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REVIEW OF FALLING WEIGHT DEFLECTOMETER FOR ASSESSMENT OF FLEXIBLE PAVEMENT

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ABSTRACT

Fast development of road networks has become a trend in India and everywhere in the world. From the past couple of decades, it has been observed that numerous highways are in a phase of deteriorations. Identifying the reasons for deteriorations requires a pavement evaluation study. Many performances study have been made out by exploring flexible pavements, by the users of widely accepted falling weight deflectometer (FWD) as a non-destructive test (NDT) and considered it as a standard for structure assessment. The primary objective of this study is to a review of an FWD instrument and the also study of the empirically derived methods and a back calculation process for computing layer moduli and factors influencing it. The essential need of correction factors to get reliable layer moduli is an also discussed, in addition to the investigation of advancement of low-cost indigenous FWD models

Keywords: Falling weight deflectometer (FWD), back calculation process, correction factors, surface deflection

Nomenclature

1. E_S = *Subgrade Modulus.*
2. P = *Applied Load.*
3. μ= *Poisson Ratio.*
4. a= *Plate Rigidity Factor.*
5. E_{BASE} = *Modulus of Base Layer.*
6. E_{AC} = *Modulus of Bituminous Layer.*
7. r, dr, D_3, D_{72}, d_2, d, W_7, D_1, D_2, D_4. D_5, D_7 = *Measured Deflection at corresponding radial distances.*
8. $D_X/12$, $D_X/36$, $D_X/60$, $D_X/200$ = *Measured Deflection at corresponding radial distance in lateral Direction.*

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9. *$D_y/0$, $D_y/305$, $D_X/36$ = Measured Deflection at corresponding radial distance in longitudinal direction.*
10. *E_{T1}, E_{T2} = Modulus @ Temp. T_1 and T_2.*
11. *D_{68}, E_{68} = Deflection and Modulus @ Temp. 68 F^0*
12. *D_T, E_T = Deflection and Modulus @ Temp. T.*
13. *E_{TC}, E_{TW} = Modulus @ Temp. T_C and T_W.*
14. *E_{To}, E_T = Modulus @ Temp. T_o and T.*
15. *λ_E, α = Correction Factor for Temp.*
16. *E_{gran_Mon} = Modulus for Granular layer in Monsoon.*
17. *E_{gran_Sum} = Modulus for Granular layer in Summer.*
18. *E_{gran_Win} = Modulus for Granular layer in Winter.*
19. *E_{sub_Mon} = Modulus for Subgrade layer in Monsoon.*
20. *E_{sub_Sum} = Modulus for Subgrade layer in Summer.*
21. *E_{sub_Win} = Modulus for Subgrade layer in Winter.*

1. INTRODUCTION

Rapid construction of road infrastructure has become a trend in India and all over the world. In past few decades, it has been observed that many road works require early stage of maintenance. To identify causes of it, require a structural evaluation study to assess the existing layers properties of pavement. Many performances study have been made out by exploring flexible pavements by the users of

Widely accepted NDT. In NDT, in situ test is conducted on in service pavement without disturbing or breaking out pavement layer. NDT tools for evaluating material layer properties of in service pavement are extensively used worldwide. Generally, a wave prorogation technique and deflection based approach have gained popularity in the field of pavement engineering. In wave prorogation techniques, vibration source kept on a surface of the pavement and velocities and wavelength of surface waves are measured, which are emitted from vibration source and transmitted through pavement layers. This approach requires highly advanced computer programmer for reliable results interpretations, therefore, it is not widely used. From the early 1970s, the surface deflection approach is extensively used for assessing pavement material because of its reliability, speedy operation and ease of use. Surface deflection is overall responses (in terms of deflections) of the full depth of pavements under predefined standard application of load. A surface deflection is measured by non-destructive deflection tests. Back calculation analysis is performed to determine the structural properties of distinct layers or to estimate the moduli value of distinct layers and computed moduli values are furthermore used for analysis of pavement and estimating the remaining life and overlay requirement analysis of pavements.

