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MODEL CALIBRATION OF LINE CONSTRUCTION–SUBSOIL ASSISTED BY EXPERIMENTAL RESEARCH

1. Introduction

The load caused by the traffic movement in road constructions should be transferred in a harmless way to the pavement as follows:
— on the stiff upper layers of the structure (e.g. layers of asphalt: abrading and binding), and
— through the layers of principal and secondary substructure,
— on the subsoil, directly or through an improved subsoil layer.

A reliable description of the interaction proceeding in a system "road construction–subsoil" should be in such case one of the basic requirements of the assessment of the size of internal forces of structure and its durability.

It should be noted that the subsoil of pavement should be recognized as virgin soil or made soil to a depth of frost penetration (not less than the depth at which the vertical stresses from the largest loads are 0.02 MPa [12]). According to [17] the subsoil is examined to a depth of not less than 1.00 m from the designed grade line of the road. According to [4], while the greatest thickness of the subsoil involved in the work of construction of the pavement is approximately 0.70 m

There is no definition which allows for synonymous determination of the thickness of the road structure cooperating with structure subsoil, which is a major problem in creating numerical computational models.

Considering the work of the system "road construction–subsoil", it is commonly accepted [14] that, as a result of repetitive loads on the subsoil under pavement, the growth of relatively small deformations in the initial phase is recognized, then this increase disappears,

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and the deformation takes on a character which is completely reversible. The reliability of this calculation model is combined with appropriate use (for a given type of analysis) of constitutive relationships. The phenomena occurring in the initial stage of the system “road construction–subsoil” is unfortunately difficult to interpret in the modeling process. The classic interpretation of the behavior of the material in the elastic-plastic model (e-p) is that elastic phase of the work (e) is undergoing to phase (e-p) by increasing the load (or growth of deformation in the damaging structure).

The paper presents the essence of the calibration process of cooperating subsystem in the calculation model of the system “road construction–subsoil”, created for the mechanistic analysis. The calibration process was directed to show the impact of certain elements on the created model and on its deformation and stress response. The proper comparative base for assessing the reliability of created models should be, however, an actual, monitored system “road construction–subsoil”. The trial of this monitoring and the first experience with the results are shown in the last chapter of this paper.

2. Numerical evaluation of the behavior of the system “road construction–subsoil” in the elastic analyses

Analyses of road constructions are based on:
- elements of mechanics, which allows us to create computational models, and
- results of the experiments included in the criteria of fatigue life analyses.

The above approach is a fundamental feature of commonly used mechanistic methods [5, 7, 15]. They allow us to use evaluations conducted for the fatigue life of structures in arbitrarily complex numerical computational models.

Here we consider the effectiveness of a simple numerical computational models in mechanistic analyses, taking into account the utility function:
- in the design or redesign (strengthening) of road construction, and
- the existing pavement control tests.

Appropriate use of mechanistic methods require (in accordance with Chapter 1) clear identification of the effects of numerical cooperation of the considered subsystems: laminar structure of the road and subsoil, usually of a heterogeneous structure.

This is the purpose of the test use in which the results are presented below, based on real traffic systems.

Analysis 1

This analysis has purely a research meaning and provides a reference basis for subsequent analyses. In the current system the following is assumed: the construction section of road is loaded by the traffic corresponding to the traffic category KR4, and the ground requirements are consistent with [9] — figure 1a. For such a system “road construction–subsoil” “an academic” purposes test was carried out. The effects of various introduced and subsequent changes in the system, were controlled by an engineer, which allows us to evaluate the efficiency of the analysis based on certain simplifying assumptions.

