survivability, weapon layout, projectile penetration, bottle and box format, paper feeding, drop trying out, sports activities gadget's effect evaluation, and packaging layout. Dytran has the capability to model and examine the complicated FSI, interplay adaptive, more than one Eulerian, and more than one gadgets impacting a couple of surfaces, catastrophic structural failure with fluid leakage, fluid filling and sloshing. It is more desirable with greater latest and advanced technologies inclusive of FSI, Cyclic float, graded mesh, non-uniform Euler mesh etc., for enhancing productivity. The Lagrangian and Eulerian solver is to be had for fluid-structure interplay along with sloshing, hydroplaning, airbag inflation, are accomplished thru the coupling. Dytran uses express technology to clear up with a huge variety of cloth models for temporary dynamic troubles. Dytran works quicker with the assist of new numerical techniques and excessive-performance laptop hardware's to provide cost-effective solutions. (31)

Capabilities:

- The availability of advanced specific nonlinear solver technology solves short duration dynamic occasions which include crash, overwhelm, and so on., through simulating and reading it in severe conditions.

- The evaluation of Lagrangian and Eulerian finite detail method for structural, fluids and multi-material drift analysis with the assist of strong and efficient touch coupling of three-dimensional elements.
- The availability of beam, shell, solids, springs, and damper with large displacement for modelling and studying the hard dynamic scenario. And the uncommon nonlinear cloth models which include metals, composites, soils, foam rubber, liquids, and gases are available. (32)

Benefits:

- Through the analysis of streamlined modelling flow and advanced fluid-structure interaction simulation capabilities, the cost of physical prototyping can be minimized.
- The simulations such as nonlinear, dynamic behaviour of real-world problems are possible only in dytran and the results can be obtained quickly.
- The analysis of more complex scenarios and simulation of model results helps to improve the products and minimize the probability of failure and cost redesigns. (32)

4.3.3. Explicit interactions:

The explicit interaction of nonlinear dynamic analysis is solved by way of the use of the imperative difference method. The balance of the vital difference integration is about by timestep and the limit of balance would be the fee between the smallest temporary time of the wave to pass the smallest detail approximately. The stability restriction may be described because the price was less than or equal to the highest eigenvalue (devisor) multiplied by the difference cost of essential damping inside the highest mode. The damping may be delivered through drawing a graph among time and displacement of the cloth or with the aid of the viscosity-strain of viscoelastic fabric behaviour. Normally the timestep of specific evaluation can be 10 to 100 instances smaller than the implicit evaluation. Courant criterion is the technique of minimal time for a stress value to move an element due to the fact the calculation of eigenvalues completely for each cycle to calculate time step is impossible. And the crucial timestep of detail depends on the divided fee of size and sound velocity of the smallest element thru the detailed cloth. The difference of explicit and implicit analysis are small time step, no big matrix inversion by using having a diagonal matrix, sturdy solution manner is used even for the high diploma of non-linearitiesIn the explicit analysis, only minimum element dimensions are considered. The explicit codes are more efficient for problems that need a short duration of time, larger number or extent of non-linearities, larger problem size.

When considering the Time step is smaller than the crucial time step for some answer steps and time step as larger than the crucial time step for a few answer steps inside the evaluation. The answer for the time step as large than essential time step turn out to be errors and blows up the stableness. This solution is expected for the only degree of freedom spring-mass system. When the time step is slightly larger than the essential time step for small spring displacement the calculation becomes partly stable and partly unstable. And the predicted result of the solution becomes error and blows up. (26)

The explicit analysis is well suitable for nonlinear materials with larger displacement results, the interaction between two or more meshed bodies. And rare materials like diverse as metals, alloys, plastics, and composites can be created easily. The transient and dynamic problems can be solved easily but it becomes difficult for non-linearities.

4.3.4. Fluid-structure interaction SPH:

With the same order of characteristic time of solid and fluid, the dynamics of both are analyzed together, this type of analysis is called Fluid-structure interaction. Fluid-structure interaction (FSI) is the deformation of the stable boundaries by means of the action of fluid drift or modification waft via the boundaries. The fluid-structure interaction troubles can be solved via an immediate or iterative approach. In the direct method, the structures are targeted via the Lagrangian system and the fluids are exact by Eulerian components even as the interactions between the solids and fluids are strong. While the fluids and solids are designated separately, the interaction between the two medium is obtained by coupling as Arbitrary-Lagrangian-Eulerian formulation. The distortion of mesh and the mathematical formulation lager and needs more computational time and errors are accumulated through time integration. (33)

For example, in a transient hydroplaning problem the tire with motion can be described by Eulerian and the ground can be described by Arbitrary-Lagrangian-Eulerian formulations. But some errors arise usually in FSI problems due to the larger formulation and more computational time. To solve this problem, when there are larger displacements and a nonlinear free surface occurs the Lagrangian descriptions can have an alternative method called smooth particle hydrodynamics method. In SPH (Smooth Particle Hydrodynamics) method the interaction between the solid and fluid boundaries are followed in time in a natural way. (33)

In SPH method the interactive surfaces (solid, fluids, etc.,) are duplicated for the original behaviour the surface and so it improves prediction of close values like hydroplaning speed, tire fluid interaction. Because the prediction of the hydroplaning speed, skid resistance are is more important to evaluate vehicle performance. SPH can implement to predict the tire hydroplaning with various conditions such as inflation pressure, critical loads, water depth, skid resistance, fluid film depth or thickness and tread groove depth etc. (34)

And the advantages of using the SPH method are no need of creating a contact algorithm, free surface tracking, and compressible fluids may be needed in a necessary situation. (33)

5. Preparation of three-dimensional models

5.1. Design of models in MSC Patran

Tire models are created in the MSC Patran software for hydroplaning stimulation. A tire with groove and no grooves are created. Line drawing is the initial stage for the model of tire. It should be noted that in order to determine not only the influence of external factors on the hydroplaning phenomenon the tire is modelled with the wet road, thus the factors that influencing deformation characteristics of the tire can be determined. The illustrations (Fig.5) below show the appearance of simplified models:

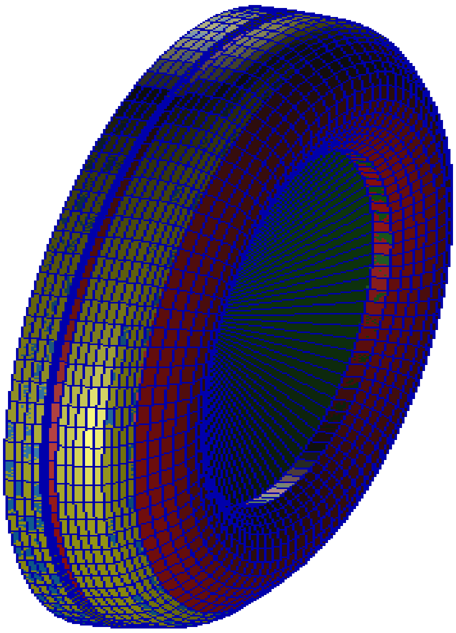


Fig. 5. Three dimensional model of tire

Tire dimensions and material properties are selected from a general tire. A 195/65 / R15 tire is used for the calculation. Since the MSC Dytran software package uses a central differentiation system for time integration, it is necessary to take into account the length of the smallest element used, i.e. the tire model is simplified without evaluating the small components of the tire (a cord, filler, etc.). There is a sequence in the modelling of the finite element models of the tire. The structural parts of the tire: rubber, tread, belt, sidewalls and rim are modelled separately from the finite elements and later integrated into the simulation using an equivalence algorithm which, connects the structure to common nodes. It is necessary to mention the rubber, the carcass, the belt forms a solid compound, and the tread is "stuck" to the rubber

5.2. Tire parts and its material properties

The material properties are designated according to the nature of it and referred from the tire model 195/65/R15. The material properties are customised in the software to get exact results after the analysis.