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Structural evaluation studies are conducted with various tools such as Benkelman beam deflection (BBD), lightweight deflectometer (LWD) and FWD. The best capable devices for measuring accurate pavement response are built on the using dynamic loading and the assessment of the deflections. Amongst the various deflectometer assembled devices, the FWD is the extensively utilized and considered as a benchmark test for pavement evaluation due to closely simulate loading condition of actual moving load [1]. The FWD has been being used now for over numerous years for pavement assessment, including utilization on unbound asphalt layers. It is a trusted apparatus and regarded by numerous researcher as a standard against another mention NDT [2]. The primary objective of this study is to a review of an FWD instrument and the also study of the empirically derived methods and a back calculation process for computing layer moduli and factors influencing it. The essential need of correction factors to get reliable layer moduli is an also discussed, in addition to the investigation of advancement of low-cost indigenous FWD models.

FWD test, in which mass is allowed to fall from a predefined height on pavement surface and surface deflections or deflections basin are measured using a velocity transducer (geophone) or deflection sensors, which are equipped with FWD. It is observed that the amplitude deflection at distinct radial point occurs at distinct time moments, which are not closely simulating the actual transient deflection conditions of moving wheel load. Therefore, a measured deflection is further evaluated through back-calculation analysis. Moreover, a detailed of operating principle, deflection basin is discussed in subsequent sections.

2. COMMERCIAL AVAILABLE FWDs

Different types of commercially available FWDs are briefly discussed in this section. An international overview of FWDs are presented in Table 1, which are not discussed here and only indigenous FWDs are discussed in this study. **(Ref Table- 1)**

2.1 IITKGP FWD Model -I

The first Indian FWD model was developed **[5]** by the transportation engineering section of the department of civil engineering, Indian institute of technology, Kharagpur, India. It is trailer mounted, towed with the help of a jeep. This model has loading capabilities ranging from 20 kN to 65 kN and loading time between 20-30 milliseconds, rubber pad used as buffer (spring) system for the obtained desired load duration, which is closely similar to a moving vehicle speed of 50-60 kmph. Surface deflections can be measured at offset distances of 300 mm apart up to 1500 mm distance with the assistance of six geophones. A string and pulley prearrangement

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is employed for raising and letting down the weight, whereas a clamp arrangement is built up for supporting the stack at any desired height. Single load cell and six geophones are used to quantify the magnitudes of load and deflections respectively. The load and deflection are read on the computer with the aid of a data acquisition system.

Numerous field investigations were made using this equipment, and it showed good repeatability of deflections **[5].** This low-cost equipment is quite suitable for developing

Countries like India. Some of the drawbacks of this model are a require many of the laborious operations such as pulling off a chain for lifting the mass, placing the geophones on the pavement surface and releasing the mass. Tests are performed physically and thus it has taken more time.

Furthermore, maneuvering the equipment on in-service highways in India was found to be hard and clumsy.

To defeat all mentioned drawbacks of IITKGP Model- I a second model was produced in the year 2001 by IIT, Kharagpur, India and works were sponsored by MORT&H.

2.2 IITKGP FWD Model –II

IITKGP FWD Model –II is a fully automatic vehicle-mounted instrument. All the processes are computerized and surface deflections data are gathered through a data-acquisition system, also one additional geophone is added for obtaining better surface deflection data. An impulse loading range from 20 kN to 100 kN can be obtained by varying dropping mass and heights ranges from of 100 kg to 225 kg and 100 mm to 600 mm respectively on 300 mm loading plate diameter. Which allows uniforming distribution of stresses on the pavement and by the help of seven geophones surface deflections are measured with observed load duration varies from 20 to 30 milliseconds.

2.3 Geotran FWD

GEOTRAN FWD is a fully automatic vehicle-mounted instrument for measuring surface deflection and requires only one man to operate all its operations. All the operations are controlled from PC/laptop through the DS4000S data acquisition system. DS4000S system is a very accurate and high-speed controlling system, that is capable of captures all required data of geophone, load cell, and temperature. GEOTRAN FWD has produced the impulse load up to 100 kN on existing pavement by dropping weight from predefined height and evaluate surface deflections using seven inbuilt geophones. It has also two temperature sensors for air temperature and road surface temperature measurement. Loading plate has a diameter of 300 mm with reinforced rubber plate.

