Falling Weight Deflectometer Analysis of Low Volume Roads

Shrikant Madhav Harle[1, *], Prakash Pajgade[2]

[1]Department of Civil Engineering, Prof Ram Meghe College of Engineering & Management, Badnera, India

[2]Department of Civil Engineering, Prof Ram Meghe Institute of Technology & Research, Badnera, India

Email address:
shrikantharle@gmail.com (S. M. Harle)
[*]Corresponding author

Abstract: The work was carried out on the village roads where the traffic intensity is very low. The roads should be constructed as durable and with minimum construction cost without affecting the strength. Therefore the experiments were carried out on different types of roads. The experiments can be performed in the laboratory but that is not sufficient and therefore the tests should also be performed on the actual constructed pavement patches. The non destructive test is the best way to check the parameters responsible for the effectiveness of pavement. The non destructive testing machines like ground penetrating radar (GPR) and falling weight deflectometer is used to assess different parameters of pavements. The subgrade moduli is also compared with the help of these machines. The falling weight deflectometer (FWD) was carried out on the plastic cell filled concrete block pavement (PCCBP), Geocell filled concrete concrete block pavement (GCCBP) and grouted macadam (GM). The deflection, modulus of elasticity, strain, thickness calculation, area, RRS were calculated through this test by the back calculation. From this observation it is found that the geocell filled concrete block pavement performed well as compared to the other pavements in terms of the calculated parameter. The deflection was more in the grouted macadam when compared with the PCCBP and GCCBP.

Keywords: Deflection, Strain, FWD, Thickness, Concrete Block Pavement

1. Introduction

The geocells are used for the pavement applications like the pavements subjected to repeated loadings. The observations included that the if the multiple gerocell reinforced section if used then it performed better as compared to the single geocell reinforced section [1-3]. The study was conducted on the geocell and the observations showed that the application of geocell is useful in the pavements, railways, reinforced wall, etc [4-6].

The dynamic response of the soil and subgrade is depending on the different parameters like frequency range of the excitation. The relevant condition for the performance of FWD on JPCP is very important to measure the deflection. The sonic method to measure the pavement deflection and temperature measurement is very good tool [7-9].

2. Methodology

Falling Weight Deflectometer (FWD) is an impulse-loading device in which a transient load is applied to the pavement and the deflected shape of the pavement surface is measured. A falling weight deflectometer (FWD) is a testing device to evaluate the physical properties of pavement [10-13]. FWD data is primarily used to estimate pavement structural capacity for overlay design also falling weight deflectometer (FWD) enables researchers to perform non-destructive, quick, and dynamic evaluations of paved surfaces, aggregate sub-bases, and soil subgrades without leaving the testing vehicle. The FWD is designed to impart a load pulse to the pavement surface which simulates the load produced by a rolling vehicle wheel [14-16]. The load is produced by dropping a large weight, and transmitted to the

pavement through a circular load plate - typically 300mm diameter on roads and 450mm on airports. Typically, the load for road testing is about 40kN recommended by IRC 115: 2014. The machine is usually contained within a trailer that can be towed to a location by another vehicle. It can also be built on a pickup truck, inside a mini-van or on a heavy truck together [17-18].

Different magnitudes of impulse load can be obtained by selection of a suitable mass and an appropriate height of fall. Under the application of the impulse load, the pavement deflects. Velocity transducers are placed on the pavement surface at different radial locations to measure surface deflections. Geophones or seismometers are used as displacement transducers. Load and deflection data are acquired with the help of a data acquisition system. Deflection sensors (geophones; force-balance seismometers) mounted radially from the center of the load plate measure the deformation of the pavement in response to the load. Some typical offsets are 0mm, 200mm, 300mm, 450mm, 600mm, 900mm, 1200mm 1500mm.

There are two different types of load impact systems; single-mass (e.g. Dynatest, Carl Bro, PaveTesting) and double-mass (KUAB). The testing machine used was double mass load impact system. The double-mass system produces a longer loading duration that more precisely represents a wheel load. The double-mass system has higher reproducibility and gives a more accurate result on pavements built on soft soils. The single-mass system may overestimate the capacity of pavements built on soft soils.