The thread and rubber material properties are Mooney-Rivlin rubber (RUBBER1), Poisson ratio of 0.49. The material properties of the belt are Linear elastic (MAT1), the elastic modulus of -3.6e+9 Pa, and the Poisson ratio of 0.49. The material property of the side wall is Linear elastic (MAT1), the elastic modulus of -2.1e+8 Pa, and the Poisson ratio of 0.49. The material property of rim is Rigid material (MATRIG), the elastic modulus of -2.1e+11 Pa, and the Poisson ratio of 0.49.

The different parts of the tire are generated separately and their nodes integrated with the help of equivalence algorithm. It is also necessary to take into account the density of the grid finite elements since excessive density can mean a very long calculation time, but the accuracy of the results obtained can be slightly influenced. Using this condition that the treads of the tires used for analysis are symmetrical, we use only half of the tires to perform the tests, thus reducing the time required for the test. Ex. Using a full tire profile, the calculation time is 6-7 hours and half-time is 3.5-4h.

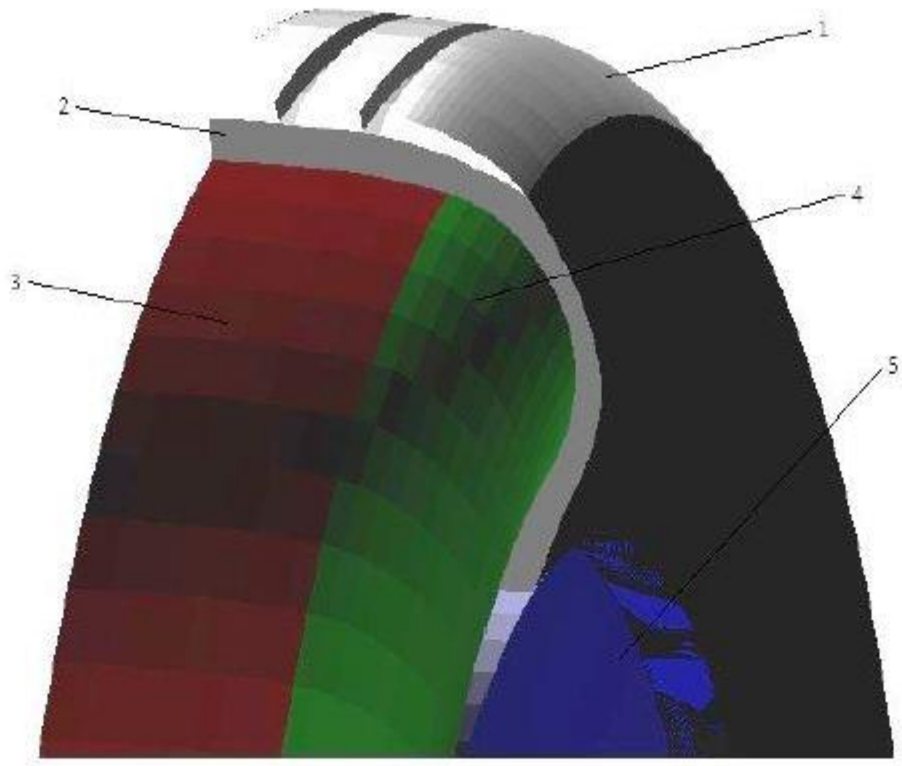
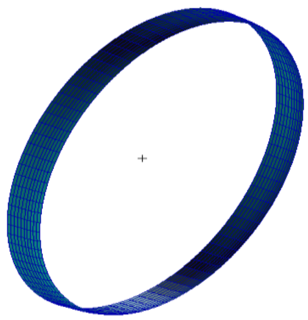
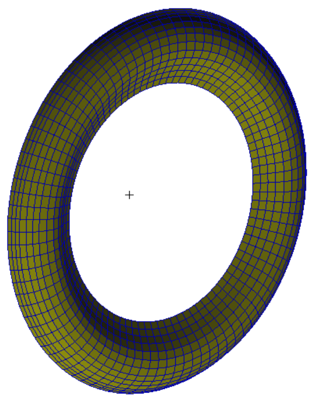
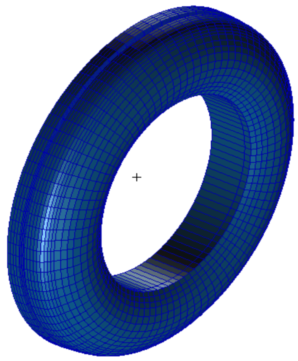
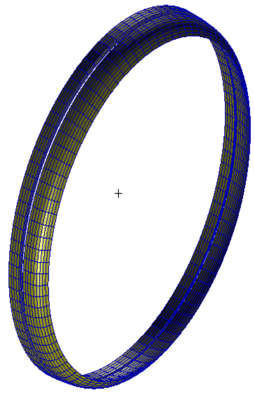
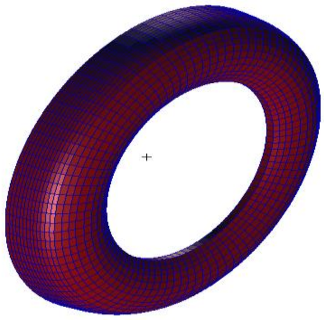
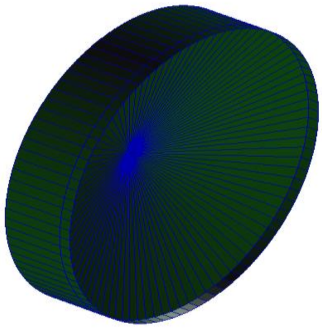
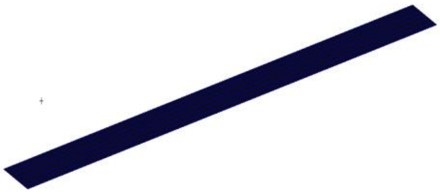
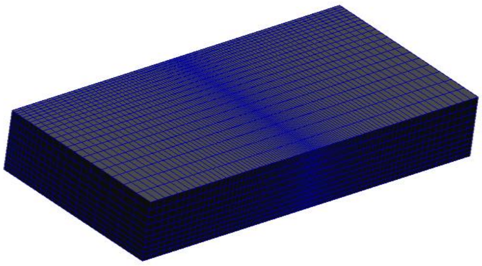
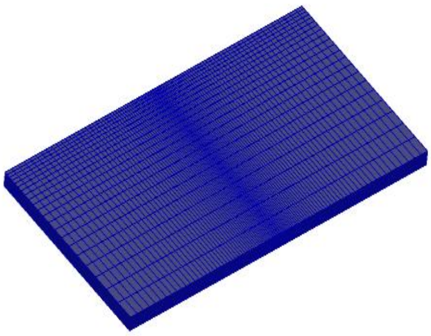


