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Stabilization of Pavement Sub Grade with Stone Dust, Fly Ash and Tire Rubber to Withstand the Fatigue and Rutting

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Abstract The existing practice of subgrade has been modified with the unique type of subgrade that can withstand running traffic >20msa with 90% reliability. This can be achieved by adding fly ash, stone dust and tire rubber to pavement subgrade. This modified subgrade Mix was prepared to improve the strength of subgrade. Conventional and modified subgrade pavement mixes were tested with CBR values and the resilient modulus of conventional and modified subgrade has been found as per IRC 37-2008. Plate load test has been carried out in the laboratory with the continuous loads on the subgrade and the moduli of subgrade reaction obtained finally were compared analytically using IIT Pave software. The optimal mix proportion of Modified subgrade denotes (subgrade soil with 22% Stone Dust, 4% Fly Ash and 2% Tire Rubber). The modified subgrade in flexible pavement showed an increase in bearing capacity, resilient modulus (M_r) and modulus of subgrade reaction (k) which gave fruitful results with the optimum mix proportion with stone dust, fly ash and tire rubber. The usage of these materials in the construction of pavements decreases the industrial waste, minimizes the environmental pollution, decreases the pavement thickness as well as increases the pavement life.

Keywords Stone Dust, Fly Ash, Tire Rubber, Resilient Modulus, California Bearing Ratio (CBR)

1. Introduction

Nowadays, industrial development has improved drastically, along with that large amount of waste as well as pollution has increased rapidly [1]. The constituents present in waste were directly polluting the environment [2]. Disposing and decomposition of these wastes and controlling pollution is a big task to the government and local municipal bodies [3]. In general, fly ash generated from thermal plants, stone dust from quarry and dumping of discarded tires are the major problems. Study with the utilization of industrial waste like fly-ash, stone dust and tire rubber, in pavement sub-grade to increase the pavement life and to reduce the pavement thickness was carried out. With the utilization of the fly ash, stone dust and tire rubber in pavement construction, major reduction of pollution and effortless decomposition can be achieved. Usage of fly-ash and stone dust in pavement construction, bind tire rubber and soil results in increase of resistance in subgrade layer for incoming loading [4]. As fly ash and stone dust have major binding properties comparatively and tensile property of tire rubber results in resisting deformations of pavement caused by the loads [5-7]. In addition, it helps to avoid pavement failures to a major extent.

2. Materials

According to the ministry of power, 226.13 million tons of fly-ash is produced by thermal power plants in the year 2019 -20. Nearly more than 20 thermal power plants were not able to utilize 50% of the fly-ash production [6]. As fly-ash has the pozzolanic property, utilization of the fly-ash in subgrade will be the power solution for fly-ash deposition [7]. Due to the high calcium content in fly ash, it imparts maximum strength to structure [8]. Adding fly ash to the sub-grade results in proper binding of soil particles and imparts the strength [9].

Stone dust deposits being a minute problem in every point of view generated by quarries in large quantity [10]. These dust particles pollute air, water and land near the area. Using this stone dust in pavement subgrade can overcome this problem to a major extent [11].

Rubber globalization has been started worldwide these years. A large amount of rubber is produced every year [12]. 60% of synthetic rubber is used in tire manufacturing along with chemicals which are very harmful when burnt. After deterioration of tire it cannot be degraded easily as the decomposition takes much time and causes environmental pollution [13]. Powdered tire rubber is used in subgrade to improve its tensile properties, which also overcomes the problem of rubber decomposition [14-15].

3. Research Significance

Stresses induced in pavements create two types of failure: one is fatigue cracking and the other is rutting. Fatigue cracking occurs at the top layer and rutting occurs at the subgrade layer of flexible pavement. Due to rutting pavement deformation occurs at the pavement surface; this leads to vehicle maintenance cost and decreases feasible movement of vehicles. Rutting failure mainly occurs due to excess movement of vehicles than anticipated; this leads to the compressive strain at the subgrade layer. To overcome this, subgrade has to be stronger enough to withstand the excess loads. The subgrade materials were modified to take more stresses and withstand the deformations as well as increase the pavement life. This research study gives solution to control the environmental pollution and utilize the industrial wastes like fly-ash, stone dust and rubber and decreases the cost of construction and pavement thickness.

