Effect of Changing Support Conditions by Erosive Attacks in Jointed Plain Concrete Pavements

[1]Asim Farooq [2]Dr.Bernhard Lechner, [3]Dr. M. Yousaf Khan, [4]Rupert Schmerback

[1]Technical University Munich, Germany
[2] Department of Road & Rail Engineering, Technical University Munich, Germany
[3]Deparment of Statistics, Ludwig Maximilians University, Munich, Germany
[4]Autobahndirection Sudbayern, Munich, Geramny

***Abstract* - The joints of Jointed Plain Concrete Pavements (JPCP) are equipped with sealants which shall work properly facing thermal impacts (effect on material properties, aging) and mechanical loading due to horizontal (temperature changes) and vertical differential deflections of adjacent slabs which are controlled by dowel bars. But penetration of water into the joint and into the interface between concrete slab and cement treated base (CTB) layer has to be expected during service life. In combination with decreasing load transfer efficiency the traffic load cycles activate erosive attack to the surface of cement treated base. If material resistance of CTB is not sufficient the concrete slabs may lose support along the joints. Such horizontal gaps will increase in terms of length and height. Changes in support conditions along joints have significant impact on deformation and stress behavior which are important factors for pavement performance. Complete modeling of these scenarios and analysis will also be done in ANSYS.**

***Index Terms* – Finite Element Analysis, Westergaard Slab Theory, jointed plain Concrete Pavements, Cement Treated Base. Dowel Bar, Load transfer efficiency, Efficiency index.**

I. INTRODUCTION

Transportation is essential for a nation's development and growth. In both the public and private sectors, opportunities for engineering careers in transportation are exciting and rewarding. Elements are constantly being added to the worlds in the form of different transport modes like Road, rail, airport, and mass transit system. And new techniques are being applied for operating and maintaining the system safely, economically and environmentally friendly.

Transportation plays a vital role in our social and basic life. The movements of people from one point to another point are based on transportation. The speed, cost and capacity of available transportation have significant impact on the economic vitality of an area and the ability to make maximum use of its natural resources (Garber, 2002)

The main purpose of transportation is to transport passengers and goods from one place to another. Increased need of travel and transport has given rise to increase in rail, road and air transport. Different people give preference to different transport modes depending on their mentality and attitude. However, people generally prefer such transport which is fast, reliable, safe and eco-friendly. For example, in Europe people are accustomed to rail transport but in America and Asia people prefer road transport. Due to the exponential increase in the number of people using the road, the need to maintain the quality of travel is now more than ever before.

The quality can only be improved by constant improvement in the technical design for road. Due to increased speed and frequency of vehicles, roads are subjected to all sorts of increased loadings. However, loads exerted by moving vehicles on the road structure and on its components require detailed investigations and studies. These loadings in combination with irregularity on the pavement surface or overloading give rise to impact loadings which are responsible for the deterioration and damage of the road structure. It is necessary to evaluate these impact loadings as they are responsible for the overall life of the road.

Objective of the research work

The main objectives of this research work is to study the load-bearing capacity of Jointed Plain Concrete Pavements (JPCP) with unbounded cement treated base layer, so there is initial bonding between concrete and CTB. Penetration of water into the joint and into the interface between concrete slab and the cement-treated base (CTB) layer has to be expected during design service life. In combination with decreasing load transfer efficiency the traffic load cycles activate erosive attacks on the surface of cement treated base layer. If materials resistance of the CTB is not sufficient, the concrete slab may lose support along the joint. As a result, if there is no support, then deformation will increase. As such, the question arises that, by how much extent the stress, deformation behavior, efficiency index along joints changes and how much it reduces the life and serviceability of pavement.

Research hypothesis

The conducted research is based on the hypothesis that the rate of deterioration in concrete pavement is affected by environmental effects, dynamic effects and excess loading. The same affect may also be possibly expected when the supporting layer (CTB) is severely affected by pumping effect. And as a result during the continuous course of these actions, the bonding is no

more found between the layers. Consequently, the support condition becomes unable to withstand against heavy loading. Such scenarios lead to the failure of the pavement.

Hence a series of finite element analysis (Design models and performs simulations to study the impact of gap dimensions using FEM) is performed in the current study to determine the magnitude of induced stress and deformation within concrete pavement, and also to study the concrete pavement with support and without support that how much penetration of water will affect the concrete pavement.

II. METHODOLOGY

In order to achieve the objectives of this research work, the following methodology was adopted.

1. Study design procedures and tools used to calculate stresses and deformations of jointed plain concrete pavements (JPCP) used for German highways (design catalogue RSTO 12).
2. Design models and perform simulations to study the impact of gap dimensions using FEM. In addition, loading of pavements affected by erosive attack and changing support conditions will be determined and evaluated.
3. Analyze expected failure modes and conclude on the impact and importance of support conditions
4. Conclude on the impact and importance of support conditions.

III. RESEARCH PROBLEM

Erosion is the loss of fine material on the lower surface of pavement due to infiltration of moisture/water in pavement through joints. This erosion of supporting layer at transverse joints causes faulting. Erosion take place when water passes through sealant and reach in between the top and supporting layer, the washout of supporting material under slab will start erosion action under slab. And with passage of time it starts damaging pavement geometry. The dynamic impact of heavy and continues traffic loading will allow fines to be pumped from one side of slab to another side of slab along transverse joints. At this stage the pumping action will lead the pavement towards deterioration, as well as such action is considered to be major contributing factor to slab cracking and eventual breakup (Initial stage of failure when cracks starts).

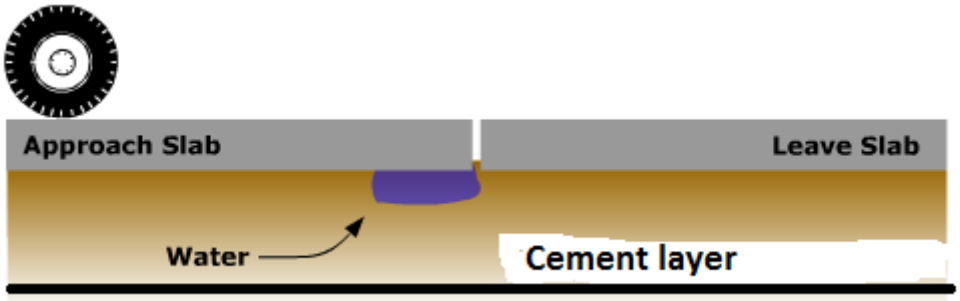


Figure 1, Pumping and Faulting Load act at approach slab (*(Muench, 2003)*

Unsealed slab joints in “undoweled jpcp” allow water to enter in the pavement structure and accumulate water under slab.

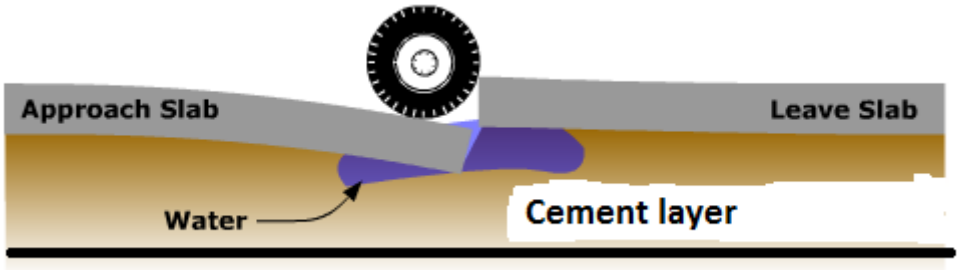


Figure 2, Pumping and Faulting Load act at approach slab *(Muench, 2003)*

When load moves and reached to joint, the joint deflect because of no support and the water under approach slab is ejected, carrying material with it, and accumulates under the leave slab. The movement of material under slab due to water pressure is called “Pumping”. When wheel load acts on “approach slab” the maximum water moves under “leave slab”.

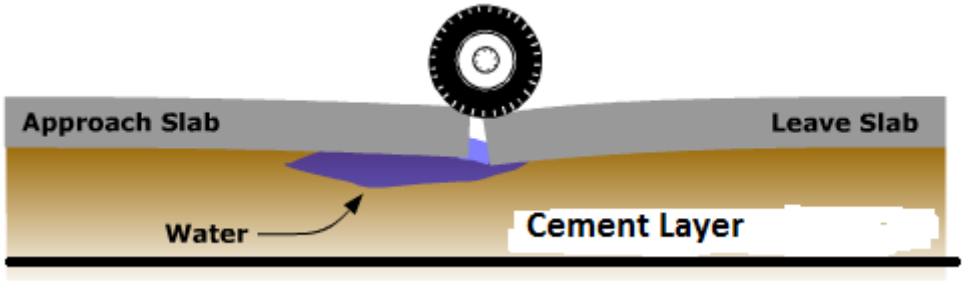


Figure 3, Pumping and Faulting Load act at joints of slab *(Muench, 2003)*

When wheel load moves from "approach slab" to "leave slab" the water comes back with high speed under "approach slab". Water and material from underneath the leave slab are pumped back to underneath the approach slab, this transferring of "water with material" moves from one slab to another with passage of loading.

First the water moves from one slab to another and then when load acts at the same slab then it is returned to previous (Unloaded slab). As a result it affects the supporting layer and this effect is severe with passage of time and length of loss of support increases.

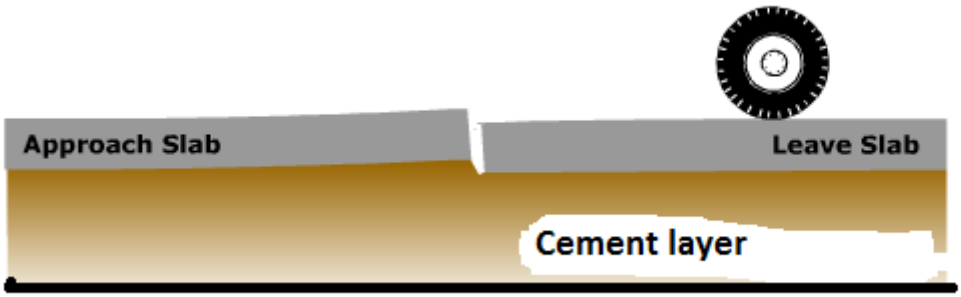


Figure 4, Pumping and Faulting Load act at leave slab *(Muench, 2003)*

When wheel load reached to leave slab, this leads the pavement to accumulation of material underneath the unloaded slab (Approach slab). As a result the approach slab bends up to accommodate extra material, while the leave slab bends down to fill the voids.

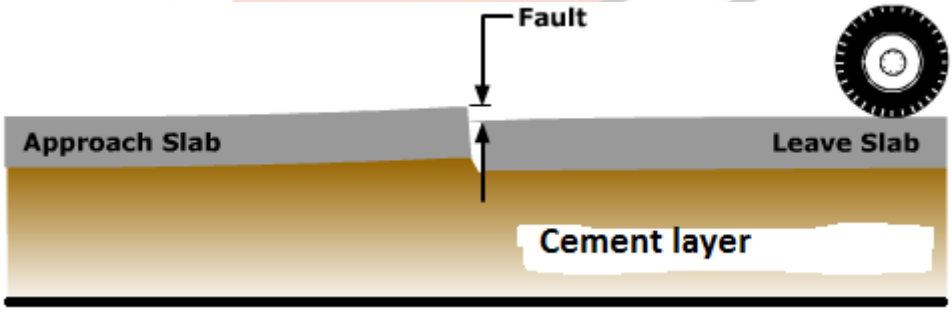


Figure 5, Faulting and Pumping *(Muench, 2003)*

Such effect will cause elevation difference between the approach and leave slabs (faulting), which is the cause of "pumping" is a major contributor to deterioration.