Fig. 6. Tire structure: 1-Tread, 2-rubber, 3-belt, 4-carcass, 5-rim

Table 3. The parts of model and its material properties

S.No	Name of the part	Material property	Image
1.	**Belt-** The belts provide rigid support to the tread by more controlled contact with the road. They are present in between the carcass and the tread which helps in optimizing the direct stability and rolling resistance.	Linear elastic (MAT1) Elastic modulus 3.6e+9 Poisson ratio 0.1 Density 7000	
2.	**Carcass-** The carcass is collection plies which are reinforced by high modulus cords. Plies are rubber layers with low elastic modulus present in it.	Linear elastic (MAT1) Elastic modulus 2.1e+8 Poisson ratio 0.1 Density 5000	
3.	**Dummy-** The tube which is an important membrane of the tire that will hold the tire inflation pressure at an elevated pressure within the structure of the tire.	Linear elastic (MAT1) Elastic modulus 2100000 Poisson ratio 0.49 Density 5000	
4.	**Protector-** It is the part that meets the surface of the road which is thick and made of most abrasion resistive material.	Moonley-Rivilian rubber (RUBBER1) Poisson ratio 0.49	

5.	**Rubber-** It is the tube which is an important membrane of the tire that will hold the tire inflation pressure at an elevated pressure within the structure of the tire.	Moonley-Rivilian rubber (RUBBER1) Poisson ratio 0.49	
6.	**Rim-** It is the part which rigid stiffness to the tire, which maintains the stability between the tire and vehicle.	Rigid MATRIG Elastic modulus 2e+11 Poisson raito 0.29	
7.	**Road-** A road is a thoroughfare route made of four or five layers of mineral aggregate.	Elastic modulus - 2.6e+11 Poisson ratio 0.1	
8.	**Void-** It is a medium of empty air where the water splashes during the movement of tire.		
9.	**Water film-** The layer of water formed over the road surface.	LinFluid (DMAT) Density-1000	

5.3. Model setup on the wet road

Water and road surfaces are used for experiments, which are made using eight-node continuous elements. The bottom layer of the water surface coincides with the upper layer of the road surface, defining the thickness of the water layer, which is respectively 5 and 10 mm. Above the water, the layer is created an empty medium (air), which allows the formation of water splashes. The water surface and air are modelled on the elements of the Euler. The size of these elements must be equal to or smaller than the width of the tread groove. To reduce computation time, the finite element grid is compacted only in and around the tire and water contact area, and the remainder is divided into larger elements. It is assumed that water is compressed and laminar flow prevails. The road and water layers are assigned at the appropriate speed, which varies with the test conditions under constant acceleration. The surface of the road is considered to be smooth, the value of the dynamic friction co-factor is 1.0

One of the primary aims of the work is to determine the behaviour of a stretched tire and to decide the time of prevalence of the hydroplaning phenomenon. It is well known that in reality, when a car moving, its wheels rotate in clockwise and move forward. When performing computer tests on the MSC Dytran software, it is modelled that the wheel will only rotate, however, will not move forward. This method makes it possible to make contact force between the wheel and road because the calculations depend on the speed of the road with water when the tire is subjected to the lifting force. The change of contact pressure allows figuring out the instant while the tire is torn off the road floor and starts evolved to hydroplaning. Also, the calculation time is decreased, which could in any other case be several instances longer and that doesn't have a vast effect on the results.

When solving the task of hydroplaning using the coupled Euler-Lagrange element formulation, it is necessary to cover the entire tire frame with a so-called dummy surface. This surface is needed to ensure the proper interaction of the Euler and Lagrange elements, in the absence of the model, the liquid elements of this surface would go into the tire elements, thus distorting the results.
To investigate the dependence of hydroplaning on various parameters, the work carries out various types of tests, changing the factors that have the greatest impact on the Hydroplaning phenomenon.

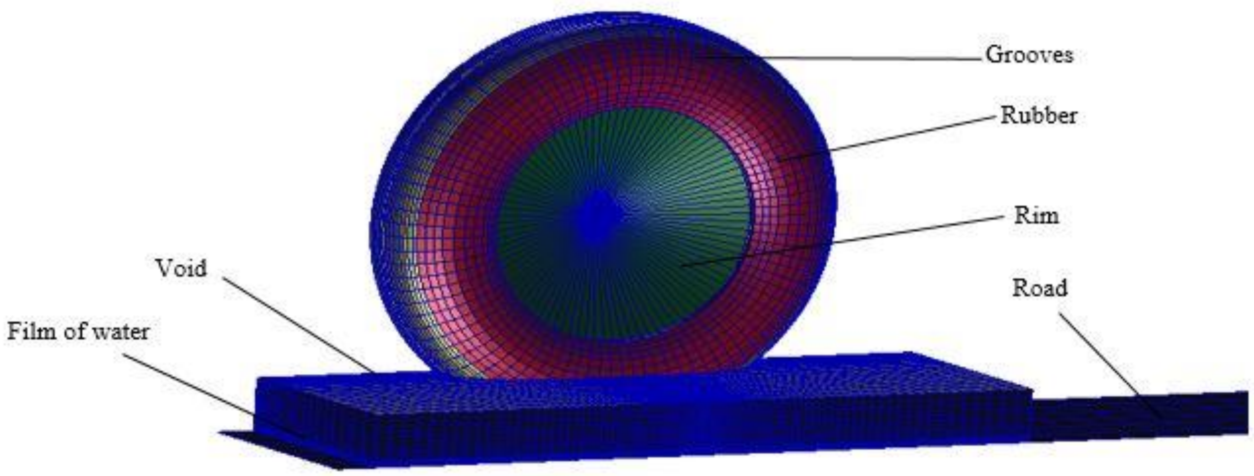


Fig. 7. Three dimensional model of tire on the road

6. Result and Discussion

As discussed previously, the speed at which the car moves, the tire pressure and the thickness of the water film are among the main factors influencing the hydroplaning phenomenon. Three different tread patterns with dimensions 195/65 / R15 have been selected for the calculation. Variable parameters include the speed of movement and the thickness of the water film. To determine the speed of the tire, the calculations for each tire profile will be made using the MSc Dytran software package. The speed used for simulations is increased from 70km / h to 112km / h in the range of 10km / h. The contact force is monitored by increasing vehicle speed. A significant decrease in contact force (close to zero) makes it possible to assume the occurrence of Hydroplaning. Visualization through ParaView 5.6 software package is performed to obtain graphical results of contact force.

The dependence of the nature of the contact force on the speed of movement makes it possible to determine precisely how the hydroplaning phenomenon occurs. The result from the graph shows the contact forces with time at different speeds. The curves of the results of the contact forces have been obtained due to the increased linear fluctuations with large spikes of contact force.

