Measuring Bearing Capacity of Forest Roads with the Advanced Benkelman Beam Apparatus

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Abstract:
Bearing capacity measurements of roads traditionally were carried out using the Benkelman beam. The Benkelman beam measurements provide the maximum vertical deflection of the pavement under 50 kN of wheel load. Nowadays the bearing capacity of public roads is measured with falling weight deflectometers. Falling weight deflectometer measurements provide the full deflection basin. It is convenient to use these high precision instruments on forest roads, but their application is inefficient and costly. Researchers of the Institute of Geomatics and Civil Engineering at the University of West Hungary developed a new instrument to measure the full deflection basin with the Benkelman beam. A new method for the analysis of the deflection basin is also developed.

Keywords: forest road, bearing capacity, Benkelman beam, deflection basin

1 Introduction

Forest roads covered with asphalt pavement represent the basis of the forest opening up networks in Hungary. Properly maintained asphalt pavements offer a high level of service. While traffic load of forest road networks have grown, expenses on their maintenance remained lower than required in the last three decades. As a result, these roads are in poor condition, generally. Renovation projects demand the knowledge of the roads' bearing capacity.

The term "bearing capacity", although widely used at pavement management projects, is hard to define. In fact, direct measurement of bearing capacity is impossible. Instead, one can measure the deflection caused by a known load, and calculate bearing capacity afterwards. In case of a road pavement, "bearing capacity" can be interpreted via appropriate stiffness parameters.

2 Material and methods

2.1 Available pavement deflection measurement methods

Remaining lifetime of asphalt-covered pavements was calculated with the AASHO-method up to now. For the calculation of the remaining traffic of the pavement, engineers had to measure the maximal vertical deflection of the pavement under 50 kN of static wheel load. This measurement was carried out by the Benkelman beam. (Boromissza 1959), (Kosztka et al. 2008).

Nowadays highway pavement engineers use falling weight deflectometers (FWD) for the measurement of the deflection basin. FWD instruments measure vertical deflection of the pavement at multiple points with geophones. The weight is dropped onto a segmented plate, causing a 50 kN equivalent dynamic load. It is convenient to use these high precision instruments on forest roads, but their application is inefficient and costly (Kosztka et al. 2008).

In Table 1 the Benkelman beam and the FWD instruments are compared.

Table 1: Properties of the Benkelman beam and FWD instruments

Properties	Benkelman beam	FWD
Instruments needed	Loaded truck 2 pieces of Benkelman beam	Falling weight deflectometer
Staff	4 persons	2 persons
Load	Static	Dynamic
Simulated vehicle speed	0 km/h	60-80 km/h
Typical measurement frequency	25 m, both wheelpaths simultaneously	25 m, in one wheelpath
Efficiency	15 km/day	15 km/day
Measured parameter	Maximal vertical deflection (1 point)	Deflection basin (6 to 12 points)
Data collection	Manual	Automated
Repeatability	Convenient	Excellent
Instrument costs	Low	High

2.2 The Advanced Benkelman Beam Apparatus

Researchers of the Institute of Geomatics and Civil Engineering developed a new method to measure the full deflection basin. The development was based on the Benkelman beam, extending its properties with automated data logging and the ability to measure multiple points of the deflection basin.

The develompent process included:

⇒ Design of the measurement process.

⇒ Selecting the additional instruments.

⇒ Designing and building the central data logging unit.

⇒ Firmware development of the central data logging unit.

⇒ Software development for data logging and processing.

The new measurement method consists of three main pillars:

⇒ Analog distance gauges of the Benkelman beams are replaced with digital ones.

⇒ Horizontal position of the truck is continuously measured with ultrasonic distance sensor.

⇒ Data of the sensors are collected by the central data logging unit.

Main steps of the measurement are as follows (see Figure 1):

⇒ Truck with known rear axle load (around 100 kN) is positioned at the place of measurement.

⇒ The Benkelman beams equipped with digital distance gauges are placed into measuring position.

⇒ The ultrasonic distance measuring sensor is placed into measuring position.

⇒ Central data logging unit is connected to the sensors.

⇒ PC (netbook with touchscreen) running custom data collecting software is connected to the central data logging unit.

⇒ As the truck moves forward slowly, data of the sensors are collected continuously.

⇒ As the measured horizontal distance exceeds 5 m, data logging stops.