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3. OPERATING PRINCIPLE OF FWDs

The working principle of all FWDs model are same. A mass is allowed to drop from a predetermined height onto a series of springs/ buffers placed on top of a loading plate to produce impulse load pulse on the pavement surface, buffer system of suitable stiffness (5 mm minimum thickness) used to simulate the actual load duration of moving traffic. The corresponding peak load and peak vertical surface deflections at different radial locations are measured using deflection sensors as shown in Figure 1, DO, D1, etc., are surface deflections measured at different radial distances and recorded in data acquisition system. **(Ref Figure- 1)**

3.1 Deflection basin

The reliability and usefulness of FWDs are based on the capability of simulate closely to the actual loading condition. It includes traffic loading and stresses induced due to environment and weather condition. When a moving wheel load passes over the pavement, it generates load pulses. Normal stresses (vertical as well as horizontal) at a specific location in the pavement and it will increase in magnitude from zero to a peak value as the moving wheel load approaches the specific location. The time taken for the stress pulse to vary from zero to peak value is termed as 'rise time of the pulse'. As the wheel moves away from the location, the magnitude of stress reduces from the peak value to zero. The time period during which the magnitude of stress pulse varies from 'zero-to-peak-to-zero' is the pulse duration. Peak load and the corresponding pavement responses are of interest for pavement evaluations are shown in **(Ref Figure 2).**

The size and shape of the deflection basin permit comprehensive structural investigation of the pavement. Fundamentally, the exterior deflections describe the modulus characteristics of the sub-grade, although the bowl nearby to the loading plate permits investigation of the modulus characteristics of the nearby surface layers. A wide basin with little curvature describes that the upper strata of the pavement are stiffer to the sub-grade. A basin with the equal peak deflection, but high curvature nearby the loading plate describes that the upper layers are weaker to the sub-grade.

4. DETERMINATION OF LAYER MODULUS

Reliable estimation of individual layer modulus from measured deflections of the FWD test is a complex procedure. By taking into account of the size and shape of radial offset deflections, various researchers attempt to find layer modulus and developed empirical relations. The pavement theories based back-calculation procedure is also reviewed in this section.

4.1 Empirical models

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Attempts were made in the past by researchers to estimate layer modulus from the measured surface deflections using NDT techniques are presented, in here and these are briefly reviewed in this section.

AASHTO (1993) [6] recommends the equation 1 for back calculated subgrade resilient modulus using a deflection measurement from the center of the load, further recommend that the minimum sensor distance (r), be estimated based on the radius (a_e) of the stress bulb at the subgrade-pavement interface so that r equal or greater than a_e, suggestive value, r is equal to or greater than $0.7a_e$.

$$E_S \text{ (psi)} = 0.24\, P/\,(dr * r) \qquad (1)$$

Garg and Thompson (1998) proposed regression equations (2-3) for estimating the subgrade modulus from FWD test using pavement deflection, in which, D_3 in miles (0.001 inches) measured at 1097 mm radial distance from the center of the loading plate [7].

For AC pavements:

$$\text{Log } E_S = 1.51-0.19\, D_3 + 0.27 \log (D_3) \qquad (2)$$

For full depth AC pavements:

$$\text{Log } E_S = 24.7-5.41\, D_3 + 0.31\, (D_3)^2 \qquad (3)$$

Choubane and McNamara (2000) proposed the equation 4 for predicting embankment subgrade modulus from FWD measured deflection at a radial distance of 1097 mm [8].

$$E_S = 0.03764\, (P/dr)^{0.898} \qquad (4)$$

Alexander et al, (1989) proposed an equation 5 for subgrade modulus from the deflection (mils) measured at a radial distance of 1830 mm (D72) from the center of the loading plate for an applied load of 111206 N [9].

$$E_S \text{ (psi)} = 59304.82\, (D_{72})^{-098737} \qquad (5)$$

Roque et al, (1998) produced the equation 6 for the appraisal of subgrade modulus based on the deflections measured at 60 inches radial distance from the middle of the dual plates using a dual load [10].

$$E_S \text{ (ksi)} = 36.334(D_X/60)^{-1.015} \qquad (6)$$

Molenaar and Van Gurp (1982) developed the equation 7 to predict subgrade soil modulus from the FWD deflections (in meters) measured at a radial distance of 2000 mm [11].

$$E_S \text{ (MPa)} = 6.614 * 10^{-3} * d_2^{-1.00915} \qquad (7)$$

Subgrade modulus can also be determined by Harr (1966) from the average deflection value measured during the third, fourth and fifth drops of the load in a portable falling weight deflectometer (PFWD) using Equation 8. [12]

$$E_s \text{ (MPa)} = 2\, P\, A\, (1-\mu^2)\, r\, a/\, d \qquad (8)$$

Wimsatt (1999) developed a regression Equation 9 using FWD deflection (mm) measured at a distance of 1828.8 mm [13].