Pumping and Faulting

To determine the most probable cause of failure of a pavement may be the existence of moisture under slab. Pumping referred to the vertical displacement of abutting slab along transverse joint, creating a deep step in the pavement due to failure of sealant material used between two slabs. Through sealant material water will penetrate to supporting layer as a result it will affect the pavement along slab joints. The failure of sealant will allow moisture infiltration leading to erosion of pavement.

Difference in elevation between slabs across transversal joint associated with the absence of reinforcement in JPCP. Usually approach slab is higher than leave slab due to pumping action, because of coming out of supporting material. As a result non reinforced JPCP behave as elastic material, but in limited duration this effect will convert to plastic deformation.

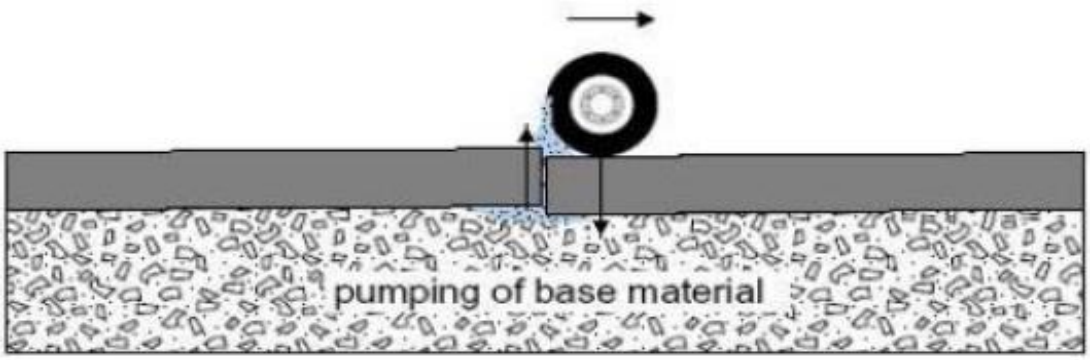


Figure 6, Pumping of Base Material *(Bautista & Basheer, 2008)*

Initial Model

The design of jointed plain concrete pavement (JPCP) is progressively becoming more scientific in nature due to the research work (both analysis and performance) carried out in different parts of the world. Development of Finite Element Method (FEM) has brought a revolution in computation of stresses and deflections in rigid pavement under different support conditions involving erosive attacks during the service life of concrete.

The initial model is based on assumption that 2 layers (Top layer concrete and supporting layer cement treated base layer), supported by continuous support. It has been assumed that during the service life of the pavement the water will penetrate (despite of all the safety measures) into the pavement making it vulnerable to erosive attack. This penetration will cause the pavement to lose its strength and stiffness over the period of time accompanied by the increase of stresses and deflections. Under such conditions the cracks are inevitable and will cause the pavement to deteriorate, reducing its service life. To analyze the above mentioned fact the models were developed using the state of art technology (ANSYS software pack for FEM analysis). The results were further checked against the results obtained by empirical analysis (Westergaard Method)

The model is based on assumption that at one side of slab there is weak support condition and the critical point (loss of support) is assumed to be at 0.25 m (of CTB) at another side of slab and wheel load acting at slab center and slab edge.

Table 1, Comparison between FEM and Westergaard slab theory 2 layer

Load acting area	Westergaard	FEM
50 KN acting on slab Centre		
Stress at Centre	0.45 N/mm^2	0.46 N/mm^2
Deflection at Centre	0.06 mm	0.05mm
50 KN acting on slab edge		
Stress at edge	0.80 N/mm^2	0.78 N/mm^2
Deflection at edge	0.22 mm	0.21mm

Wheel load acting at slab edge

This analysis is based on three scenarios, when wheel load acting at slab edge and there is weak support condition along slab edge at a distance of 0.25m, 0.50m and 1m. This case is based on when there is weak support at one side and at Critical edge wheel load is acting.

Table 2, wheel load acting at edge

Scenario	Thickness (mm)	Total Stress at edge (N/mm^2)	Deflection at edge (mm)	Critical support length (m)
1	250+250	0.78	0.23	0.25
2	250+250	0.82	0.28	0.50
3	250+250	0.97	0.58	1

2" Layer model analysis, wheel load acting at slab Edge

The current research is done for 2 cases, when wheel load act at Centre and edge and there is loss of support at one side of slab. To predict that how much changes will occur on overall system the pavement is modeled and analyzed for "Centre and Edge'' and it has been find out that there will be no effect on stress and deflection when load act at center.

But for edge results are different and it has been found that the loss of support will cause the increase in stresses and deflection which are directly proportional to the loss of support. And this will cause the cracking of pavement with the passage of time.

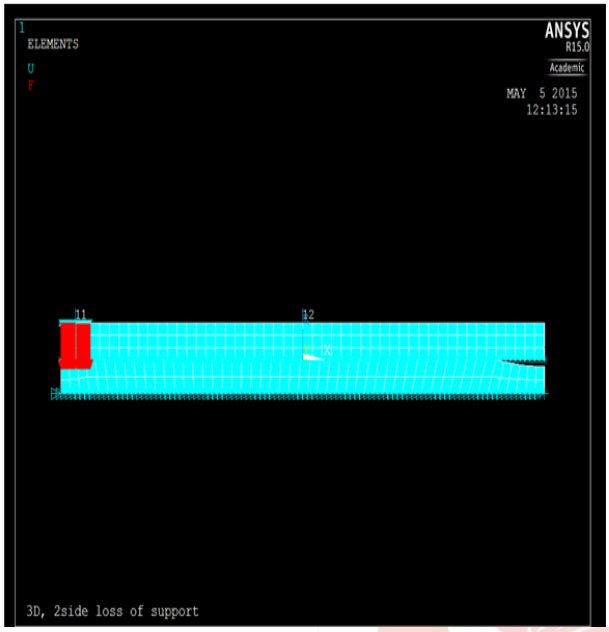
Extension in Model Loss of Support at Both sides of Slab

The Initial model was based on assumption that at one side of slab there is weak support condition but now the critical point (loss of support) is assumed to be at 0.25m and 0.50m at two sides of slab respectively.

This model is based on assumption that loss of support is extended to both sides of slab edge. And the parameters are, at one side there is loss of support at 0.25m and another side there is loss of support at 0.50m. The load is applied on the critical edge to study the erosion effects.

In initial model the assumption was based on the Scenario that the height of 0.25m is 0.05m and the loss of support for 0.50m is assumed 0.10m. This model is also based on the same parameters but this model is based on assumption that loss of support is not equal to each other at one side there is loss of support of 0.25m and another side the loss of support is 0.50m and the height is also change, at one side its 0.05m and another side its 0.10m, to measure the effect in more detailed when wheel load act at slab edge.

Scenario 1, 2D View load act at 0.25m critical edge



Stress and deflection of Scenario 1

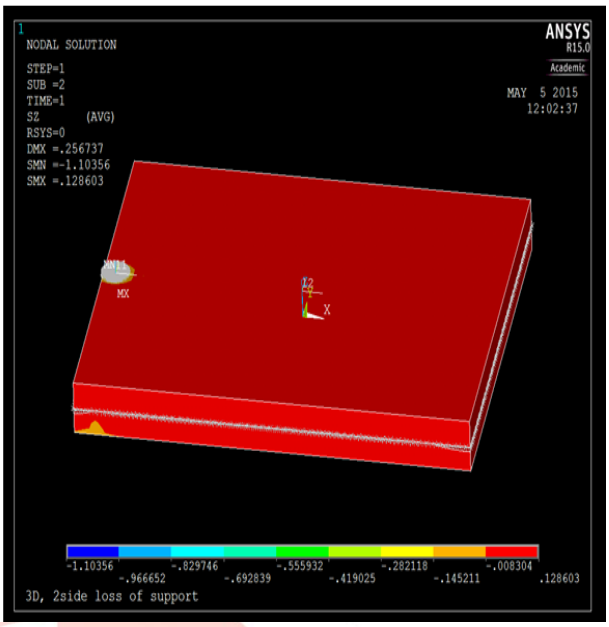


Figure 7, Scenario 1 Loss of support at both Sides load acting at edge

The main aim to display this bottom view of slab is to explain that when there is loss of support at both sides, then there will be an imbalance in slab, which will cause the slab to uplift. In the Initial model this effect was low, because the loss of support was at one side and as a result the slab will be in balance. But in this specific scenario this effect is increasing and if we increase loss of support at this specific point this effect will spread on the whole edge. Now this effect only cover the specific part of slab, but increase in load cycles with the passage of time will increase the loss of support and this effect will increase the effect in horizontal as well as vertical direction. And as a result cracks will increase with the passage of time ultimately leading to the slab failure. Such action will also increase erosive attack at another side of slab, because load is acting at 0.25m edge, and due to this load action the other side will be at compression, so there will be higher chances of erosive attack at non load acting edge.

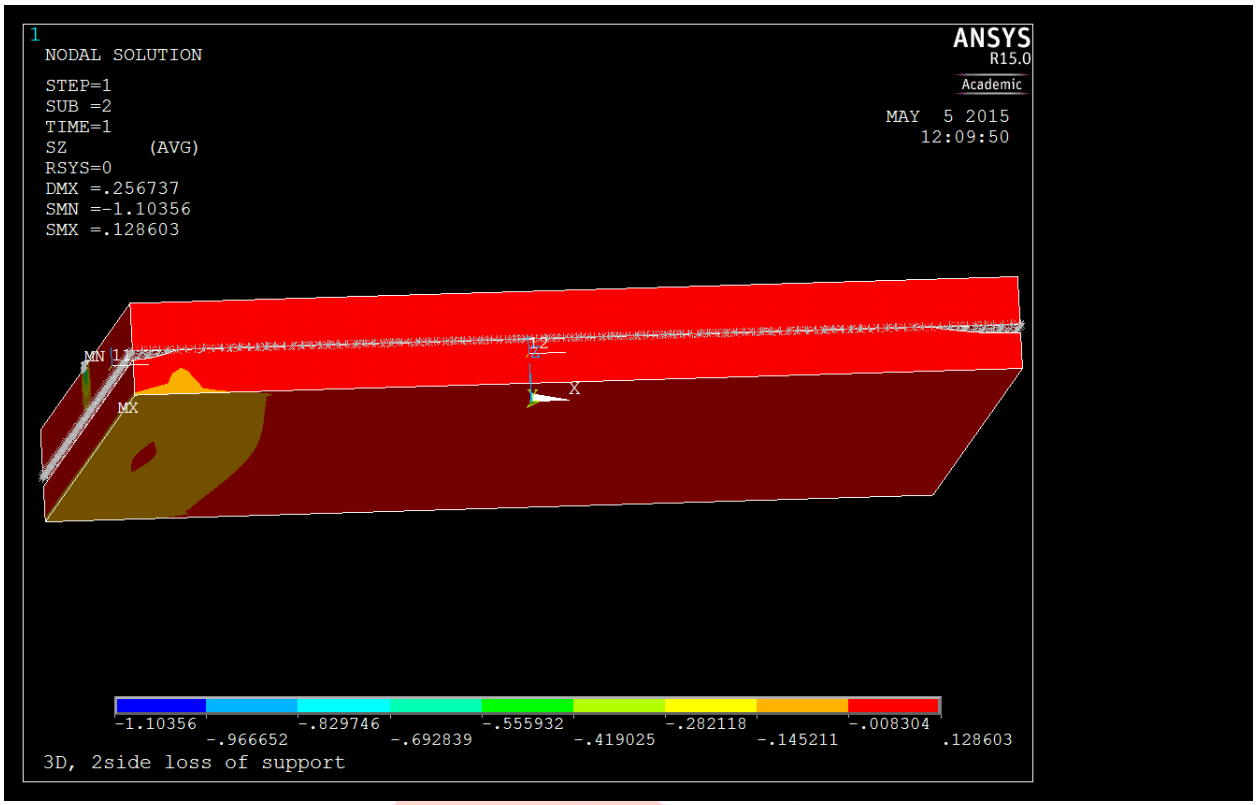


Figure 8, Critical edge model Rotation (Movement)

