# Lightweight Deflectometer for Compaction Quality Control

**Chennarapu Hariprasad, Balunaini Umashankar and Thejesh Kumar Garala**

**Abstract** Quality assessment and control (QA/QC) of compacted pavement layers involve regular monitoring of density and moisture content during compaction. In situ density is traditionally determined using sand-cone test method. However, many recent studies have indicated that stiffness- or strength-based quality measurements are easy to determine and more reliable than the density-based quality measurements. In this study, lightweight deflectometer (LWD) is used as a quality control device to assess the quality of compacted pavement layers. As a part of this study, an extensive LWD field testing program is undertaken on the expressway along the Outer Ring Road (ORR) located in Hyderabad, India, to determine the modulus of deformation ($E_{\mathrm{LWD}}$) of base and surface pavement layers. $E_{\mathrm{LWD}}$ of compacted base and surface layers was found to commonly range from 37.6 to 58.6 and 89.3 to 125.7 MPa, respectively. In addition, a case study on a low-volume road is presented to demonstrate the relationship between the $E_{\mathrm{LWD}}$ and in situ density obtained from the sand-cone test. LWD is found to be simple to operate and provides quick test results on any pavement layer. Hence, the frequency of quality control tests can be increased leading to an improvement in the overall quality of compacted pavement layers.

**Keywords** Pavements · Quality control · Stiffness · LWD · Modulus of deformation

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# 1 Introduction

Conventionally, in situ density and moisture content tests are performed to assess the quality of compacted pavement layers. Maximum dry density (MDD) and optimum moisture content (OMC) of the pavement materials are determined from laboratory tests such as standard or modified Proctor compaction tests depending on the intensity of loading on to the pavement layers. In the field, the pavement layers are compacted to meet in situ density of greater than or equal to 98% of MDD with the moisture content around ±1% of OMC. However, McCook and Shanklin (2000) concluded that the sand-cone test results are least consistent compared to rubber balloon, drive-cylinder, and nuclear gauge measurements by performing numerous tests on several embankment construction sites in USA. Even though several researchers (Rahman et al. 2008; Berney and Kyzar 2012; Meehan et al. 2012) appreciated the role of nuclear gauge as a pavement quality control device for its ease to operate, frequent readings, and the reliability of the test results, this device failed to gain wide acceptance owing to safety concerns due to radioactive emissions during testing. Quality control or assessment (QC/QA) procedures of compacted pavement layers have moved from density-based to stiffness-/strength-based criteria because of the shift from empirical to mechanistic-empirical methods in pavement design over the last decade (Uz et al. 2015). Several innovative techniques, such as Clegg hammer test, soil stiffness gauge, dynamic cone penetrometer, and lightweight falling deflectometer, have been developed and used to measure the strength/stiffness of compacted layers. Among various methods available, Fleming et al. (2007), Rahman et al. (2008), Vennapusa and White (2009), and Gosk (2016) investigated LWD as a quality control device by performing numerous laboratory and field experiments. In this study, field LWD testing has been performed on four test pads covering 64 test locations to assess the quality of compacted pavement layers. LWD device supplied by Zorn Instruments of Germany has been used in this study. Correlation between in situ density and modulus of deformation ($E_{\mathrm{LWD}}$) of pavement layer of a low-volume road is also proposed.

# 2 LWD Test Device

Lightweight deflectometer (LWD) is a portable device used to measure the in situ modulus of deformation of the pavement layers (Fig. 1). It consists of a hammer of 10 kg falling mass with a height of fall equal to 72 cm, and it is dropped on 30-cm-diameter bearing plate consisting of inbuilt accelerometer sensor (Zorn 2011).

Equation (1) based on theory of elasticity is used to calculate the deformation modulus of the compacted material.