$$E_s \text{ (MPa)} = 0.24\, P/(W_7 * 1828.8) \qquad (9)$$

Discussion

An empirically developed relation for determining individual layer modulus is a based on the size and shape of a deflection basin. Fundamentally the outer deflections describe the modulus of the subgrade while deflection closer

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to the loading plate permits analysis of the near surface layers, it is based on the typical pattern of load distribution or stress zone observed under applied load in the flexible pavement. Development of subgrade modulus from exterior peak deflection is not a straight forward process. It is crucial to characterize a radial distance from center of the loading plate to the exterior deflection center. Although, it is well-known that a from the specified interval of distance, applied load doesn't induce any deflection. Therefore, AASHTO (1993) defines minimum radius distance based on the radius of the stress bulb induced due to the applied load and suggest minimum radius is equal to or greater than 0.7 times of the radius of bulb stress [6]. Garg and Thompson (1998) and Choubane and McNamara (2000) used radius distance of 1097 mm from center loading plate [7-8]. In addition, Alexander et al, (1989); Roque et al, (1998); Molenaar and Van Gurp (1982) and Wimsatt (1999) used radius distance of 1830 mm, 1524 mm, 2000 mm, 1828.8 mm from the center of the loading plate respectively [9-11,13]. Moreover, Equations 1,4,8 and 9 are developed by using deflection measured at a radial distance from the center of loading plate, applied load, and radial distance, which are based on Boussinesq solution, particularly applied to the axis of symmetry. While, empirical equations 2,3,5,6 and 7 are based on, only a function of deflection measured at a radial distance from the center of loading plate. These equations are employed only outer sensor deflection values; Equations 2,3,5,6 and 7 are not widely used because of these are based on the only deflection, while equations 1,4,8 and 9 consider important, which attribute to strength characteristics, such as deflection, applied load, and radial distance.

Again, the load distribution approach is utilized to determine the modulus of granular and the surface layer. The equations 10-13 are a function of surface course thickness and the combination of measured deflection at a radial distance at 0, 200, 500, 800, 1600 mm etc... from the center of the loading plate. Badu et al. (1989) developed equations 10-11. [14]

For Granular layer:

$$\mathbf{\log E_{BASE}\,(ksi) = 3.280-0.03326(t_1)-0.1179\log(D_7) + 3.3562\log(D_1-D_2) -9.0167\log(D_1-D_4)-4.8423\log(D_1-D_5)} \qquad \mathbf{(10)}$$

For Bituminous layer:

$$\mathbf{\log E_{AC}\,(ksi) = 2.215-0.2481\,(t_1) -12.445\log(D_1-D_2) + 17.205\log(D_1-D_3) -5.87\log(D_1-D_4)} \qquad \mathbf{(11)}$$

Roque et al. (1998) developed equation 12-13. [10]

For Granular layer:

$$\mathbf{E_{BASE}\,(ksi) = 105.81136(t_2)^{-1.0785} * (Dx/36 - Dx/60)^{6.02523+2.4888/\ Dx\ /\ 60} * (Dy/\ 0+ Dx/12)-1.15(Dx/36)^{2.1609-1.6202/(Dx/36)-5.302/t_2} * (Dx/60)^{3.6706-0.0498t_1-0.686t_{2-3.09/Dx/60)}}} \qquad \mathbf{(12)}$$

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For Bituminous layer:

$$\mathbf{E_{AC}\ (ksi) = 78.2254\ (t_1)^{0.5554}\ (D_{y/0} - D_{y/305})^{(0.7966-19.1332/t_1)} * (D_{y/0} - D_{x/200})^{17.4791/t_1}} \quad \mathbf{(13)}$$

Several combinations of measured deflections have sometimes contributed to inappropriate modulus results; therefore, these are not widely practiced.