Table 3, Wheel load acting at edge under different supporting scenarios

Scenarios	Thickness (mm)	Stress at edge (N/mm^2)	Deflection at edge (mm)	Critical support length at both edges (m)	Load acting edge (m)
1	250+250	1.10	0.25	0.25+0.50	At 0.25 loss of support edge
2	250+250	1.10	0.29	0.25+0.50	At 0.50 loss of support edge

According to 2 layer verification process where there is perfect support condition and there is no problem in supporting layer, and then compare result with initial model and extended model. The resulted stress and deflection values have changed by changing the supporting conditions. In perfect conditions the stress at edge was 0.77 N/mm2 and in initial model this value reached to 0.78 N/mm2 (Loss of support at one side of slab), but in current study stress value has jumped to 1.10 N/mm2.This analysis shows that changes in supporting condition will trigger the stress and deflection. The change of 25-30% is observed in the overall stress value by changing the support conditions.

These 2 studies were based on loss of support in slab edges. In combination with decreasing load transfer efficiency the traffic load cycles activate erosive attack to the surface of cement treated base. If material resistance of CTB is not sufficient the concrete slabs may lose support along the edges. Such horizontal gaps will grow in terms of length and height, and with passage of time and increase in load cycle the pavement overall handling capacity is reduced, and increase in traffic load cycle is directly proportional to increase in impact of Gap. Changes in support conditions along edges have significant impact on deformation behavior and stresses acting in concrete pavements which are indicators for pavement performance.

Erosion and Joint Effectiveness

The First Mechanistic approach for the design of jointed plain concrete pavement at the transverse joints, According to (Westergaard, 1929)theory was based on assumption that deflection of “dowel joined concrete slabs” have equal deflection at edges. And second part of theory is based on assumption that only the two relative dowel bars will be active in load transfer mechanism. The maximum bending stress from edge loading at the mid slab location of a JPCP is the critical response the leads to bottom up cracking.

Therefore the first requirement for the development of model is to calculate the transverse cracking in JPCP at the mid slab and slab edge. Of interest was the maximum combined edge stress from wheel loading and environmental changes (penetration of water, loss of support etc) that leads the pavement towards cracking. This structural model used to predict the “Load Transfer Efficiency” and “Joint Effectiveness” under changing support conditions.

Model Based on Finite-Element Method without reinforcement

The model of jointed plain concrete pavement (JPCP) was in three dimensional Cartesian coordinate system and corresponded to a selected German highway, the model specifications are, the length and width of slab 5000mm x 4000mm, thickness of concrete layer 250 and cement layer 250. The model is based on assumption that 2 layers (Top layer concrete and supporting layer cement treated base layer), supported by continuous support. It has been assumed that during the service life of the pavement the water will penetrate (despite of all the safety measures) into the pavement making it vulnerable to erosive attack. This penetration will cause the pavement to lose its strength and stiffness over the period of time accompanied by the increase of stresses and deflections. Wheel load of 50KN acting exactly at slab edge, the research work is dividing in three Scenarios

Scenario 1

Scenario 1 is based on when wheel load acting on one side of slab while the other slab edge is unloaded. We assume that the wheel is acting on one slab, and does not transfer load to another. The model is based on two slab geometry, without reinforcement with gap of 8mm with perfect supporting geometry. The goal is to predict the joint effectiveness, load transfer efficiency.

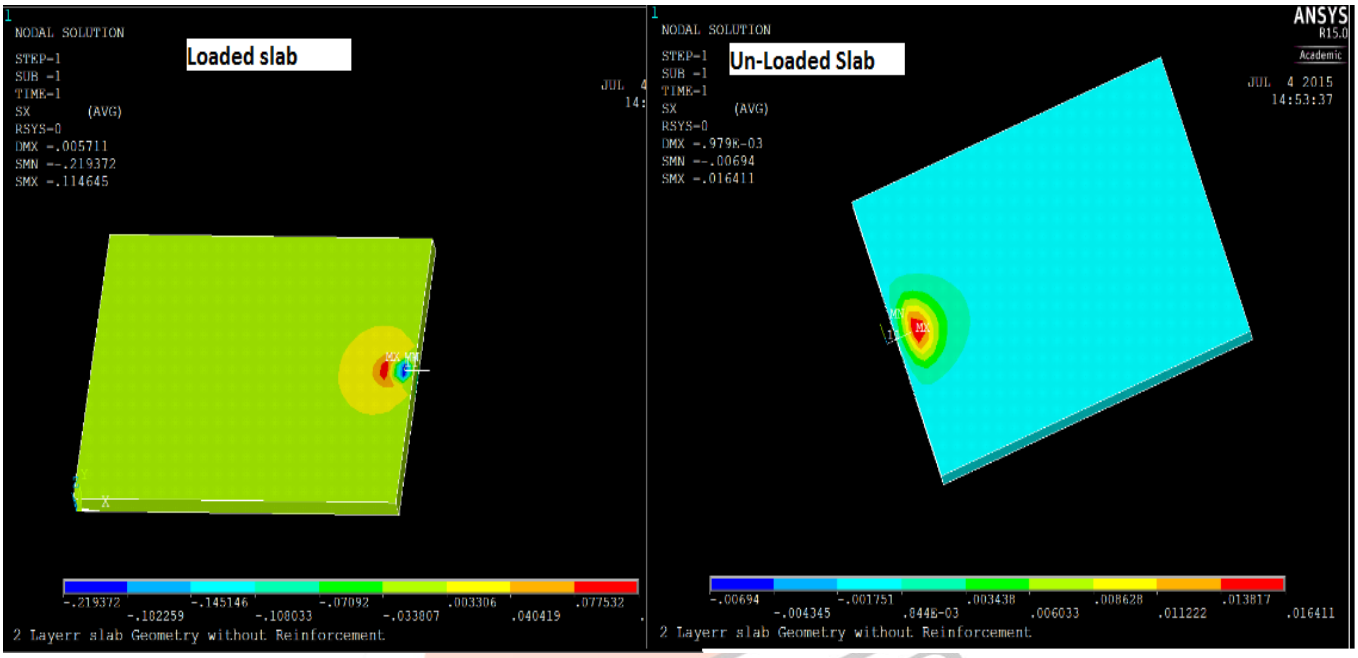


Figure 9, Scenario 1 Loaded and Unloaded slab (Stress and Deflection)

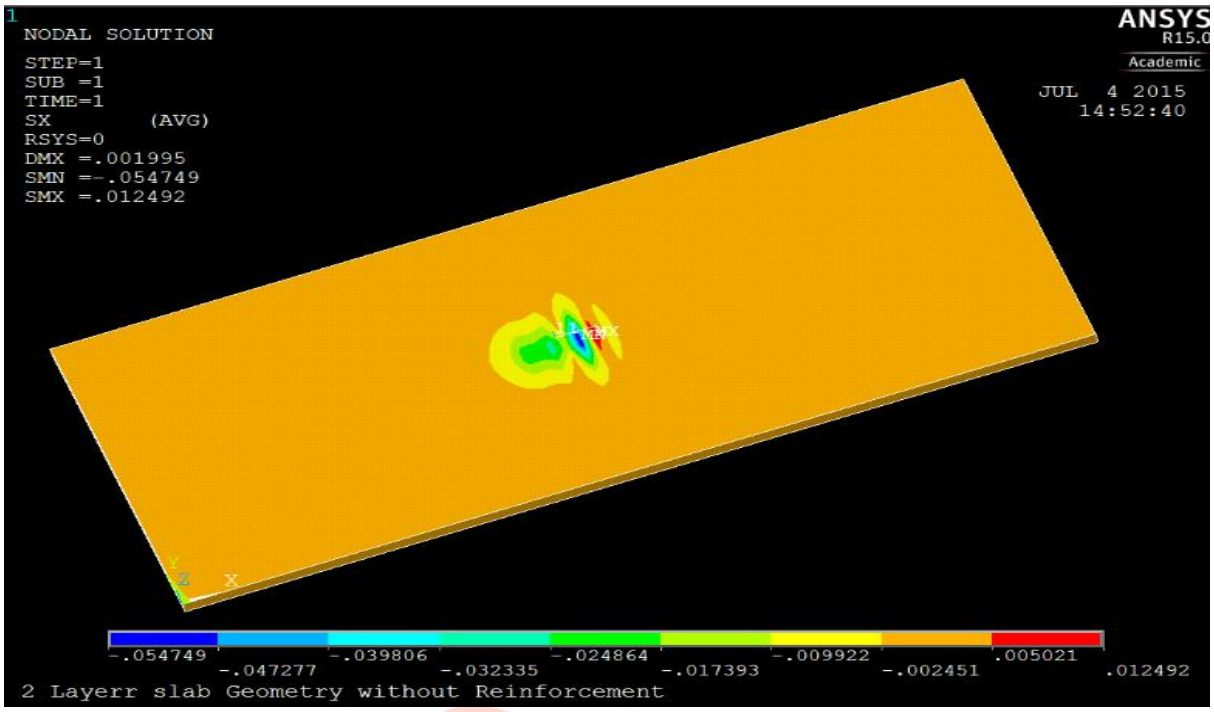


Figure 10, Scenario 1, Load distribution on Supporting Layer

When load act at slab edge, due to no reinforcement the load is not transferred 100% to supporting layer. As a result the wheel load will tend to move the slab in downward direction. And according to Figure of simulation result of loaded and unloaded slab, the efficiency index for this scenario is 31% and the load stress transfer efficiency is 15% for perfect supporting geometry (without loss of support). According to above figure the load distribute across area, in this situation when load act at edge, at one side of slab there is enough space to transfer the load, but at another side slab will tilt due to higher stress. At this location the driver will feel kink, so load impact edge will be in tension and downward will be in compression. If vehicle pass at higher speed there will be higher change of velocity which increases the momentum, so overall there will be higher impulse. The animation of the same model shows that when load act on one slab, due to impact of load slab move in downward direction. And due to loaded slab downward deflection there will be maneuver in un-loaded slab that will also push the unloaded slab near gaps in downward direction.

Scenario 2

Model is based on when wheel load is acting at slab edge and the loss of support is under another slab. Which can be seen clearly in figure, the aim is to analyze the efficiency index and load transfer efficiency ratio along joints due to weak geometry of supporting layer.

