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Original Research

Parameters for Evaluating Bearing Capacity of Subgrade and Base Forest Road Layers

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Abstract

Forest roads, such as special-purpose roads, are designed under substantially limited conditions (financial, time) and with significantly different requirements in comparison with common road pavements. The design parameters (class of traffic volume/heavy vehicles, level of damage, life span, transport mode) are different, and the survey and design/project process are limited. In addition, forest roads are evaluated from the environmental viewpoint in terms of maintaining environmental quality.

Optimization of the road pavement design and implementation process is based on the selection of economical road arrangement, materials, and the use of mechanisms and work procedures with the aim to make as slight an impact as possible on the forest ecosystem. The selection of an alternative parameter for the evaluation of the bearing capacity of subgrade and base courses and the selection of suitable materials is based on the evaluation of laboratory and *in situ* tests and their correlation relationships in connection to road pavement materials (soil, layers).

The evaluation of a large set of simultaneous measurements by a static loading test and a light dynamic plate, and the determination of their correlation allowed us to use the deformation modulus of the test by the light dynamic plate Edyn, Evd, Mv, and as the main parameter for the evaluation of forest road pavement layers. When constructing forest road pavements, environmentally, socially, and economically suitable procedures for the survey, design, construction, and construction monitoring can be used.

Keywords: forest roads, testing methods, bearing capacity, ecology

Introduction

Conditions

Forest ecosystems are irreplaceable parts of the Czech and European countryside. Forests cover 34% of the Czech Republic and 40% of the whole European Union. Forest ecosystems have a number of functions that affect the whole countryside and society. Some of the synergic and equivalent functions include organic-productive function, ecological and stabilization function, edaphic and soil protection function, hydrologic and water management function, health and hygienic function, and health and social function. Forest ecosystems are exposed to significant socio-economic pressure by many interest groups. This pressure should be reflected in forestry, but also in other activities in forest ecosystems such as building, reconstruction, and repairs of forest road network. Out of many requirements for building the forest road network, ecological, environmental, and economic criteria need to be particularly respected. Therefore, building of the forest road network should focus on affecting the forest environment as little as possible (road

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arrangement, forest road horizontal alignment), on using economically available, environmentally friendly, and harmless secondary raw materials while preferring the materials from local sources. Suitable technologies should be used for all phases of the forest road construction process.

Regulations, Requirements, Procedures

Requirements for road pavement materials and requirements for testing procedures related to road construction in general are particularly included in national, international, and European standards. Low capacity road pavements (low class roads, with lower traffic volume and lower designed damage level) – his article concerns forest road pavements – are often classified as the lowest road class according to the technical specification in the Czech Republic [1]. Further specific properties of these roads, higher loading, lower frequency (seasonal) of transit, required/permitted level of damage and life span, variety of road surfaces (pavements), and their multi-purpose nature, but particularly the possibilities (financial included) to run the whole building process and its subsequent operation (not concerning the transport resort), prevent it from using the above-mentioned procedures. In addition, they are exceedingly (financially and personally) demanding and complicated for the needs of forestry engineering.

In the Czech Republic, there is a regulation for the issue of forest roads [2] that follows for the transport technical specification [1] and the related standards and regulations; however, due to the above-mentioned reasons the standards and regulations are not fully used.

In Germany, roads are dealt with by directives [3], applicable also to forest roads. In Poland there is an extensive and detailed regulation [4]. The instructions for the reconstruction of low-capacity roads, design models, methods, and techniques for monitoring road conditions for the region of northern countries are dealt with by project ROADEX [5]. Design methods for low-capacity roads are dealt with in detail by a study of The University of Nottingham [6], which evaluates road design methods and full-scale test results in Scotland. The bearing capacity of forest roads [7] on soft subgrade [8, 9] is estimated and simulated by FEM [10].

Methods

Bearing Capacity Evaluation

The basis for designing forest roads should be the investigation on the spot with geotechnical survey while using suitable methods to determine particularly the bearing capacity of a subgrade of a future road. This work does not mention all possible survey methods. Regarding the above-mentioned need to simplify, this article mentions generally less demanding methods still suitable for the design of forest roads, which was verified within the current national project [11]. They are methods and test/parameters (*in situ* as well as laboratory ones) that can be used to verify deformation characteristics and to evaluate the degree of compaction of subgrade as well as base structure layers in compliance with the regulations. Research in the above-mentioned project [11] examined a combination of these methods in order to determine their suitability for the optimization of the testing process.