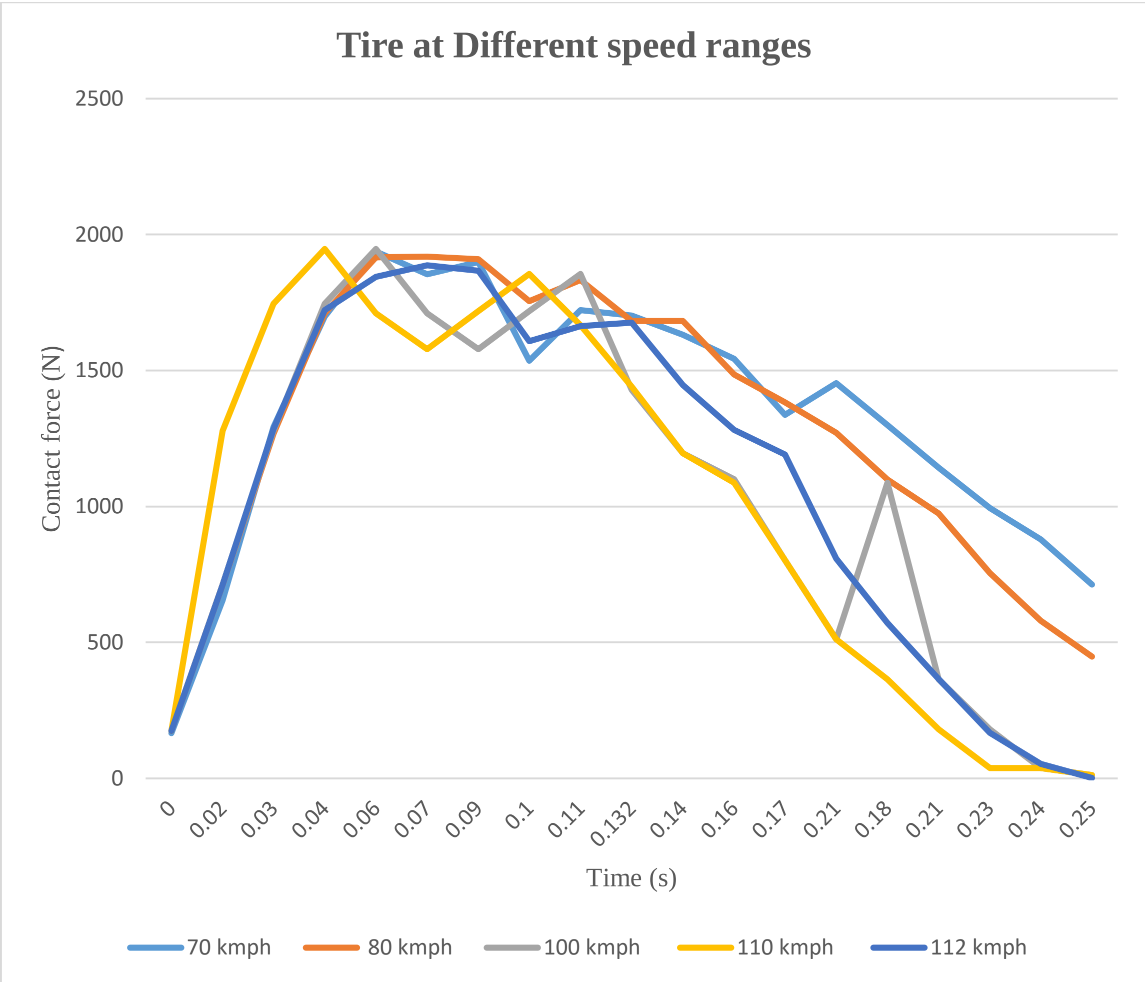


Fig. 8. Tire at different speed ranges

The above graph (Fig.8) is between the contact force and time, the contact force at a different speed such as 70, 80, 100, 110, and 112. Form the graph above it is understood that with an increase in the speed of the vehicle the contact force decreases gradually. So it’s clear that the speed of the vehicle is directly proportional to the contact force.

So the tire is travelling at five different speeds such as 70, 80, 100, 110, 112 kmph on a road with the same depth of water film. The contact force is monitored and analyses the difference between the varies ranges of speed. When the tire at speed 70 kmph, the contact force is increased at the initial stages when the tire hits the road and attains zero contact force at a time more than 0.30 seconds. And at 80 kmph also the tire attains zero at the time nearly 0.30 seconds. When the tire travelling at 100 kmph attains zero contact force at 0.28 seconds. And while travelling at 110 & 112 kmph the tries attains zero contact force at time 0.23 & 0.24 seconds respectively. When the tire attains zero contact force that indicates that the initiation of hydroplaning.

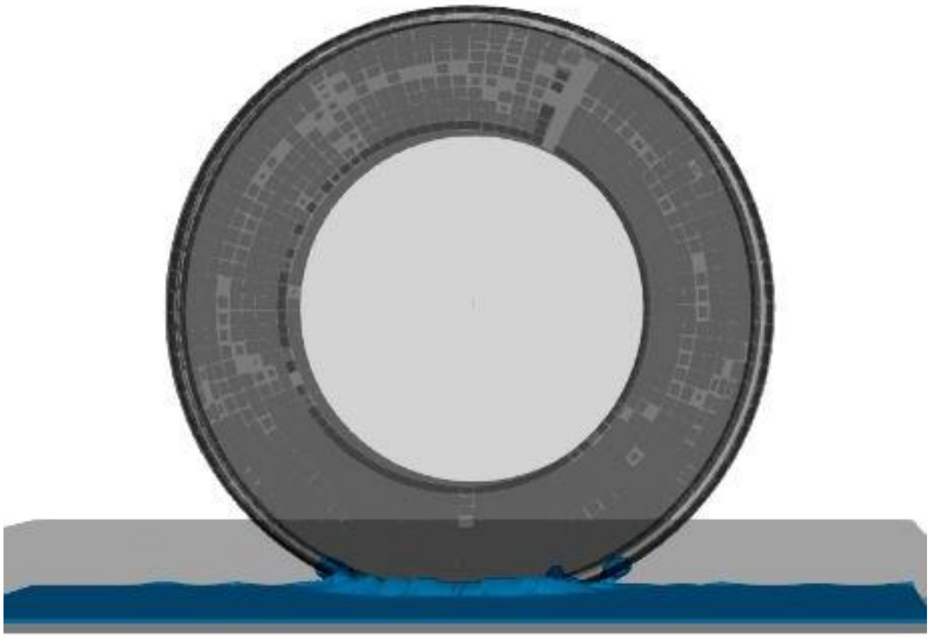


Fig. 9. Tire at speed 70 kmph in water film

The figure above (Fig.9) shows the tire travel over the water film at a speed of 70 kmph. This tire attains the zero contact force at 0.30 seconds which shows the speed is lower than the critical speed. So the probability of hydroplaning is low due to the low speed of the vehicle tire which is lower than the critical speed of hydroplaning.

From the image (Fig.10) it would be able to visualize the tire contact with the road. Because the tire travels at 110 kmph have contact force of about 1900 N which denotes that the tire has friction which helps to contact with the road.

