COMMUNICATIONS

Libor Izvolt – Jan Kardos *

INTELLIGENT COMPACTION TECHNIQUE AS A TOOL OF OBJECTIVE AND EFFECTIVE APPLICATION OF GEOSYNTHETICS

The paper focuses on evaluation of the current state of designing and realization of railway substructure layers on modernized Slovak railway tracks with the emphasis on an effective use of geosynthetic products. The presented method of intelligent compaction may significantly increase efficiency of design and realization of construction layers with the objective use of geosynthetics and other adjustments at various geological conditions of subgrade.

1. Introduction

Intensive modernisation of railway tracks belonging to Trans-European railways (*TER*) has been realized in Slovakia at present. A technical level of these modernized tracks (in Slovakia they are represented by corridors No. IV, V, VI and the North – South interconnection of the corridor IX with the total length of 1 033 km) has to meet international requirements based on European Agreement on Main International Railway Lines (*AGC*) and European Agreement on Important International Combined Transport Lines and Related Installations (*AGTC*). The modernisation of the railway tracks improves their technical parameters, namely the adaptation of the railway substructure to the axle force of 225 kN and the speed of 60 km/h (with the outlook for 200 km/h). This increase of the technical level of the railway substructure presents a considerable problem because the tracks are in different technical conditions and are built in various geological conditions of subgrade. The design of a sleeper subgrade construction, i.e. its structure and dimensions of layers as well as the determination of minimum values of chosen physical and mechanical properties of the applied materials and components has to be based on:

- results of an engineering geological (*EG*) exploration in those places where the modernized track will not be built on the original earth structure;
- evaluation of current technical conditions of the sleeper subgrade in those places where the modernized track will remain on its original earth structure;
- given technical requirements for the railway track construction, particularly *Z11* [1] a *TNZ 73 6312* [2].

At present the main problem of a sleeper subgrade design is an insufficient *EG* exploration. Its main disadvantage is its point-by-point character (boreholes or field soundings realized on the railway track axis in the distance of 100 – 250 m, sometimes more than 250 m). This type of the EG exploration cannot reflect sufficiently real conditions of the sleeper subgrade construction or railway substructure bottom layer in both, longitudinal and transversal directions. Project engineers are aware of this fact. Regarding their responsibility for a design of a reliable railway substructure construction and its bottom layer, they are often forced to design a construction with a high degree of safety by which they eliminate insufficient input data from the EG exploration. An example of such an ineffective (unsubstantiated) use of building materials is an extensive use of geosynthetics as can be seen in Tab. 1 which presents consumption of geosynthetic products on modernized/reconstructed track and station sections.

Some types of geosynthetic products still present unconventional products in our conditions, particularly when they are compared to the sleeper subgrade structure of track sections built in the past (on some corridors often more than 100 years ago). In some cases, insufficient experience with their application (not only in the Slovak Republic) together with insufficient standard specification documentation make it impossible to evaluate objectively the necessity of their application. It is important to mention that the modernized tracks given in Tab. 1 copy the original earth structure in ca 90 % of the track sections length. This original earth structure and its bottom layer may have due to long-time operation sufficiently reduced deformability which means that it is not necessary to design a railway substructure with built-in geosynthetics.

After identifying the above mentioned problems we will focus on an alternative approach to a design of railway substructure layers with the emphasis on elimination of non-objective and ineffective use of geosynthetics. One of possible steps towards more efficient use of geosynthetics in the railway substructure is the use

* **Libor Izvolt[1], Jan Kardos[2]**
[1] Department of Railway Engineering and Track Management, Faculty of Civil Engineering, University of Zilina, Slovakia,
E-mail: libor.izvolt@fstav.utc.sk
[2] Vahostav – SK a. s., Zilina, Slovakia

An overview of amount and approximate costs of geosynthetics used on chosen SR sections [3], [4] Table 1