Figure 1. *Falling Weight Deflectometer Machine Testing on the pavement.*

3. Results

The requirement for rigid pavement actual test track is constructed with Sub base as flexible crust layer and top layer with concrete and geocells to be treated as rigid pavement crust layer. Normal FWD test is to be carried out at min. 150 m. Being test constructed for research purpose to innovate various strength parameters, analysis is done with rigid and also with flexible pavement strength analysis. For this analysis three test points are located on test track and testing has been carried out for 60KN dynamic loads. In flexible analysis Pavement crust has been divided in two layers of each 2 Layers 7.5cm concrete as rigid pavement and 2 layers of 25cm of subbase as flexible pavement.

The data for PCCBP is as follows:

Table 1. *Deflection and Lifetime for PCCBP.*

Position	D0	Lifetime (Years)
M	µm	
0	355	20
2	424	20
4	359	20
8	415	20

Table 2. *Back calculations for PCCBP.*

Layer	Thickness	Poissons ratio	Emax	Emin	Eseed	Reference	Kexponent
	cm		Mpa	Mpa	Mpa	µ-strain	
1	75	0.15	3000	1000	3000	195	5.62
2	75	0.15	3000	50	3000	885	4
3	250	0.15	500	50	500	885	4
4	250	0.15	500	20	500	885	4

The modulus of elasticity of different positions are obtained as follows:

Table 3. *Modulus of Elasticity for PCCBP.*

Position	D0	E0	Ecor	Emod2	Emod3	Esub	HasfH5app	Critical	Aoverla
M	µm	Mpa	Mpa	Mpa	Mpa	cm	Cm		cm
0	355	1324	1000	58	50	20	75	1	0
2	424	1253	1000	148	50	25	75	1	0
4	359	1206	1000	149	50	25	75	1	0
8	415	1193	1000	104	50	20	75	1	0

The similar data of falling weight deflectometer is mentioned in the Annexure-B.

The strength parameters computerized analysis is as per the KUAB analysis by PVD software.

The deflection at different points is in the case of plastic cell filled concrete pavement obtained as follows:
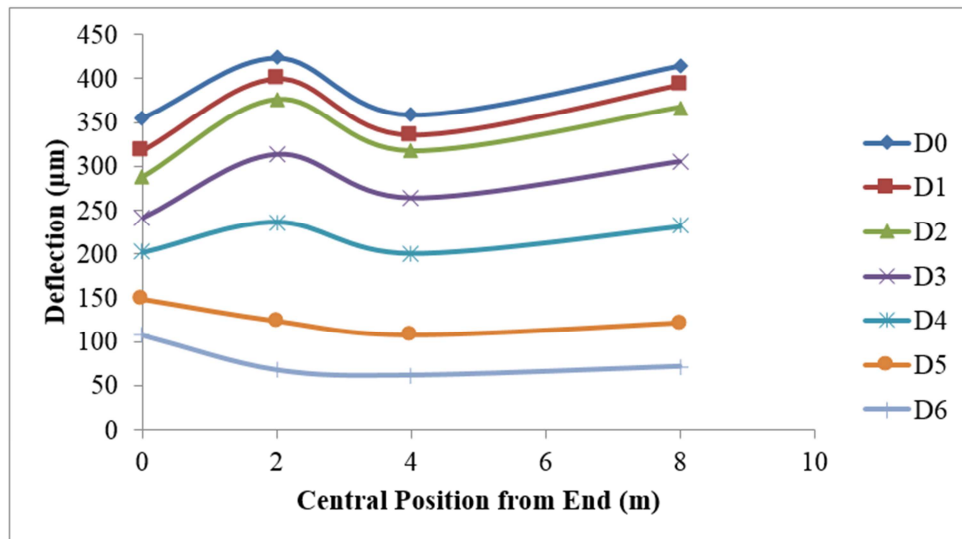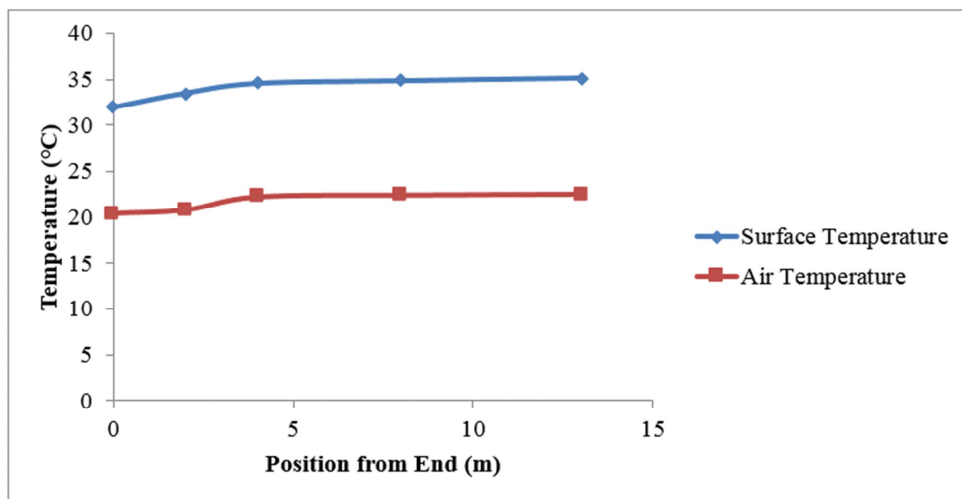
Figure 2. Deflection v/s position of sensors.