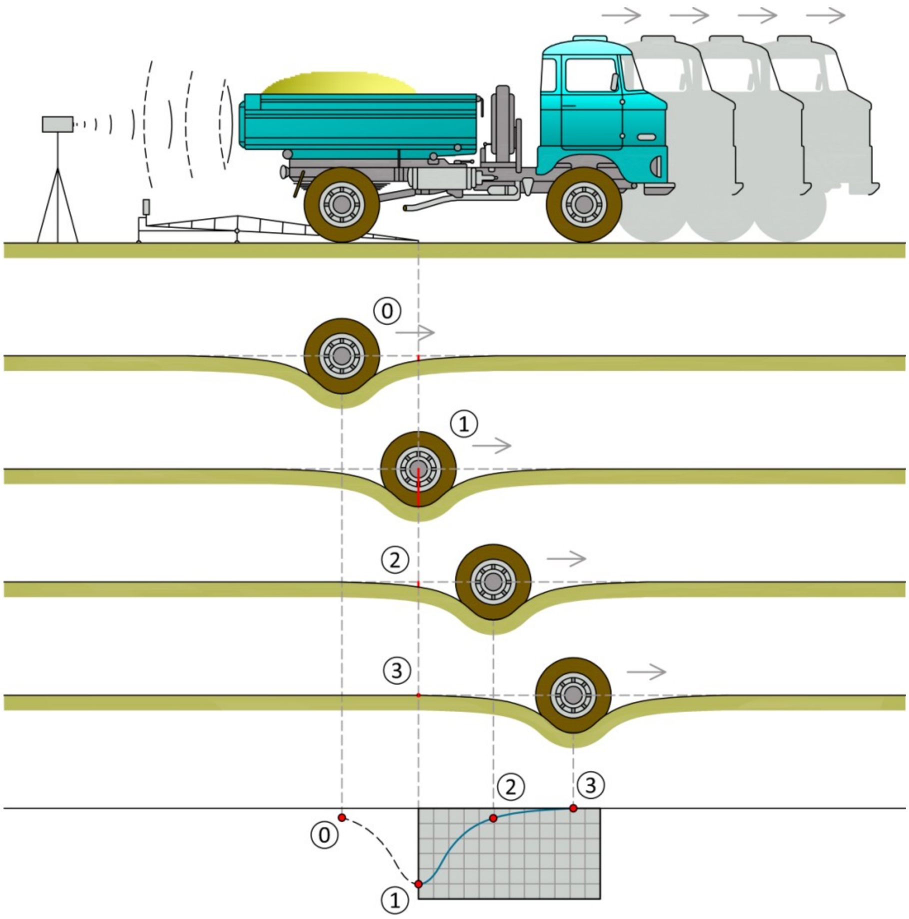

Figure 1: Measurement process of the Advanced Benkelman Beam Apparatus

The Advanced Benkelman Beam Apparatus continuously measures the vertical displacement of one point on the surface of the pavement, together with the horizontal position of the truck. After processing the raw measurement data, X and Y coordinates of the deflection basin can be calculated. Frequency of data logging is set to 10 measurements/second, therefore one deflection basin consists of 20 to 50 points.

Figure 2: The central data logging unit with the sonar sensor and one Benkelman beam with digital gauge

Figure 3: The Advanced Benkelman Beam Apparatus in action

2.3 The shape of the deflection basin

The deflection basin is approximated with the next equation:

$$d(x) = \frac{d_0}{c \cdot \left(\frac{x}{D}\right)^2 + 1} \qquad (1)$$

where:

- $d(x)$ = Vertical deflection at distance x from the center of the load, (mm).
- d_0 = Maximal vertical deflection at the center of the load (x=0), (mm).
- D = Diameter of the loaded equivalent plate, (300 mm).
- c = Shape coefficient of the deflection basin.
- x = Distance from the center of the load (mm).

Equation (1) has several advantages:

⇒ The function can describe different deflection basin shapes with great flexibility.

⇒ The function has two independent parameters, d_0 and c, where d_0 is measured and c can be numerically determined with least squares method.

⇒ The function is able to be derived continuously, multiple times.

Detailed description of the suggested function can be found in paper (Primusz and Tóth 2009).

2.4 Pavement stiffness factors

Based on equation (1), the minimal radius of curvature of the deflection basin can be calculated as (Primusz and Tóth 2009):

$$R_0 = \frac{2 \cdot r^2}{c \cdot d_0} \qquad (2)$$

where:

R_0 = Minimal radius of curvature, (mm).
d_0 = Maximal vertical deflection at the center of load, (mm).
r = Radius of the loaded equivalent plate, (150 mm).
c = Shape coefficient of the deflection basin.

Once the minimal radius of curvature calculated, the relative stretch of the underside of the asphalt layer can be determined as well:

$$\varepsilon = \frac{H}{2 \cdot R_0} \qquad (3)$$

where:

ε = Relative stretch of the underside of the asphalt layer, (mm/mm).
R_0 = Minimal radius of curvature, (mm).
H= Thickness of the asphalt layer(s), (mm).

The relative stretch can be expressed in µstrain (µm/m) as well, by multiplying the result dimensioned in (mm/mm) with 10^6.

The distance of the inflexion point of function (1) from the center of load can be calculated as follows:

$$L = \frac{2 \cdot r}{\sqrt{3 \cdot c}} \qquad (4)$$

where:

L = Distance of the inflexion point from the center of load, (mm).
r = Radius of the loaded equivalent plate, (150 mm).
c= Shape coefficient of the deflection basin.

The above presented distance (*L*) is called the “radius of stiffness”. Once this radius calculated, the Young moduli of the pavement layers can be determined (Primusz and Markó 2010).

3 Results

The first application of the Advanced Benkelman Beam Apparatus took place on a forest road of the “Kisalföld” Forest Company. The length of the inspected road is 3.9 kilometers. Distance between the measurements was set to 50 meters. Measurements were made in both weelpath simultaneously. Both the new method and the developed instrument approved its applicability. The next parameters were determined after the field measurements:

⇒ Central vertical deflection (d_0, mm).

⇒ Shape coefficient of deflection basin (*c*).

⇒ Minimal radius of curvature (R_0, m).

⇒ Relative stretch of the underside of the asphalt layer (ε, μstrain),

⇒ Young modulus of the asphalt layer (E_a, MPa).

⇒ Young modulus of the granular subgrade (E_s, MPa).

Table 2: Results of the measurements

Section values of the limits of homogeneous sessions (hm)	Central vertical deflection d_0 (mm)	Minimal radius of curvature R_0 (m)	Relative stretch of the underside of asphalt layer ε (μstrain)	Young moduli Asphalt layer E_a (MPa)	 Granular subgrade E_s (MPa)
0+00					
	1,25	98	306	3620	84
2+25					
	1,85	61	492	2390	64
11+25					
	1,29	99	303	3660	99
21+75					
	1,26	64	469	1990	94
28+25					
	0,89	107	280	3490	106
31+75					
	1,1	72	417	2560	116
39+00					

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