Track or station section / project company	Length of section / length of railway line	Original earth structure of the track sections length	Amount of geosynthetics / Price of geosynthetics			Total amount / Price of building-in	Total price / Price of geosynthetics
			geogrids	geotextiles	geocomposites		
Žilina – Krásno nad Kysucou Sudop Košice, a.s.	18.869 km 42.206 km	ca 96 %	140,000 m² 675,000 €	230,000 m² 270,000 €	45,000 m² 260,000 €	415,000 m² 190,000 €	155,000,000 € 1,395,000 € (0.90 %)
Žilina – Teplička – zriaď. stanica Prodex, spol. s r.o.	6.300 km 37.158 km	ca 87 %	85,000 m² 380,000 €	5,000 m² 5,000 €	0 m² 0 €	90,000 m² 90,000 €	125,000,000 € 475,000 € (0.38 %)
Nové Mesto nad V. – Zlatovce Reming Consult, a.s.	17.457 km 36.720 km	ca 78 % without tunnel 88 %	280,000 m² 1,900,000 €	450,000 m² 800,000 €	5,000 m² & 30,000 m 3,800,000 €	735,000 m² a 30,000 m 400,000 €	255,000,000 € [1] 6,900,000 € (2.71 %)
Trenčianska Teplá – Beluša Reming Consult, a.s.	20.409 km 49.839 km	ca 95 %	420,000 m² 1,450,000 €	505,000 m² 525,000 €	20,000 m² 40,000 €	945,000 m² 540,000 €	290,000,000 € 2,555,000 € (0.88 %)
Zlatovce – Trenčianska Teplá Reming Consult, a.s.	11.952 km 32.700 km	ca 91%	200,000 m² 625,000 €	560,000 m² 480,000 €	25,000 m² 60,000 €	785,000 m² 330,000 €	260,000,000 € 1,495,000 € (0.58 %)
Total for evaluated track or station sections	74.897 km 198.623 km	ca 90 %	1,125,000 m² 5,030,000 €	1,750,000 m² 2,080,000 €	95,000 m² & 30,000 m 4,160,000 €	2,970,000 m² & 30,000 m 1,550,000 €	1,085,000,000 € 12,820,000 € (1.18 %)

[1] the price includes a railway tunnel with the length of 1 740 m which represents over 30 % of given costs

Note: The prices are quoted without VAT and the amounts are only approximate. The costs of geosynthetic products for one metre of a double-track are in average ca 130 € without VAT.

of named intelligent compaction technique. It enables us to localise such critical places where the potential application of geosynthetics may make a major contribution. At the same time the intelligent compaction technique enables more effective building of materials and components into the railway substructure and its bottom layer (e.g. by increasing a synergetic effect between reinforcing geosynthetics and aggregate) and thus it increases deformation resistance and durability of the construction.

2. Intelligent Compaction Technique

Recompaction of railway substructure layers due to the operation of a track and bottom layer consolidation due to the increased geostatic embankment loading are the main reasons of geometrical position disintegration and track distortion. Compaction is the easiest and most effective technology used for increasing mechanical efficiency of railway substructure layers and its bottom layer consisting of various types of soils. The results of quality compaction are such changes in a soil structure which reduce its settlement to minimum even during long-time operation loading. To reach these changes in the soil structure, it is necessary to apply such force actions during the compaction process which will exceed its shear strength threshold. This will change the soil structure, reduce space between soil particles, and reduce pore volume (it will increase bulk density of soil). The equipment which is used for compaction is represented mainly by flat-surfaced compaction rollers, which can be divided according to the compaction method into static, vibratory, oscillatory, and nutatory.

As for quality of cohesive and non-cohesive soil compaction, flat-surfaced vibratory rollers were the most effective for a long time. Compaction technique producers' continual effort was to make use of more progressive and sophisticated systems which enabled high-quality and more effective (as for finances and tech-

nology) compaction of soil with various physical and mechanical properties. The final result of compaction technique producers' effort was the production of named "intelligent rollers" which automate several controlling processes of compaction with the use of mutually interconnected systems (Fig. 1).
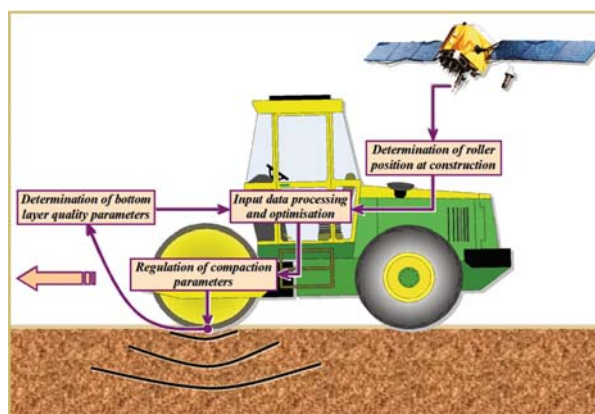

Fig. 1 System of intelligent roller [5]

The first required system component of intelligent compaction technique is continual determination of the achieved quality of a compacted bottom layer (construction layer) during compaction. It is possible to quantify the compaction quality parameter by various parameters of conventional diagnostic methods, e.g. D (compaction degree determined by bulk density test), PS (standard Proctor compaction test), I_d (relative density index determined by bulk density test), M_z (compaction degree determined by static plate loading test), E_0 (deformation module determined by static plate loading test), E_r (deformation module determined by dynamic plate loading test), CBR (bearing capacity determined by California

