Indian Journal of Science and Technology, Vol 8(19), DOI: 10.17485/ijst/2015/v8i19/75989, August 2015
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Determining Pavement Layers Thickness and Moduli According to Non-Destructive Testing and Back Analysis (Case Study: Azadegan Freeway-Tehran)

Reza Jafari Zave*

Department of Civil Engineering, Payam Noor University, Tehran Shomal, Tehran, Iran; Reza.jafarizave@gmail.com

Abstract:

Background/Objectives: The engineers are permanently looking for a way to be informed and evaluate current conditions of pavement in order to estimate structural pavement conditions and the remained lifetime. **Methods/Statistical Analysis:** Present study aimed to conduct a back analysis on pavement layers moduli of elasticity in one of sections of Azadegan Freeway through the data obtained from an assessment on pavement status by DCP and GPR tests as well as the deflection results of FWD device for 9 sensors on the desired section. Back analysis of pavement layers moduli was carried out using the Software ELMOD. **Results:** The results from this study can be summarized as follows: 1. For both loading levels of 49.2KN and 58.42KN, asphalt layer moduli has the highest changes. 2. Changes trend of the rigid layer depth is in a direct proportion with subgrade moduli. 3. Rigid layer has a direct effect on moduli-related results of other pavement layers. 4. Geophone D3 has the highest mean differential deflection. **Conclusion/Application:** In conclusion, this study indicates that for both load levels, asphalt layer moduli has the highest changes and the moduli changes are less in lower layers.

Keywords: Layer Thickness, Non-Destructive Tests (NDT), Pavement

1. Introduction

Evaluation of current pavement conditions is so important to estimate the remained lifetime and strength of different layers particularly for coating design. Given the novel mechanistic-experimental design method in which having pavement materials properties (e.g. elasticity moduli) is required; importance of this issue has been increased. Compared to destructive tests, Non-Destructive Tests (NDTs) offer two major advantages: 1. in the former due to its nature, the jugate layers of pavement will be manipulated and taking them to the laboratory is necessary while in the latter which is in fact an in situ test, the pavement is evaluated with no materials manipulation or change. The second advantage of NDTs is their relatively high speed and low cost so they allow for complete test because they often provide less traffic disruption[1]. Regarding NDT, it is recommended to employ some cores to validate layers thickness as well as to carry out back calculation and to precisely determine layers moduli. However, generally the number of destructive tests necessary for a pavement (in addition to NDT) is very low. The results from NDT in asphalt pavements are used to determine elasticity moduli of each pavement layer, structural adequacy of pavement, thickness design of coating, allowed load limits, remained structural lifetime and also in concrete pavements for determination of elasticity moduli of concrete and reaction moduli of the bed, the way of power transmission through the seams, gap, structural adequacy of pavement and repair operations design[2].

2. Materials and Methods

The present paper aimed to determine pavement layers moduli and the hard layer thickness in desired

*Author for correspondence

section by the back analysis gained from Falling Weight Deflectometer (FWD) for two load levels including 49.18 and 58.42 KN through the software ELMOD, assuming the hard layer. Generally, the method can be summarized as follows:

- Determination of asphalt layer thickness in the desired section using the data from Ground Penetration Radar (GPR)
- Determination of underlying layers (base and sub-base layers) thickness in the desired section using the data from Dynamic Cone Penetrator (DCP)
- Determination of pavement layers moduli and hard layer thickness in the desired section using the back analysis gained from FWD for tow load levels of 49.18 and 58.42 KN through the software ELMOD, assuming the hard layer.

The software ELMOD (developed by Dynatest consultants) was used for reverse calculation of pavement and determination of the corresponding layers moduli. This software is capable of finding pavement layers moduli, considering one of the following methods[3]:

- The Equilibrium thickness method which employs Odemark-Boussinesq for the section conversion and section determination. The maximum number of pavement layers can be considered 4 in this method.
- Fitting the settlement dish obtained from analysis conducted by FWD test for back calculation. The maximum number of pavement layers can be considered 5 in this method.

  In this software, nonlinear properties of granular pavement layers can be taken into account and temperature dependability of the materials can be included, as well. For this purpose, the temperatures for 24 hours a day are required to be imported in the software.