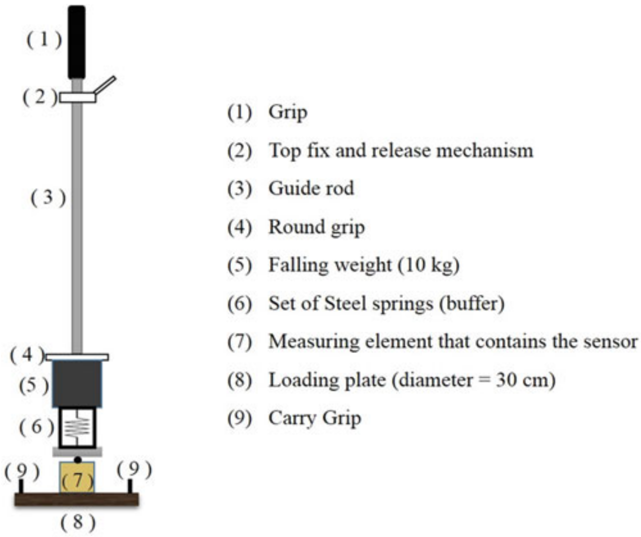


**Fig. 1** Schematic of lightweight deflectometer

$$E_{\mathrm{LWD}} = \frac{qr(1-\upsilon^2)}{w} f_{\mathrm{R}} \tag{1}$$

where $E_{\mathrm{LWD}}$ is the modulus of deformation of pavement layer; $f_{\mathrm{R}}$ is the plate rigidity factor (taken as $\pi/2$ for a rigid plate); $q$ is the maximum contact pressure; $r$ is the radius of the bearing plate; $\upsilon$ is the Poisson's ratio of the soil; and $w$ is the settlement of the bearing plate measured at the center. However, in this study, the inbuilt data processor directly shows the average central deformation and the average modulus of deformation of pavement layer considering three blows of impulse load.

## 3 Materials

The main objective of the study is to evaluate the quality of compacted base and surface layers using LWD. Base layer consists of graded aggregates and granular material mixed with water, known as wet mix macadam (WMM), and it is laid on a sub-base layer. The MDD and OMC of WMM material were found to be equal to 2.23 g/cc and 4.5%. Further, WMM layer was compacted in two lifts of thickness equal to 125 mm each following MORTH (2001) regulations. The final layer of the pavement is the asphalt surface layer which is constructed using dense-graded bituminous macadam (DBM), and it is laid on a prepared base layer and compacted in 50–100-mm-thick lifts (MORTH 2001).

# 4 Site Description and Test Pad Construction

LWD tests were performed on four test pads constructed on Outer Ring Road (ORR), Hyderabad, which is an 8-lane ring road expressway of 158 km length. The test pads site is located at Ghatkesar, Hyderabad, along National Highway 202. In order to place and spread the base layer (WMM), a bulldozer was used to spread the material in uniform thickness along the roadway, and the layer is compacted using a smooth drum-vibratory roller (Make: HAMM, model: BW 212-2) to the maximum dry density at optimum moisture content. Dense bituminous layer was laid on a base layer as a surface layer by using a spreader and allowed to dry after compaction. LWD tests were conducted on compacted base and surface layers at selected points. Test points were chosen in a rectangular grid pattern along length and width of test pads with the spacing between the points in the range of 10–30 m, and the variation in modulus of deformation values was assessed from LWD test measurements at these points. Test locations on test pads 1 and 2 correspond to LWD testing on base layer, whereas test locations on test pads 3 and 4 correspond to LWD testing on surface layer. Figure 2 shows the typical layout of test locations on test pad 3, and test locations on other test pads also resemble the similar pattern.

# 5 Results and Discussion

## 5.1 Base Layer

The modulus of deformation of base layer was found to commonly range from about 37.6 to 58.6 MPa (Table 1). The modulus of deformation values was found to vary along the length and width, possibly due to variation in the compaction energy imparted due to compactor passes.

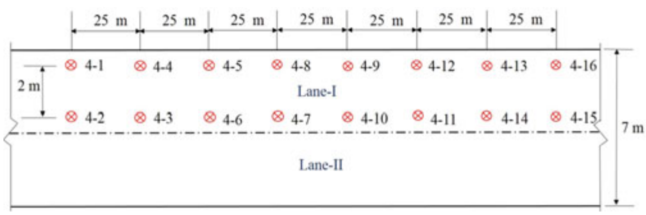


**Fig. 2** Schematic view of test locations on test pad 3

**Table 1** Summary of test results on base layer

| Test point | $E_{LWD}$ (MPa) | Test point | $E_{LWD}$ (MPa) |
|---|---|---|---|
| 1-1 | 45.60 | 2-4 | 53.44 |
| 1-2 | 48.60 | 2-5 | 43.10 |
| 1-3 | 52.60 | 2-6 | 53.44 |
| 1-4 | 52.20 | 2-7 | 40.69 |
| 1-5 | 49.00 | 2-8 | 44.21 |
| 1-6 | 49.70 | 2-9 | 43.69 |
| 1-7 | 37.60 | 2-10 | 44.38 |
| 1-8 | 44.20 | 2-11 | 42.53 |
| 1-9 | 48.30 | 2-12 | 40.83 |
| 1-10 | 39.70 | 2-13 | 39.82 |
| 1-11 | 58.60 | 2-14 | 46.68 |
| 1-12 | 50.80 | 2-15 | 48.39 |
| 2-1 | 47.17 | 2-16 | 45.09 |
| 2-2 | 50.11 | 2-17 | 44.47 |
| 2-3 | 47.17 | 2-18 | 45.09 |

## 5.2 Surface Layer

The LWD deformation modulus of the surface layer (DBM) was found to range from 89.3 to 125.7 MPa (Table 2).