An overview of compaction technique producers and parameters describing a compacted bottom layer condition   Table 2

Producer of compaction technique (state - year of development)	System name / GPS (yes/no)	Designation of a parameter and a unit of parameter	Determination of a parameter describing a bottom layer condition	Determined correlations of a bottom layer quality parameter with conventional diagnostic methods
AMMANN - CASE (SUI - 1998) [6]	ACE Ammann Compaction Expert (yes)	k_B MN/m	The parameter k_B (dynamic reaction module) is expressed as a ratio between the load affecting the roller and the decline of the roller which is determined indirectly via accelerometer.	The measured value k_B is almost identical with the deformation module E_{v2} from the static loading test according to DIN 18196.
BOMAG (GER - 2000) [7]	BVC Bomag Vario Control (yes)	E_{VIB} MN/m²	The parameter E_{VIB} (vibration rigidity module) is determined from the tangent of the curve of contact load dependence on bottom layer deformation measure (input parameters are determined indirectly via accelerometer).	The measured value E_{VIB} correlates well with the deformation module E_{v2} from the static loading test according to DIN 18196.
CATERPILLAR (USA - 2006) [8]	CAT Compaction Monitoring System (yes)	CMV or energy of roller drive	The CMV parameter is defined below. The parameter of drive energy of a roller represents mechanical energy needed for the roller drive which is changed according to the height of material wave pressed by the compaction roller and the height of pressed wave depends on bottom layer quality.	The correlation dependence between CMV (compaction meter value) and DCP (dynamic cone penetrator) which achieved good parameters [8].
DYNAPAC (SWE - 2003) [9]	DCA Dynapac Compaction Analyzer (yes)	CMV Compaction Meter Value	The non-dimensional CMV parameter developed by the company. Geodynamic from 1978 is based on the ratio between the first harmonic amplitude of acceleration and acceleration amplitude of double frequency.	The non-dimensional value CMV correlates well with the deformation module from the static loading test [10].
VOLVO - INGERSOLL RAND (USA - 2008) [11]	– (no)	CMV Compaction Meter Value	The non-dimensional CMV parameter developed by the company. Geodynamic from 1978 is based on the ratio between acceleration amplitude of double frequency and the first harmonic amplitude of acceleration.	The non-dimensional CMV value correlates well with the deformation module from the static loading test [10].
HAMM (GER - 2004) [12]	HCQ Hamm Compaction Quality (yes)	HMV Hamm Meter Value	The non-dimensional parameter similar to CMV developed by the Swedish company Geodynamic (details in [12]).	The non-dimensional HMV value correlates well with the deformation module from the static loading test E_{v2} and the CMV value [12].
SAKAI (JP - 2002) [13]	CIS Compaction Information System (yes)	CCV Compaction Control Value	Non-dimensional parameter similar to CMV based on the ratio of acceleration amplitudes sum of 0.5-, 1.5-, 2- and 3-multiple of frequency and acceleration amplitudes sum of 2.5 and 3.5-multiple of frequency.	The CCV value correlates well with the bulk density of compacted material [13].

bearing ratio test), etc. Determination of the compaction quality parameter via compacting rollers is a more complex problem since soils are defined as non-homogeneous materials with a considerable difference in their physical and mechanical properties. Soil diagnostics has to be realized continually and, at the same time, a really (conventional diagnostic methods are point in their character) during compacting process (the speed of compaction rollers during compaction is approximately 2 – 6 km/h). Important compaction technique producers, for example, AMMANN, BOMAG, CATERPILLAR, DYNAPAC, VOLVO, HAMM a SAKAI have a different approach to the determination of a bottom layer condition during compaction. However, mutual correlation with the conventional methods of compaction quality diagnostics has reached satisfactory significance in all parametric studies (Tab. 2).

The second required system of the intelligent compaction technique is monitoring and recording of a coordinate position of the roller at a given construction. It means that after identifying the quality parameter value of the bottom layer, the location of the roller is recorded with a satellite GPS signal in real time. Then these position coordinates are matched with the monitored parameter value of the bottom layer. Accuracy of location determination of the compaction roller is usually up to 0.10 m [5]. At the same time the location system interconnects the geometrical design of the construction as a vector 3D model with the controlling of con-

struction machines without necessity of demanding, expensive, and detailed geodetic surveying of the construction. When using construction machines with GPS (grader and compaction roller) it is possible to save 20 – 50 % of costs needed for geodetic stake-out of the construction. An example of a compaction map which is a standard graphic output of intelligent rollers is given in Fig. 2. Based on this map it is possible to localise vertical non-homogeneities of the bottom layer in the whole compacted plane. Then compaction rollers are able to optimise parameters for the next roller pass.