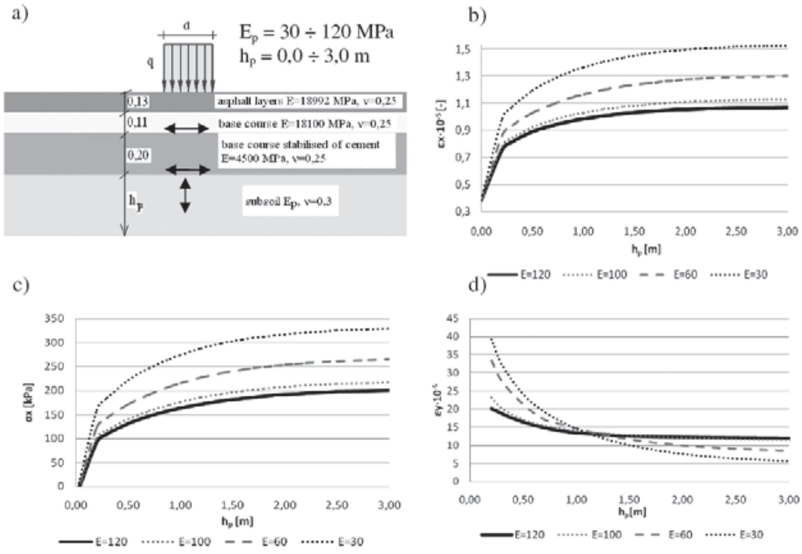


Fig. 1. a) Section of the tested system applied in mechanistic analysis, b), c), d) Numerical effect of cooperation of the two subsystems, modeled with the use of linear-elastic relations

Introduced simplification calculations to the numerical model are consistent with the simplification calculations used in the mechanistic analyses in general engineering. They are:

— linear constitutive relations for the materials,
— the “seasonal” modules in the upper layers of construction, and
— “homogenised” subsoil.

In numerical analysis the thickness h_p of the subsoil, showing the contractual range of cooperation between structure and subsoil, is subjected to changes (Fig. 1a). The effect of cooperation between structure and subsoil, expressed in figure 1b, c, d by the functions ε_x, σ_x, ε_y accurately should be called — the numerical result of cooperation between the two modeled subsystems.

Functions in bold correspond to the subsoil with a capacity of G1 (E = 120MPa). It should be noted that the determined numerical values ε_x, σ_x, ε_y (introduced to the criteria of fatigue [10]) should be accompanied by further numerical deflection control of the bowl. Namely, if for the tested system we assume that the „stabilizing” solution is achieved when the subsoil thickness h_p = 2.2 m for the subsoil G1 obtains bowl deflection of the size about f = 0,0002 m. For the substrates with E < 60 MPa range of bowl increases in an unacceptable manner, interpreted in the elastic analyses as a weak subsoil in cooperation with the construction of the road [3, 6].

For a system “road construction–subsoil” G1 the value of design fatigue life of the structure was determined for the stable values of ε_x, σ_x, ε_y (for h_p = 2,2 m). According to the criteria of fatigue N_f = 5757035 [number of computational axes 100 kN/20 years], where the range of values of fatigue life for KR4 is 2500001–7300000 [number of computational axes 100 kN/20 years] [9, 10].

Analysis 2

This analysis applies to the access road to the logistics hall with a traffic load corresponding to the traffic category KR6, shown in Figure 2. Figure 3a shows the actual cross-section of a system "road construction–subsoil" with the modulus E < 120 MPa. The behavior of the tested system, due to "analogy" of construction of the structure (thickness and stiffness of the upper layers, and the rigidity of the materials forming the non-aggregate subsoil) is compared with results obtained from the Analysis 1.

Fig. 2. Part of research field located on the access road to the logistics hall

Today's accepted solutions to improve soil are various and technologically advanced. Subsoil, which has been stabilized, usually fulfills the requirements for improved soils, and additionally it may be considered as a material applicable for road, parking spots or hall subbase. Solutions introducing the stabilized road's base courses utilizing secondary products of the combustion (SPC = UPS) are near the above conception (Fig. 3a).

So, the analysis (Fig. 3b, c, d) concerns the pavement construction in which both the subbase layer and stabilized soil layer are represented by material from the group of the UPS. Such an approach enables the substitution of all-in aggregates by alternative materials; in UPS case they originate from energetic waste materials.

The course of function ε (σ)–h_p (representing the numerical effect of cooperation of the system "road construction–subsoil" from figure 3a) testifies to the correct choice of the stiffness of the strengthened subsystems (Fig. 3b, c, d).

Stabilization of the designated functions can happen (as we see in the figure) at different values of h_p, depending on the stiffness of the structure.