**Table 2** Summary of test results on surface layer

| Test point | $E_{LWD}$ (MPa) | Test point | $E_{LWD}$ (MPa) |
|---|---|---|---|
| 3-1 | 104.17 | 4-2 | 110.84 |
| 3-2 | 109.76 | 4-3 | 111.39 |
| 3-3 | 99.12 | 4-4 | 100.90 |
| 3-4 | 97.40 | 4-5 | 125.70 |
| 3-5 | 89.29 | 4-6 | 103.69 |
| 3-6 | 97.40 | 4-7 | 104.17 |
| 3-7 | 94.94 | 4-8 | 109.22 |
| 3-8 | 117.19 | 4-9 | 117.19 |
| 3-9 | 108.70 | 4-10 | 116.58 |
| 3-10 | 107.14 | 4-11 | 111.39 |
| 3-11 | 104.17 | 4-12 | 109.22 |
| 3-12 | 119.05 | 4-13 | 122.95 |
| 3-13 | 119.05 | 4-14 | 125.70 |
| 3-14 | 104.65 | 4-15 | 125.00 |
| 3-15 | 110.84 | 4-16 | 109.22 |
| 3-16 | 103.69 | 4-17 | 105.60 |
| 4-1 | 105.63 | 4-18 | 117.80 |

The modulus of deformation values for base and surface layers determined in this study are in good agreement with the published literature. It is obvious that the difference in weight of hammer or height of fall will result in different $E_{LWD}$ values for the same test location. The influence of bottom pavement layers on measured $E_{LWD}$ values was also investigated using finite element analysis and published elsewhere (Umashankar et al. 2015).

## 6 Low-Volume Road: Case Study

In order to illustrate the significance and usage of LWD as a quality control device, a low-volume road is selected. Native materials having sufficient strength to support loads from vehicles are the key materials in the construction of low-volume roads. As per MORTH statistics, low-volume roads occupy more than 80% of the total road network in India.

Low-volume road site was located in Shankarpalli, Ranga Reddy, Telangana, a rural village near to Ordnance Factory Estate, Telangana. LWD device was used to perform the base layer compaction quality control tests. Base layer was constructed by using the WMM material. Prior to QC testing, a test pad of base layer was constructed, and both sand-cone and LWD tests were performed at two locations separated by a distance of 10 m. Tests were performed corresponding to various compaction energy levels as shown in Table 3. It is evident from Table 3 that $E_{LWD}$ increases with the increase in the compacted density of the pavement layer. Figure 3 is the calibration chart showing the variation of deformation modulus with the relative compaction. In this case, $E_{LWD}$ corresponding to relative compaction of 98% was found to be 32.5 MPa, and this value was used to perform QC check of the compacted base layer.

Thus, similar correlations between in situ density from traditional sand-cone test and $E_{LWD}$ from LWD can be developed for any compacted embankments or pavement layers in order to have more frequent quality control tests based on LWD testing. The target value of modulus of deformation ($E_{LWD}$) can be obtained corresponding to target relative compaction (e.g., relative compaction of 98%), and this deformation modulus value can then be used to perform QC check of pavement

**Table 3** LWD testing on low-volume road

| Description | Field density (g/cc) | Relative compaction (%) | $E_{LWD}$ (MPa) |
|---|---|---|---|
| Without passes | 2.10 | 93.3 | 28.0 |
| One plain pass | 2.15 | 95.6 | 30.5 |
| Two plain passes | 2.20 | 97.8 | 32.0 |
| Two low vibratory passes | 2.25 | 100.0 | 34.5 |
| Two high vibratory passes | 2.28 | 101.3 | 35.0 |