Another required system component of the intelligent compaction rollers is a computer in which the information about bottom
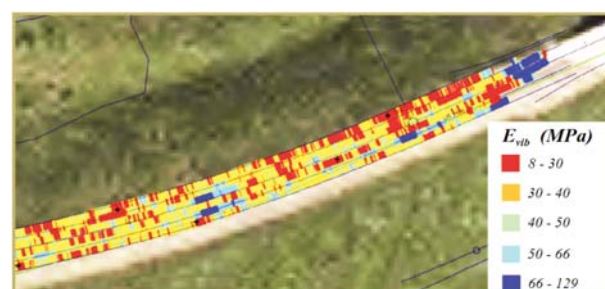

Fig. 2 An example of a compaction map [7]

layer conditions and roller positions are continuously saved (a compaction map). All gathered information is processed with the installed software in order to optimise compaction parameters of the roller. Optimisation of compaction parameters can be linear, non-linear or dynamic (all details are given in [14]). It presents identification of such values of variable compaction parameters which provide the required definiteness of result values in the process of the following compaction.

Elimination of non-homogeneities works thanks to the third required system component of the compaction technique which is equipment for continuous transformation of compaction parameters (most often it is the change of compaction frequency, amplitude and centrifugal force). The result of the mutual interconnection of system components is the fact that intelligent compaction rollers regulate automatically variable vibration, oscillation, and nutation parameters with the criterion of the minimum input energy for achieving the maximum compaction effect with regard to previous compaction effects (Fig. 3). After supplying energy necessary for the compaction process, the bottom layer conditions are determined again, and then, after evaluation of changes and new conditions, we return to the beginning of the optimisation process again with new input values. Simultaneously, it is necessary to monitor the relation to the final state of compaction (required or limit) during
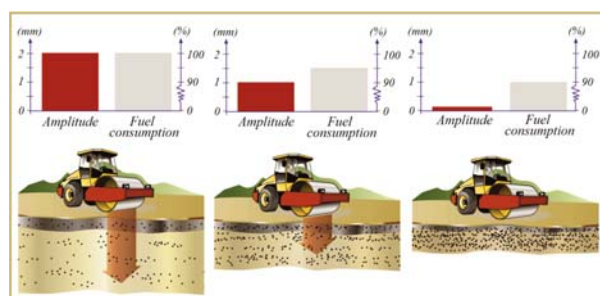

Fig. 3 Optimisations of compaction parameters – controlled vibration

this process, while meeting the criterion of minimum compaction energy. The result of compaction with intelligent rollers is an achievement of a remarkably more homogeneous layer (which will be reflected on its longer durability) while using minimum compaction energy.

3. The use of Intelligent Compaction Technique in Connection with Objective and Effective Application of Geosynthetics

Long-term, costly, and technically problematic and unsuitable certification process of geosynthetic products (it is necessary for a producer or distributor of geosynthetics to obtain a licence issued by Slovak Railways (*SR*) before its application into track constructions of *SR*) causes that mainly geosynthetic materials with a wide range of use and a large amount of consumption are applied in Slovak Railways. These are according to Tab. 1 mostly geotextiles (ca 55 %), geogrids (ca 40 %) a geocomposites (ca 5 %).