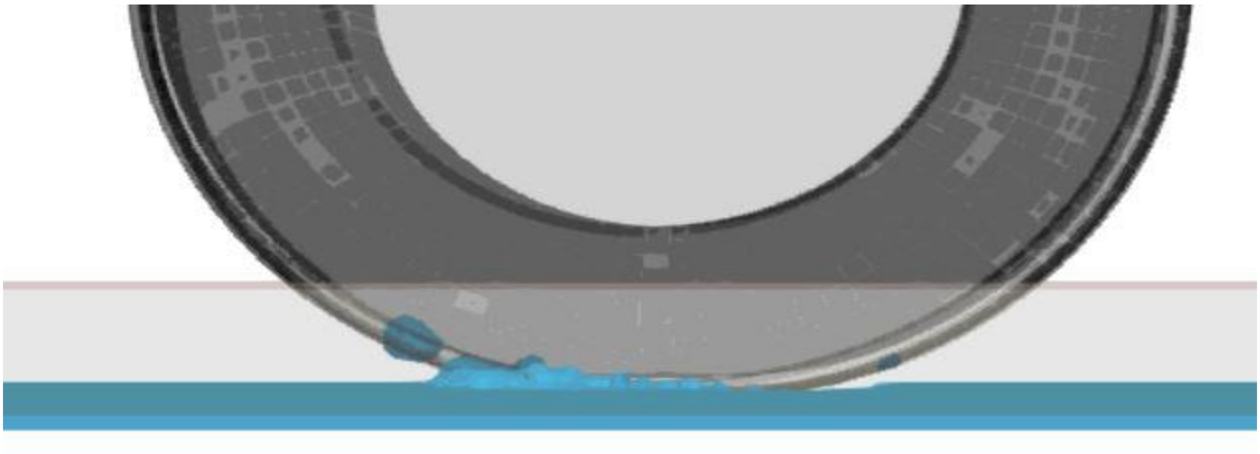


Fig. 10. Tire at 110 kmph contact road at initial stage

From the figure (Fig.11), it would be able to understand that the tire which travels at a speed of 112 kmph in a water film loss the contact force and initiation of hydroplaning starts.

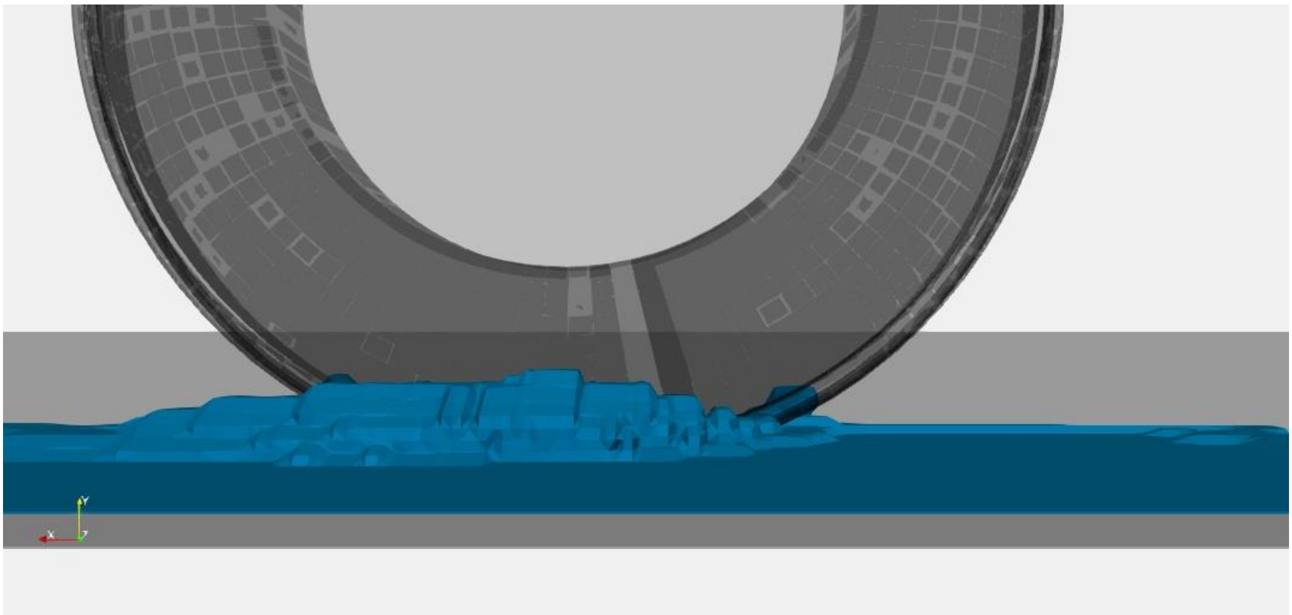


Fig. 11. Tire at 112 kmph loss contact with road at 0.24 second

Fig. 12. Tire at 112 kmph loss contact with road

The hydroplaning comparison is carried out between the tire with and without grooves travelling at the same speed of 70 kmph and the same depth of water. Grooves, tread pattern is one of the important factors that influences hydroplaning. In this the tire without grooves loss contact with the road in less time than the tire with grooves even though they travel at the same speed and in the same depth of water.

Fig. 13. A tire with and without grooves at 70 kmph

In the graph above (Fig.13) the tires travel at the same speed but the modification is done with tires. There two tires on with grooves and another without grooves travel at speed of 70 kmph in the same depth of water film. The tire with grooves attains zero contact force at a time of more than 0.28 seconds which shows that the influence of hydroplaning initiation is reduced by the grooves present. But in the tire without grooves attains zero contact force at a time of 0.14 seconds which shows the initiation hydroplaning is high at this tire. So from this, it is able to understand the importance of the grooves. The tire with grooves is able to gain contact with the road surface by penetrating through the water film.

The hydroplaning of the vehicle tire is carried out between the tire with varies tire inflation pressure such as 2 bar, 2.2 bar & 1.8 bar travelling at the same speed of 112 kmph and the same depth of water. Inflation pressure of the tire is one of the important factors that influences hydroplaning. In this the tire with low pressure of 1.8 bar contact with the road in less time than the tire with an inflation pressure of 2 & 2.2 bar even though they travel at the same speed and in a same depth of water.