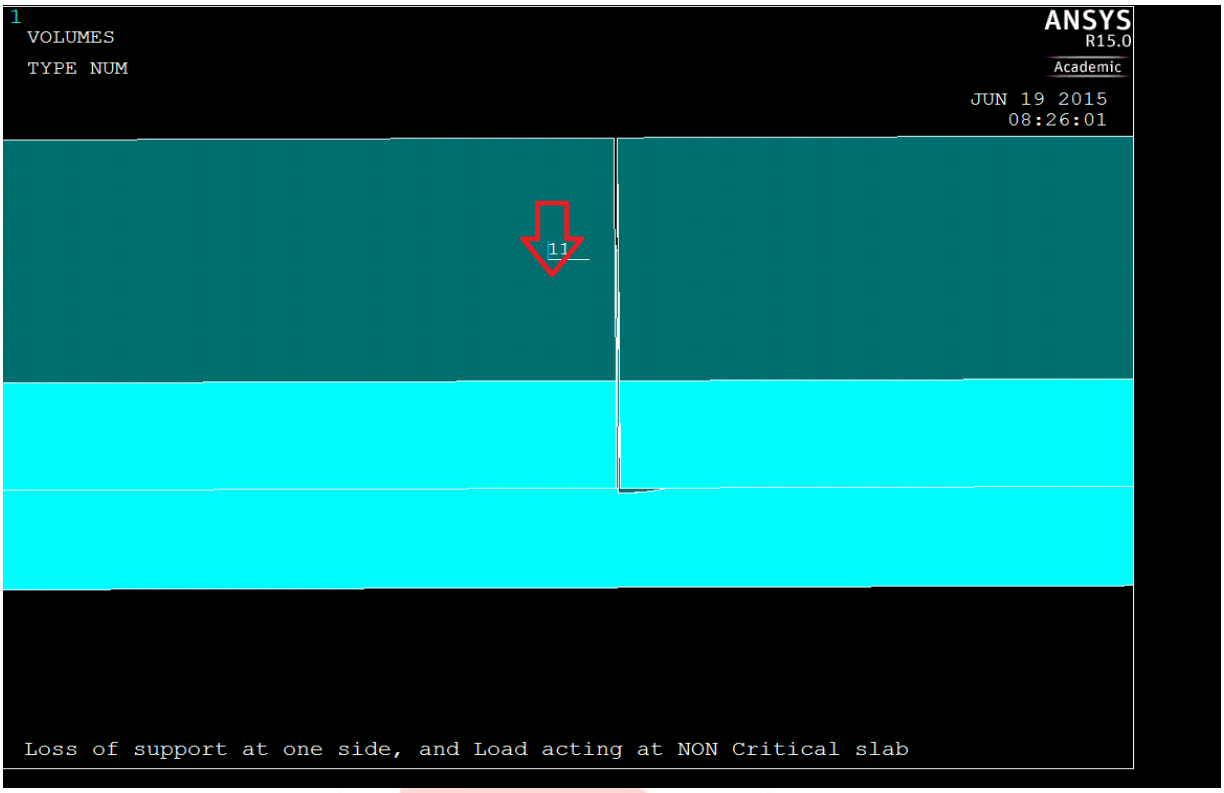


Figure 11, Scenario model with loss of support and Load act at non Critical edge

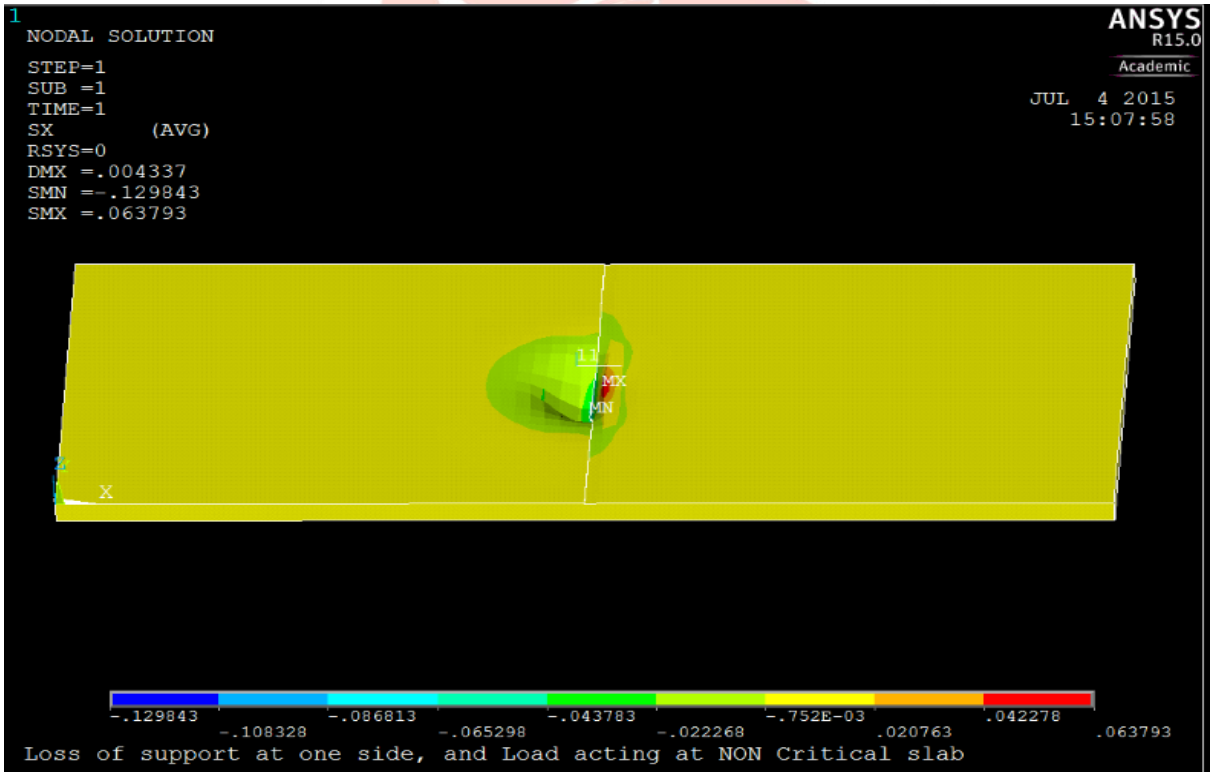


Figure 12, Supporting Layer Distribution

It is analyzed from the above simulation the efficiency index is 8% and load transfer efficiency 14%. For this specific scenario that due to geometry of supporting layer this is quite uneven near the joints edge, so the loss of support is assumed to be 100mm. As a result this specific section the reaction force from supporting layer will be very less, and from simple structure reaction. As it is explained above that concrete has very less capacity of resistance against tension, so this part will be in tension as result at this point there will be higher stress and deflection. As a result at loss of support section there will be settlement (Tiling of slab, along

force direction clockwise direction). And the effect of moisture will increase and also start disturbing the edge of next slab when load act at leave slab. Due to erosion intensive effect will increase when load reach to approaching slab.

Due to concrete rigidity the tension will increase in concrete, hence concrete has very low resistance against tension and as result "Hair Cracks" will start producing at the higher stress and deflection area. Due to continuous impact of wheel load at the same slab location residual deflection will start in concrete, and due to repeated load at the same edge there is chance of fatigue.

So if we calculate the impact load on this specific loss of support, which is equal to force overtime. If the speed of vehicle is higher it will leave heavy impact on the slab.

Scenario 3

Model is based on scenario when loss is at one side and load acting at critical section. Now the purpose is to see as mention in scenario 2, where load was acting at non critical edge. This specific scenario is to compare the result of loading location at critical edge and non-critical edge. due to critical section and critical loading location due to pumping action after impaction of loading some particles comes out .To study this effect is the aim of this simulation, and to analyze the pumping and faulting action in detail), and also to analyze the erosion interaction with load transfer at joints.

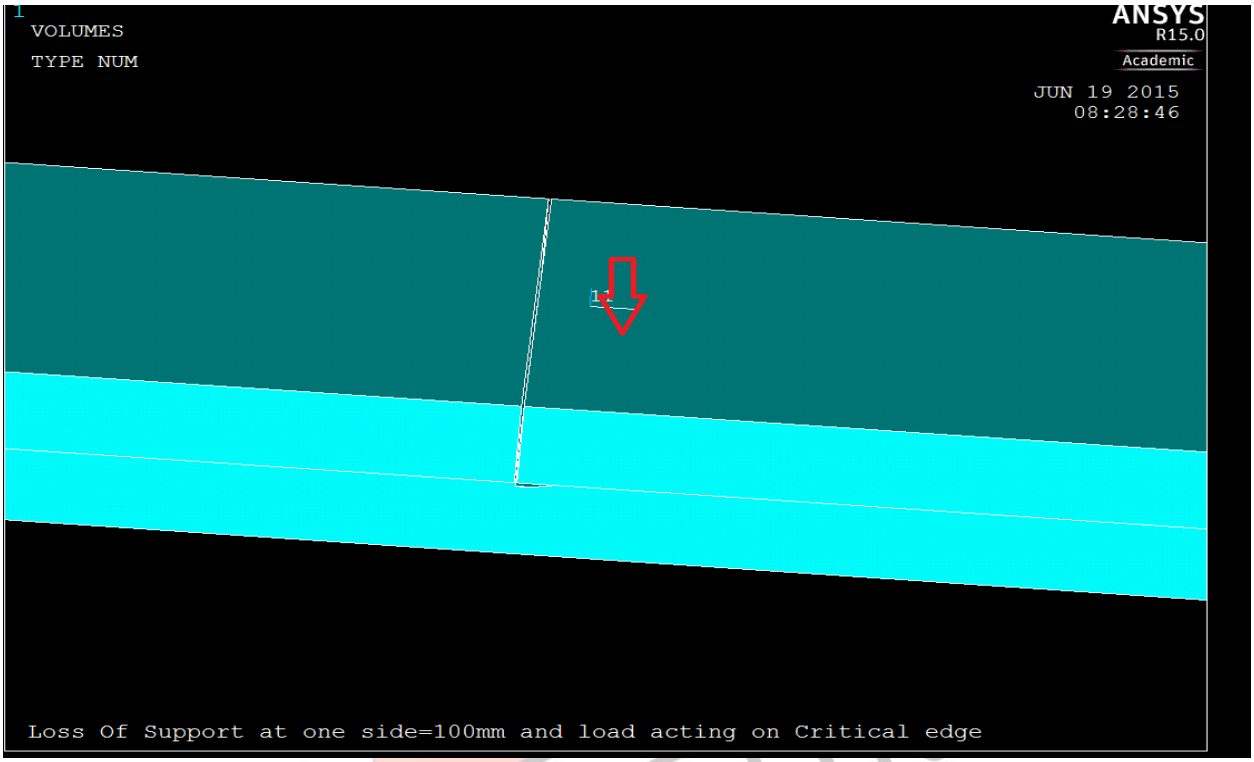
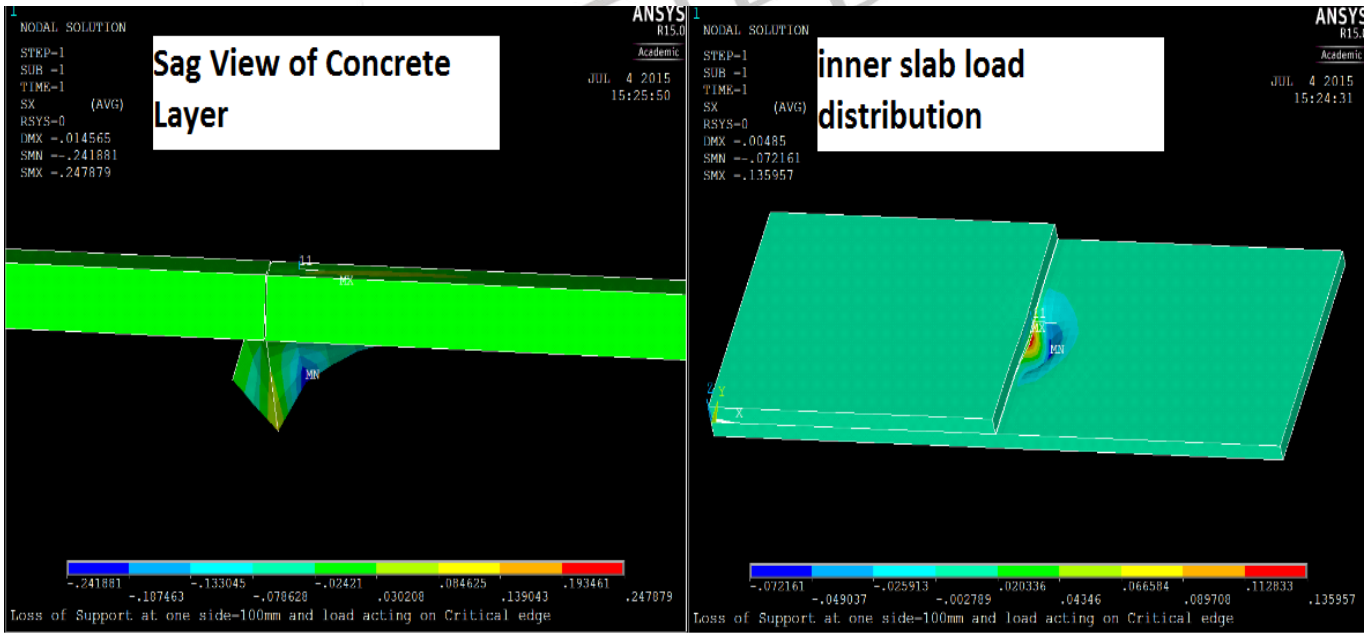