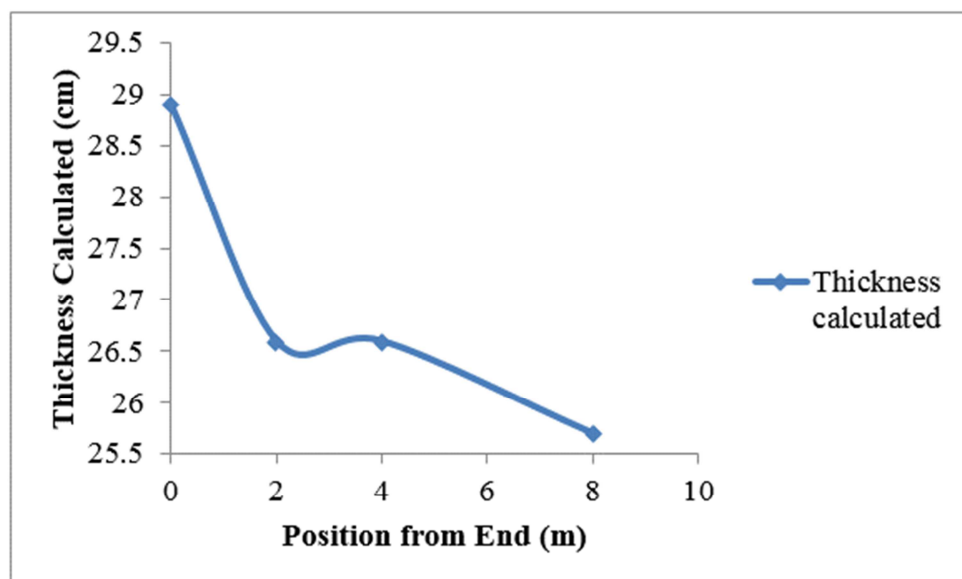*Figure 3. Temperature v/s position of sensors.*

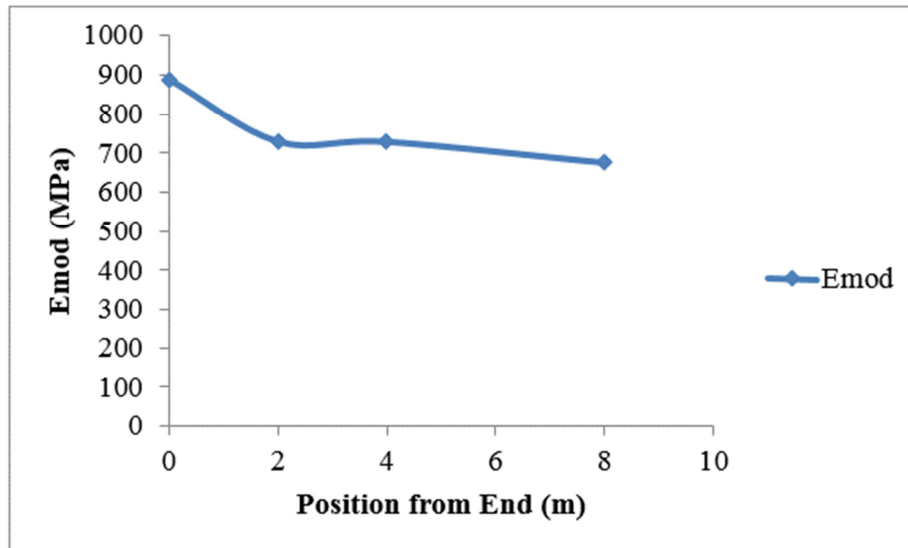*Figure 4. Thickness calculated (cm) v/s different position of sensors.*