4.2 Back calculation

Back-calculation is a reverse analysis for finding a layer moduli from pavement response (in terms of surface deflection) underneath the application of a given load. The back-calculation is a numerical technique concerning the following modeling mechanisms as shown in Figure 3: (a) loading model, (b) pavement and material models, (c) a pavement response model, and (d) back-analysis model **[4].**

Loading model is a defined on the basis of a mode of applied load, which consist a static load, a moving load, a vibratory load, and an impulse load. The dynamic loading model yields more precise results, but it is a creates inertia and resonance as extra effects. The modulus of the subgrade could be devalued by half or more, and the base and subbase moduli were exaggerated by about the same fringe when dynamic impacts are precluded from the analysis [15]. Pavement model is consisting of a modeling of the pavement compositions, layer thickness, and Poisson ratio. Material model is a defined as a properly modeling of the nature of materials under the application of load. Granular materials and subgrade materials are stress-dependent and nonlinear in nature. Subgrade modulus decreases with the increasing in stress levels, therefore it is a demonstrating stress-softening type characteristic. The vital factor affecting the subgrade modulus is the vertical deviator stress. A modulus of granular materials increases with increasing in stress states (stress-hardening), especially with confining pressure and/or bulk stress, and slightly with deviator stress. The response models have analyzed the pavement responses based on the kinds of material model and loading model employed for analysis. Mostly, it is classed as four varieties of models (a) linear static analysis, (b) nonlinear static analysis, (c) linear dynamic analysis, and (d) nonlinear dynamic analysis.

In the linear static analysis, linear material model and static loading model are utilized, layer thicknesses and Poisson's ratios are known and only one unknown (i.e., elastic modulus) for each layer. Most widely used linear static layered elastic programs is KENLAYER [16]. In the nonlinear static analysis, it is also employed static loading model, but the main change lies in the material models, which is a utilizing nonlinear material model. This gives more than one unknown model parameters for each layer and also the trustworthiness of back calculated values of these parameters is a significant matter to be considered. Linear and nonlinear dynamic

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investigations required the time history information of load and the deflection bowl defined by the amplitude values. The time history of deflections might be utilized rather than the peak deflection bowl for better results.

The back-analysis portion is grounded on the minimization of the "output error," i.e., the uniqueness between the deliberate and figured surface deflections. The three normal measures of output error utilized by analysts are: (a) the sum of the absolute differences (SAD), (b) the sum of the squared differences (SSD), and (c) the sum of the squared relative errors (SSRE). Various methods have been utilized to land at an answer that gives a worthy match between the evaluated and measured deflection bowl. The most widely recognized assault is one that uses an iterative gradient search algorithm, for example, the gauss–newton method. Contrasted and the alleged database techniques [17-18] and the regression equation based methodology [19-20], this methodology, for the most part, takes longer time because of the need to perform the forward structural response model over and again.

Discussion

Back-calculation procedure is depending on coordinating of computed and measured pavement deflections and it comprises of the accompanying three noteworthy strides: (a) determination of a trial set of qualities for the obscure pavement parameters, (b) forward calculation of pavement response taking into account the parameter values chose, and correlation of the computed response with the measured, and (c) changing the chose parameter values by method for a suitable search algorithm to accomplish enhanced coordinating of the computed and measured responses. The accuracy of layer modulus depends on the choice of loading, pavement and material, pavement response and back analysis models employed for analysis. A most widely used example is a linear material model and static loading model based layered elastic programs is KENLAYER. It needs an only one unknown parameter (i.e. layer modulus) requires to find, but it doesn't consider a non-linearly characteristic of materials and that lead to inappropriate results. To get accurate results it is recommended that to use a non-linear dynamic pavement response model. For that a requires a profoundly computational effective PC program, for example, Finite element method (FEM).

5. CORRECTION FACTORS

Properties of bituminous mix changes with temperature, modulus values got at distinctive temperatures are typically set to fit a standard temperature for the design of pavements and overlays. Attributes of a granular layer are highly altered by moisture content, thus seasonal moisture correction and also particular temperature alteration factors were created by

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different experts for confirming the modulus as well as deflection are studied in this section.

Ullidtz and Peattie (1982) employed the deflection data from AASHO road test and the SHELL procedure for finding of mix stiffness and developed the equation 14 for comparing the moduli obtained at two different temperatures [21].

$$\mathbf{E_{T1}/ E_{T2} = (2.6277- 1.38 \log_{10} T_1) / (2.6277 - 1.38 \log_{10} T_2)} \quad \mathbf{(14)}$$

Rada et al (1988) gave the expression for modeling the variation of stiffness with temperature [22].

$$\mathbf{E_{T1} / E_{T2} = 10^{3.245 \times 10^{-4} (T_1^{1.798} - T_2^{1.798})}} \quad \mathbf{(15)}$$

Antunes (1993) proposed the equations 16-17, based on the analysis of back calculated moduli obtained from the FWD data collected at different temperatures [23].