Figure 13, Scenario 3 Load acting at Critical Edge



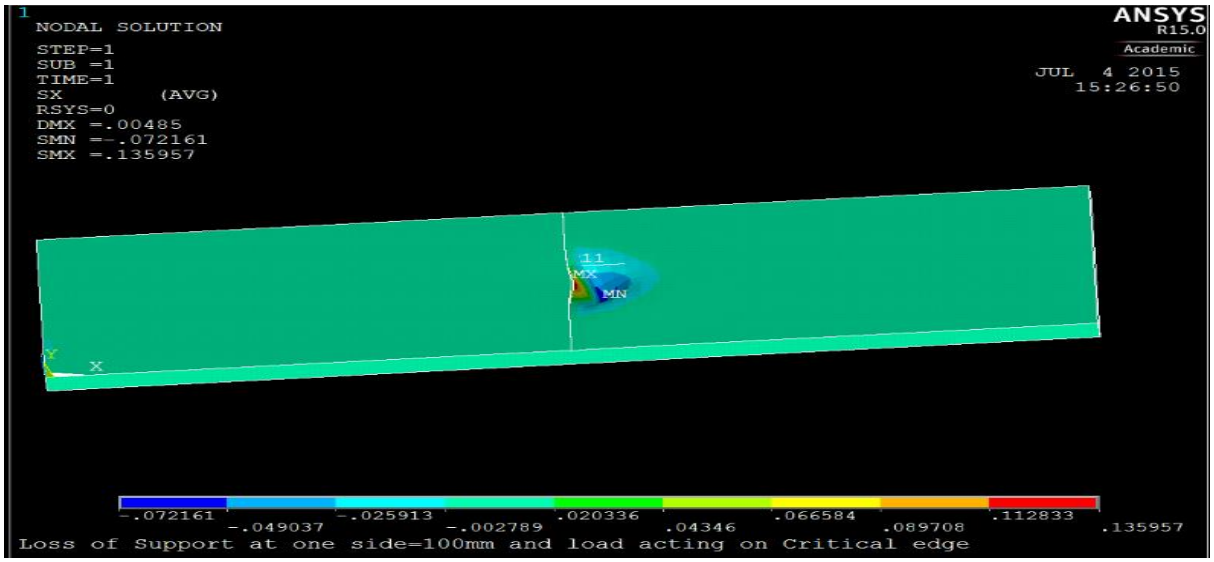


Figure 14, Sag view of Top Layer and supporting layer distribution Pattern

When load acting exactly at the same edge where there is loss of support, from FEM result it shows that loaded slab stress reached to 0.24N/mm2, which is twice when load was acting at the other edge. Efficiency index is measured 4% and load transfer efficiency drop from 14% to 1%. And from above result of loaded and unloaded slab, it's quite clear that unloaded slab shows very uneven stress and deflection distribution pattern. This means that when loaded slab will goes down that will start affecting the unloaded slab as well, as result there will be higher erosion action at both sides of slab.

From the supporting layer stress and deflection distribution pattern it's clear that the magnitude of stress has increased due to no dowel present in either slab. So both slabs will acts independently not supporting each other. The higher stresses are observed with an addition of loss of support. And the EI and LTE index also deviated.

Scenario 4

Model Explanation In this scenario loss of support extends to both sides of slab and critical supporting conditions also reached to 200mm as can be seen in figure 17 in more detail. The aim of this simulation is to simulate the erosion effects at both sides when load will act also on the critical edge.

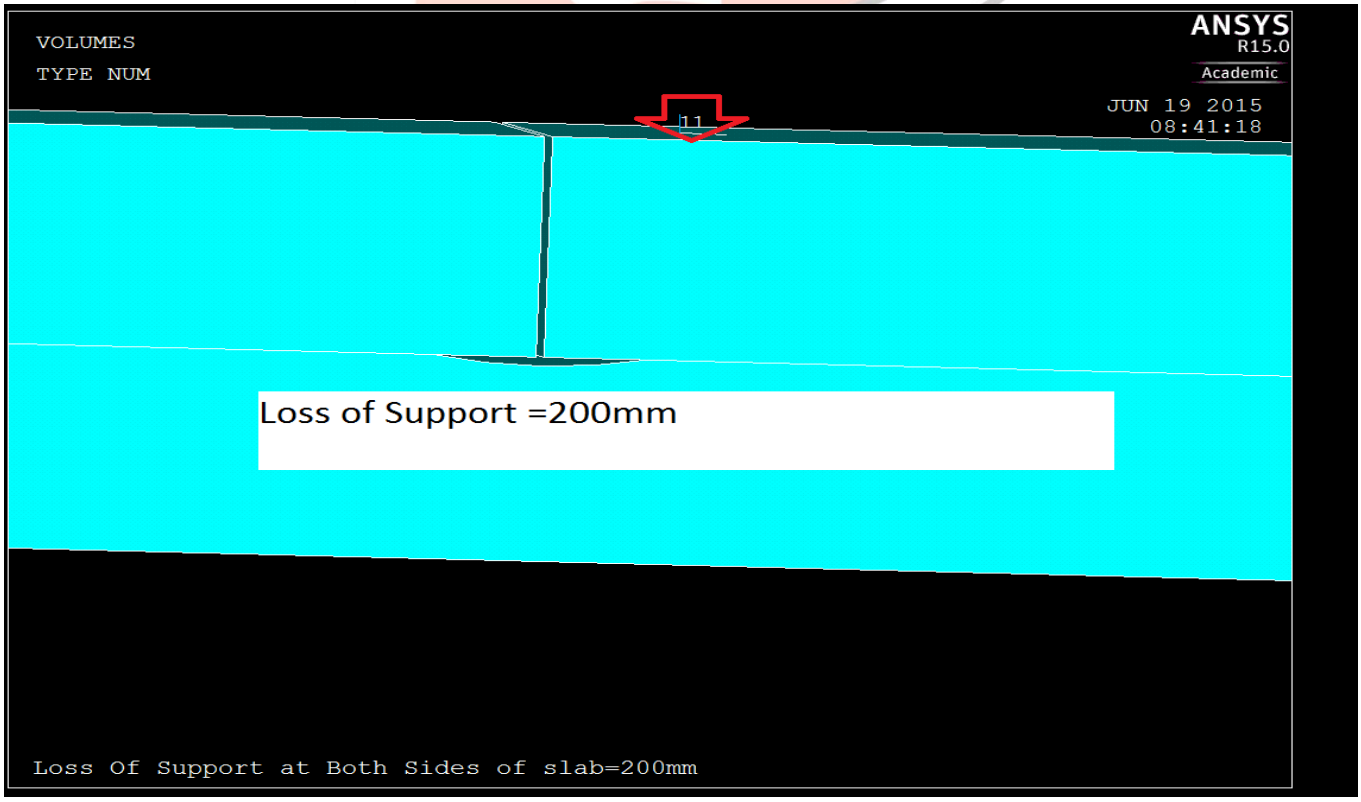


Figure 15, FEM Model Scenario 4 Loss of support at Both Sides

In this scenario which is based on the loss of support at both sides and load acting exactly on the critical edge of slab. And loss of support for this case assumed to be 200mm, from calculation the efficiency index value for this scenario is calculated 2% and load transfer efficiency is 5%.

When erosion effect will increase and reaches to both sides of slab, then from above simulation result of loaded and unloaded slab along edge joint that load transfer efficiency is dwindle from 11% to 5%, when load act at edge the water under approach slab is ejected, carrying material with it, and accumulates under the leave slab.

Water and material will move from underneath from one slab to another with high pressure depend on the speed of vehicle, if the speed is higher than moving Moisture speed under slab will be higher which will start effect the supporting layer this transferring of "water with material" moves from one slab to another with passage of loading.

First the water moves from one slab to another and then when load acts at the same slab then its returned to previous (Unloaded slab) as result its effect the supporting layer and this effect is severe with passage of time and length of loss of support increases. Such effect will cause elevation difference between the approach and leave slabs (faulting), which is the cause of "pumping" is a major contributor to deterioration.

And the bending moment diagram will show the sag due to loss of support. Sag will lead the pavement towards settlement and due to moisture content under slab it will move with high speed, as result from the both sides of slab edges the erosion will increase and there will be another effect which is called faulting, when the supporting material will dispose of underneath then there will be difference in elevation between slabs across transversal joint associated with non-reinforced JPCP, usually approach slab is higher then leave slab due to pumping action, because of washout of supporting material.

Scenario 5

In this scenario loss of support extends to both sides of slab and critical supporting conditions also reached to 400mm as can be seen in figure 21 in more detail. The aim of this simulation is to simulate the erosion effects at both sides when load will act also on the critical edge. It is also to compare the erosion effect at 200mm support condition and 400mm support condition.