3.1. Research Problem

Many researchers have carried out research studies to increase the pavement life and to decrease the pavement thickness without effecting pavement strength, with different material combinations. Still, research has to be carried in the area of increasing the maximum quantity utilization of materials like Fly Ash, Stone Dust and Tire rubber. An attempt has been made to utilize the maximum quantity of industrial waste materials with different combinations to decrease the pavement thickness and produce the maximum pavement strength, to withstand deformations.

3.2. Objectives

The main objective of the study is

1. To make the pavement subgrade to withstand the compressive strain deformations.
2. To decrease the pavement thickness layers by increasing the strength of subgrade layers.
3. To analyze the parameters like modulus of subgrade (k) and resilient modulus (M_r) of subgrade.
4. To bring solution to the industrial waste like fly-ash, stone dust as well as tire rubber which is difficult to decompose or degrade.

4. Methodology

To achieve the objectives, the following methodology has been adopted as shown in Figure 1.

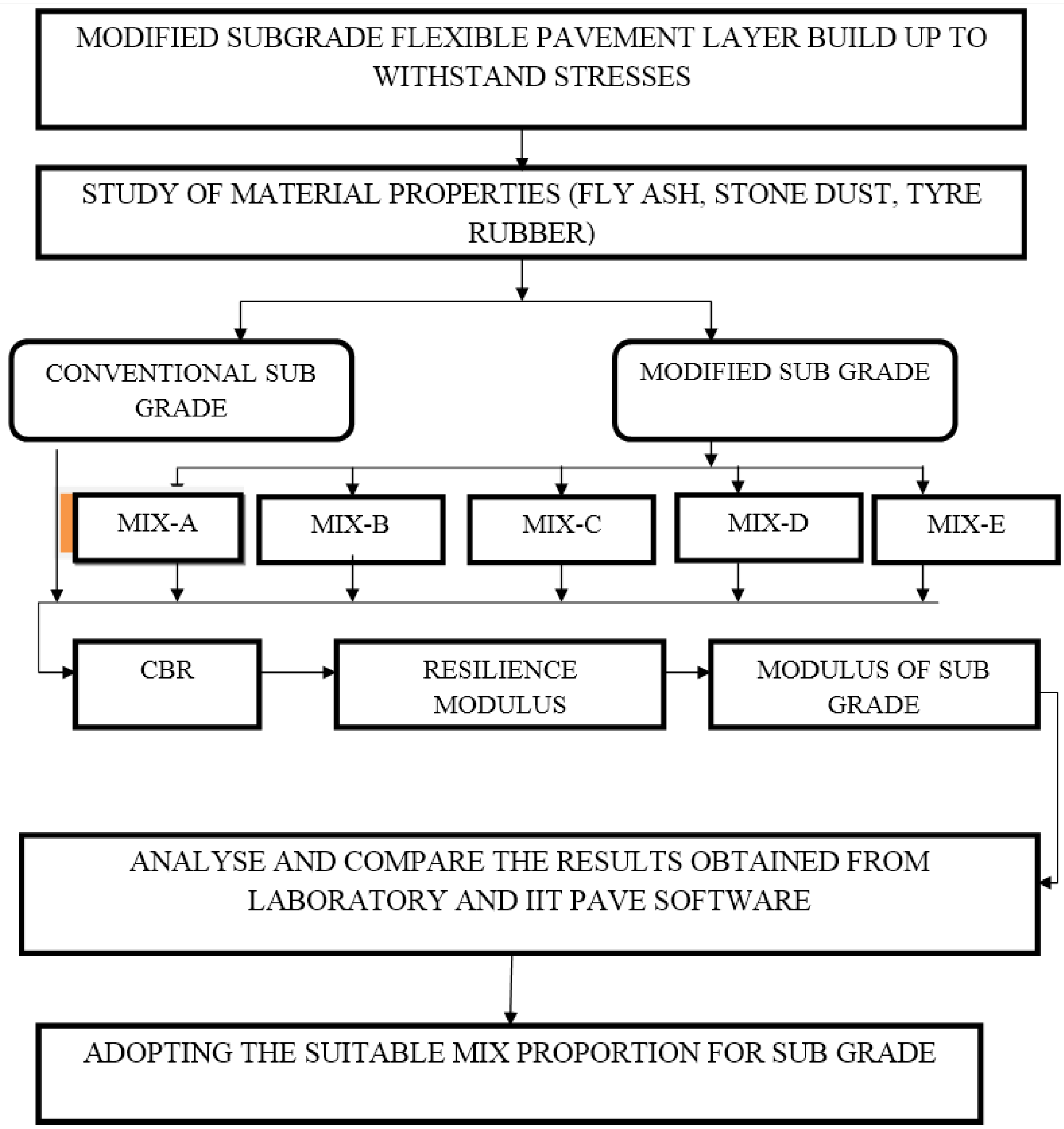

Figure 1. Methodology

5. Tests on Conventional subgrade

5.1. California Bearing Ratio (CBR) Test

The bearing capacity of the soil was determined with the California bearing ratio (CBR) test. Basic tests were carried out in the laboratory with compacted soil samples collected from the selected area. Test has been carried out for conventional subgrade and modified subgrade mixes. The values obtained by the CBR test with the modified subgrade material were indicated in Table 1.

In mix proportions, stone dust has taken as major industrial waste to prepare subgrade because it's a finer material so that it will easily mix the remaining proportions.

MIX-A: subgrade soil +22% sd+5%fa+1%rubber
MIX-B: subgrade soil +22% sd+4%fa+2%rubber