- Back calculation and determination of pavement layers moduli according to the data gained from FWD test.

2.1 Determination of the Method and Analysis Type of Back Calculation

In case of elastic materials, moduliof elasticity are decreased with increasing distance from the load and then approachthe bed coefficient value. However, in practice, considering linear elastic behavior for pavement materials will cause some errors in calculations trend due to exist nonlinear behavior in granular and soft clay materials. In fact, nonlinear behavior is often governed in the pavements. For instance, moduliof elasticity of the bed are increased with enhanced depth where slag is increased[4].

Nevertheless, nonlinear elastic analysis is validated when no rigid layer exists up to depth of 6m from pavement surface or in case where any hard layers of pavement are close to the pavement surface. Otherwise, dynamic resonance effect should be included which results in deviation of settlement dish relative to static mode. In this case, dynamic analysis should be carried out and deflections time histories should be studied[4].

For back calculation of pavement and determination of the corresponding layer moduli, following tests are required to be carried out:

- For determination of pavement layers structural thickness such as GPR, DCP, spudding and core taking.
- FWD test and obtaining pavement surface deflection in certain spaces from the load application place (settlement dish).

2.2 How to Determine Asphalt Layer Thickness

Therefore, the first step is to determine thickness of pavement layers including asphalt concrete layer, base layer and sub-base layer. For this purpose, GPR test was conducted in 10.2-12.2 km from Azadegan Freeway with 50m distances. Table 1 shows the values obtained for thickness.

For this study, mean value of all chain ages which was set to 200mm (shown in Figure 1) was selected as asphalt layer thickness.

2.3 The Way of Underlying Layers Thickness Determination

In order to determine thickness of base and sub-base layers, the results of DCP test were used. This test which is based on kicking the cone at an angle of 60 degrees and its influence in the ground is carried out to evaluate strength and measure pavement and resilient moduli of pavement bed in different depths. In doing so, according to influence level of cone in different depths of pavement versus specific number of blows, the strength value and in fact layers influence location change inside the pavement can be found. The number of blows versus cone influence is logged for each test in order to obtain influence rate. By

Table 1. The obtained thicknesses from GPR test

Chainage (m)	Thickness (mm)	Chainage (m)	Thickness (mm)	Chainage (m)	Thickness (mm)	Chainage (m)	Thickness (mm)
11750	185	11200	204	10700	203	10200	205
11800	187	11250	200	10750	190	10250	211
11850	203	11300	196	10800	197	10300	197
11900	207	11350	199	10850	203	10350	201
11950	202	11400	189	10900	202	10400	203
12000	194	11450	196	10950	211	10450	204
12050	194	11500	200	11000	204	10500	205
12100	203	11550	204	11050	198	10550	201
12150	201	11600	204	11100	197	10600	202
12200	210	11650	195	11150	203	10650	194

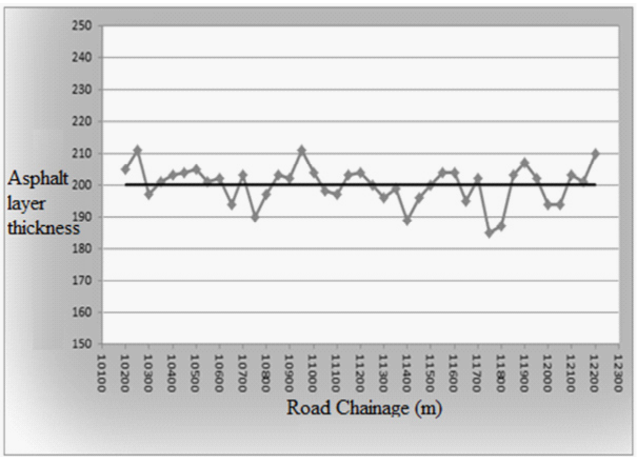

Figure 1. The changes of asphalt concrete layer thickness in desired length of the path-GPR test.