In order to set suitability, the selected methods were tested in a series of forest roads in different localities, on an experimental forest road segment, and in a testing segment in a full scale test in the laboratory hall of CDV. In this case, the following tests/parameters were evaluated and used for the research work and measurements in laboratories:

- dry bulk density $\rho_{d,max}$
- moisture content, optimal w , w_{opt}
- compaction parameter (Proctor Standard, D% PS, or density index ID)
- deformation modulus $E_{def,2}$ ($E_{v,2}$, $E_{v,1}$, $E_{v,2}/E_{v,1}$) from Static Plate Load Test (SPLT)
- deformation modulus from dynamic plate load tests light dynamic plate test E_{dyn}, E_{vd}, $M_{v,d}$ – Light Falling Weight Deflectometer *(LFWD)*
- light dynamic penetration test, q_{dyn} – Lightweight Dynamic Penetrometer *(LDP)*
- heavy dynamic penetration test, q_{dyn} – Heavy Dynamic Penetrometer *(HDP)*
- Soil classification – relationship to the content of fine particle (% *f*).

The issue of correlation of some of the mentioned testing methods is still under theoretical examination and testing *in situ* in different, controlled conditions. [12-16], Static Plate Load Test is recommended as one of the methods for the evaluation of earth work quality in the Czech Republic as well as in many other European countries. The evaluation is based on the deformation modulus, in the Czech Republic it is the minimum required deformation modulus value from the second loading cycle $E_{def,2}$ [1].

In the Czech Republic the procedure of this test, which belongs to the category of indirect control methods of degree of compaction, is specified in the standard [17]. The minimum required values of deformation modulus $E_{def,2}$ of the subgrade are specified according to [1] in relation to the designed damage level and traffic volume category. In neighbouring countries Germany [18], Austria, Switzerland, and Slovakia the requirements are similar; in Poland, the values are specified by the above-mentioned regulation [4].

The light dynamic plate was also developed as an equivalent to the static test plate. The test with the use of the light dynamic plate is specified as one of the impact tests in the Czech standard [19], as an equivalent to German standard [20]. However, it is necessary to know the type of the set, since the differences in results are based on the differences between the testing method principles as well as on the measurement methods (testing device type) [21]. In addition, the use of LFWD test for attestation test in the Czech Republic is currently limited and based on correlation measurements for individual homogeneous measured segments.

Although there are generally certain limits in the use of LFWD – its use for the degree of compaction specification is partially allowed by a German regulation [22] – with the knowledge of the correlation relationship between the static and dynamic load test (and a single used type of a test in the Czech Republic) we consider it suitable and desirable thanks to its advantages concerning its use for lower-class roads.

The research work and *in situ* measurements aimed to determine the undemanding measurement to finding a parameter in practice for the above-mentioned evaluation of subgrade and base layers (bearing capacity, compaction parameters). The work and measurements included the verification of correlation of the mentioned parameters at *in situ* tests on the existing forest roads, forest roads under reconstruction, or new forest roads under construction and in GLTF (full-scale test).

Based on the determination of grading and classification of soil, particularly in relation to the fine particle content, it is possible to divide subgrade into categories by bulk density in relation to bearing capacity of these soils.

Scope of Comparison Tests and Findings from Measurements

A higher number of *in situ* measurements (at approx. 10 localities) was selected in order to verify the correlation relationship of the selected tests. It aimed to identify the correlation of the measured quantities (parameters) and potential differences in different geological and morphological conditions at different terrain configurations and under different road loadings. At the same time, a varied range of subgrade and construction road layers was tested by indoor test conditions; apart from different construction road layers, subgrade modifications were tested in a Geotechnical Laboratory Testing Field and on the testing road section (Figs. 1 and 2). Several monitoring measurements and methods were used. Measurement profiles were equipped with sensors for measuring stress and deformation in selected depths in soil (at overruns).