MIX-C: subgrade soil +22% sd+3%fa+3%rubber
MIX-D: subgrade soil +22% sd+2%fa+4%rubber
MIX-E: subgrade soil +22% sd+1%fa+5%rubber

From Table 1, the CBR values for conventional subgrade and modified subgrade, respectively, are to withstand the loads acting over the pavement. With the modified subgrade material with the 22% stone dust, 4% fly ash and 2% tire rubber increased the subgrade strength to about 12.5% more than the conventional subgrade which reduces the pavement thickness.

Table 1. CBR readings for conventional subgrade and modified subgrade

CONVENTIONAL SUBGRADE		MIX-A		MIX-B		MIX-C		MIX-D		MIX-E	
Penetration	Load	Penetration	Load	Penetration	Load	Penetration	Load	Penetration	Load	Penetration	Load
0	0	0	0	0	0	0	19.3	0	0	0	0
0.5	16.4	0.5	16.7	0.5	18.2	0.5	35.2	0.5	14	0.5	14.7
1.0	29.6	1.0	31.2	1.0	33.4	1.0	49.6	1.0	32.1	1.0	33.1
1.5	39.7	1.5	41.5	1.5	46.4	1.5	71.4	1.5	44	1.5	43.1
2.0	52.8	2.0	64.4	2.0	68.2	2.0	84.2	2.0	66	2.0	66.4
2.5	77.8	2.5	82.3	2.5	86.3	2.5	85.2	2.5	79.4	2.5	73.9
3.0	81.2	3.0	86.4	3.0	92.4	3.0	91.2	3.0	83.2	3.0	84
3.5	86.4	3.5	90.4	3.5	95.6	3.5	96.4	3.5	86.4	3.5	87.1
4.0	92.1	4.0	94.3	4.0	102.3	4.0	101.2	4.0	90.1	4.0	91.4
4.5	94.5	4.5	97.2	4.5	104.2	4.5	104	4.5	94.2	4.5	93.2
5.0	96.1	5.0	105	5.0	107	5.0		5.0	99.2	5.0	95
CBR = 5.76		CBR = 6.09		CBR = 6.30		CBR = 6.23		CBR = 5.8		CBR = 5.6	

5.2. Resilient Modulus of Subgrade

Resilient modulus of subgrade is a key factor to analyze the mechanical response of a pavement under loads. In asphalt and in concrete pavement layer the fatigue cracking is analysed with the resilient modulus M_r of subgrade soil, the stiffness parameter according to IRC37-2018 as 10 times of CBR value for CBR value less than 5% and 17.6 times of $CBR^{0.64}$ for CBR values greater than 5%. For conventional subgrade, the resilient modulus was obtained as 53.96 MPa and the resilient modulus for the modified subgrade material was indicated in Table 2 for different mix ratios.