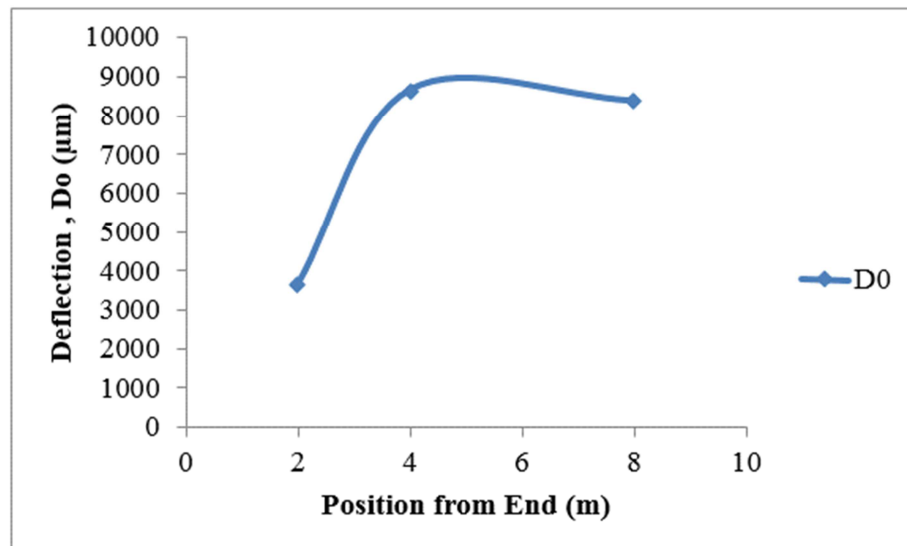*Figure 5.* Modulus of elasticity v/s position of sensors.

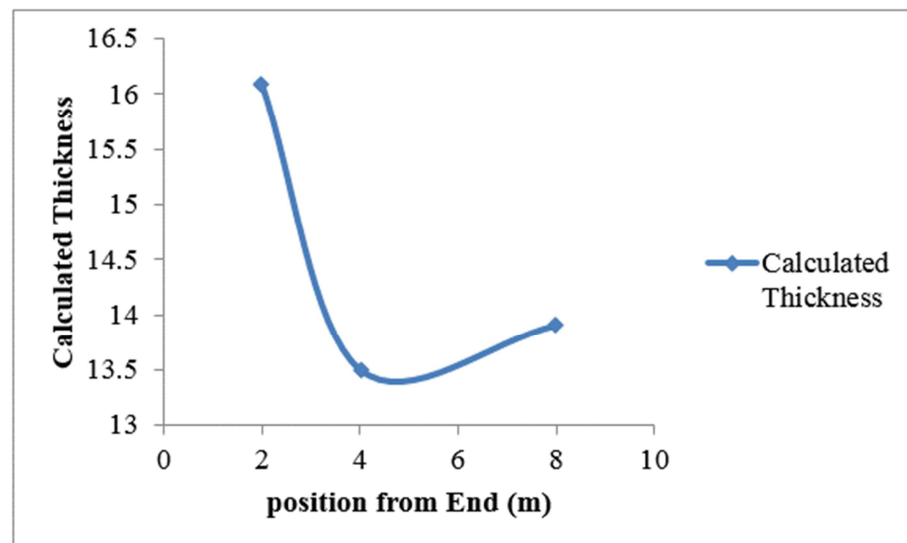*Figure 6.* Deflection v/s position of sensors.

Figure 7. Calculated thickness (cm) v/s position of sensor.

From the above diagram it is found that the sensors which are placed at the distance of 0.0cm (D0), 20.0cm (D1), 30.0cm (D2), 45.0cm (D3), 60.0cm (D4), 90.0cm (D5) and 120.0cm (D6), the deflection is obtained through the sensors. It is found that the deflection is maximum in case of sensors placed at the first point.

Also, the temperature sensors placed in the machine and it has given the following results for the case of surface and air temperature.

From the above graph it is found that the surface temperature is more as compared to the air temperature since the readins are noted till the surface has absorbed sufficient heat.

The thickness is back calculated by the FWD and it has given following results for different points.

From the above graph it is observed that the thickness for the first four is higher as compared to the last point. The modulus of elasticity was calculated by FWD is shown in the following graph.