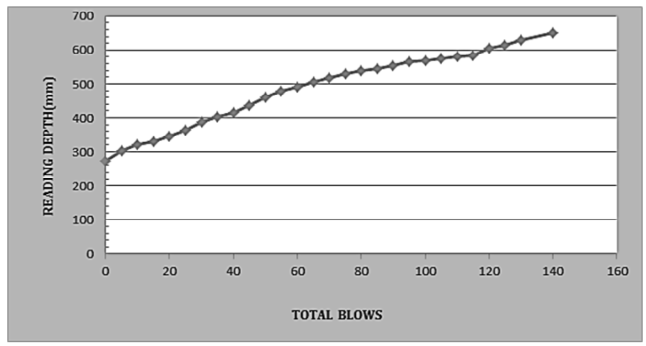

Figure 2. Number of blows versus influence depth of cone in DCP test for chainage 11.8.

an analysis on data of this test, some useful data can be found about current pavement status such as thickness and strength of adhesive layers of pavement. Figure 2 illustrates the number of incurred blows on the cone versus its influence depth in pavement depth.

Since the test was conducted up to a depth of 700mm, some better information can be found about underlying layers thickness. In this diagram, a sudden change was occurred in influence rate at a depth of about 6000mm. So, given the asphalt thickness in this section, pavement layers thickness was selected for 3-layer analysis where the last layer is the rigid one:

- Thickness of asphalt layer: 200mm
- Total thickness of sub and sub-base layer: 400mm
- Thickness of rigid layer: 6000mm

2.4 Back Calculation and Determination of Pavement Layers Moduli According to the Data Gained from FWD Test

Since thickness of pavement layers is clear, back calculation of pavement can be conducted and the corresponding layers moduli can be specified, using measured deflections by 9 sensors. For this purpose, the software ELMOD ver.5.0 was used.

Since pavement layers moduli determination was desired to be conducted in chainage of 10.2 to 12.2 therefore the deflections measured in stations 69 to 82 had to be used is shown in Table 2. According to the obtained information from the former tests, the asphalt layer thickness, base and sub-base layers total thickness and main layer depth of 200mm, 400mm and 6000mm, respectively, were considered.

FWD test was iterated for four times and the load value in loading sub-plate and deflections were measured at the location of 9 sensors in every station. The used

Table 2. Properties of the used stations for pavement layers moduli determination

75	74	73	72	71	70	69	Station No.
11+100	10+952	10+827	10+650	10+500	10+351	10+202	Chainage (km)
82	81	80	79	78	77	76	Station No.
12+154	12+500	11+879	11+701	11+552	11+400	11+250	Chainage (km)

loading plate in FWD device had a radius of 150mm and there embedded 1 sensor beneath the loading plate and 8 sensors at distances of 200mm, 300mm, 450mm, 600mm, 900mm, 1200mm, 1500mm and 1800mm, respectively, from the loading plate.

For two load levels of 49.18KN and 58.42KN in present study, with considering above sections for pavement (the asphalt layer thickness, base and sub-base layers total thickness and rigid layer depth of 200mm, 400mm and 6000mm, respectively) from the path and importing the measured deflections by FWD to the software ELMOD, pavement layers moduli was determined within the path and in different stations. Also, radius of curvature was used to carry out back analysis. In this method, asphalt moduli is obtained in terms of the closest geophone to the loading center, subgrade moduli based on the furthest geophone and intermediate layers moduli according to the intermediate geophones information relative to the loading center.

3. Results

3.1 Asphalt Layers Moduli Determination

Mean asphalt layer moduli, base and sub-base and subgrade in different sections of the freeway for the studied load levels (49.2 and 58.8 KN) are presented in Figures 3 and 4 and also Table 3.

As it can be seen from the figures for both load levels, asphalt layer moduli have the highest moduli and in lower layers, the moduli changes are less. The highest moduli value for all three layers in the load level of 49.2KN was E_1 = 4447, E_2 = 876 and E_3 = 168 which were occurred in the chainages of 12.005, 11.552 and 12.154, respectively.