Table 2. Resilient Modulus of Modified Subgrade

S. No	MIX	Resilient Modulus, M_r (MPa)
1	Mix A	55.9
2	Mix B	57.1
3	Mix C	56.7
4	Mix D	53.01
5	Mix E	53.9

From Table 2, the Mix B with 22% stone dust, 4% fly ash and 2% tire rubber, the resilient modulus obtained as 57.1 MPa with a 2.15% increase.

5.3. Fatigue and Rutting Strains using IIT Pave Software

The Resilient Modulus of each mix results obtained(Mr) were incorporated in software at each layer with depth pavement(Z), Radial distance from tire centre(R), Displacement and wheel loads at each layer EpZ, epT and epR are the strains which present on pavement layers are indicated in Figure 2.

Figure 2 shows the results of the stresses and the displacements obtained from IIT Pave Software, with the output of Mix A in the form of Rutting strain and Fatigue strain at various depths Z. i.e. Pavement thickness to radial distance of tire and will consider the maximum strain obtained at epZ and epT for pavement life as indicated in Figure 3.

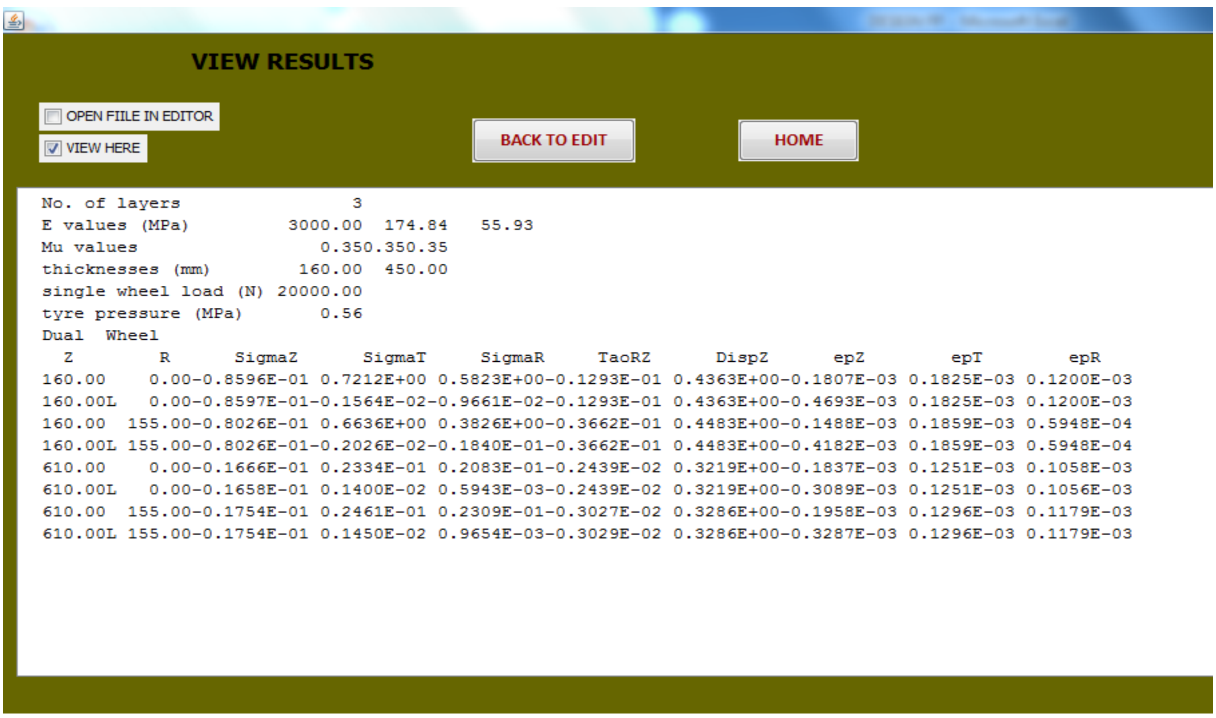

Figure 2. The result of fatigue and rutting strains for modified subgrade Mix-A shown in IITPAVE software