From the above graph it is observed that the Modulus of Elasticity observed to be higher for the first point as compared to the last point.

The deflection for the case of Grouted macadam is obtained in the following graph.

From the above graph it is observed that the deflection is higher for the last point. Since this is a grouted macadam the deflection as compared to the PCCBP is very large. This means that the PCCBP is stronger as compared to GM.

The back calculations were obtained from FWD for the case of GM is shown in the following graph.

The thickness is back calculated by the software of FWD and it is observed that the thickness is somewhere only 13.5cm but the thickness was maintained as 15cm. Therefore it shows that the cement grout is not penetrated upto the full depth at certain locations.

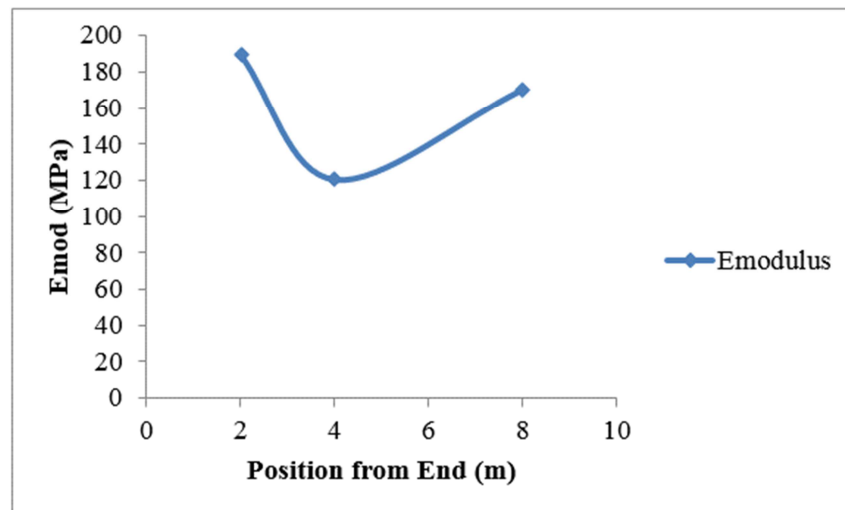The modulus of elasticity for the case GM is obtained as follows:

Figure 8. *The Modulus of Elasticity v/s position of sensors.*

When compared with the PCCBP Emod is lesser and it showed that the PCCBP is stronger as compared to the GM.

When compared to the grouted macadam the PCCBP has given good results and therefore the further analysis of strain is carried out for the PCCBP. The Appendix shows the results for the other types of low volume roads.

differently from each other. The semi-rigid pavement condition existed in the present research. From the above research papers it is found that the PCCBP and GFCBP gives good result in terms of the deflection, modulus of elasticity and strain when compared with grouted macadam. The lifetime period for this type of pavement is also high.

4. Conclusion

The falling weight delflectometer (FWD) is good non destructive machine to know the parameters of pavement. The flexible, rigid and semi-rigid pavement behaves

Appendix

a) Falling Weight Deflectometer (FWD) Analysis for Plastic Cell filled Concrete Block Pavement (PCCBP):

Table 4. *Deflection for Sensor distance with positions for PCCBP.*

Sensor distance (cm)	0	20	30	45	60	90	120
Position	D0	D1	D2	D3	D4	D5	D6
M	μm	μm	μm	μm	μm	μm	μm
0	355	318	287	241	202	148	107
2	424	400	376	313	236	123	68
4	359	336	317	264	201	107	62
8	415	393	367	305	231	121	72

Table 5. *Temperature for the position of sensors for PCCBP.*

Position	Surface Temperature	Air Temperature
m	°C	°C
0	31.9	20.4
2	33.5	20.8
4	34.6	22.3
8	34.9	22.5
13	35.2	22.6

Table 6. *Input values for PCCBP.*

Poisson's ratio	0.15
Joint transfer ratio (%)	80
Axle Load (Ton)	40
Joint Distance	7.5
Slab temperature difference (°C)	30
Slab E modulus (Mpa)	32908
Stress allowed in PCC-Centre (Kgf/cm^2)	30
Stress allowed in PCC-Edge (Kgf/cm^2)	75
Stress allowed in PCC-Corner (Kgf/cm^2)	100

Table 7. *Modulus of Elasticity for different positions of sensors for PCCBP.*

Position	D0	Area	RRS	k	Thickness	Emod
m	μm	cm^2			cm	Mpa
0	358	27	60	5	28.9	888
2	355	25	51	7	26.6	729
4	358	25	51	6	26.6	728
8	418	25	51	6	25.7	675

b) FWD Track: Cement Grouted Macadam (CGM):