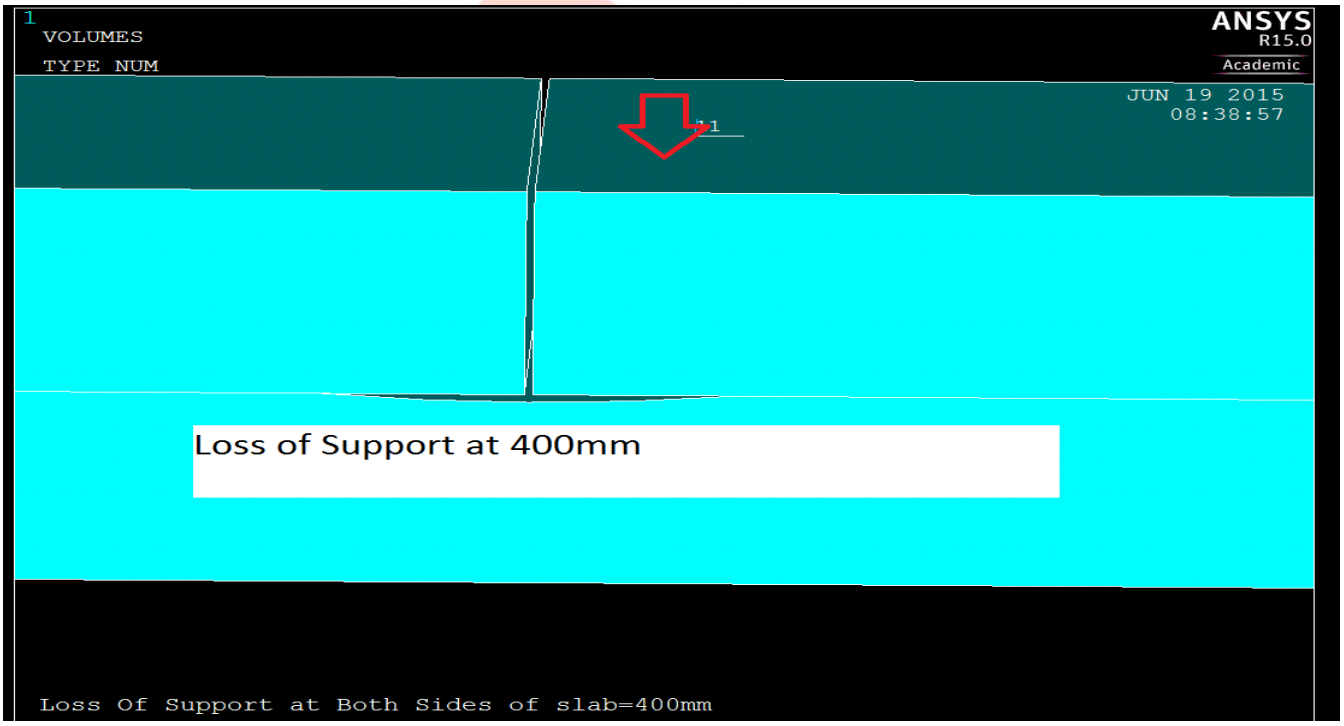


Figure 16, FEM Model Scenario 5, Loss of Support extend to 400mm at both sides

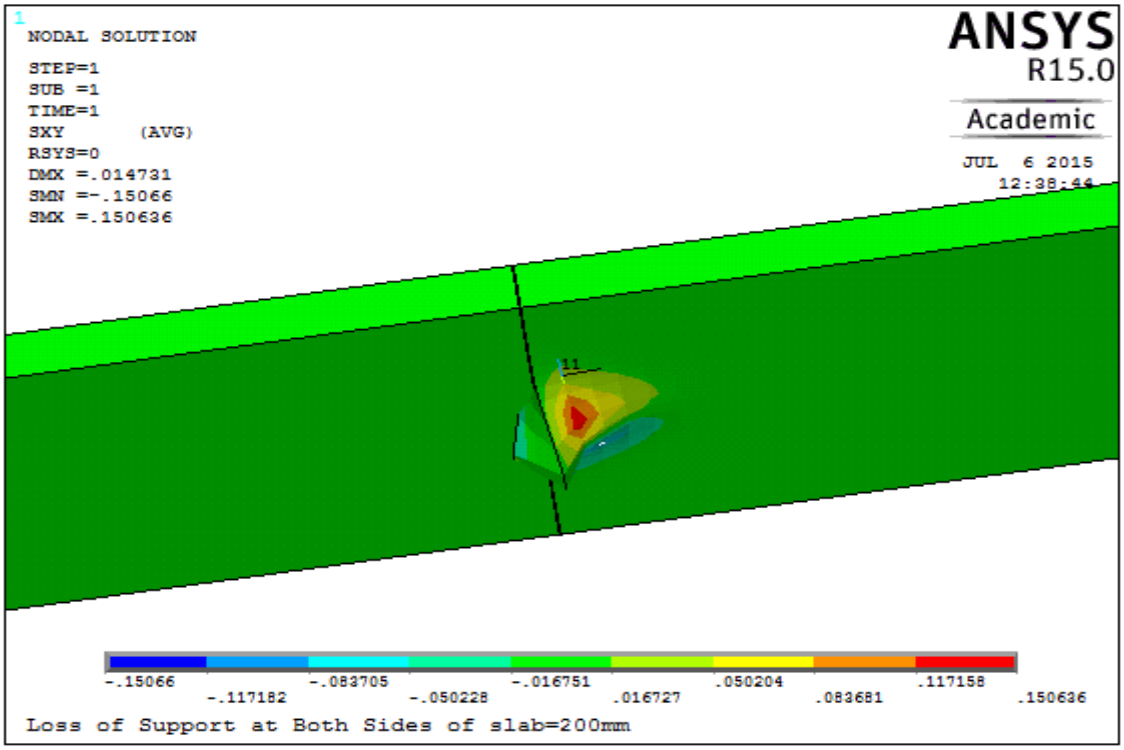


Figure 17, Deformation of concrete layer due to no reinforcement

In above scenario the loss of support extended from 200mm to 400mm, so that creates huge problem and as a result from unloaded slab pattern its shows higher area is under extreme stress and deflection which will affect the overall performance of the model, and increase the erosion action. And the pattern of supporting layer shows sag at the middle of loaded area where it will completely bend the slab in downwards direction.

With extension of loss for support from 200mm to 400mm the stress on loaded slab jumped to 0.40 N/mm2. In current scenario the deflection is found in loaded and unloaded slab, the loaded slab bend down due to load and unloaded bend due weak loss of support and due to the impact of loaded slab.

Load transfer relation with Erosion

In case of un-dowelled slab the erosion will be higher and it's quite clear from simulation result, but due to insertion of dowel bar the erosion across joints will decrease due to holding of slab and transferring of load, because dowel bar is load transfer agents. While in un-dowelled geometry due to no reinforcement the load transfer efficiency is very less. When the value of LTE is between 70 and 100 percent, the joint still provides sufficient load transfer for heavy load.

In this research, the joint LTE defined by (AASHTO Pavement Load Transfer Relation) will be used to evaluate the performance of jointed pavements containing dowels and without dowels.

Table 4, Scenario 1-5 Model Result in Absence of Reinforcement

Scenario no	Length of Loss of Support (mm)	Stress of Loaded Slab (N/mm^2)	Stress of Unloaded Slab (N/mm^2)	Deflection of Loaded Slab (mm)	Deflection of Unloaded slab (mm)	Efficiency index (%)	Load transfer Efficiency (%)
		Sigma l	Sigma u	Dl	Du	2*du / (du+dl)	LTE= sig u / sigl
1	_	0.11	0.016	0.005	0.0009	31%	15%
2	100	0.14	0.02	0.008	0.000289	10%	14%
3	100	0.24	0.027	0.014	0.000392	4%	11%
4	200	0.26	0.013	0.017	0.000169	2%	5%
5	400	0.40	0.005	0.023	0.0000989	1%	2%

Conclusion of Joint Effectiveness and Erosion

The simulation in which geometry based on absence of reinforcement shows that with changing of supporting condition there is deviation in "Efficiency index" (EI) and "Load transfer efficiency (LTE) index. According to table 1 for perfect geometry LTE is scrutinize 15%. And then with changing condition its shows breathtaking drop in LTE and EI. With loss of support at 100mm it

shows 14%, but when load acting at critical section LTE is analyzed 11%. So under the same condition but when load acted on critical support then a huge deviation is seen in LTE. At loss of support at 200mm the LTE interpret 5% and for 400mm loss of support the LTE and EI splash to 2% and 1%.

Infusion of Dowel Bar

The load transfer at joints will calculate in three expected scenarios, when there is gap in support layer at one side and another scenario will explain when there is loss of support at both sides of slab edges. As we studied in the previous model loss of support in JPCP under different conditions, this model will briefly explain the Pumping action due to water and load transfer efficiency and then with insertion of Dowel bar overall the improvement of system will be measured.

According to (Mascio & Panunzi, 2012) explain that Past Research regarding JPCP shows that rack-up of cracks are due to fatigue damage. According to (National Cooperative research program about JPCP, 2003)the increases of stresses in JPCP are induced by "traffic and Environmental loading"

Stress in the concrete surrounding dowel bars is the major factors that contribute to transverse joint distress in jointed plain concrete pavement (JPCP). Dowel bar are used across transverse joints in jointed plain concrete pavements to transfer the load across adjoin slabs. The dowel bar presence in JPCP is a "Load transfer agent". According to (Haung , 1993) he explain that with insertion of dowel bar the faulting and pumping effect can be play down. Studies from (Freiberg, 1938) explain the dowel-concrete interface, and he further explain that increase of compressive stress are develops at dowel-concrete interface. Because dowel bar hold the concrete but when the loss of support increase and gaps in supporting layer also increases. as result due to no back support and dynamic wheel load application the concrete will lose its rigidity (Bascoul, Duparat, & Pinglot). And as result the stress and deflection along joints will be boost, the same simulation is done below. According to (William , 2001) under the effect of wheel load the dowel deflect in downward direction establish compressive stress beneath the effect of wheel loads.

Although many studies done but it's still needed to have a broad empathetic of dowel-concrete interaction interface and predict that what's the effect on overall system after and before of Dowel bar insolation (Mackiewicz, 2015). This will explain mainly how to reduce the pumping and faulting effect with insulation of Dowel bar in Slab, and how much erosive effects and EI can be upgraded.

Model Based on Finite-Element Method with Dowel bar

According to European standard (Euro code-2) the diameter of the dowel bar 25mm, length 500mm, and spacing between dowel bar is 250mm, young modulus of dowel bar 2.1 x 105 MPa, Poisson ratio = 0.30.

Placing/inserting position of dowel bar = top layer thickness/2 (Half of thickness of concrete layer), dowel bars will be inserted in Transverse joints and this model will show the modeling for two layers, so the gap between two layer is 8mm. The gap is basically a chamber between two slabs used for filling of lower layer with concrete and then later on filled with Sealant.

According to (Euro code-2) under section 3, and the (Normenausschuss bauwesen (NABau) use for rigid pavement C30/37 from both standards it's give the Crushing strength value for concrete should be around 30-37 MPa, while using concrete crushing value we can find the percentage of load transfer to through the joints.

The general pavement system, including the role of joints, the concept of the load transfer mechanism, and the methods of measuring efficiencies based on stress and deflection which is already discussed in section 3 (Load Transfer Efficiency). The joints are assumed to be very important parameters for the transfer of loads. Therefore joints should be provided in a concrete pavement system to prevent or control severe cracking caused by water or temperature changes.