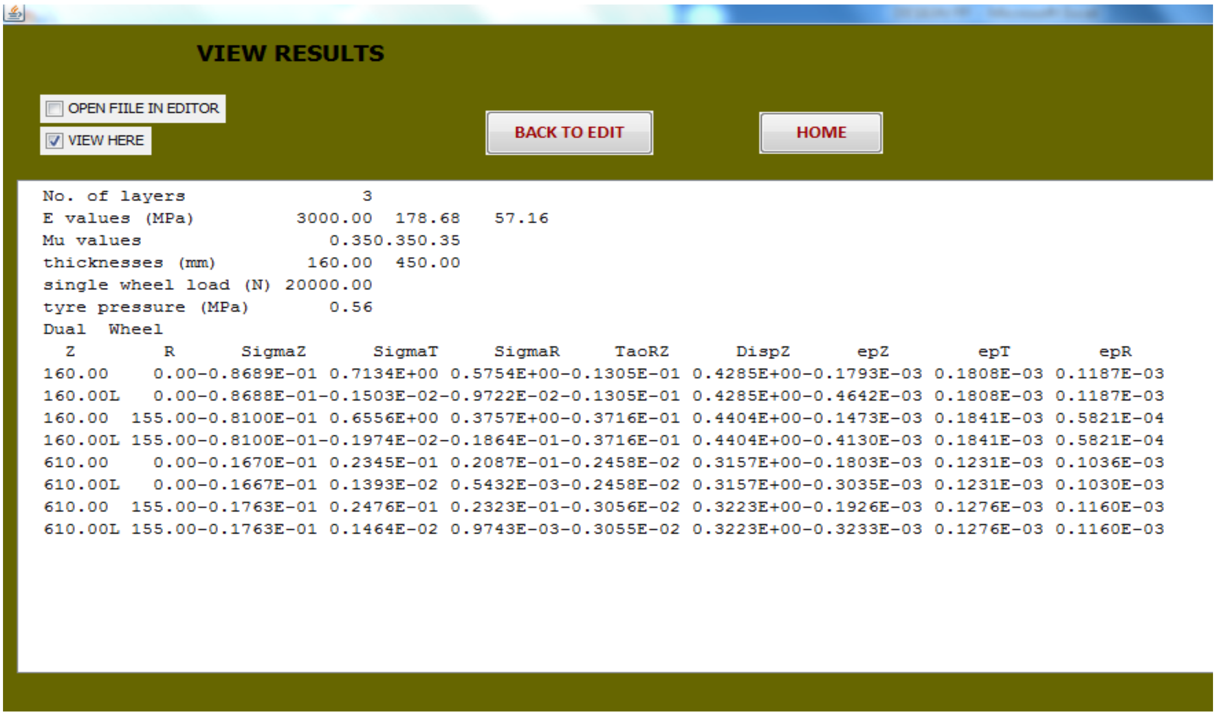

Figure 3. The result of fatigue and rutting strains for modified subgrade Mix-B

Figure 3 indicates the results obtained for Mix B in the form of Rutting strain and Fatigue Strain from IIT Pave Software at various. Depth Z. i.e. Pavement thickness to radial distance of tire with the maximum strain obtained at epZ and epT for the pavement life.