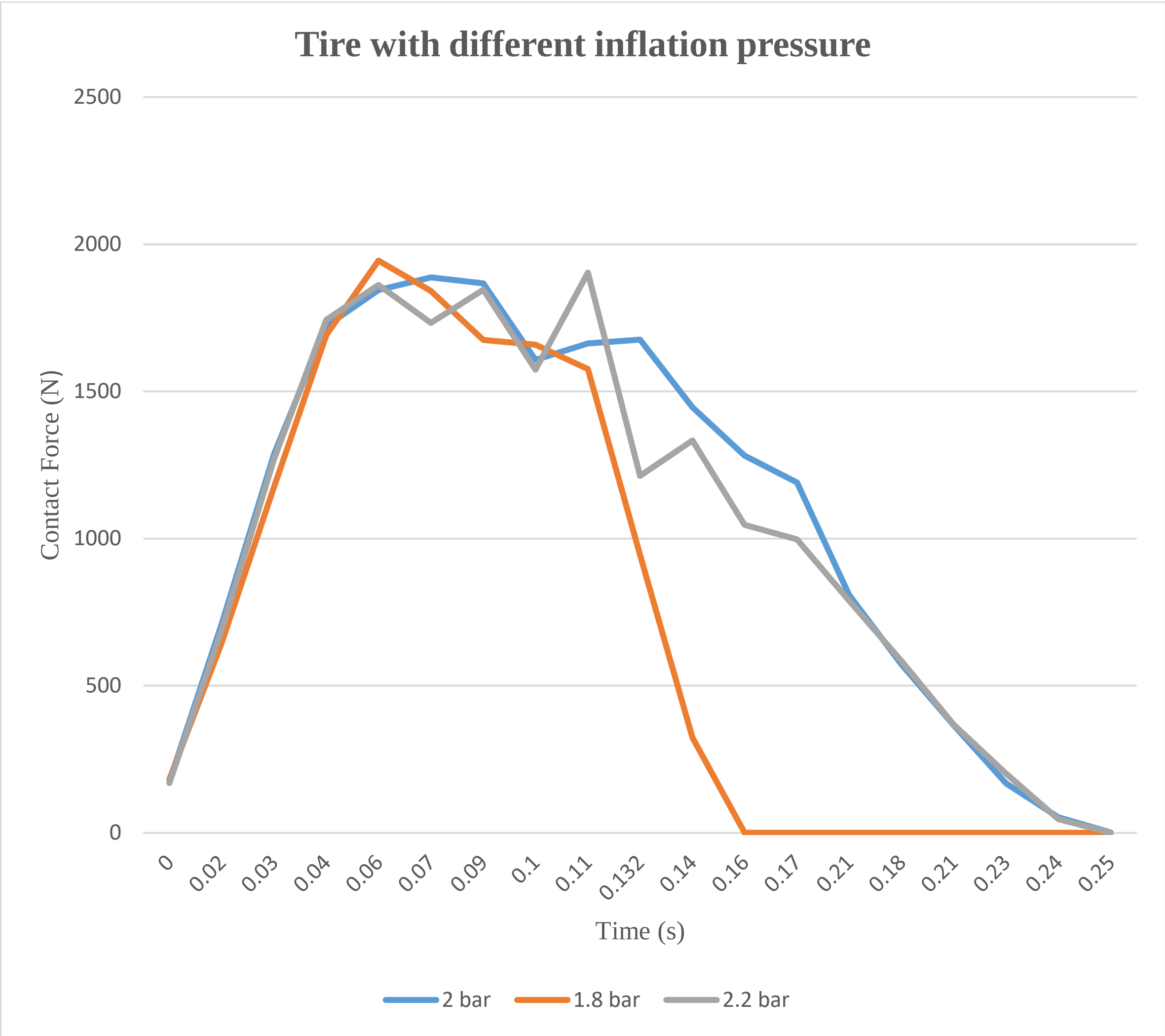


Fig. 14. A tire with different inflation pressure

From the graph above (Fig.14) the tires travel at the same speed but the modification is done with tire inflation pressure. The tire is with three variations of pressure such as 2 bar, 2.2 bar & 1.8 bar travels at a speed of 112 kmph in the same depth of water film. The tire with the pressure of 2 bar & 2.2 bar attains zero contact force at a time of 0.25 seconds which shows that the influence of hydroplaning initiation is reduced by the inflation pressure. But in the tire with the pressure of 1.8 bar attains zero contact force at a time of 0.16 seconds which shows the probability hydroplaning is high at this tire. So from this, it is able to understand the importance of the inflation pressure. The tire with the pressure of 2 bar & 2.2bar is able to gain contact with the road surface.

The hydroplaning comparison is carried out between the tire at a 5mm depth of water film and normal water depth travelling at the same speed of 112 kmph. Thickness or depth of water film is one of the important factors that influences hydroplaning. In this, the tire at a normal depth of water film attains zero contact force before the tire at a 5mm depth of water film.

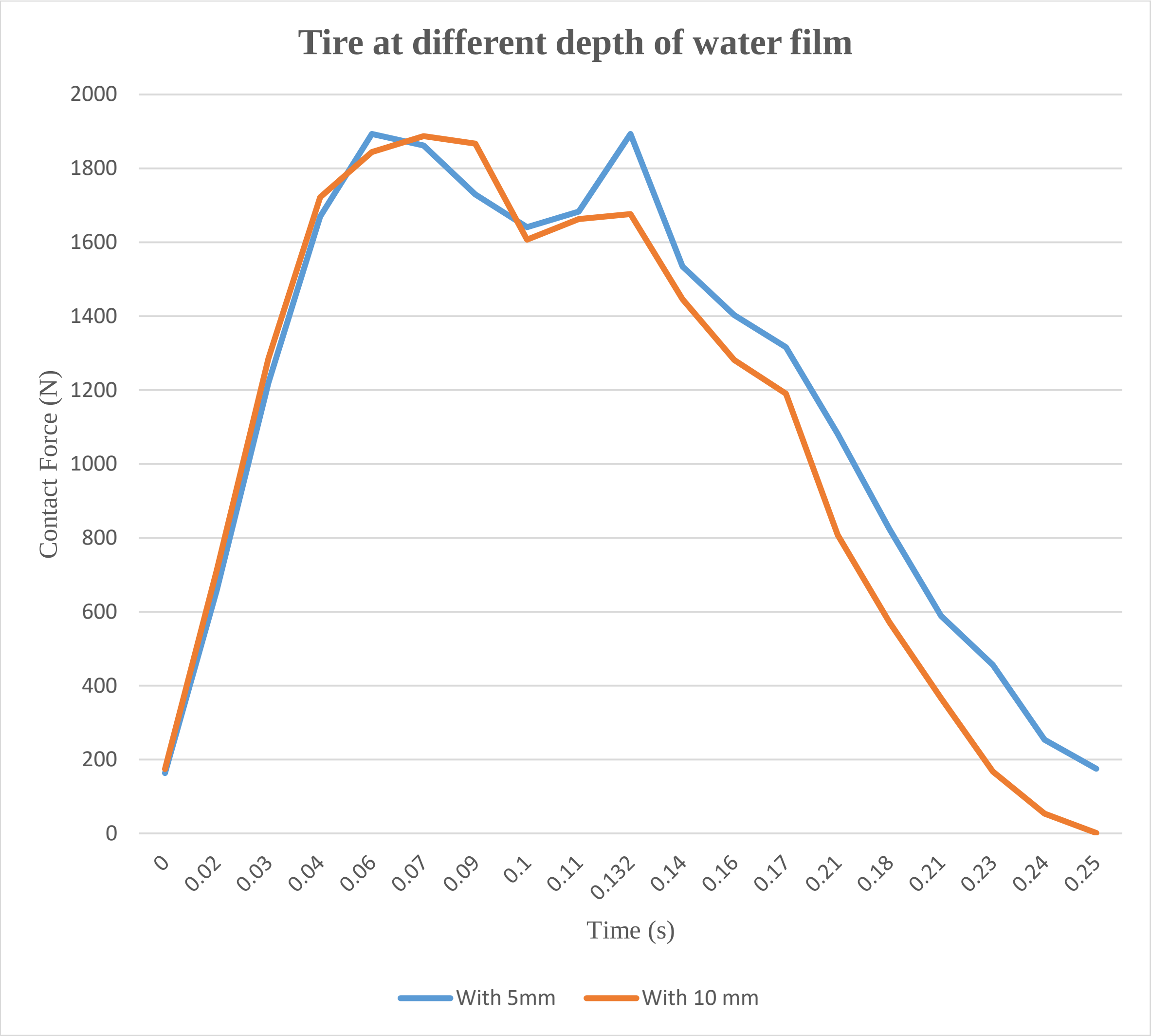


Fig. 15. A tire with different depth of water film

From the graph above (Fig.15) the tires travel at the same speed but the modification is done with the thickness of the water film. The tire is with two variations of water film thickness such as 5mm and 10mm travels at a speed of 112 kmph on the road. The tire travelling at 5 mm thickness of water film attains zero contact force at a time more than 0.25 seconds which shows that the influence of hydroplaning initiation is reduced by the increase of water film thickness. But the tire travelling at 10mm of water film thickness attains zero contact force at a time of 0.25 seconds which shows the probability hydroplaning is high at this tire. So from this, it is able to understand the importance of the water film thickness.