The weather, soil conditions (soil moisture, soil texture, soil profile), and other further parameters were recorded.

The impact of the static plate test, and sizes of flexible and permanent deformations within the first and second loading cycles were tested and analyzed.

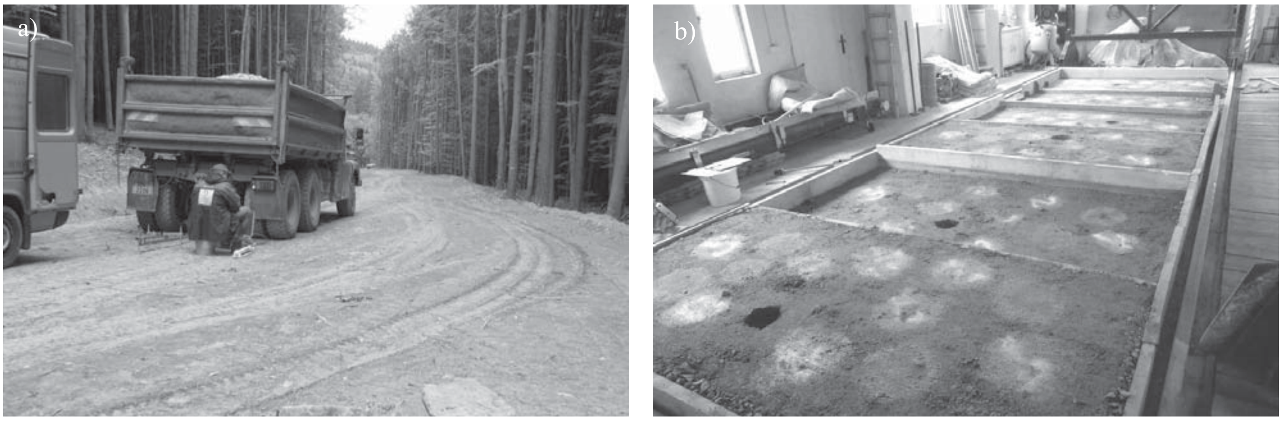

Fig. 1. a) Forest road “ Kultury” – tests in construction b) GLTF – construction layer tests.

Fig. 2. a) Static Plate Load Test *in situ* b) LFWD test in GLTF c) DCP test in forest road.

Table 1. Overview of test results by locality (number of performed tests).

Locality	Measured profiles	SPLT	LFWD	BD	LDP
LGZP	PF 1-6	12(55)	36(138)	9(19)	24(36)
Borovice	PF 1-6	6(14)	16(44)	10(22)	24(72)
Navojna	PF 1-10	10(24)	40(96)	10(22)	40(120)
Nove Mesto n. M.	PF 1-10	30(40)	40(80)	20(30)	40(40)
Rasna	PF 1-10	10(20)	39(76)	10(20)	40(80)
Kultury	PF 1-10	10(40)	30(120)	10(20)	40(120)

The determination of the correlation relationship of the deformation modulus from SPLT and LFWD was crucial; the evaluations of a wide range of concurrent measurements, not only within this project for approx. a decade of research activities [23] or for commercial research, were used. Partial results from author's own research and other research projects concerning the relationships between deformation moduli, are presented by the co-author in [24]. Article [25] mentions a parametric study of an impact of the formation of soils in the subgrade and a comparison of SPLT and LFWD tests. After the evaluation of a set of comparison measurements with the above-mentioned research programme, the potential use of the correlation was summarized in official national guidelines "Methodology for the Use of Light Load Tests – Static Plate Tests and Light Dynamic Tests and their Correlation for Building Roads" [26]. The LFWD test is particularly recommended for its significant advantages: speed and thus higher frequency of measurements (regarding the variety of subgrade soils in the Czech Republic, the number of measurements is very important), simplicity (no counterweight necessary, test is fully automated), and favourable economical costs.