3.1 Objectivisation and effective application of geotextiles

Geotextiles are applied on *SR* tracks mainly in order to assure separation (prevention of two granulometrically different layers from interblending) and filtration (prevention of suffosion and colmatage of particles between layers) of construction layers. As for filtration, an impulse for geotextile application is not meeting a Terzághi's filtration criterion. Thus a project engineer has to be acquainted with a grain size analysis (determined by a sieve test and density analysis) when making a decision about the application of geotextile. This assumes the realization of the *EG* exploration in the axis of the future track (in the case of modernisation it can be either in the axis or out of the axis of the existing track), as well as determination of embankment material (it is necessary to choose appropriate borrow pits, gravel pits and stone pits) and subbase material (subbase material has a defined required grading curve in *TNZ 72*
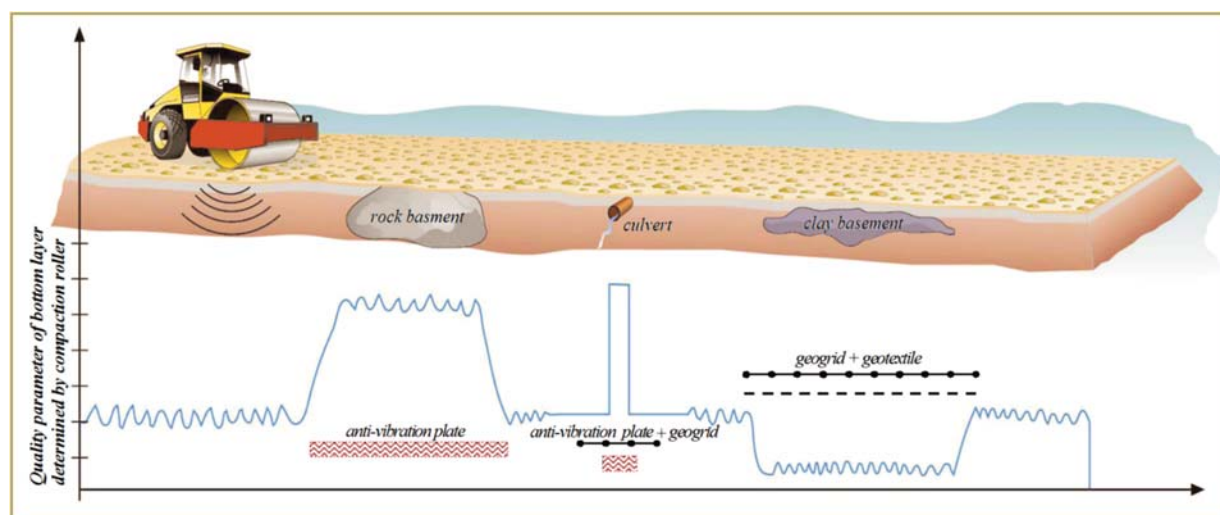

Fig. 4 An example of objectivisation of geosynthetics application during intelligent compaction [15]

1514). The *EG* exploration provides material samples of the embankment bottom layer (in the case of constructing a track on a new earth structure) or the subgrade surface (in the case of track built on the original earth structure) by a drilling ring with core drilling. The problem of objective planning of geotextile application is input data, particularly (a) an insufficient or incomplete *EG* exploration of the railway substructure (samples taken in the distance of every 250 m or more are not representative, mainly in hard geotechnical conditions), (b) assumptions connected with material basis for the embankment (constructors may use a different embankment material from the one presupposed in the project documentation), (c) wide range of grading curve of aggregate for the subbase (the supplier of aggregate can mix aggregate of various grading curves within the given curve limits according to *TNZ 72 1514*). Evaluation of criteria for the application of a particular geotextile type directly during the realization of the construction, for example, via a geotechnical consultant, could eliminate geotextile usage remarkably. It could also help to objectivise places where its application is of real and fundamental importance. The intelligent compaction rollers could localise (during the compaction process based on a considerable decrease of the parameter monitoring compaction quality (Fig. 4)) also those places which have not been presupposed or found out on the level of the open embankment bottom layer or subgrade surface during the *EG* exploration, e.g. hidden local beds of plastic saturated fine-grained soils which have not been revealed in the point *EG* exploration. The application of geotextile in places with extremely low quality of the bottom layer determined during compaction may lead to elimination of occurrence of increased suffusion and colmatage and thus it can increase durability of the construction as a whole. The construction durability increase may also be influenced by controlled vibration which enables to regulate such parameters of "sensitive" compaction that will not mean any risk of damage for the applied geotextiles (it is possible to carry out a simple compaction test to determine these target/limit parameters of compaction). The intensive compaction can subsequently be applied in its full range only in higher construction layers where compaction cannot damage the applied geotextile.

3.2 Objectivisation and effective application of geogrids

Geogrids (biaxial and triaxial) are to have mainly a reinforcing function in the railway substructure, its bottom layer or a track bed. It means that they are to increase deformation resistance in those places where it is not possible to achieve the required minimum values only by compaction. When designing a construction with a geogrid, in the project phase it is necessary to know coefficients *TBR* (*Traffic Benefit Ratio* – a coefficient expressing the increase of layer durability from the point of view of its reinforcement) or *BCR* (*Base Course reduction Ratio* – a reduction coefficient of layer thickness from the point of view of its reinforcement) which are possible to reach for the given geogrid, aggregate, and place of application under certain technological conditions [16], [17]. However, determination of the *TBR* and *BCR* parameters would require an extensive experimental measurement on model constructions with dynamic loading (pulsator), or directly in-situ (requirements for

experimental measurements are not defined). This is one of the reasons why it is not obligatory to define these parameters in *SR* licences. The *SR* licences for a particular geogrid and given local conditions specify a layer structure (in this case only a subbase structure) with the guaranty of certain reachable equivalent deformation module values from a static plate loading test (*PLT*) on the surface of this construction. Reaching the required equivalent deformation module values is according to an analysis realized in [16] often wrongly attributed only to a reinforcing effect of the geogrid, while an important reason of the deformation resistance increase of a reinforced construction is also high-quality compaction of construction layer material. The compaction quality (presented, for example, by the compaction measure M_z from the *PLT*) should be a decisive parameter for the evaluation of the construction quality and its required values for a given reinforced construction should be specified in *SR* licences [19].