The hydroplaning comparison is carried out between two different forces on the tire at a water depth travelling at the same speed of 112 kmph. Force or load on the tire is one of the important factors that influences hydroplaning. In this, the tire with force 1 attains zero contact force before the tire with force 2 at water film on a road.

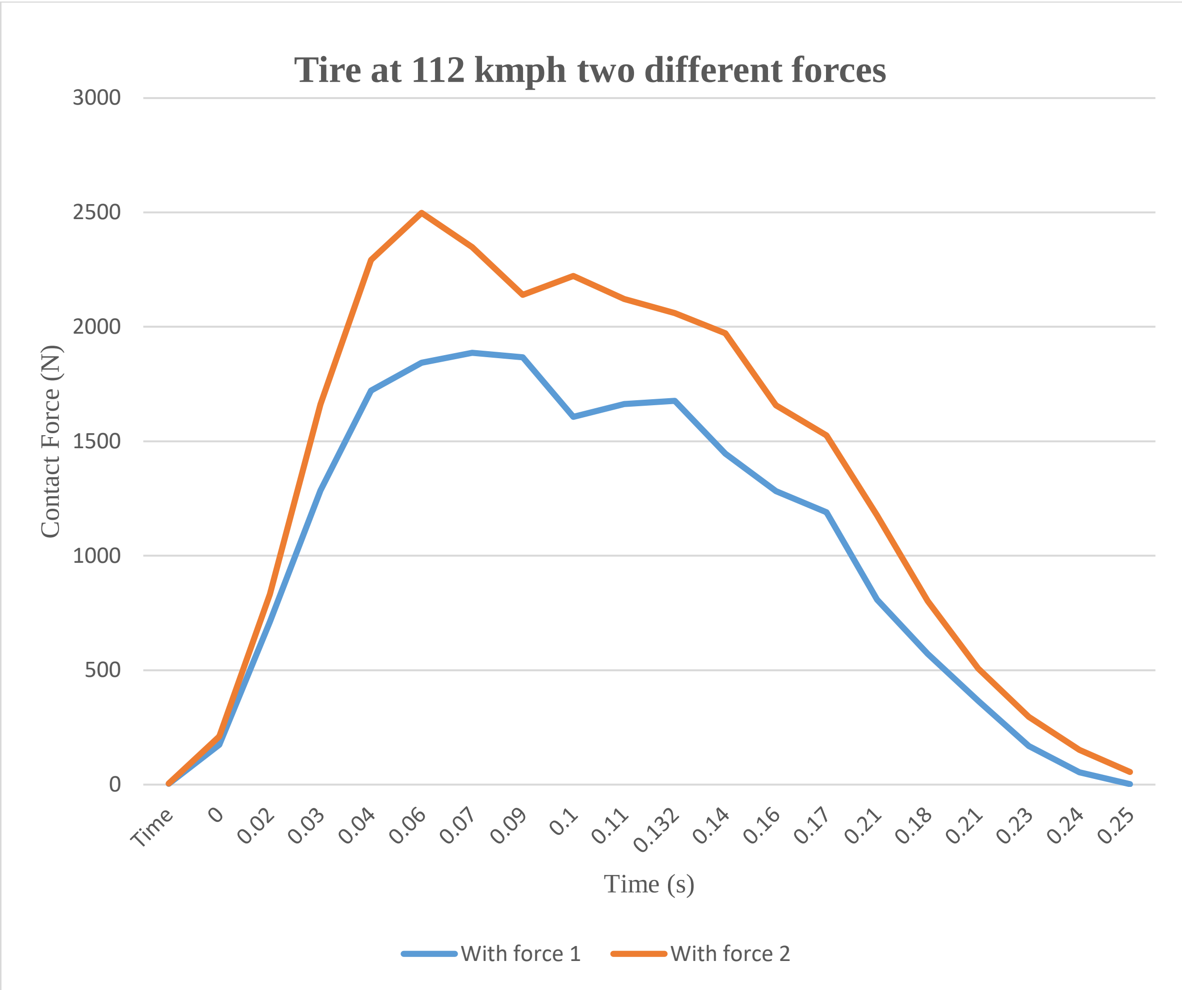


Fig. 16. A tire with two different forces

From the graph above (Fig.16) the tires travel at the same speed but the modification is done with force or load on the tire. The tire is with two variations of forces such as force 1 and forces 2 travels at a speed of 112 kmph on the road. The tire travelling with force 1 attains zero contact force at a time less than 0.25 seconds which shows that the influence of hydroplaning initiation is increased by the force value. But the tire travelling with force 2 attains zero contact force at a time more than 0.25 seconds which shows the probability hydroplaning is low at this tire. So from this, it is able to understand the importance of the force on the tire.

Conclusion:

The report defines the concept and analyzes various factors that influence the hydroplaning process. From the simplified tire-water interaction models have been developed in the MSC Patran and computations analysis are done in MSc Dytran. The vehicle travel on the wet surface has been analyzed, as well as the critical speeds at which the hydroplaning for the tire model are determined which start directly affecting the stability and safety of the vehicle. The hydroplaning is influenced by various factors such as tire inflation pressure, depth or thickness of the water film, road surface texture, speed of the vehicle, tread or grooves present on the surface of the tire, depth of the tire pattern. Among those factors tire inflation pressure, depth of the water film, speed of the vehicle, grooves of tires, force or load are considered and results are compared.

1 In the tires travelled at five different speed such as 70, 80, 100, 110 & 112 kmph on a wet road. The tires which travel at high-speed losses contact force and hydroplaning occurs. The tire which travels at low speeds has contacted over the road for a long duration than the tire which travels at high speed. So from this, it can be concluded that the speed of vehicle influences the hydroplaning. The hydroplaning speed is directly proportional to the speed of the vehicle. With the low speed of the vehicle, the hydroplaning speed can be controlled to some extent.

2 When the tires travel with three different levels of inflation pressure. At 2 bar, 2.2 bar & at 1.8 bar on the road with the same speed and at the same depth of water film. The tire with a high value of pressure has resistance towards hydroplaning. But the tire with reduced inflation pressure, the hydroplaning is initiated within a small duration of time.

3 The thickness of the water film is varied and in two different situations, the experiment is carried out. The tire at 10 mm and 5 mm of water film thickness. In that, the tire which travels at 5 mm of water film has contact force for a long duration of time. But tire at 10 mm of water film thickness losses friction and contact force value reaches zero. With a high depth of water film, the chance of tire to make contact with the road is reduced due to the penetration of the water at tire pattern.

4 When two different forces are applied to the tire while travelling on a wet road. The results show a small variation in the contact forces of the tire. So this shows the importance of the forces which influence hydroplaning.

5 When two different tires are modelled, one with grooves and another without grooves but travelling at the same speed and at the same depth of water film. The tire with grooves has the capability to control hydroplaning than the tire without grooves.