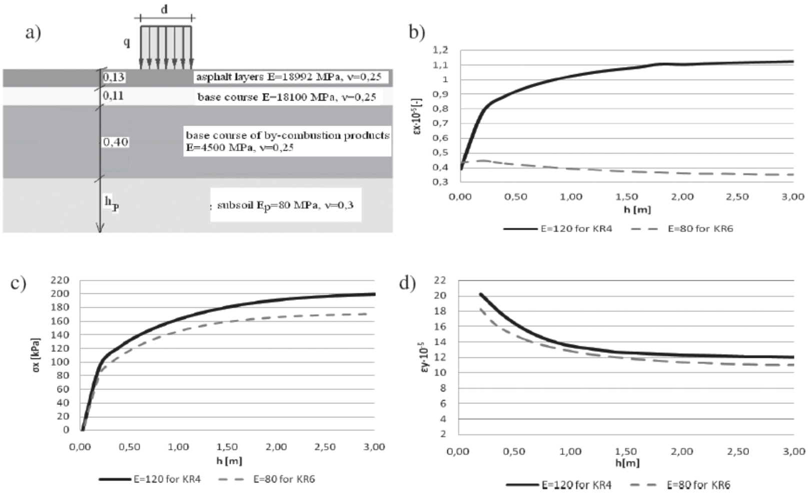


Fig. 3. a) Section of the tested system applied in mechanistic analysis, b), c), d) Numerical effect of cooperation of the structure and subsoil form Analyses 1 and 2

For the system "road construction-subsoil" G1 the value N_i = 22770522 [number of computational axes 100 kN/20 years] is assigned for the stable values ε_x, σ_x, ε_y (for h_p = 2,2 m) determining the fatigue life.

Analysis 3

National Road number 79, in the area of Sosnowiec, was rebuilt (tests performed by the Department of Roads and Bridges at the Civil Engineering Faculty in the work [1]). In the case of the control study of existing pavements, the backward elastic modules of pavement layers are determined in analysis based on measurements:

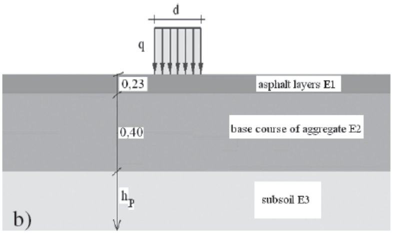
— of bowl deflections (determined by use of Falling Weight Deflectometer), and
— of pavement thickness, determined from the bore-holes.

On the basis of deflection *s* which is caused by dynamic load of a value *q* (a circular area of radius D/2 = 0.15 m), the equivalent modulus ($E = q{\cdot}D/s$) is determined. Then the layer thickness is determined on the basis of bore-holes and layers modules are determined in the reverse analysis; at the assumed level of confidence. In Figure 4b are given the most reliable values modules obtained for ratio $E2/E3$ = 2.8, and for the "fixed depth of non-deformable subsoil" (Fig. 4a) [1].

The results of the measured deflections imposed deflections pavement defined in the model, for which the modules given in the subsequent sections (Fig. 4b) are assigned to the layers, where the thickness of the subsoil $h_p = h_3$ = 2.2 m is given (Fig. 5), the dashed line.

Comparing the functions shown in figure 5 (solid and dashed lines) one can observe that the numerical effect of cooperation between the two subsystems (measured here by the structure deflections) can be considered as a coupled effect, combining the impact of the subsoil thickness h_p and the impact of structural stiffness.

a)



	Left lane	Right lane
E^r_1 [MPa]	2 638	2 449
E^r_2 [MPa]	324	320
E^r_3 [MPa]	116	114

b)

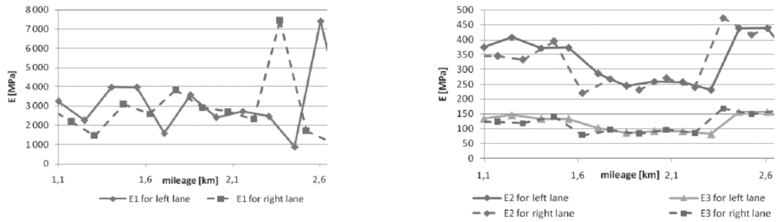


Fig. 4. a) Merged layers system with characteristic parameters,
b) module obtained due to reverse analysis of tested segment