For Asphalt Concrete:

$$\mathbf{E_{T1} / E_{T2} = (1.635 - 0.0317\ T_1) / (1.635 - 0.0317\ T_2)} \quad \mathbf{(16)}$$

For Bituminous Macadam:

$$\mathbf{E_{T1} / E_{T2} = (1.795 - 0.0398\ T_1) / (1.795 - 0.0398\ T_2)} \quad \mathbf{(17)}$$

Kim et al (2000) presented the equations 18-19 for adjusting the deflection value and moduli value for temperatures of 68^0F, where, t is thickness of the Asphalt Concrete (AC) layer (inch) and T is AC layer mid-depth temperature (^{0}F) at the time of FWD testing, α is $3.67 \times 10^{-4} \times t^{1.4635}$ for wheel paths and $3.65 \times 10^{-4} \times t^{1.4241}$ for lane centers [24].

For Deflection:

$$\mathbf{D_{68} = D_T * [10^{\alpha (68 - T)}]} \quad \mathbf{(18)}$$

For Modulus:

$$\mathbf{E_{68} = E_T * [10^{0.0153 (68 - T)}]} \quad \mathbf{(19)}$$

Chen et al (2001) suggested the equation 20 for adjusting the layer modulus for a given temperature [25].

$$\mathbf{E_{Tw} = E_{TC}/ [(1.8Tw +32)^{2.4462} * (1.8Tc +32)^{-2.4462}]} \quad \mathbf{(20)}$$

Johnson and Baus (1992) recommended the equation 21 for adjusting the bituminous layer modulus for a standard temperature of 70^0F [26].

$$\mathbf{E_{Tw} = E_{TC}/ [(1.8Tw +32)^{2.4462} * (1.8Tc +32)^{-2.4462}]} \quad \mathbf{(21)}$$

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Ullidtz (1987) built up a theoretical account for temperature correction based on back calculated moduli values obtained from AASHO Road Test deflection data [27].

$$E_{To} = (1/3.177-1.673 \log_{10} T)\, E_T \qquad (22)$$

Baltzer and Jansen (1994) built up the temperature correction model 23 based on statistical analysis of back calculated moduli and measured AC temperatures [28].

$$E_{To} = 100.018\,(T-20) * E_T \qquad (23)$$

Ali and Slezneva (2000) acquired a relationship for estimating AC layer modulus as a function of average AC layer temperature (^{0}C) and temperature gradient in the AC layer (^{0}C/m) [29].

$$E_{AC} = -934 + e^{(9.53-0.033*(T_p)+0.0018*(T_G))} \qquad (24)$$

IRC:115-(2014) developed equation 25 temperature correction factor corresponding to a 35^0 C temperature; this component is valid for temperature ranges 25^0 to 40^0 C [30]

$$E\,(T_1{}^0\,c) = \alpha\, E\,(T_2{}^0\,c) \qquad (25)$$

Where, $\alpha = [1-0.238 \ln T_1 / 1-0.238 \ln T_2]$

Granular layer and subgrade materials are susceptible to moisture variation, therefore IRC:115-(2014) recommended equation 26-29 for moisture correction by considered summer and winter seasons variation for granular layer and subgrade [30].

For Summer:

$$E_{gran\_Mon} = -\,0.0003 * (E_{gran\_Sum})^2 + 0.9584 * (E_{gran\_Sum}) - 32.989 \qquad (26)$$

For Winter:

$$E_{gran\_Mon} = 10.5523 * (E_{gran\_Win})^{0.624} - 113.857 \qquad (27)$$

For Summer:

$$E_{sub\_mon} = 3.351 * (E_{sub\_win}{}^{0.7688}) - 28.9 \qquad (28)$$

For Winter:

$$E_{sub\_mon} = 0.8554 * (E_{sub\_sum}) - 8.461 \qquad (29)$$

5.1 Discussion

Bitumen material is susceptible to the temperature variation and does change in characteristics of it, also the temperature variation effect on the FWD measured deflections. Granular layer and subgrade materials are susceptible to moisture variation. Therefore, requires a correction factor for standard temperature and worst moisture content for pavement design. It is a basic methodology

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to apply a correction factor to back calculated modulus values. Since at last focus of FWD test is to the determination of layer modulus, although the few researchers tried to developed a correction factor for deflection. Correction factors are geographical locations, environment and material specified, and varies from place to place. On account of the empirical nature of it, it is not considered as standard and requires separately specified correction factors. For Indian conditions, 35 C^0 temperature and monsoon measured modulus are considered as a standard for pavement design.