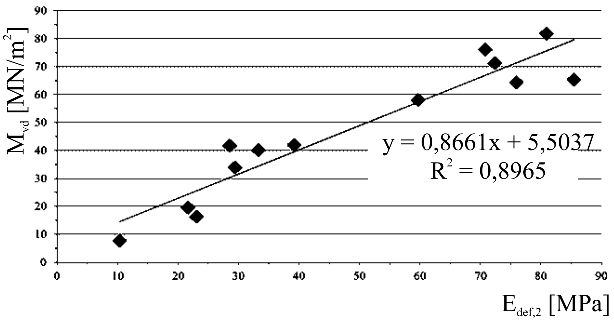

Fig. 3. Test results from GLTF – correlation relationship of test results of SPLT and LFWD.

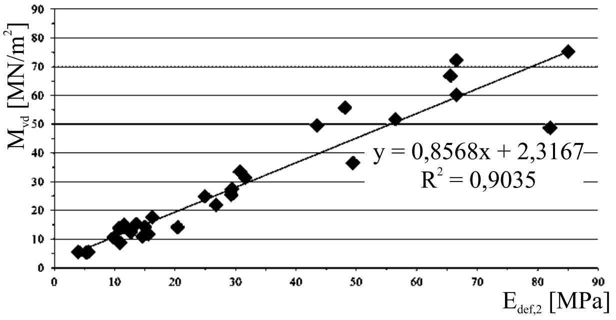

Fig. 4. Test results from FR Kultury – correlation relationship of test results of SPLT and LFWD.

The measurements on select localities provided results that will be summarized below. At the same time, the findings from practice which were collected from surveys, designing, implementation, construction monitoring, maintenance, and operation of forest roads. The conditions (financial, personnel, etc.) of the administration bodies (regional forest administrators in the Czech Republic), which are responsible for these activities, do not generally allow for the use of procedures for road construction [1] for the public road network in its full extent.

The aim is to find possibilities for a simple survey of a locality, for environmentally friendly routes (reduced interventions to landscape), use of available materials, etc., for design and selection of a suitable forest road composition based on the above-mentioned parameters. It is also necessary to take into account other specific features of forest roads, their multifunctionality, loading, and frequency. Therefore, the project [11] results shall include a "Methodology/manual," that summarizes the principles and procedures for forest road construction from the above-mentioned viewpoints. Therefore, forest road layout landforms, as well as traffic density, traffic vehicle type, etc., will be considered.

Apart from the generally known variety of the configuration of the terrain and soils, the experience from measurements show that, from a geotechnical viewpoint, the composition of layers in the forest road profile changes very often under the conditions in the Czech Republic. The above-mentioned also show a necessity to consider the parameters in shorter individual road segments, i.e. to prefer higher frequency of tests.

Results and Discussion

The results of the measurements were evaluated in terms of their usability for surveys, design, construction, and monitoring of forest roads. The correlation between SPLT and LFWD tests, specified in the new regulation [26], was verified on an extensive set of these measurements.

The overview of measurements at localities, including the number of profiles and selected tests, is shown in Table 1.

Furthermore, samples of inputs from the evaluation of the extensive set of measurements (particularly in the form of graphs) are shown for illustration.

The graphs in Figs. 3 and 4 show examples of test results in the form of graphs of SPLT and LFWD tests correlation, including the high value of the "coefficient of determination," which implies a close correlation

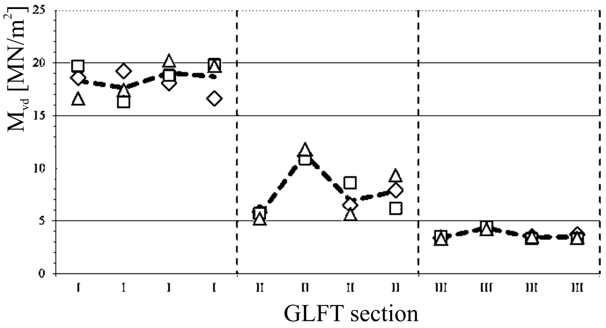

Fig. 5. Test results from GLTF - correlation relationship of test results of moisture content and LFWD, (averages: I: 17.4%; II: 20.9%; III: 21.53%.

relationship of the tested subgrade soils and forest road base courses.

Fig. 5 shows the relationship of the deformation modulus from LFWD test and the moisture in individual fields of LGTF.