The quality parameter of a compacted layer determined by intelligent compaction rollers has, on the contrary to the parameters from the *PLT*, better utterance value, particularly for these reasons:

- character of loading which converges better to the character of real dynamic loading caused by running of a train set (the frequency of compaction vibratory rollers is most often 25 – 45 Hz, with the amplitude 0.4 do 2.0 mm during the compaction),
- amount of loading (the weight of a roller is usually 7.5 – 27 t which means static linear loading 20 kN.m^{-1} – 80 kN.m^{-1}),
- area of loading (width of a roller drum is most often 1.60 – 2.20 m).

On the one hand, intelligent rollers for objective application of geogrids enable us to localise efficiently places with a considerable deformation resistance reduction where the application of geogrid may have its justification and, on the other hand, they make it possible to build in the geogrid more effectively (because of reaching a better compaction). Here it is important to emphasize that for the realization of more effective compaction and thus reaching a higher deformation resistance, it is necessary for the aggregate and applied geogrid to have suitable physical and mechanical properties (geogrid should have mainly high complex rigidity and gravel should have mainly high compression strength) and shape characteristics (shapes of tensile components for geogrids and shape index, roughness, and angularity for aggregate) and at the same time the geogrid cannot be damaged during the compaction. This condition, as well as the condition of the required toothing and fixation of compacted material particles in geogrid apertures in order to create a named interlock effect (details given in [16], [17], [18]) is best fulfilled by named continuous geogrids with crushed sharp-edged aggregate of a suitable granulometric composition. These geogrids are the most suitable and recommended for application into reinforced layers. The area application of such a geogrid also out of places with non-homogeneous bottom layer localised by intelligent rollers (i.e. diagnostics procedure via the *PLT*) would theoretically mean a deformation resistance increase on the whole area with the applied geogrid. In this case the elimination of non-homogeneity would not be achieved effectively, but (as a consequence of various compaction processes) only in higher construction layers. In the case of geogrid application it is necessary to take into con-
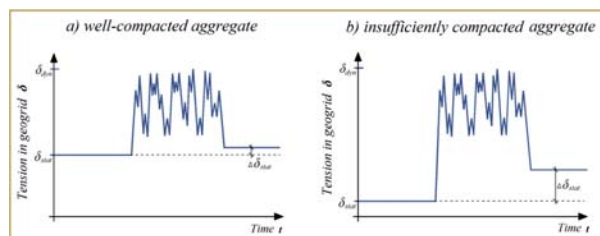
*Fig. 5 An illustration of tension development
in geogrid during loading*

sideration also the fact that potential reinforcing efficiency decreases with the increasing depth of geogrid placement. This is the reason why present worldwide research concentrates on application of geogrid into higher construction layers, particularly between a sub-grade surface and track bed. If good aggregate compaction is reached, a static prestress value of geogrid δ_{stat} is higher. It means that the geogrid transmits the loading more effectively and there is no remarkable deformation of the geogrid (which further causes a decline of the construction after the dynamic loading caused by train traffic δ_{dyn}) as it is in the case of insufficient compaction (the importance of aggregate compaction above geogrid is characterised in Fig. 5). The minimum value of aggregate compaction which is necessary to take into consideration for the effective application of geogrid is on the level of 95 % of the maximum compaction. Intelligent compaction rollers make it possible to reach this required compaction value.

3.3 Objectivisation and effective application of anti-vibration plates

Anti-vibration, or under-ballast plates are used in the railway substructure layers for reduction of mechanical vibration waves emitted by traffic. These are emitted mainly in the case of a contact of two rigid structural parts of the railway track (Fig. 6). The railway track construction should be designed and built in order to have a compressibility coefficient C_z reaching a certain minimum value
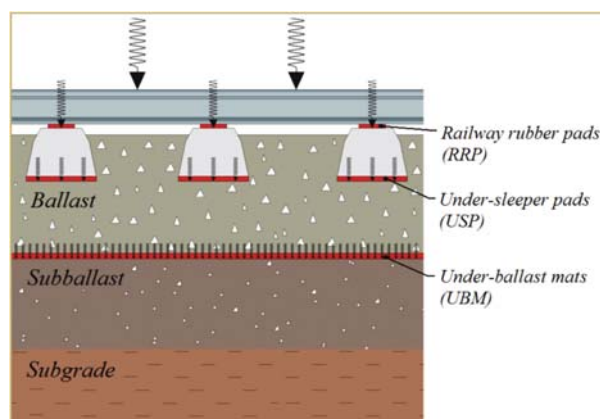