Table 8. *Deflection for sensor distances with positions for CGM.*

Sensor distance (cm)	0	20	30	45	60	90	120
Position	D0	D1	D2	D3	D4	D5	D6
m	μm	μm	μm	μm	μm	μm	μm
2	3666	1195	325	16	2	89	68
4	8658	4409	344	4	0	36	27
8	8378	1829	376	13	-1	15	15

Table 9. *Temperature for positions of sensors in CGM.*

Position	Surface Temperature	Air Temperature
m	°C	°C
2	36.8	23.1
4	35.3	22.8
8	35.6	22.6

Table 10. *Input values for CGM.*

Poisson's ratio	0.15
Joint transfer ratio (%)	80
Axle Load (Ton)	40
Joint Distance	7.5
Slab temperature difference (°C)	30
Slab E modulus (Mpa)	30000
Stress allowed in PCC-Centre (Kgf/cm^2)	27
Stress allowed in PCC-Edge (Kgf/cm^2)	75
Stress allowed in PCC-Corner (Kgf/cm^2)	100

Table 11. *Modulus of elasticity for CGM.*

Position	D0	Area	RRS	k	Thickness	Emod
m	μm	cm^2			cm	Mpa
2	3666	18	33	3	16.1	189
4	8658	17	32	1	13.5	120
8	8378	17	32	2	13.9	170

c) FWD Analysis for Geocell filled concrete block pavement (GFCBP):

***Table 12.** Deflection for the position of sensors in Geocell filled concrete block pavement.*

Sensor distance (cm)	0	20	30	45	60	90	120
Position	D0	D1	D2	D3	D4	D5	D6
m	μm	μm	μm	μm	μm	μm	μm
0	355	318	287	241	202	148	107
2	424	400	376	313	236	123	68
4	359	336	317	264	201	107	62
8	415	393	367	305	231	121	72

***Table 13.** Temperature for the position of sensors in Geocell filled concrete block pavement.*

Position	Surface Temperature	Air Temperature
m	°C	°C
0	31.9	20.4
2	33.5	20.8
4	34.6	22.3
8	34.9	22.5
13	35.2	22.6

***Table 14.** Input values for Geocell filled concrete block pavement.*

Number of loads per day	200
Growth in number of loads per Year (%)	5
Design lifetime for section (years)	10
modulus for asphalt overlay (E) –Mpa	5000
Poissons ratio for asphalt overlay	0.35
Reference temperature for calculations	40°C

***Table 15.** Modulus of Elasticity for Geocell filled concrete block pavement.*

Layer	Thickness	Poissons ratio	Emax	Emin	Eseed	Reference	Kexponent
	cm		Mpa	Mpa	Mpa	μ-strain	
1	75	0.15	3000	1000	3000	195	5.62
2	75	0.15	3000	50	3000	885	4
3	250	0.15	500	50	500	885	4
4	250	0.15	500	20	500	885	4

Nomenclature

PCCBP	Plastic Cell filled Concrete Block Pavement
GFCBP	Geocell Filled Concrete Block Pavement
CGM	Cement Grouted Macadam
CGBM	Cement Grouted Bituminous Macadam
E0	E modulus of layer 1, at the temperature of the measurement, calculated value
E	E modulus of layer 1, at the temperature of the measurement, calculated value
Ecorr	E modulus of layer 1, after temperature correction, calculated value
Emod2	E modulus of layer 2, calculated value
Emod3	E modulus of layer 3, calculated value
Emod4	E modulus of layer 4, calculated value
RRS	Radius of Relative Stiffness
Esub	The E modulus of the subgrade, calculated value
Hasf	The thickness of the asphalt layer, before overlay, user input
Ecorr	E modulus of layer 1, after temperature correction, calculated value
Esub	The E modulus of the subgrade, calculated value
Hasf	The thickness of the asphalt layer, before overlay, user input
Critical layer	Critical layer, the layer with the shortest lifetime
A overlay	The overlay necessary to reach the requested life time, calculated value
Lifetime	Life time for the existing structure, calculated value Poisson Ratio-The Poisson ratio for the layer

Emax	The maximum possible value of E modulus that the layer might have, at reference temperature, If the modulus reaches this value in the iteration process it is not further increased
Emin	The minimum possible value of E modulus that the layer might have, at reference temperature, If the modulus reaches this value in the iteration process it is not further deceased
Eseed	The most likely value of E modulus that the layer will have
Reference strain	The value of the strain (in microstrain) that will produce excessive damage after one million loads

References

[1] Andrzej, M. & Marta, M., 2014. Modern NDT Systems for Structural Integrity Examination of Concrete Bridge Structures. Procedia Engineering, Volume 91, pp. 418-423.