For all three moduli at the space between chainages 10.7 and 11.5, no major change was occurred and almost the moduli are fixed at the space between these chainages. Also, for the load level of 58.42 KN, the highest moduli value was E_1 = 3830, E_2 = 799 and E_3 = 177 which were occurred

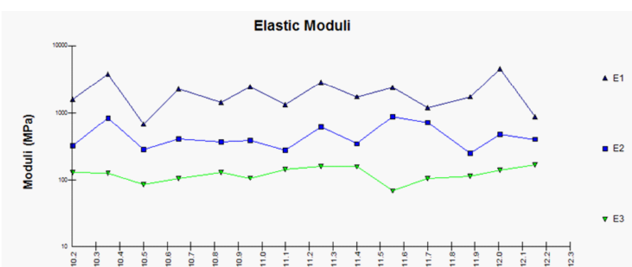

Figure 3. Estimated moduli for pavement layers through the desired path for the load level of 49.2 KN.

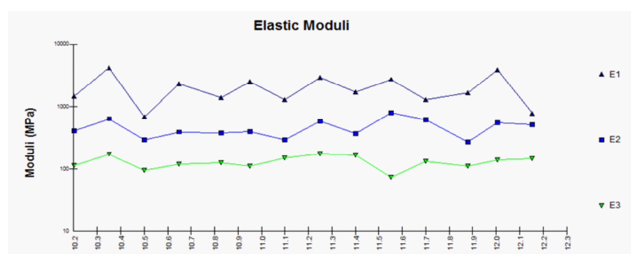

Figure 4. Estimated moduli for pavement layers through the desired path for the load level of 58.42 KN.

Table 3. Mean estimated moduli for pavement layers at both load levels of 49.18KN and 58.42KN by back calculation in the software ELMOD

	Load level of 49.18KN			Load level of 58.42KN		
	Mean Value (Mp)	Standard Deviation (Mp)	Coefficient of Variation (%)	Mean Value (Mp)	Standard Deviation (Mp)	Coefficient of Variation (%)
E_1	1801	1.69	0.094	1795	1.72	0.096
E_2	431	1.53	0.35	440	1.391	0.37
E_3	121	1.277	1.05	127	1.276	1

in the chainages of 12.005, 11.552 and 11.25, respectively and the lowest module of asphalt, base and sub-base layers and subgrade were seen in the chainage of 10.5.

As it can be seen from Table 3, the mean moduli for asphalt layer in the load level of 49.2 KN are higher than that of 58.42KN. Nevertheless, the mean moduli for underlying layers (base, sub-base and subgrade) in the load level of 58.42 KN are higher than that of 49.2KN. Given the low difference, mean moduli of the two load levels for asphalt layer, base and sub-base and subgrade were $E_1 = 1798$, $E_2 = 435.5$ and $E_3 = 124$, respectively. Also, the ratio of Standard Deviation to the mean moduli (Coefficient of Variation) at any load levels was about 1 percent which is lower than 2percent. Therefore, obtained moduli are acceptable.

3.2 The Distance of Rigid Layer from Pavement Surface

The obtained results for the rigid layer through the software are shown in Figures 5 and 6 for both loading levels. It's noteworthy to mention that maximum depth of rigid layer for input parameter of the software was limited to 6m while calculated values in the software were as follows: 2800mm for loading level of 49.2KN and 3000mm for loading level of 58.42.

A comparison on Figures 5 and 6 shows that changes trend of the rigid layer depth is in a direct proportion with subgrade moduli. For example, in chainages of 10.5 to 11.9 where subgrade moduli has an increasing trend, depth of rigid layer is also increasing and in chainages of 10.5 to 11.9 where depth of rigid layer shows no considerable change, subgrade moduli has also an approximately fixed value between these chainages.

3.3 Measured and Calculated Deflections

Figures 7 and 8 shows measured and calculated differential deflections through the software for each geophone

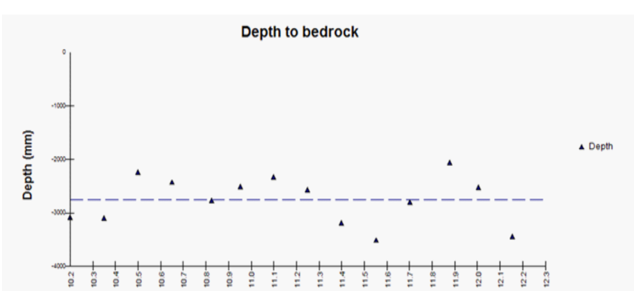

Figure 5. Estimated depth of the rigid layer for different chainages in load level of 49.2KN.