Fig. 6 An example of antivibration plates usage

under the loading area of sleepers, and at the same time it should be homogeneous. It is also possible to determine a compressibility coefficient value C_z from deformation resistance requirements based on the PLT (E_{ekv}) for the bottom layer or for individual railway sub-structure layers. In those places where the required compressibility coefficient value is exceeded, it is possible to use anti-vibration plates with various parameters according to given requirements. The main parameters determining elasticity characteristics of anti-vibration plates are static (equivalent of compressibility coefficient) and dynamic area rigidity. When using anti-vibration plates, the intelligent compaction technique may also have a remarkable contribution, either in the accurate localisation of anti-vibration plate application (Fig. 4) or when verifying the parameters of construction built in this way.

4. Conclusions

Intelligent compaction technique represents a significant means for reaching technically remarkably more effective railway track. Except for a general contribution, intelligent compaction has also other advantages for objective and effective application of geosynthetics, particularly:

- accurate and reliable localisation of vertical non-homogeneities of the bottom layer based on which it is possible to optimise a type, characteristics and amount of the applied geosynthetics (Fig. 3),
- "sensitive" compaction of aggregate above geotextile,
- high-quality compaction of aggregate above geogrid in order to reach the required dynamic toothing and increase the efficiency of geogrid,
- localisation of places with a high compressibility coefficient in which it is possible to design anti-vibration plate with the required parameters,
- direct verification of results of geogrid and anti-vibration plate application,
- economic impact caused by the application of a smaller amount of geosynthetics,
- ecological consequences following from the application of a smaller amount of geosynthetics, (geosynthetics is made from petroleum products and imported from abroad via truck transport, etc).

In spite of many advantages which compaction rollers offer, there have not been realized any studies that would monitor a correlation relation between parameters of bottom layer quality defined in *ZSR* Directive *S4* [20] and parameters detected by compaction rollers (Tab. 2). Thus the use of these parameters does not have such importance in practice as it could have. This is the reason why it is still necessary to verify the quality of a compacted structure during its construction only with conventional parameters from the *PLT* in accordance with the *ZSR* Directive S4 [20]. Involving intelligent rollers into complex problematics of a railway substructure and bottom layer design would make the construction design more accurate during its own realization. This would save costs considerably in the case of an insufficient or ineffective geotechnical exploration in pre-project preparation of the construction. It

would also help to specify designers' assumptions in a project phase which would lead to a more effective design of the construction based on real geotechnical conditions. From this point of view it seems to be very suitable and useful to establish a status of a geological consultant who would be responsible for a design of the railway substructure and bottom layer [21] during preparation, designing and realization of the construction. At present a similar status of a consultant is used effectively, for example, in connection with tunnel constructions.

Problematics described in this paper reveals many activities which are necessary to perform in order to design and construct an effective railway substructure and its bottom layer. Firstly, it is verification of the correlation between bottom layer quality parameters diagnosed by intelligent compaction rollers and conventional diagnostic methods according to *ZSR* Directives. Based on these correlations it would be possible to reduce the use of conventional diagnostic methods whose main disadvantages are presented in this paper. Objectivisation of geosynthetics application provided by intelligent rollers thanks to continual and area diagnostics is also very important. As for a reinforcing function of geogrids, intelligent rollers enable us to verify their efficiency in various constructions since the variability of measure and development of loading is almost identical to a real traffic loading. After the correlation analysis it is also possible to use intelligent rollers for an effective design of anti-vibration plates, particularly when using a parameter of dynamic area rigidity. Subsequently after the realization of a comparison test, it will be necessary to update several normative documents in order to prevent the use of intelligent compaction technique from encountering legislation problems and in order to make a full use of all technical possibilities they offer. Apart from this, it is desirable to re-evaluate the requirements for issuing *SR* licences for geogrids in the way that values of static deformation modules from the *PLT* would be completed with values of compaction quality and the contribution from geogrid application in the railway track construction layers would be specified by *TBR* or *BCR* coefficients (it is possible to realize their quantification with intelligent rollers, as well).

References

[1] Predpis ZSR Z11: *General Principles and Technical Requirments for Modernisation of Railway Line with Track Gauge 1.435 mm,* ZSR : Bratislava, 02/2001 (in Slovak).

[2] TNZ 73 6312: *Designing of Construction Layer of Railway Subgrade,* GR ZSR : Bratislava, 08/2005 (in Slovak).

[3] KARDOS, J. et al.: *Tender Price Quotations for Modernisation of Railway Lines in Slovak Republic,* VAHOSTAV – SK, a.s. : Zilina, 2008, 2009, 2010 (in Slovak).