7. List of references

1. Monforton,Robitaille,Bezaire&Mejalli. Gregmonforton and partners. www.gregmonforton.com. [Tinkle] 2018 m. November 12 d. https://www.gregmonforton.com/windsor/car-accident-lawyer/auto-accident-causes/hydroplaning-collision-information.html.
2. Handy & Handy. Handy & handy attorney at law. Handy & handy business development website. [Tinkle] 2016 m. April 26 d. https://www.handylawutah.com/blog/2016/04/summer-or-winter-when-do-more-wrecks-occur.shtml.
3. Government of Lithuania. Statistics of fatal and injury road accidents in Lithuania, 2014-2017. Vilnius: Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania, Traffic safety and environmental protection division, 2018.
4. Attorney consultancy. Mike lewis Attorneys. Mike lewis attorneys. [Tinkle] 2017 m. june 18 d. https://www.mikelewisattorneys.com/our-practice/auto-accident-attorney/hydroplaning/.
5. Hydroplaning and roadway tort liability. T.Bartoskewitz, John M.Mounce and Richard. 1993 m., Transportation research record 1401, p. 117-124.
6. Automobile tire hydroplaning- what happens. III, A.Y. Casanova. Washington, D.C : Safety standard engineer, National safety bureau, Department of transportation, 1970 m., T. III.
7. Hydroplaning speed and infrastructure characteristics. Véronique Cerezo, Michel Gothie, Michaël Menissier, Thierry Gibrat. 224, France: SAGE Publications, 2013 m., T. 9. ISBN.
8. Fenghua, Ju. Modelling skid resistance of rolling tires on textured pavement surfaces. Singapore: National univesity of singapore, 2013.
9. Study of hydroplaning influencing vehicle hydroplaning speed. Ghim ping ONG, Tien fang FWA. Singapore : Journal of the eastern Asia society transportation studies, 2007 m., T. 7.
10. Study of Hydroplaning Risk on Rolling and Sliding Passenger Car. Srirangam Santosh Kumara, Kumar Anupamb, Tom Scarpasc, Cor Kasbergend. 3, 2012 m., SIIV - 5th International Congress - Sustainability of Road Infrastructures, T. 53, p. 1019-1027.
11. Characteristics and model of the initial spray caused by an aircraft elastic tire rolling on the water-contaminated runway. YujiaZhang, PeiqingLiu, QiulinQu, TingLiu, TianxiangHu. Beijing : Elsevier, 2018 m. June 18 d., T. 79, p. 610-624.
12. Friction of rubber on ice:A new machine,influence of rubber properties and sliding parameters. Gerasimos Skouvaklis, JaneR.Blackford n, VasileiosKoutsos. Edinburgh : Elsevier, 2012 m. January 10 d., T. 49, p. 44-52.
13. Mesh generation considering detailed tread blocks for reliable 3D tire analysis. J.R. Choa, K.W. Kimb, W.S. Yooa, S.I. Honga. Pusan : Elsevier, 2004 m. October 10 d., T. 35, p. 105-113.
14. Review of the state of the art in experimental studies and mathematical modelling of tire performance on ice. Anudeep Kishore Bhoopalam, Corina Sandu. Blackburg : Elsevier, 2014 m. April 13 d., T. 53, p. 19-35.
15. Numerical investigation of hydroplaning characteristics of three dimensional patterned tire. J.R. Cho a, H.W. Leea, J.S. Sohna, G.J. Kimb, J.S. Woob. Busan : Elsevier, 2006 m. march 31 d., T. 25, p. 914-926.
16. Transient dynamic response analysis of 3-D patterned tire rolling over cleat. J.R. Cho a, K.W. Kimb, D.H. Jeona, W.S. Yooa. Busan : Elsevier, 2005 m. March 4 d., T. 24, p. 519-531.
17. Tire slip-angle force measurements on winter surfaces. Barry A. Coutermarsh, Sally A. Shoop. Hanover : Elsevier, 2009 m. November 1 d., T. `46, p. 157-163.

18. Fractal Evaluation of Pavement Skid Resistance Variations I: Surface Wetting. Alexandros G. Kokkalis, Olympia K.Panagouli. Thessaloniki : Pergamon, 1998 m. July 21 d., T. 9, p. 1875-1890`.
19. Research of the influence of tire hydroplaning on directional stability of vehicle. Jonas Sapragonas, Artūras Keršys, Rolandas Makaras,Vaidas Lukoševičius, Darius Juodvalkis. 4, Kaunas : Vilnius Gediminas Technical University, 2013 m. October 16 d., T. 28, p. 374-380. ISSN 1648-4142 print / ISSN 1648-3480 online.
20. Hydroplaning Simulation using MSC.Dytran. Toshihiko Okano& Masataka Koishi THE YOKOHAMA RUBBER CO., LTD. Oiwake Hiratsuka Kanagawa : s.n.
21. Augmented Lagrangian and penalty methods for the simulation of two-phase flows interacting with moving solids. Application to hydroplaning flows interacting with real tire tread patterns. Stéphane Vincent, Arthur Sarthou , Jean-Paul Caltagirone , Fabien Sonilhac , Pierre Février ,. France : Elsevier, 2011 m. October 28 d., T. 230, p. 956-983. 10.1016/j.jcp.2010.10.006.
22. Mattias Hjort, Mattias Haraldsson, Jan M. Jansen. Road Wear from Heavy Vehicles – an overview. Borlänge, Sverige : NVF committee vehicle and transport, 2008. ISSN: 0347-2485.
23. Different types of tyres used under different operating conditions. Brajesh Loya, Gaurav Pradhan. 2, 2016 m. March 2 d., International Journal of aerospace and mechanical engineering, T. 3. ISSN (O): 2393-8609.
24. Technology assessment of tire mould cleaning system and quality finishing. Cristiano Fragassa, Martin Ippoliti. 3, 2016 m. March 07 d., International journal fro Quality research , T. 10, p. 523-546. ISSN 1800-6450.
25. Bathe, Klaus-Jurgen. Finite Element Procedures. United stated of america : Prentice Hall, Pearson Education, Inc., 2014. ISBN 978-0-9790049-5-7.
26. Hydroplaning simulation using fluid structure interaction in LS-DYNA. Masataka Koishi, Toshihiko Okano, The Yokohama Rubber Co.,Ltd. Lars Olovsson,Hideo Saito and Mitsuhiro Makino.
27. Anupam Saxena, Birendra Sahay. Computer aided engineering desing. Kanpur : Springer, Anamaya, 2005. ISBN 1-4020-2555-6 (HB).
28. MSc software Corporation. MSc software. [Tinkle] Hexagon, 2019 m. https://www.mscsoftware.com/product/dytran.
29. MSc Software. MSc Software Product Datasheet. MSc Software. [Tinkle]
30. software, MSc. MSc software. MSc software . [Tinkle] MSc software corporation, 2019 m. https://www.mscsoftware.com/product/patran.
31. MSc software Corporation. MSc software Datasheet. Engineering products of Dytran. [Tinkle] 2015 m.
32. Application of SPH in Fluid-Structure Interaction Problems Involving Free-surface Hydrodynamics. Ruben Paredes, Len Imas. Hawaii : American society of Naval Engineers, 2011 m. September 11 d., p. 200-208.
33. Improved tire-soil interaction model using FEA-SPH simulation. Zeinab El-Sayegh, Moustafa El-Gindy , Inge Johansson , Fredrik Öijer. Göteborg : Elsevier, 2018 m. May 22 d., Journal of Terramechanics, T. 78, p. 53-62. doi.org/10.1016/j.jterra.2018.05.001.
34. Evans, M.S. Tyre compounding for improved performance. s.l. : Kumho European Technical Centre, 2000. ISBN: 1-85957-306-1