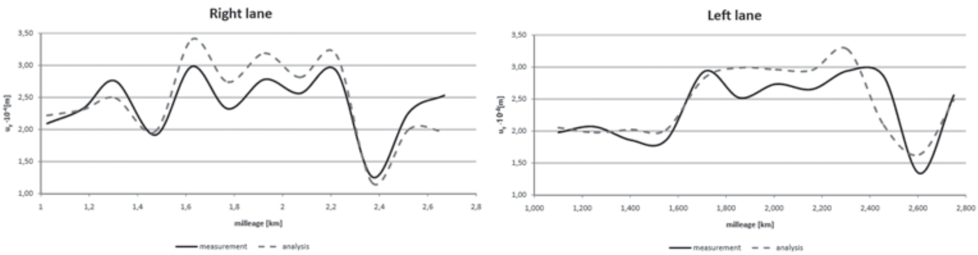


Fig. 5. Deflection distribution for the right and left traffic line of National Road 79
in Sosnowiec with imposed results of numerical analysis

3. Influence of the ground model on assessment of size of the design value h_p

Ambiguity of the interpretation of the subsoil behavior in the elastic analysis is associated both with accepting the thickness of the subsoil cooperating with the structure hp, and expressed by stiffness module *E*. Figure 6 shows the correct interpretation of the subsoil response — elastic, vertically anisotropic. In figure 6a we see a response to the uniform subsoil (E = 120 MPa) and layered subsoil (upper layer E = 120 MPa, the lower layer E = 60 MPa). The load Q_r represents the actual load impact, transferred to the subsoil by a structure of a certain stiffness.

Assuming that condition $(dQ/ds)_{\text{numer}} = (dQ/ds)_{\text{in situ}}$ [16] should occur in any calculation area of the model (expressed by the size of h_p), a horizontal line from point A (Fig. 6b) must intersect the response functions α for increasing values of the modulus E. This finding is consistent with the results of earlier studies, which introduce a constant value of subsoil modulus (Fig. 3), but cannot formulate rules for determining the value of h_p, adequate for the analyzed system.

Observing the close coupling of the numerical effect of cooperation of investigated subsystems with the thickness of the subsoil h_p, it is considered below to evaluate the possible range of cooperation between structures and subsoil using inelastic (specific for geotechnical issues), model of subsoil.

Let us assume the existence of road in a bed of the pre-consolidated soil across the external load Q_r, for which a set of model parameters corresponding to the critical state Modyfied Cam-Clay (MCC) [2] is determined.

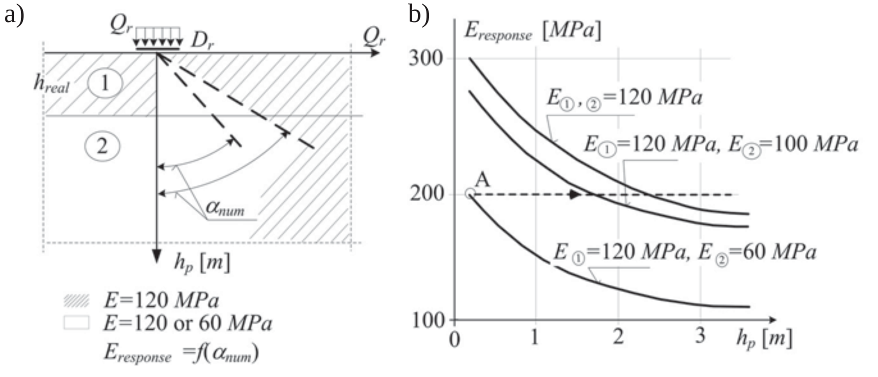


Fig. 6. a) Response to the uniform subsoil and layered subsoil on load transferred from construction b) interpretation of condition $(dQ/ds)_{numer} = (dQ/ds)_{in\ situ}$ in elastic model [2]

If the distribution function of the vertical component of stress along the depth in axis of the anticipated load distributed over a circle of given diameter D_r (as in Figure 6) is a function $\Phi_i(z)$, which is possible to determine according to [13], so the unit shortening ($\Delta h/h$) of conventional layer h at a depth of z, is considered through estimation of subsoil thickness h_p as it is given in [2]:

$$\frac{\Delta h}{h} = \frac{\kappa}{1 + e_z} \cdot \ln\left(\frac{\gamma \cdot z + Q_r}{\gamma \cdot z}\right) \cdot A \tag{1}$$

in accordance with [13]:

$$A = \left[1 - \frac{8 \cdot \eta_i^3}{\sqrt{(1 + 4 \cdot \eta_i^2)^3}}\right] \tag{2}$$

where:

κ — MCC model parameter (slope of the relaxation line),
e_z — the initial value of void ratio in the state of *in situ*.