[2] Anon., 1997. Nondestructive evaluation of concrete with impact-echo and pulse- velocity techniques: 47640 Limaye, H. S.; Krause, R. J. Materials Evaluation, Vol. 49, No. 10, pp. 1312–1315 (Oct. 1991). NDT & E International, Volume 30, pp. 262-263.

[3] Asli, C., Feng, Z.-Q., Porcher, G. & Rincent, J.-J., 2012. Back-calculation of elastic modulus of soil and subgrade from portable falling weight deflectometer measurements. Engineering Structures, Volume 34, pp. 1-7.

[4] Březina, I., Grošek, J. & Janků, M., 2017. Measurement of Deflections and Determination of Jointed Plain Concrete Pavements Stiffness by Falling Weight Deflectometer. Procedia Engineering, Volume 190, pp. 162-169.

[5] Davis, A. G., 2003. The nondestructive impulse response test in North America: 1985–2001. NDT & E International, Volume 36, pp. 185-193.

[6] Edwards, L. & Bell, H. P., 2016. Comparative evaluation of nondestructive devices for measuring pavement thickness in the field. International Journal of Pavement Research and Technology, Volume 9, pp. 102-111.

[7] Gosk, W., 2016. Stiffness Estimation of the Soil Built-in Road Embankment on the Basis of Light Falling Weight Deflectometer Test. Procedia Engineering, Volume 143, pp. 395-402.

[8] Guzzarlapudi, S. D., Adigopula, V. K. & Kumar, R., 2016. Comparative studies of lightweight deflectometer and Benkelman beam deflectometer in low volume roads. Journal of Traffic and Transportation Engineering (English Edition), Volume 3, pp. 438-447.

[9] Hegde, A., 2017. Geocell reinforced foundation beds-past findings, present trends and future prospects: A state-of-the-art review. Construction and Building Materials, Volume 154, pp. 658-674.

[10] Lam, M. N.-T., Jaritngam, S. & Le, D.-H., 2017. Roller-compacted concrete pavement made of Electric Arc Furnace slag aggregate: Mix design and mechanical properties. Construction and Building Materials, Volume 154, pp. 482-495.

[11] Nega, A., Nikraz, H. & Al-Qadi, I. L., 2016. Dynamic analysis of falling weight deflectometer. Journal of Traffic and Transportation Engineering (English Edition), Volume 3, pp. 427-437.

[12] Pokharel, S. K., Han, J., Leshchinsky, D. & Parsons, R. L., 2017. Experimental evaluation of geocell-reinforced bases under repeated loading. International Journal of Pavement Research and Technology.

[13] Rehman, S. K. U., Ibrahim, Z., Memon, S. A. & Jameel, M., 2016. Nondestructive test methods for concrete bridges: A review. Construction and Building Materials, Volume 107, pp. 58-86.

[14] Ruta, P., Krawczyk, B. & Szydło, A., 2015. Identification of pavement elastic moduli by means of impact test. Engineering Structures, Volume 100, pp. 201-211.

[15] Sack, D. A. & Olson, L. D., 1995. Advanced NDT methods for evaluating concrete bridges and other structures. NDT & E International, Volume 28, pp. 349-357.

[16] Sirithepmontree, H. & Sapsathiarn, Y., 2017. Dynamic Soil Models for Backcalculation of Material Properties from Falling Weight Deflectometer Deflection Data. Procedia Engineering, Volume 189, pp. 152-157.

[17] Suku, L., Prabhu, S. S., Ramesh, P. & Babu, G. L. S., 2016. Behavior of geocell-reinforced granular base under repeated loading. Transportation Geotechnics, Volume 9, pp. 17-30.

[18] Thakur, J. K., Han, J., Pokharel, S. K. & Parsons, R. L., 2012. Performance of geocell-reinforced recycled asphalt pavement (RAP) bases over weak subgrade under cyclic plate loading. Geotextiles and Geomembranes, Volume 35, pp. 14-24.