[4] *Tender Documentation for Modernisation of Railway Lines in Slovak Republic,* 2008, 2009, 2010 (in Slovak).

[5] POKORNY, J., VAVERKA, M., KASPAREK, J.: Technology of Intelligent Vibratory Rollers and their Exploitation and Interconnection, In: *Stavebni technika* 1/2009. Available in: http://stavebni-technika.cz/pdf/743.pdf (in Czech).

[6] ANDEREGS, R., DOMINIK F., KAUFMAN, K.: *Compaction Monitoring Using Intelligent Soil Compactors*, Proc. of GeoCongress 2006, Geotechnical Engineering in the Information Technology Age, American Society of Civil Engineers, 2006. Available in: www.intelligentcompaction.com/downloads/PapersReports/Ammann_Anderegg_Compaction%20Monitoring%20Using%20Intelligent%20Soil%20Compactors.pdf.

[7] DENNISON, D.: *Bomag Americas, Bomag Fayat Group, firm presentation.* Available in: www.intelligentcompaction.com/downloads/Presentation/NYIC_Open%20House_Bomag.pdf

[8] PETERSEN, L., PETERSON R.: Intelligent Compaction and InSitu Testing at Mn/DOT TH53, Final Report, Minnesota Department of Transportation : Minnesota, 05/2006. Available in: www.lrrb.org/PDF/200613.pdf

[9] LUNDHAL, L.: *Intelligent Compaction,* Company presentation, 08/2008. Available in: www.infraestructura.org.co/memoriaseventos/segundoencuentronacionaldepavimentos/INTELLIGENTCOMPACTION-DYNAPAC.pdf

[10] BOUAZZA, A., KODIKARA, J., RARKER, R.: *Enviromental Geotechnics*, Rotterdam, 1997, ISBN 9054109033. Available in: www.books.google.sk

[11] MOONEY, M., ADAM, D.: *Vibratory Roller Integrated Measurement of Earthwork Compaction:* An Overview, In: FMGM 2007: Seventh International Symposium on Field Measurements in Geomechanics, Boston, 2007. Available in: http://control.mines.edu/mooney/index.php?option=com_docman&task=doc_download&gid=6

[12] RIMSTEDT, M.: *Uppfoljning av barighet och deformationsutveckling av terminalytor vid inventering och nybyggnad i Goteborgs Hamn,* Examensarbete inom civilingenjorspro-grammet Vag och vattenbyggnad, Goteborg, 2006. Available in: http://documents.vsect.chalmers.se/CPL/exjobb2006/ex2006-031.Pdf

[13] RAKOWSKI, S.: *Intelligent Compaction for Soil and Asphalt,* Sakai America Inc. Available in: http://www.eerc.iastate.edu/events/2009icwkshp/9_Sakai.pdf

[14] POKORNY J., VAVERKA, M., KASPAREK, J.: Controls and Automated Systems of Compaction Technique Control, In: *Stavebni technika,* No. 4, 2007. Available in: http://stavebni-technika.cz/pdf/452.pdf (in Czech).

[15] SIEKMEIER, J.: *Intelligent Compaction Mn/DOT Demonstrations, Iowa Geotechnical Workshop,* Ames, 12/2005. Available in: http://www.dot.state.mn.us/materials/re-searchdocs/iowa_geotech_johns_revised.pdf.

[16] KARDOS, J.: *Exploitation of Geosynthetic Components in Track Bed Structure.* Dissertation thesis, Zilina, 2008 (in Slovak).

[17] IZVOLT, L.: *Railway Subgrade – Loading, Diagnostic, Designing and Building of Construction Layers of Earthwork Structure.* EDIS : Zilinská univerzita, No. 2, 2008, p. 324, ISBN 978-80-8070-802-3 (in Slovak).

[18] IZVOLT, L., KARDOS, J.: Parameter von Geogittern und ihr Einfluss auf deren Wirksamkeit im Eisenbahnunterbau. *Eisenbahntechnische Rundschau,* April 2010 - 59. Jahrgang, pp. 176–185, ISSN 0013-2845.

[19] IZVOLT, L., KARDOS, J.: *Application of other Chosen Parameters in Sleeper Subgrade Dimensioning.* In: 4. Forum kolajovej dopravy. Bratislava, 2008 (in Slovak).

[20] Predpis ZSR S4 *Railway subgrade.* Nakladatelstvi dopravy a spoju : Praha, 1988 (in Czech).

[21] ROZSYPAL, A.: *Importance of the Geotechnical Consultan´s Activities in Railway Corridors Modernization* In: 4. Forum kolajovej dopravy, Bratislava, 2008 (in Czech).