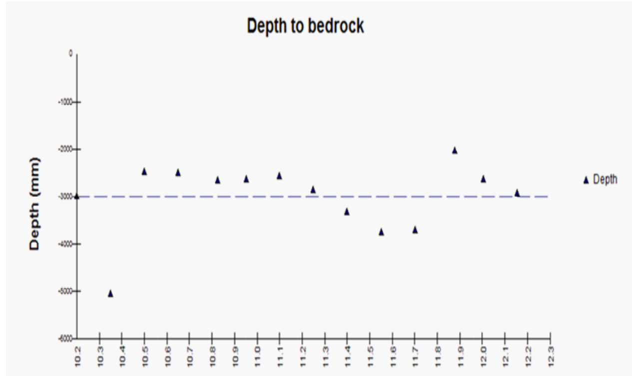

Figure 6. Estimated depth of the rigid layer for different chainages in load level of 58.42KN.

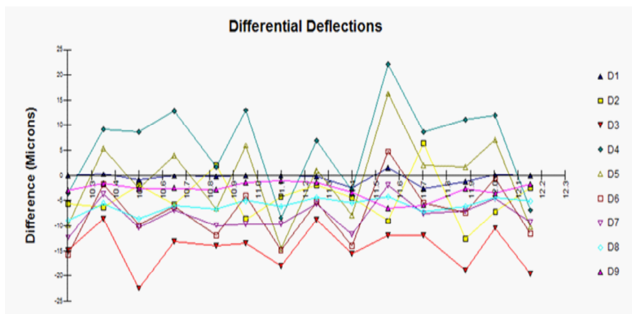

Figure 7. Measured and estimated deflections for each geophone at all chainages in loading level of 49.2KN.

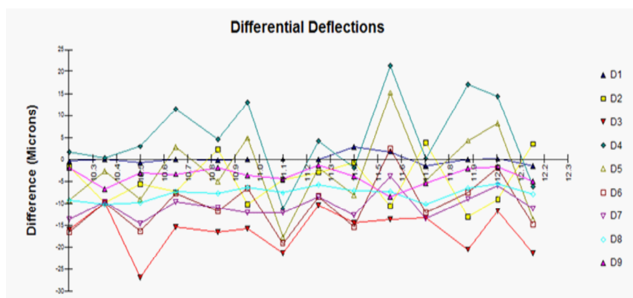

Figure 8. Measured and estimated deflections for each geophone at all chainages in loading level of 58.42KN.

in each chainage. Accordingly, Tables 4 and 5 present mean and standard deviation of geophones deflection in different chainages. As it can be seen from the results, the highest mean differential deflection exists for the geophone D3. Figures 7 and 8 show the comparison of measured and calculated deflections where the maximum difference at all geophones in both loading levels is less than 20 micron.

Table 4. Mean and standard deviation of measured and estimated deflections for each geophone in loading level of 49.2KN

Geophone Name	D1	D2	D3	D4	D5	D6	D7	D8	D9
Distance from the load center (mm)	0	200	300	450	600	900	1200	1500	1800
Mean measured and calculated differential deflection (micron)	1	6	14	9	7	8	8	6	3
Measured and calculated standard deviation (micron)	1	3	4	5	5	5	3	1	2

Table 5. Mean and standard deviation of measured and estimated deflections for each geophone in loading level of 58.42KN

Geophone Name	D1	D2	D3	D4	D5	D6	D7	D8	D9
Distance from the load center (mm)	0	200	300	450	600	900	1200	1500	1800
Mean measured and calculated differential deflection (micron)	1	6	16	8	8	11	11	8	4
Measured and calculated standard deviation (micron)	1	4	5	7	5	5	3	2	2

4. Conclusion

The results from this study can be summarized as follows:

- For both loading levels of 49.2 KN and 58.42 KN, asphalt layer moduli have the highest changes.
- Changes trend of the rigid layer depth is in a direct proportion with subgrade moduli.
- Rigid layer has a direct effect on moduli-related results of other pavement layers.
- Geophone D3 has the highest mean differential deflection.

5. References

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