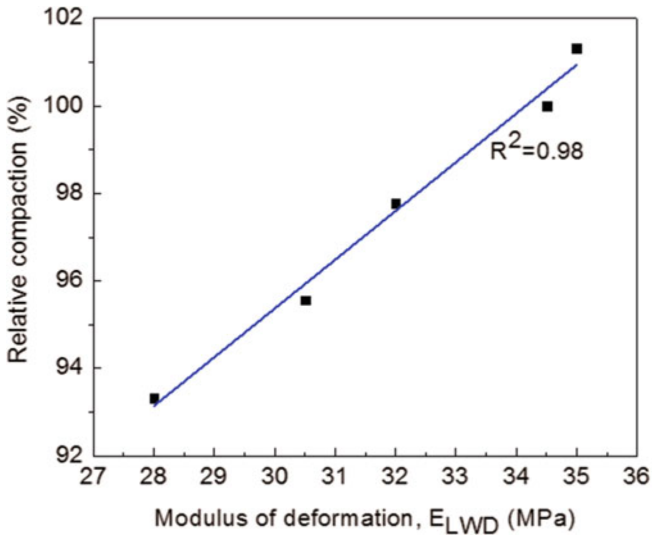


**Fig. 3** Relative compaction versus LWD modulus of base layer of a low-volume road

layers using the lightweight deflectometer. The site engineers or field personnel must give proper importance to the parameters like type of LWD device, size of loading plate, height of fall of hammer, type and location of deflection transducer, contact stress beneath plate, plate rigidity and importantly maintain the moisture contents of the test pads close to the targeted levels during construction as the moisture content has significant effect on the measured modulus from LWD testing (Fleming et al. 2007; Vennapusa and White 2009).

## 7 Conclusions

LWD testing is adopted to assess the quality control of pavement layers. Testing is performed on two surface layers and two base layers. From the study, LWD device is found to be as a simple device to operate and provide quick test results, and hence, the frequency of QC tests can be increased leading to an improvement in the overall quality and performance of compacted pavement layers.

The modulus of deformation of compacted base and surface layers found to be in the range of 37.6–58.6 and 89.3–125.7 MPa, respectively, corresponding to a relative compaction of 98%. A case study on low-volume road showed a good correlation between the modulus of deformation and the compacted density obtained from sand-cone tests with a regression coefficient of 0.98. Similar calibration charts can be developed to perform compaction quality control of pavement layers and embankments based on LWD and sand-cone measurements on test pads. LWD is found to be a reliable device to perform compaction quality control of fill or pavement materials.

## References


Berney, E. S., & Kyzar, J. D. (2012). Evaluation of non-nuclear soil moisture and density devices for field quality control. *Transportation Research Record 2310* (pp. 18–26). Washington, D.C.: Transportation Research Board.

Fleming, P. R., Frost, M. W., & Lambert, J. P. (2007). Review of lightweight deflectometer for routine in situ assessment of pavement material stiffness. *Transportation Research Record 2004* (pp. 80–87). Washington, D.C.: Transportation Research Board.

Gosk, W. (2016). Stiffness estimation of the soil built-in road embankment on the basis of light falling weight deflectometer test. In *The 3rd International Conference on Transportation Geotechnics (ICTG 2016)* (Vol. 143, pp. 395–402). Procedia Engineering, Elsevier.

McCook, D. K., & Shanklin, D. W. (2000). NRCS experience with field density test methods including the sand-cone, nuclear gauge, rubber balloon, drive-cylinder, and clod test. In D. W. Shanklin, K. R. Rademacher, & J. R. Talbot (Eds.), *Constructing and controlling compaction of earth fills* (pp. 72–92). West Conshohocken, PA: ASTM.

Meehan, C. L., Tehrani, F. S., & Vahedifard, F. (2012). A comparison of density-based and modulus based in situ test measurements for compaction control. *Geotechnical Testing Journal, 35*(3), 387–399.

MORTH (Ministry of Road, Transport and Highways). (2001). *Specifications for road and bridge works* (4th ed.). India: Indian Road Congress.

Rahman, F., Hossain, M., Hunt, M. M., & Romanoschi, S. A. (2008). Soil stiffness evaluation for compaction control of cohesionless embankments. *Geotechnical Testing Journal, 31*(5), 1–13.

Umashankar, B., Hariprasad, C., & Kumar, G. (2015). Compaction quality control of pavement layers using LWD. *Journal of Materials in Civil Engineering ASCE, 28*(2), 1–9.

Uz, V. E., Saltan, M., & Gökalp, I. (2015). Comparison of DCP, CBR, and RLT test results for granular pavement materials and subgrade with structural perspective. In *International Symposium on Non-Destructive Testing in Civil Engineering* (NDT-CE), Berlin, Germany.

Vennapusa, P. K. R., & White, D. J. (2009). Comparison of light weight deflectometer measurements for pavement foundation materials. *Geotechnical Testing Journal, 32*(3), 239–251.

Zorn Instruments. (2011). User manual for the light weight deflectometer (LWD). *ZFG 3.0*, Hansestadt Stendal, Germany.