First Scenario is based on when wheel load acting on one side of slab and then another, the model consist of 15 dowel bars in mid depth of slab in transverse direction of traffic to reduce joint faulting and corner cracking. The model is based on two layers and the overall two slabs are connecting with dowel bars with perfect geometry. The goal is to predict the joint effectiveness improvement and efficiency index with insertion of dowel bars,

Second Scenario is based on loss of support 0.10m (100mm), (To Study Impact of Gaps) under the slab and another slab is without any loss of support. But these two slabs are connected with each other through dowel bar, and load is distributed on both sides of slab equally. The weak support will allow the pavement to lose its strength and stiffness over the period of time accompanied by the increase of stresses and deflections. Under such conditions the cracks are inevitable and will cause the pavement to deteriorate, reducing its service life. But due to effect of dowel bar that will connect the both slab together and also transfer the load to supporting layer, and to predict to joint effectiveness and load transfer efficiency.

Third Scenario is based on the loss of support extend to both sides of slabs, i-e, 0.10m. (Total =200mm) and in height its 0.01m and both slab are connected through Dowel bar, and load act one side of edge and anther is unloaded and then on another and the previous is unloaded. Now we compare this scenario with first and second scenario to analyze the importance and impact of support in jointed plain concrete pavement which is the core purpose of master thesis. In this scenario there will be the rough value of stress and deflection when condition changes under joint, according to (Hansen, 2011) and (Ya & Hansen, 2011) the cracking in JPCP initiates at the bottom of slab near mid-panel. Fatigue cracks initiates from top to bottom. Penetration will mainly trigger the stress, deflection and will increase chances of failure.

Table 5, Infusion of Dowel bar Improvement of JPCP

Scenario no	Length of Loss of Support (mm)	No of Dowel bar	Deflection of Loaded slab (mm)	Deflection of Unloaded slab (mm)	Load transfer Efficiency (%)	Cement layer Distribution Pattern
1	Perfect Geometry	15	0.080	0.05	78	Uniform

2	100	15	0.081	0.05	78	Uniform
3	200	15	0.087	0.051	74	Non-uniform
4	500	15	0.092	0.051	71	Disrupt

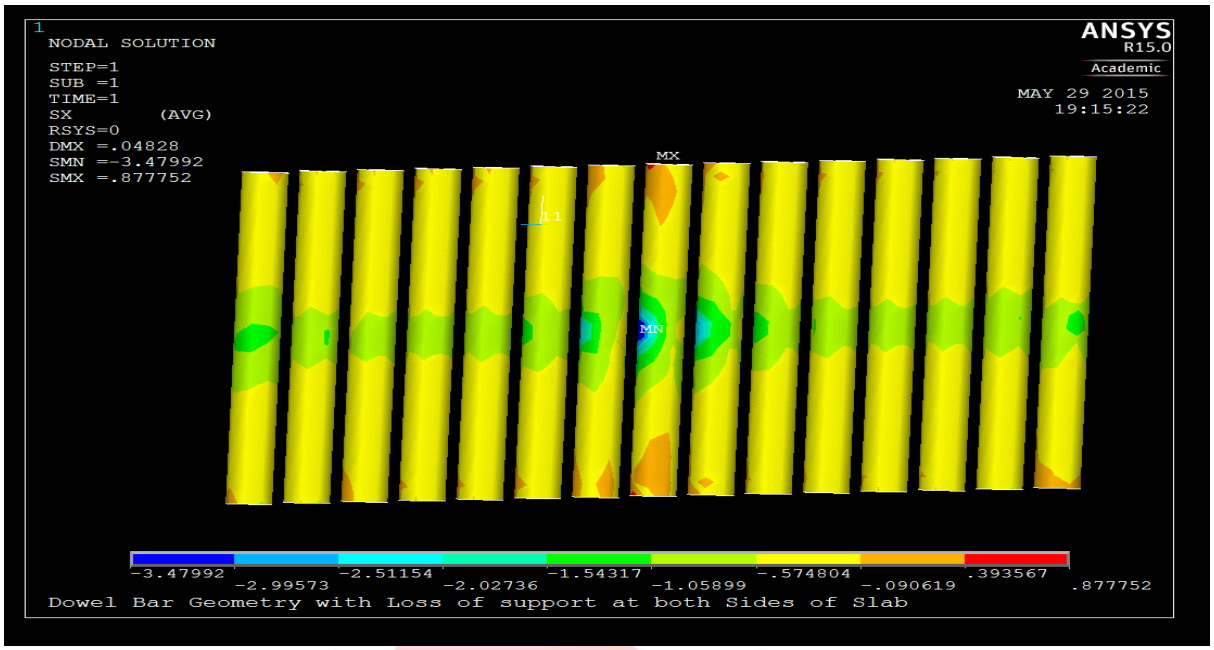


Figure 18, Dowel bar active participation in Load Transfer

Dowel bar Load transfer Agents

According to Westergaard equation of "Load transfer across joints" (Freiberg, 1938) used the same concept and found out that the dowels within a distance of "1.8 *l*" from the load carried the applied load. So form dowel bar figure it's clear that at the location of load acting these dowel bar more active in transferring load to supporting layer, and hence the equation of Westergaard also satisfy that at distance *l* will be more active, *l* is the distance of dowel bar which are active in load transferring. The rigid pavement is supported in vertical direction by strong base course and in y and z direction is holding by dowel bar to counter the lateral stress and deflection, and also to assure the pavement to withstand under different loading and supporting conditions.

