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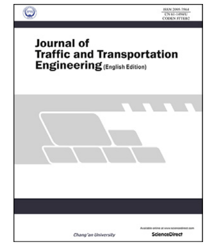

Original Research Paper

Comparative studies of lightweight deflectometer and Benkelman beam deflectometer in low volume roads

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ARTICLE INFO

Article history:
Available online 25 September 2016

Keywords:
Low volume road
Lightweight deflectometer
Backcalculated subgrade moduli
Composite moduli of subgrade
Static moduli of subgrade

ABSTRACT

A comparative subgrade moduli study is carried out by static and dynamic deflection methods using lightweight deflectometer and conventional Benkelman beam deflectometer on low volume road. Field and laboratory tests are performed at 40 test locations on in-service road of 2 km stretch that contains three common types of cohesive soils (CH, CI, and CL). Pavement static and dynamic responses are estimated to ascertain static, backcalculated, and composite moduli of subgrade. The backcalculated and composite moduli of subgrade is validated at given moisture content using repeated triaxial test. Static moduli values are on lower side as compared with dynamic moduli values whereas the composite, and laboratory moduli of subgrade are approximately consistent with 2% to 7% variation, respectively. Correlation analyses between static and dynamic moduli of different types of subgrade soils depict good correlation of determination (R^2) varies between 0.75 and 0.91. Subsequently, validation of static moduli with California bearing ratio (CBR) related subgrade moduli shows moderate correlation of 0.67 to 0.74 whereas dynamic moduli shows good correlation of 0.74 to 0.93 for different types of soils, respectively. Therefore, the comparative analysis shows that lightweight deflectometer provides reliable subgrade moduli values, and it can be used as a quick subgrade strength evaluating tool for low volume roads.

1. Introduction

The current method of structural evaluation system largely depends upon static deflection techniques for Indian low volume roads (Reddy and Veeraragavan, 1997). Recently, government of India estimated that, approximately for low volume roads (LVRs), the 5-year routine maintenance cost was in the range of 6%–13% of construction cost during the base year 2013 (Barodiya and Pateriya, 2014). The non-destructive testing techniques are recommended in road construction and evaluation practices for Indian highways to

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2016.09.005

Table 1 – Summary of expressions for deformation modulus.

Name of the device	Expression for deformation modulus	Parameter
Static beam (press)	$E_v = 1.5r(\Delta\sigma/\Delta_s)$	E_v is the deformation modulus, E_{vd} is the dynamic deformation modulus, E_0 is the surface modulus in centre of loading plate, r is the radius of a loading plate, $\Delta\sigma$ is the change in stress under the beam in the centre, Δ_s is the change of soil deformation in the centre of the beam, k is the load transfer coefficient measured by deflection indicator and wheel ($k = 0.85$), P is the pressure of vehicle wheel on pavement, D is the reduced wheel path diameter, μ is Poisson's ratio ($\mu = 0.3$), I_p is the reduced pavement deflection, δ is dynamic load to 0.1 MN/m^2, s is the soil deformation under loading plate, l is the deflection, f is the stress distribution ratio (2-even segmented loading plate; π/2-rigid plate; 8/3-granular soils rigid plate; 4/3-cohesive soils rigid plate), σ_0 is the contact pressure under the loading plate.
Static Benkelman beam deflectometer (BBD)	$E_v = [kPD(1-\mu^2)]/I_p$	
Light dynamic devices (Zorn ZSG 02), LWD (Prima 100)	$E_{vd} = 1.5r(\delta/s)$	
Falling weight deflectometer (FWD)	$E_0 = [f(1-\mu^2)\sigma_0 l]/r$	

implement the mechanistic-empirical based analysis and design (IRC, 2012, 2014). However, for low volume roads various researchers suggested the estimation of deformation modulus with a constitutive equation and finite element programs (AASHTO, 1993; Fleming, 2000; Rajagopal and Justo, 1989; Zhou et al., 2010). But its applicability in India is very limited.

According to AASHTO guidelines, pavement evaluation measurements and analysis had a significant impact using static and dynamic devices in the context of mechanistic-empirical approaches (Bertuliene and Laurinavicius, 2008). In these mechanistic-empirical approaches, the structural integrity of pavement layers was primarily governed by the principle parameter widely termed as the resilient modulus (Senseney and Mooney, 2010; Solanki et al., 2011). The resilient behaviour of pavement layer materials was being assessed globally and in Indian National Highways using non-destructive field investigation tools such as falling weight deflectometer (FWD) and lightweight deflectometer (LWD) (Fleming et al., 2007).

Recently, LWD, a dynamic stiffness device, gained popularity as portable and cost effective tool for the determination of in-situ responses like deflections and surface modulus on thin bound, and unbound layers (Grasmick et al., 2014). These in-situ responses were being analyzed by a predominant technique known as backcalculation to estimate resilient layer moduli (ASTM, 2007; Senseney et al., 2010). Also, these in-situ responses were being used to estimate the residual life of in-service pavement and also defining various maintenance strategies such as overlays etc. (Zhou et al., 2010). LWD devices can also be used as quality control/quality assurance and structural evaluation tool by assessing in-situ compacted stiffness. However, use of portable dynamic deflectometers for structural evaluation of low volume roads is very limited in India (Senseney and Mooney, 2010; Tehrani and Meehan, 2010).

Although, structural evaluation using Benkelman beam deflectometer (BBD) for low volume roads is current regular practice in India. Significant limitations and various comparative studies are discussed by researchers focusing on identifying the limitations of static devices, such as: (1) stress condition evaluation in pavement layers from measured rebound deflection data is questionable; (2) variations in profile and magnitude of rebound deflection bowls from point to point (Rajagopal and Justo, 1989); (3) difficulty in extrapolating the deflections at transient loadings generating due to higher speeds of vehicles; (4) lack of stable zero reference led to erroneous values that resulted in underestimation of pavement deflections and unrealistic assessment of structural integrity (Meier and Rix, 1995); (5) slow performance, data uncertainty, and low reliability of results (Murillo Feo and Urrego, 2013).

A comprehensive comparative study was conducted by Bertuliene and Laurinavicius (2008) between static beam (Strassen test), light dynamic device (Zorn ZSG 02), LWD (Prima 100), and FWD (Dynatest 8000) by measuring resilient moduli named as deformation modulus of road subgrade and frost blanket course using the following expressions as shown in Table 1. Table 1 provides various expressions used to estimate deformation modulus based on the deflections measured by using different static and dynamic devices. The description of each variable used in the expressions is also summarized in Table 1. Bertuliene and Laurinavicius (2008) stated that for subgrade layer the mean deformation modulus estimated by light dynamic device (Zorn ZSG 02), LWD (Prima 100) were 14% – 17% lower than static beam values, and FWD (Dynatest 8000) values were 70% higher than the static beam values. Whereas, on frost blanket layer light dynamic device (Zorn ZSG 02), LWD (Prima 100) were 33% – 43% lower than the static beam values, and FWD (Dynatest 8000) values were 40% higher than the static beam values due to its differences in measuring methods and calculation methodologies.

Davies (1997) and Livneh et al. (1997) developed correlation between loadman portable falling weight deflectometer (PFWD) and BBD deflections on surface layers yielding poor correlations.

Zhou et al. (2010) carried out a comparative study of falling weight deflectometer (FWD) and Benkelman beam deflectometer (BBD) by developing correlation between BBD and FWD deflections for the junction of A30 and A12 in Shanghai as shown in Eq. (1).

$$\text{FWD} = 4.39\,\text{BB} - 15.8 \tag{1}$$