Designated functions (1) in Figure 7 can be regarded as monograms for determining with the fixed error *ds* the subsoil thickness h_p cooperating with the structure of the system under consideration. Thus, the subsoil thickness in the analyzed system can take values $h \geq h_p$ without breaking the accuracy of the solution [2]. This value, dependent on the value load Q_r transferred to the subsoil can be defined as in figure 7.

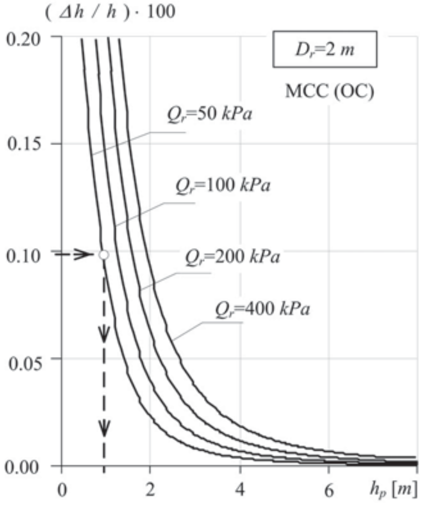


Fig. 7. Functions which allow to determine with fixed error of thickness hp of subsoil in computational model [2]

4. *In situ* investigations. Summary

In the system "road structure-subsoil" we operate values of vertical strains ε_y incomparably smaller than in the case of foundations. Proper assessment of the values directly influences the assessment of strain in the layers of asphalt and subbase.

These dependencies directly affect the assessment of durability (acc. to criteria) in mechanistic pavement-design methods. So, a full description of reality is obtained by the calculation model should have two levels of reference — laboratory studies and studies in situ. This paper describes shortly the preparation of monitoring system for an investigated road (Analysis 2 in chapter 2).

Photos attached below (Fig. 8) show the sequence of setting up the measurement base on the monitored experimental plot — electronics measurement and NeoStrain integration [11].

The adopted system of research –and at the same time the response control system for sensors set in a ground — shows diagram in figure 9 (vertical strains measured by the system of sensors).

The long-term task of the system is to register changes in the material, which works loaded and is aging over the years. But the fundamental task of the monitoring is the role of "supporting" construction to the rational computational models for systems "road structure subsoil".

Fig. 8. Sequence of setting the measurement base on the monitored experimental plot

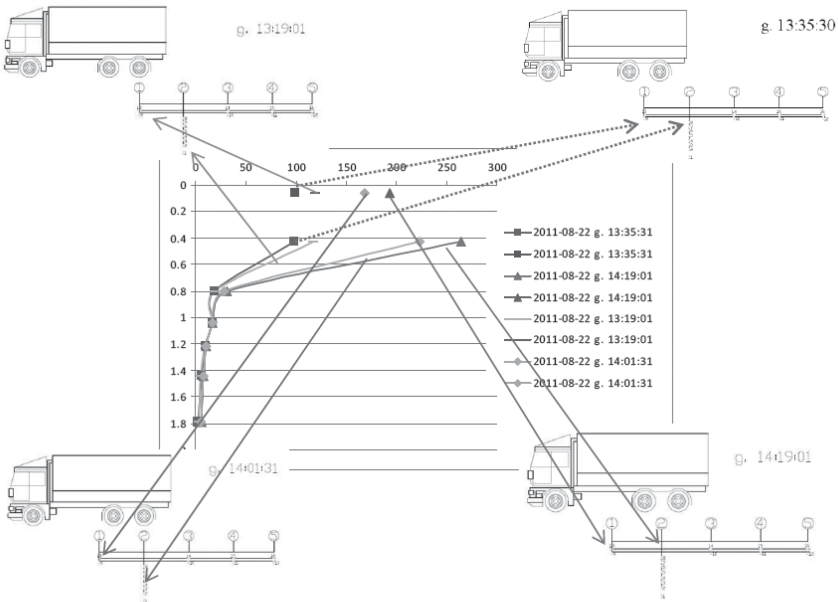


Fig. 9. Vertical strains measured by the sensors system

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