Based on the analysis of a set of concurrent measurements, a good informative ability of LDP (see as well [13, 16]) of undemanding testing methods, not only in relation to the identification of base course boundaries (changes in materials/soil) but also in relation to bearing capacity parameters, was found. This finding from the testing allows us to determine the presence of a different bearing capacity (usually lower) of soil – boundary between courses, which is important for the correction of a correlation relationship, as shown below (Fig. 6).

Fig. 7 shows graphic results of the measurements of selected tests in 10 profiles in the construction of a new forest road in Kultury (length 1.622 km). Despite rather non-homogeneous subgrade (initial bearing capacity and moisture content) in individual profiles, the relationships SPLT and LFWD are acceptable.

This fact is even more obvious in Fig. 8, showing the values of deformation moduli from SPLT and LFWD in individual profiles for subgrade (CS) and for a base course (G-F) of 300 mm thickness.

The test results were analyzed in terms of a correlation relationship of the selected testing methods as well as in terms of the selected soil parameters (moisture content, bulk density) and published in e.g. [27, 28]. As mentioned previously in Methods, related parameters such as soil condition, pressure condition, and accessibility and serviceability and unassumingness of test methods were considered.

The key final result of the works is the evaluation of the following testing procedures in terms of their availability and usability for survey and monitoring of forest road construction:

- SPLT is the most common method generally used for road construction, but is time demanding (lower frequency of measurements), counterweights are required (a truck or another heavy construction vehicle), and construction work is limited – therefore less suitable for forest roads.
- LFWD is a fast test, no counterweight is required, additional measurements are possible, with the knowledge of correlation (see [20]) the result $E_{v,d}$ can be converted into the corresponding value $E_{def,2}$, which allows us to evaluate bearing capacity, (with the knowledge of soil parameters from the Proctor Standard test, and compactness parameters).
- LDP is fast for the examined depths (up to 1.0 m), but physically demanding, suitable for illustrative determination of bearing capacity and layer thickness; equivalent – trial hole, drill hole, etc. are more

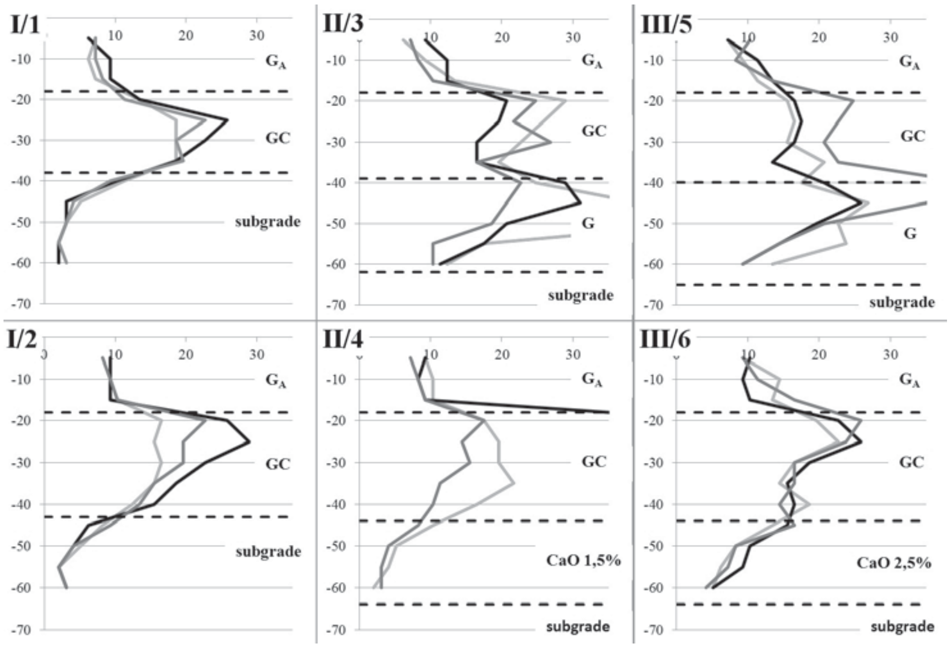

Fig. 6. Test results from GLTF – determination of construction layer boundaries of forest road DCPT.

demanding in time and costs, and often impossible to be performed.