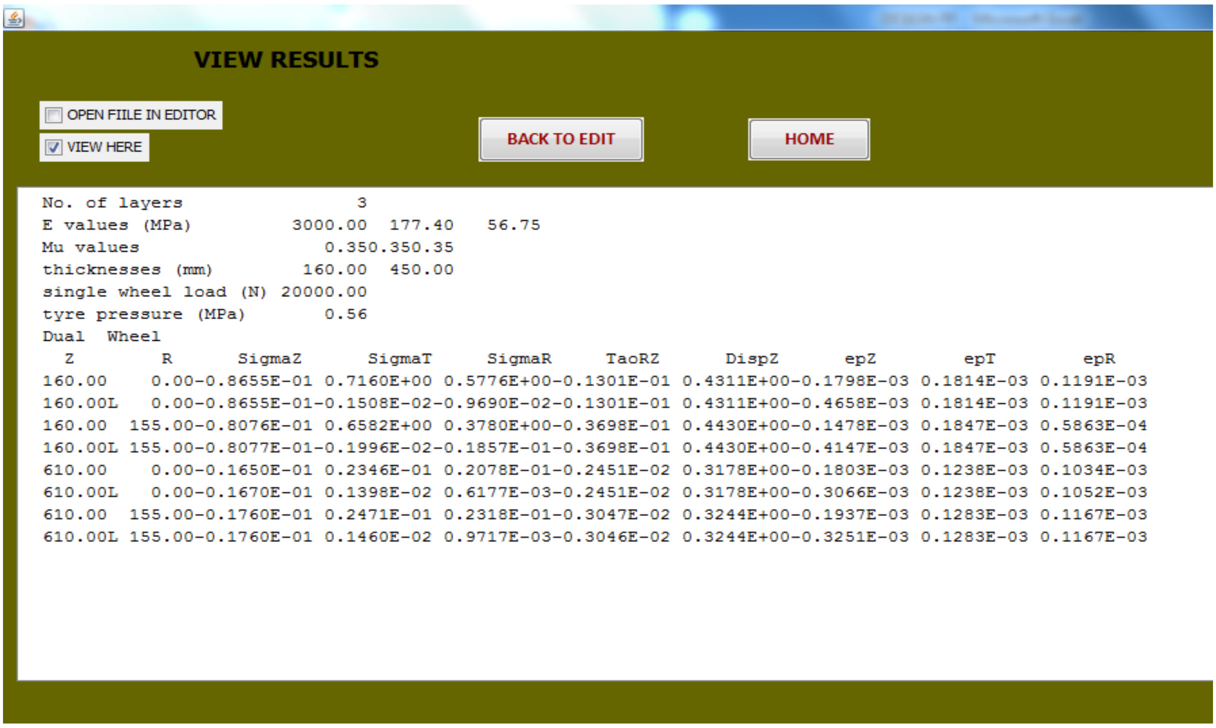

Figure 4. The result of fatigue and rutting strains for modified subgrade Mix-C shown in IITPAVE software

Figure 4 shows the results from IIT Pave Software. It gives output of Mix C in the form of Rutting strain and Fatigue Strain which can be bare. Here we take the values from depth Z. i.e. Pavement thickness to radial distance of tire and will consider the maximum strain obtained at epZ and epT for calculation of pavement life.