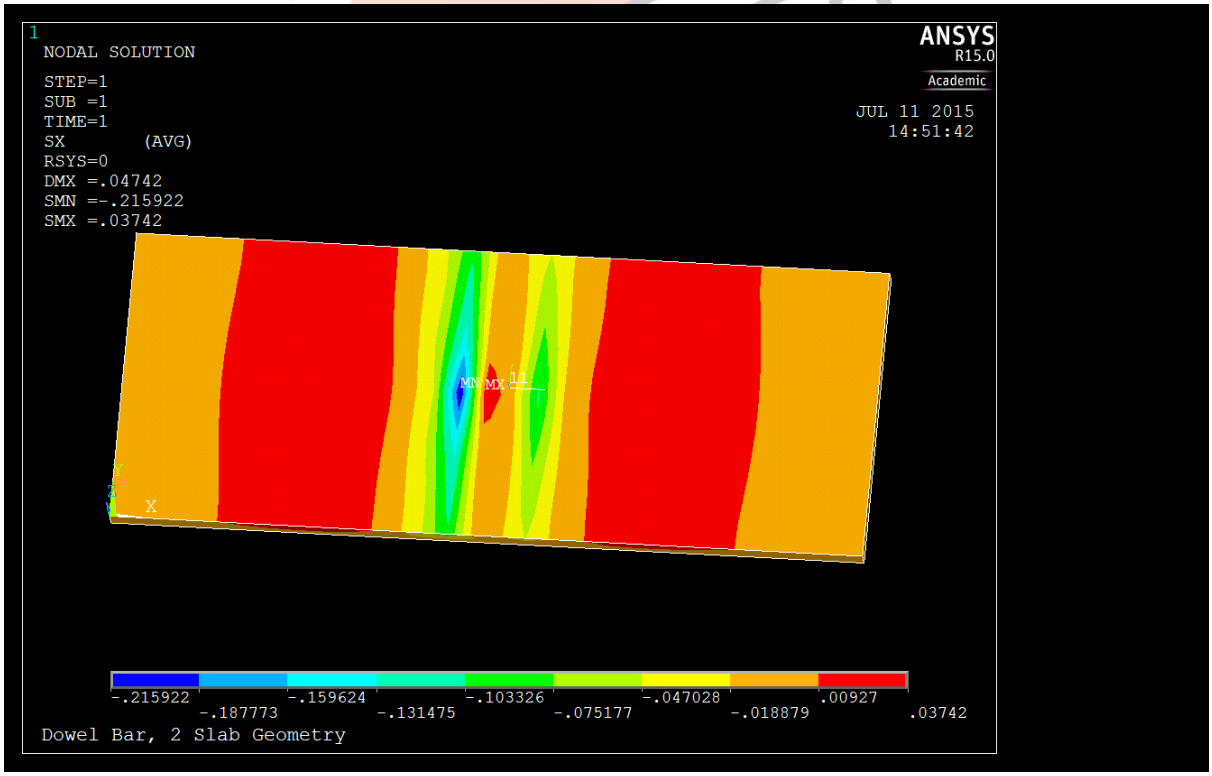


Figure 19, Cement layer Load distribution without critical support

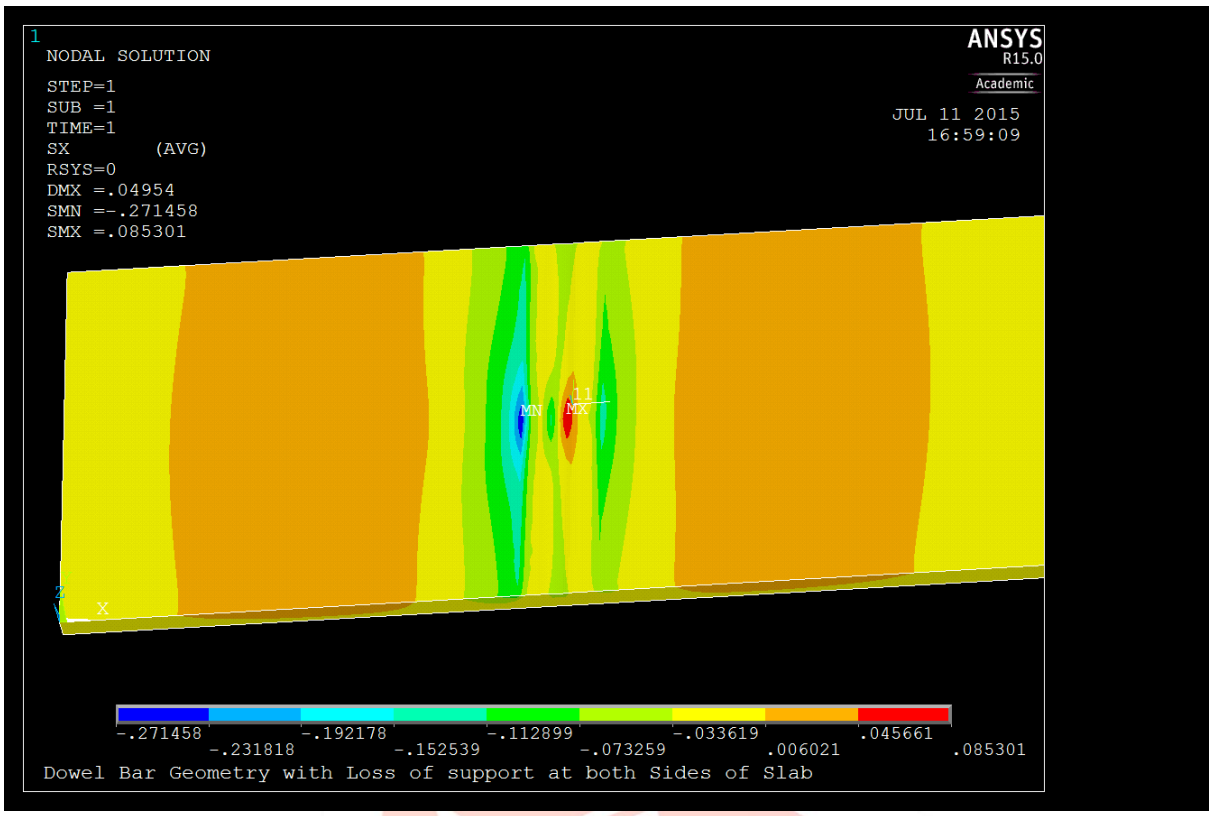


Figure 20, Cement layer Load distribution at 200mm critical support

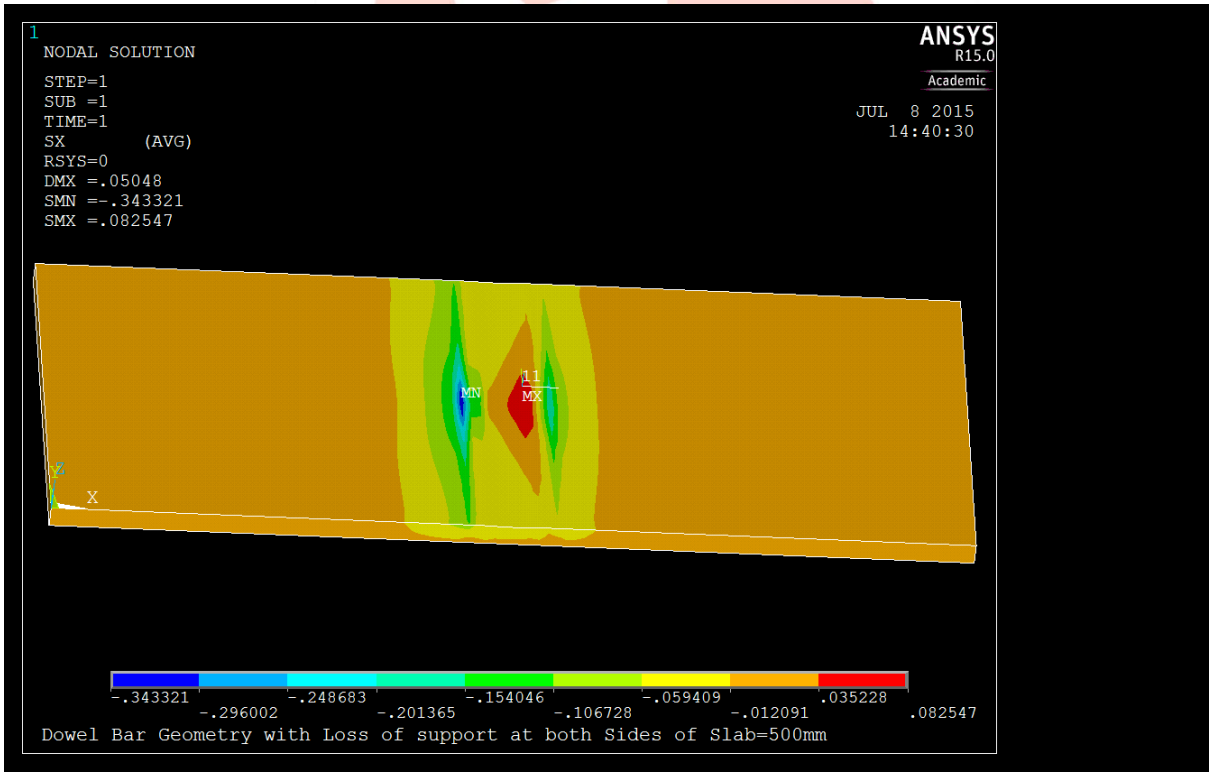


Figure 21, Cement layer Load distribution at 500mm critical support

Supporting Layer Performance

Supporting layer play significant role in distribution of wheel load over a large area, so the participation of base layer cannot be ignored. The aim to display above figure is to show that looseness that develops in the dowel bar embedment tends to reduce the load characteristic of pavement about 5-15%. And with analyzing different scenario with different supporting conditions. Its inspect that distribution pattern changes and structure without loss of support shows quite uniform distribution of load across both slabs,

but when loss of support extend to both sides of slabs this pattern shows disturbance, but when loss of support reached to 500mm. this is the extreme holding capacity of dowel, because both slab are connected with dowel of distance 500mm, before there was support but now when wheel load impacts there is no support along joints, so due to dynamic application of wheel loads, the dowel concrete interface will lose its strength and failure expected in the same scenario.

Conclusion of Joint Effectiveness and Erosion

From FEM result EI value is analyzed 78 %, and for loss of support it display around 78%, and when losses of support extend to both sides of slab its pageant 74%. For long term service life of pavement is evaluated that "Load transfer efficiency" and "Efficiency index" will revamp with providing dowel bar that will upgrade load transfer in JPCP. In JPCP typically uses dowels to transfer loads across transverse contraction and construction joints and even occasionally for isolation joints. And also analyzed during symmetrical loading the maximum stress is holding by middle of dowel bar layer. And primarily the dowel under load is predicted to be more active in transferring the load to supporting layer.

Relationship

From above simulation it's measured that with changing support condition, increase of deflection and stresses are measured that leads to overall deviation of efficiency index at joints. Hence there is correlation between support, deflection and EI.

So support is directly proportional to deflection and EI, hence due to loss of support the EI will be decreased. And when EI decreases there will be less load transfer across joints and due to poor effectiveness the erosion effect will be higher.

Penetration of water $\propto$ Loss of supports $\propto$ increase of gaps $\propto$ Increase of Deflection & Stress $\propto \frac{1}{EI} \propto \frac{1}{LTE}$ and $\propto$ Erosive attacks

Where

$\propto$ = proportionality constant

EI= efficiency index

LTE= Load Stress transfer efficiency index

Relationship of α is directly with Penetration of water , Loss of support , increase of gaps and increase of deflection and stress and α is indirectly proportional to EI, LTE. Moreover the relationship is directly proportional to erosive attack.

From above relationship its predicted that increase in penetration of water will severely affect the supporting condition. As result supporting layer lose its ability to withstand against heavy wheel loads. And the effect increase along horizontal as well as vertical direction in supporting layer. Simulation work is done to analyze different scenario while assuming different gaps in supporting layer increase in horizontal and vertical direction. Another parameter is predicated that due to loss of support the same wheel load acting on the model as twice and with increase of gaps effect the same load will act may be more than that.

Limit

If we compare the result of simulation in absence of reinforcement and for the purpose of infusion of dowel bar the result are improved and LTE and EI reached to overall more than 70%. According to (AASHTO Pavement Load Transfer Relation) standard when EI is more than 70%, it's predicated the joints are working properly and load distributed on both sides of equally.

IV. CONCLUSION

The supporting structure plays immense importance for the performance and durability of JPCP. In this study the JPCP are taken into account. Due to lack of potential sealant water undergoes through joint in pavement structure which affect the interface between concrete and supporting layer. This action disturbs the supporting condition which causes the efficiency index of load transfer to decreases which in turn leads to the deterioration of pavement.

An irregularity in supporting structure often leads the pavement towards damage. In this Master's thesis three scenarios are modeled using FEM with slab dimension of 5m x 4m. Small sections of loss of support are modeled at edge of supporting layer, to analyze the action of wheel load at slab center and slab edge. The losses of support along horizontal axis were assumed to be 0.25m and height being 0.05m which increases at a continuous interval of 0.25m till it reaches 1m.

The increments in loss of supporting conditions were modeled to analyze the effect of changing support conditions. Initial model were based on loss of support at one side of slab. FEM result shows when wheel load is acting at slab center, there is no effect analyzed on the slab center if there is loss of support.

But when wheel load act at slab edge, edge results are different and it has been found that the loss of support will cause the increase in stresses and deflection which are directly proportional to the loss of support. This will cause the cracking of pavement with the passage of time. At this stage initial cracking is expected.

The next models are based on loss of support at both sides of slab which varies in horizontal axis as well as in vertical direction. When the load applied on edge load conditions the stress at edge was 0.77 N/mm2 and in initial model this value reached to 0.78 N/mm2 (loss of support at one side of slab). In current study where loss of support is at both sides, stress value jumps to 1.10 N/mm2. This analysis shows that changes in supporting condition will trigger the stress and deflection. The change of 25-30% is observed in the overall stress value by changing the support conditions. Another important factor that is analyzed is when the load act at one side of slab edge and loss of support are at both sides then there will be an imbalance in slab geometry which will cause the slab to uplift.

The final model based on the geometry of two slabs with 8mm gap without reinforcement. To predict the load transfer efficiency (LTE) and efficiency index (EI) with changing geometry due to erosion. In this analysis the loss of support assumed 100mm, 200mm and 400mm. According to perfect geometry LTE and EI is scrutinize 15% and 31%. And then with changing condition its shows breathtaking drop in LTE and EI. With loss of support at 100mm it shows 14%, but when load acting at critical

section LTE is analyzed 11%. At loss of support at 200mm the LTE interpret 5% and for 400mm loss of support the LTE and EI splash to 2% and 1%.

The slabs are then connected through Dowel bar to analyze the improvement in pavement important durability. FEM simulation section is done for the ambition to evaluate that with the infusion of dowel bar how much LTE, EI, stress and deflection is enhanced. From FEM result EI value analyzes 78 %, and for loss of support it displays around 78% and when loss of support at both sides its 74%. And for loss of support at 500mm the EI reached to 71%. So the perfect joint effectiveness is still there. For long term service life of pavement it is evaluated that "Load transfer efficiency" and "Efficiency index" will revamp with providing dowel bar that will upgrade load transfer in JPCP. In JPCP typically uses dowels to transfer loads across transverse contraction and construction joints and even occasionally isolation joints. And also analyzed during symmetrical loading the maximum stress is holding by middle of dowel bar layer. And primarily the dowel under load is predicted to be more active in transferring the load to supporting layer.

The loss of support will increase with passage of time in horizontal as well as vertical direction, so overall it will damage the pavement geometry. There is probability of inefficiency in drainage system in future which leads the system to loss of support. Top surface drying and bottom surface water absorption is very important factors which cannot be ignore in such kind of scenarios, because if water remains inside slab it will trigger the effect of loss of support. Top surface of pavement can be subjected to external drying, and the bottom surface can be in contact with water from ineffective drainage. Under the application of load and vehicle moments it will increase the moment of moisture in supporting layer, as according to (Neithalath , 2006) the bottom of slab will take at least 28 days because of relative humidity level, as you go deep this level goes down. So due to the presence of water in supporting layer the loss of gap action will increase which will affect the overall support conditions and this effect will continues.

V. RECOMMENDATION

This analytical study is carried out to predict the effects of changing support conditions by erosive attacks and to model and simulate different scenarios in order to analyze the impacts of gap dimension using FEM.

- The same model can further be investigated with loss of support from all sides of the slab while using arrangement of dowel and tie bars.
- This model considers loss of support and gap generation only due to water penetration. Further parameters are suggested to consider the temperature changes as well in order to analyze the relationship between moisture along with temperature.
- To improve the predication of LTE, further investigation of different supporting conditions, doweled rotations, and aggregate wear out can be considered for further simulations.
- By using herring bone with perforated pipe mechanism in the drainage system, the water can be drained efficiently and hence erosion can be controlled.
- This model is analyzed for 8mm joint thickness therefore joint spacing with different thickness of concrete slab can be further investigated.

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