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Technology Research in Transport Infrastructure

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INTRODUCTION

Due to the continuing decrease in the amount of material and energy sources during the recent years, as well as the increase of their prices, there has been more emphasis on the reliability, lifespan and safety of transport infrastructure constructions, while minimising their negative effects on the living environment. Therefore the Transport Research Centre (Centrum dopravního výzkumu - CDV), specifically the Infrastructure Department, has been trying to help this trend by a research in the field of geotechnics, technology of concrete and non-destructive structures testing.

1. GEOTECHNICS

In the field of geotechnics the research activity concentrates on projects linked to the relationship between geotechnical quantities and geosynthetics influence on increase of soft soil bearing capacity. In order to make the geotechnical research more effective, a Geotechnical Laboratory Testing Field (GLTF) was built in the year 2001.

1.1. Geotechnical Laboratory Testing Field (GLTF)

The GLTF is a laboratory tool, which allows the measurement, in a laboratory, of some of the geotechnical quantities usually measured in the field (such as a plate test, dynamic loading test, penetration test, etc.) on various soils and soil layers for different compaction rate and water regimes. Unquestionable advantage of GLTF is the possibility to carry out all kinds of geotechnical tests on constructions of real scale while still in the laboratory-protected conditions.

The GLTF, Figure 1 left, consists of concrete pit split by removable dividers into separated measuring (testing) spaces and a watering/dewatering drain channel separated by removable dividers too. There is a drain layer placed on the bottom of each measuring space closed off by a grate with a geotextile drainage filter. Both the concrete pit and the drain channel are interconnected at their bottoms. A moveable frame can be slid in a longitudinal direction along guide rails fastened to the top of the pit. The moveable frame serves for mounting or supporting of measuring equipment (plate test, CBR in situ test equipment etc.) and can be locked in both horizontal and vertical senses during testing.

The GLTF has been recently equipped with a loaders for accelerated testing of soil and unbound layers, see Figure 1 right. The GLTF is becoming an accelerated loading testing equipment. Currently the geosynthetics behaviour under cyclic loading (simulation of traffic loading) is tested. There is also a plan for a research project focused on the accelerated testing of reinforced joins. The project should be aimed on tolerance findings of reinforcing dowels angular displace and durability of additionally placed dowels.

The GLTF description has been published [1,2] and is protected by the utility design [3].

Fig. 1 – Laboratory Geotechnical Testing Field (GLTF) left – general view with static plate test, right – equipment for cyclic loading

1.2 Correlation of California Bearing Ratio CBR and deformation modulus

Deformation modulus, especially its value detected by static loading test in the second loading cycle E_{v2}, is one of the most important parameters checked at the final subgrade, just after the compaction rate and moisture content of the soil. Deformation modulus is used for verifying deformation characteristics of final subgrades. In a number of European countries, e.g. in Germany, Austria, Czech republic, Slovakia, etc. there is a minimum value of this modulus specified by standards, which has to be reached.

Predictability of the compliance with a specific minimum value of the deformation modulus is a crucial condition for the economy proposal for the earth works, as the real value of this modulus can be detected only after the earth works have been finished. The final subgrade, or the capping layer, then either meets or doesn't meet the given criteria. If the deformation modulus detected at the given deformation and moisture ratio is lower then required, the subgrade has to be usually remoulded, adjusted and then compacted again. It is obvious that this causes undesired extra expenses.

From the problem described above it can be seen that it is useful to know the expected deformation modulus of the subgrade already at the time of the proposal, given the specific soil type; or alternatively to know what sort of soil adjustment should be suggested so that the expected value of the deformation modulus is sufficient. As can be observed from the professional studies, one of the means for this prediction can be the correlation of the deformation modulus and the California Bearing Ratio (CBR). Unfortunately, in the literature available, no relation between the deformation modulus in the second load cycle and CBR specified at the same or optimum moisture content has been found.

Assumptions, methodology and evaluation from the research described here have been continuously publicised, e.g. [4, 5] (they are also available from the author of the English version). So it would be only superfluous to give here their detail description here, and moreover it would unproportionately excess the capacity of this article. However it should be state here that the tests have been carried out on real construction sites and in GLTF, on various soil types, on various compaction and moisture. The California Bearing Ratio *CBR* has been detected at intact samples, which were collected within a minimum distance from the compaction modulus testing place. Thus both of the correlated geotechnical quantities (*CBR* and E_{v2}) have been detected under the very same conditions (moisture, compaction ratio, etc.).

One of the solution output is table 1. This is in a certain modification also included in the draft revision proposal of the Technical Conditions of the Transport Ministry TP 77 – Road design whose elaborator is the Faculty of Civil Engineering, Brno University of Technology. Table 1 has been done by compiling the results of the CDV research (column E_{v2}) and the enclosures from the Czech Standard CSN 72 1002.