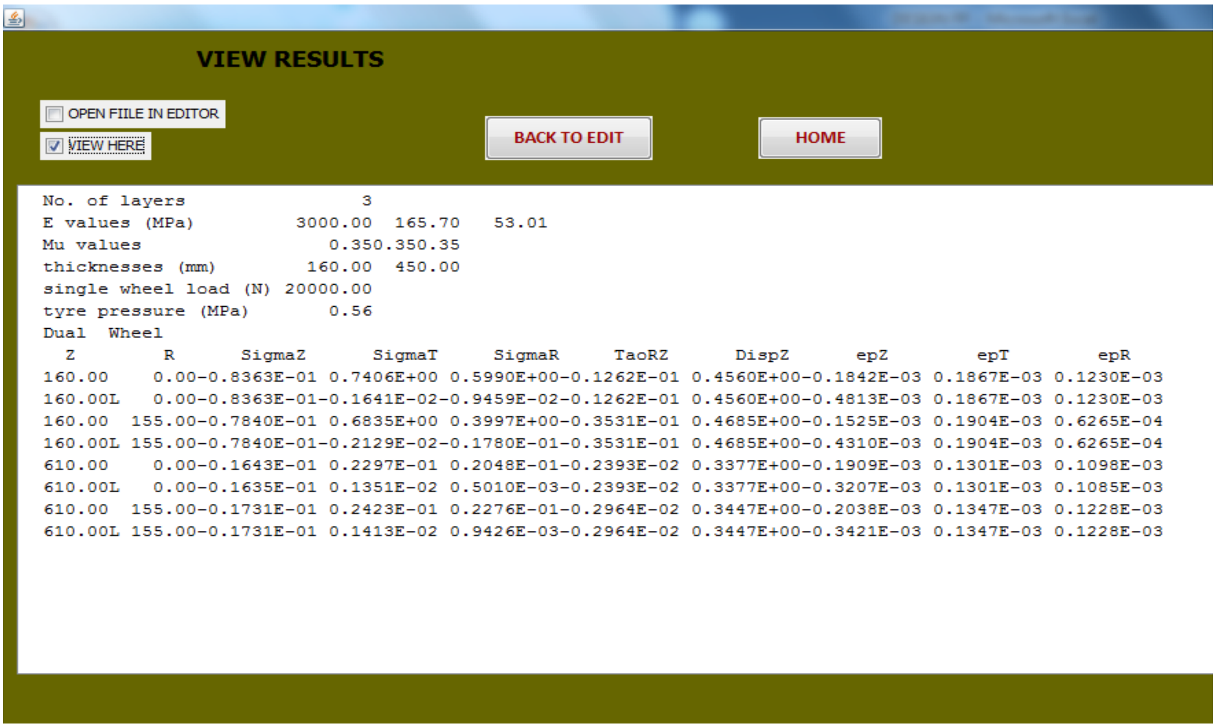

Figure 5. The result of fatigue and rutting strains for modified subgrade Mix-D shown in IITPAVE software

Figure 5 shows the results from IIT Pave Software. It gives output of Mix D in the form of Rutting strain and Fatigue Strain which can be bare. Here we take the values from depth Z. i.e. Pavement thickness to radial distance of tire and will consider the maximum strain obtained at epZ and epT for calculation of pavement life.

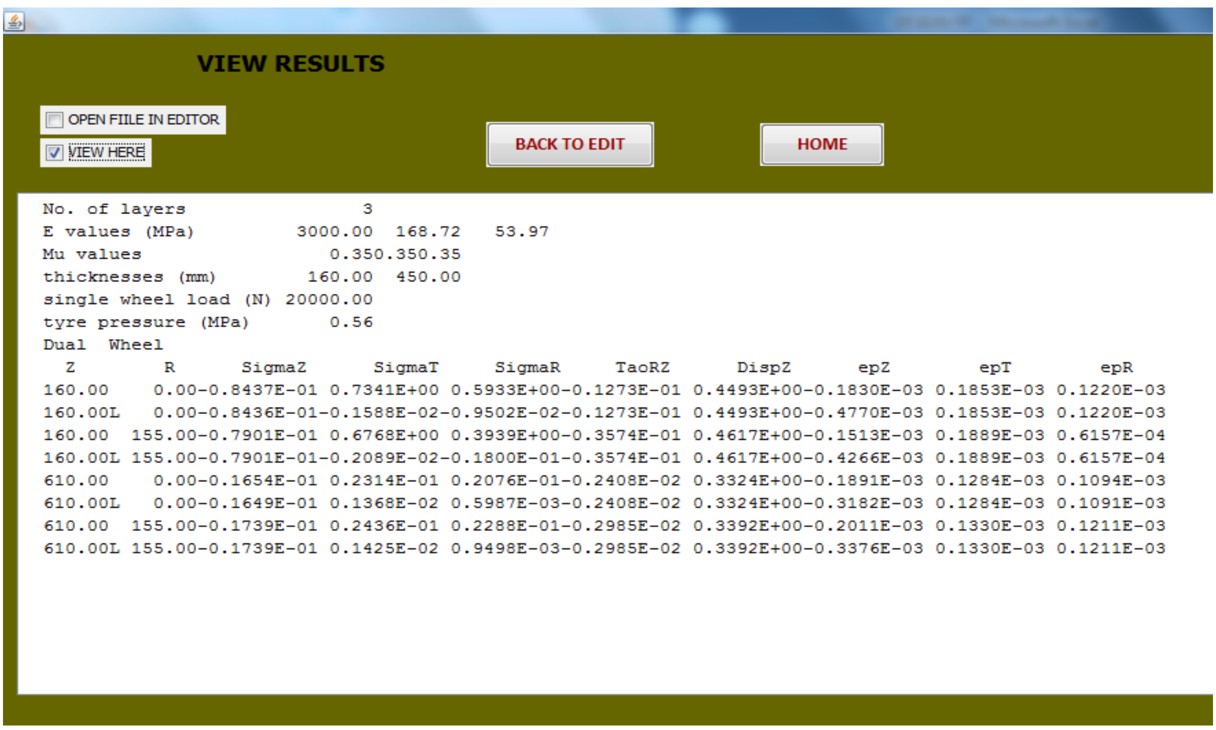

Figure 6. The result of fatigue and rutting strains for modified subgrade Mix-E shown in IITPAVE software

Figure 6 shows the results from IIT Pave Software. It gives output of Mix E in the form of Rutting strain and Fatigue Strain which can be bare. Here we take the values from depth Z. i.e. Pavement thickness to radial distance of tire and will consider the maximum strain obtained at epZ and epT for calculation of pavement life.