6. CONCLUSION

FWD is extensively used for assessing pavement material because of its reliability, speedy operation and ease of use, and also consider as a benchmark test for pavement evaluation due to closely simulate loading condition of actual moving load. The degree of utilization of FWD in developing nations like India is constrained due to the high cost of international commercially available FWD. Keeping up such profoundly immoderate equipment is turned out to be troublesome due to the absence of skill. Henceforth the improvement of an ease FWD will be useful in the legitimization of the pavement assessment approach in India. Indigenous low-cost GEOTRAN FWD is a fully automatic vehicle-mounted instrument for measuring surface deflection and requires only one man to operate all its operations. Vital components of the equipment are: - (i) it is equipped for applying a drive load up to 100 kN with a pulse duration of around 20-30 milliseconds and (ii) all the operations are controlled from PC/laptop through the DS4000S data acquisition system.

The size and shape of the deflection basin permit comprehensive structural investigation of the pavement. Fundamentally, the exterior deflections describe the modulus characteristics of the subgrade, although the bowl nearby to the loading plate permits investigation of the modulus characteristics of the nearby surface layers. A number of empirical models are developed for the estimation of layer moduli from radially measured deflection basin with another parameter such as applied load, layer thickness. However, these models are effective for the sets of conditions and construction methodology for which they were developed. Therefore, it is a necessary to validate these models for a different set of conditions and also due to empirical nature of these models, they are not widely used for estimation of layer moduli.

Extensively used method for the estimation of layer moduli is back-calculation method. Back-calculation procedure is depending on coordinating of computed and measured pavement deflections. A most widely used example is a linear material model and

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static loading model based layered elastic programs is KENLAYER. but it doesn't consider a non-linearly characteristic of materials and that lead to inappropriate results. To get accurate results it is recommended that to use a non-linear dynamic pavement response model. For that a requires a profoundly computational effective PC program, for example, Finite element method (FEM).

Bitumen material is susceptible to the temperature variation and does change in characteristics of it, also the temperature variation effect on the FWD measured deflections. Granular layer and subgrade materials are susceptible to moisture variation. Correction factors are geographical locations, environment and material specified, and varies from place to place. On account of the empirical nature of it, it is not considered as standard and requires separately specified correction factors.

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LIST OF TABLE:

Table 1 International overview of FWD

Manufacturer Model	Peak load (KN)	Weight and height of falling mass	Load durations (ms)	Deflections Sensors	Loading plate diameter (mm)	Remarks
Dynatest Model 8000	7 to 120	50 to 300 kg 20 to 380 mm	25 to 30	7 velocity transducers Spacing 2.25 mm apart	300	Denmark and UK
Dynatest Model 8081	30 to 240	--	25 to 30	7 velocity transducers Spacing 2.25 mm apart	--	
Phonix FWD Model ML-10000	10.2 to 102.3	30 to 150kg 50 to 400 mm	--	6 velocity transducers Spacing 2.4 mm apart	--	Europe and US
KUAB 2M-FWD Model 8333	14 to 150	--	--	5 velocity transducers	300 and 450	(Sweden) 2 – Mass system. a falling weight dropped on
KUAB 2M-FWD Model 8714	7 to 65	--	--	5 velocity transducers	300 and 450	

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second
buffer
weight

Source: [3] (R-81 Research Scheme (2003)) and [4] (Fwa, T. F. (Ed.). (2005)).