- HDP is the most demanding test; it is usually unnecessary to perform deeper measurements; however, it is suitable/necessary for an examination of the existing forest road structures for reconstruction (LDP is unusable for bound layers in practice).
- Bulk density and moisture content allow us to describe soil and its condition; determination of moisture is necessary for the evaluation of bearing capacity parameter, which is obviously significantly related to moisture (Fig. 5).
- Determination of grain size is a basic test for the determination of soil classification; as mentioned above, together with Proctor Standard, it also allows us to evaluate the degree of compaction.

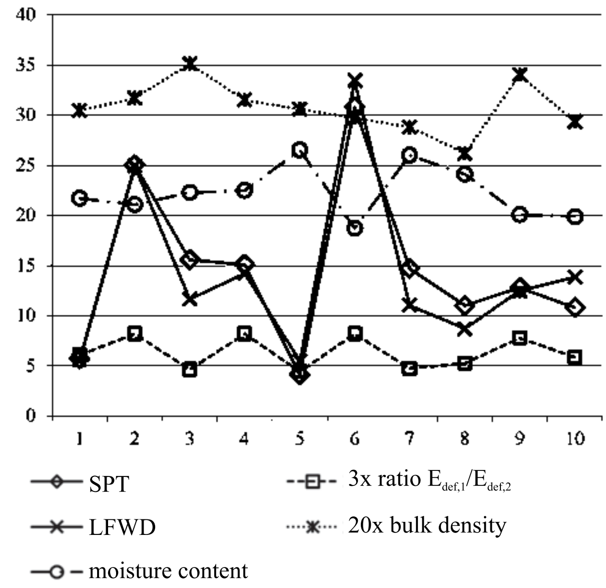

Fig. 7. Test results from subgrade in locality Kultury.

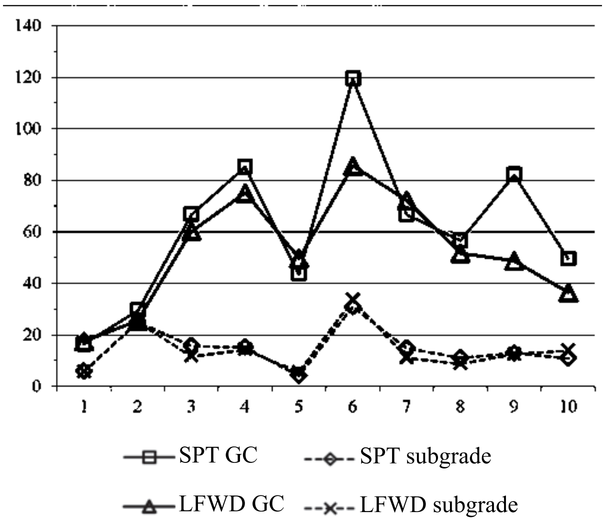

Fig. 8. Test results from locality Kultury – comparison of SPLT and LFWD on subgrade and layer GC.

For their non-demanding nature, the mentioned tests (apart from SPLT) can be used as a part of survey activities (for new construction or reconstruction) as material for a forest road project (design) as well as for inspections of construction work.

It is then possible to evaluate the subgrade and, in the case of insufficient bearing capacity, design its modifications (complete compactness, improvement, replacement, or use of geosynthetics [29]) and design forest road construction layers with suitable selection of materials, from local sources if possible. LFWD test can also be used for the monitoring of meeting the required bearing capacity parameters, or degree of compaction respectively, as a basic prerequisite for high quality construction and function of a forest road.

Conclusion

This article describes the possibilities for simple evaluation of bearing capacity and compaction of subgrade and construction layers of forest roads. It is based on the selection of parameters for specific features (particularly simplification) of survey works, designing, construction, and monitoring of construction or reconstruction of forest roads.

Although the above-mentioned procedures were selected while taking into account the above-mentioned requirements and specific features for forest roads (damage level, surface/pavement quality, frequency of loading, life span, etc.) and the financial and personnel potential (limits) of the resort which is responsible for forest roads, these procedures allow for construction on an appropriate sufficient level and are sufficient for the given use. The use of the simplified procedure is particularly based on a suitable selection (combination) of non-demanding testing methods for evaluation as well as on verification of the use of the LFWD test in relation to sufficient correlation relationship in connection to SPLT (for details see Methodology) [26].

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