Table 3. Remaining Life of Existing Pavements

Resilient Modulus of Bitumen Layer	Obtained Strains through (IITPAVE)		Life of Existing Pavements(MSA)		
	Fatigue Strain	Rutting Strain	Fatigue Strain	Rutting Strain	Life of the Pavement
3000	0.0001889	0.0003376	53.4	77.3	53.4
3000	0.0001859	0.0003287	56.9	87.3	56.9
3000	0.0001841	0.0003233	59.1	94.1	59.1
3000	0.0001847	0.0003251	58.3	91.8	58.3
3000	0.0001885	0.0003365	53.9	78.5	53.9
3000	0.00019.4	0.0003421	51.8	72.8	51.8

Table 3 shows the strains of fatigue and strain obtained through software, also calculated the remaining life existence of pavement for each mix and shows the layer safety thickness.

5.4. Plate Load Test for Modulus of Subgrade Reaction

Plate load test is a field test, performed to determine the probable settlement under a given load (IS code). An area sufficiently large to receive the loading plate shall be leveled using suitable tools or by turning the loading plate back and forth. Test area should be two times the diameter of the plate. A 30mm plate is used for the test and four dial gauges are used to note the settlement. An 8 ton reaction load is applied on the hydraulic jack. Load increment is noted for every consecutive 0.25mm settlement until it reaches the 1.75mm settlement. Load and settlement on conventional subgrade as well as for the modified subgrade mixes are indicated in Table 4.

Table 4. Plate load test on conventional and modified subgrade

CONVENTIONAL SUBGRADE		MIX-A		MIX-B		MIX-C		MIX-D		MIX-E	
Load	settlement	Load	settlement	Load	settlement	Load	settlement	Load	settlement	Load	settlement
0	0	0	0	0	0	0	0	0	0	0	0
60	0.24	60	0.26	63	0.24	66	0.26	61	0.24	60	0.25
150	0.49	150	0.49	170	0.53	180	0.52	170	0.51	140	0.56
255	0.73	255	0.76	310	0.74	310	0.76	280	0.73	270	0.75
410	1.1	410	1.01	490	1.01	480	1.01	450	1.01	431	1.01
523	1.23	523	1.25	590	1.24	570	1.25	540	1.26	521	1.25
610	1.5	610	1.51	660	1.50	648	1.53	621	1.5	560	1.54
670	1.76	670	1.76	730	1.76	715	1.75	690	1.76	630	1.75
k = 6.09 kN/cm^2		k = 6.34 kN/cm^2		k = 6.71 kN/cm^2		k = 6.45 kN/cm^2		k = 6.18 kN/cm^2		k = 5.83 kN/cm^2	

Subgrade reaction Modulus is obtained with the pressure sustained by the soil sample under a rigid plate of standard diameter per unit settlement measured at a specified pressure or settlement. Test results in Table 4 show the subgrade reaction “k” values for conventional subgrade and modified subgrade, with the stone dust, fly ash and rubber. Fly ash acts as binder material in modified subgrade and rubber can withstand the strains. With an increase in rubber percentage, it will not able bind with other materials properly.

6. Conclusions

Based on the laboratory experiments, it has been found that fly ash, and tire rubber are the key components that affect the strength of the subgrade. With decrease in fly ash content and increase in tire rubber, there is continuous decrease in bearing capacity and modulus of subgrade reaction of subgrade soil. With the 22% stone dust with 4% fly ash and 2% tire rubber (Mix-B) proportion increased the subgrade resilient Modulus and modulus of subgrade reaction. With all these parameters, pavement thickness can be reduced without affecting the strength of the structure. By adopting Mix-B proportion in subgrade pavement construction resulted in increase of bearing capacity and resistance to deformation. It is also a solution for degradation and deposition of industrial waste like fly ash, stone dust and tire rubber that pollute the environment.

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