LIST OF FIGURES

Figure- 1

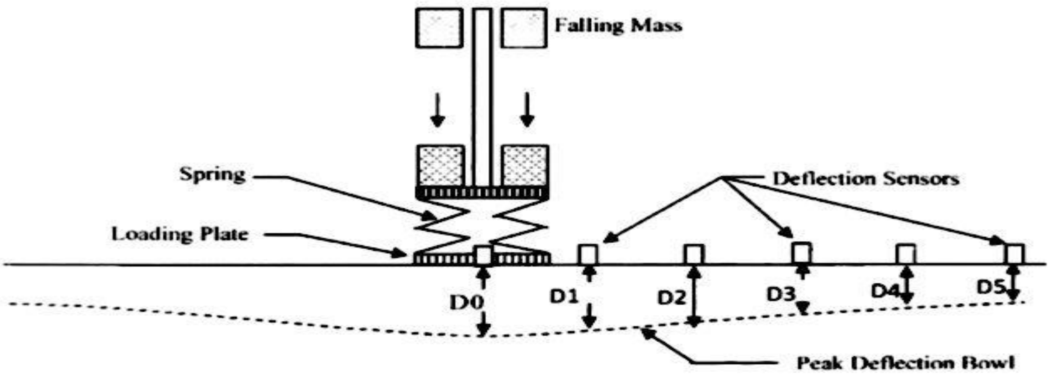

Figure 1 Working Principle of Falling Weight Deflectometer with deflection bowl

Figure- 2

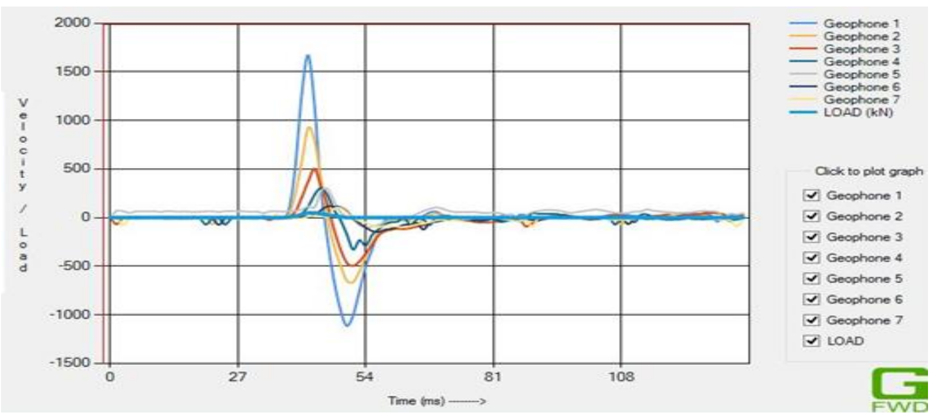

Figure 2 Load-Deflection time histories

Figure- 3

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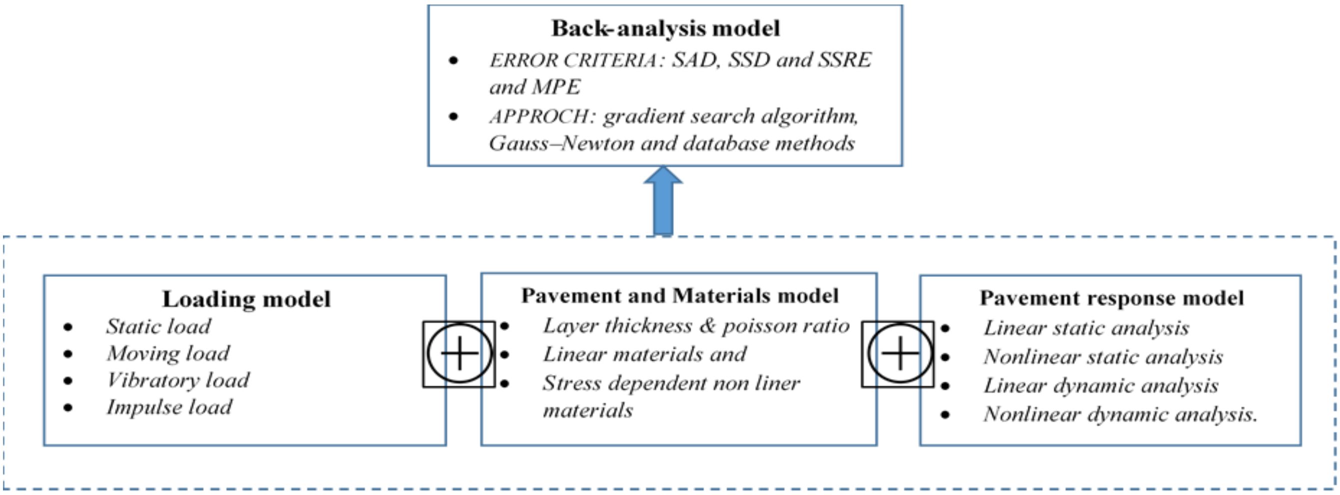

Figure 3 components of back calculation