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Table 1 – Deformation Modulus of the second cycle $E_{def,2}$ for various soil types

Serial No.	Soil type	Symbol	Fine particle content f [%]	California Bearing Ratio *CBR* [%] Optimum Moisture	California Bearing Ratio *CBR* [%] 95% saturation	Modulus E_{v2} [MPa]
1	gravel silt	F1 MG	35 – 65	8 – 18	5 – 10	20 - 40
2	gravel clay	F2 CG	35 – 65	5 – 10	3 – 7	15 - 30
3	sandy silt I	F3 MS_1	35 – 50	5 – 25	4 – 15	15 - 45
4	sandy silt II	F3 MS_2	50 – 65	3 – 15	2 – 5	5 - 40
5	sandy clay I	F4 CS_1	35 – 50	5 – 30	5 – 20	15 - 50
6	sandy clay II	F4 CS_2	50 – 65	2 – 20	0 – 4	0 - 40
7	low plasticity silt	F5 ML	> 65	2 – 20	2 – 7	0 - 40
8	medium plasticity silt	F5 MI	> 65	2 – 15	1 – 6	0 - 40
9	low plasticity (lean) clay	F6 CL	> 65	3 – 20	1 – 8	5 - 40
10	medium plasticity clay	F6 CI	> 65	2 – 20	0 – 6	0 – 40
11	high plasticity silt	F7 MH	> 65	3 – 7	0 – 4	5 – 25
12	very high plasticity silt	F7 MV	> 65	2 – 6	0 – 3	0 – 20
13	extremely high plasticity silt	F7 ME	> 65	2 – 5	0 – 2	0 – 20
14	high plasticity clay	F8 CH	> 65	2 – 7	0 – 3	0 – 25
15	very high plasticity clay	F8 CV	> 65	1 – 7	0 – 3	0 – 25
16	extremely high plasticity clay	F8 CE	> 65	1 – 6	0 – 3	0 – 20
17	well-graded sand	S1 SW	< 5	-	-	-
18	poorly-graded sand	S2 SP	< 5	-	-	-
19	sand with fine soil additive	S3 S-F	5 – 15	8 – 70	6 – 25	20 – 65
20	silty sand	S4 SM	15 – 35	6 – 50	4 – 15	15 – 55
21	clayey sand	S5 SC	15 – 35	4 – 30	2 – 12	10 - 50
22	well-graded gravel	G1 GW	< 5	-	-	-
23	poorly-graded gravel	G2 GP	< 5	-	-	-
24	gravel with fine-soil additive	G3 G-F	5 – 15	20 – 90	6 – 60	35 - 65
25	silty gravel	G4 GM	15 – 35	10 – 60	4 – 40	25 - 60
26	clayey gravel	G5 GC	15 – 35	5 – 30	3 – 20	15 - 50

1.3 Study of the geosynthetics effect on the increase of the bearing capacity of subgrade

Geosynthetics (geotextiles, geogrids, geonets, geocells and geocomposits) are suggested as substances for improving the characteristics of materials of constructions used in transport civil engineering. Every geosynthetic should fulfil at least one or more of the following functions: filtration, separation, draining, protection, anti-erosive and reinforcing function. The last mentioned reinforcing function used for example in case of embankment construction when steeper slope of embankment can be designed is determined relatively well. While in the literature, especially in the company materials, one can often find information that by using geosynthetics one can be increased even the bearing capacity of soft soil, the problem has not been solved satisfactorily yet.

The research carried out at CDV concentrated especially on the study of the geosynthetics' effect on the increase of the bearing capacity soils. A number of validation tests have been carried out in GLTF recently. The specialists/professional public have been informed about the continuous results through journal and conference papers, for example see [6, 7]. The quoted publications discuss in detail the results of the surveys carried out. For this reason, it is described here the research resume only.

Presumptions and parameters

Measurements of the bearing capacity were done by modulus of deformation obtained from the second loading cycle of the static plate test, see Figure 1 left, according to two methods. The first method is widely used in Europe for highway subgrade evaluation and it is described some European standards, e.g. in DIN 18134 (German Standard) of CSN 72 1006, Appendix A (Czech Standard), and the resulting modulus is called E_{v2}. The second method used for railway subgrade evaluation is described in Czech Railway Standard S4, and the resulting modulus is called E_0. Both methods vary mainly in the ways of loading, and there is also a small dissimilarity in the modulus of deformation calculation. However, for our purpose, it is possible to say that both methods are able to express the impact of geosynthetics on the bearing capacity in a similar way.

The GLTF was divided into 3 testing spaces for measurement and experiments to be performed according to the following conditions. A 70cm thick bed of loess, compacted layer by layer, simulating a soft-soil subgrade was placed on the drainage layer of all three testing spaces of the GLTF. The compaction of the soft soil was about 95 % Proctor Standard (PS) and its bearing capacity was set by moisture content on 5 MPa, 7 MPa and 15 MPa respectively.

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Selected geosynthetics were laid down in to two GLTF testing spaces and one testing space was kept without geosynthetics for comparison. After that, a crusher-run material was spread as a sub-base layer. It was placed in 15cm or 20cm thick layers, and compacted to at least I_D = 0.85, as measured. After measuring the modulus on the top of sub-base layer, an additional 10cm, 15cm, or 20cm thick sub-base layer was spread and the measurement was repeated.

Measurement and results

As indicated above, measurements were carried out in the GLTF, which had been divided into the three same size (3 m x 3 m) testing spaces. Two geosynthetics were measured in one step – one by one in each of two testing spaces and one testing space was kept without geosynthetics a for comparison. Measurement of moduli was carried out three times in each testing space according to both highway and railway standards mentioned above. The following tables display average values of both moduli measured on 15 cm or 20 cm level and on 30 or 40 cm level of sub-base.

Table 2 Measurement on Subgrade with Bearing Capacity of 5 MPa

Testing space	Geosynthetics	Layer thickness	Modulus E_0 [MPa]	Bearing capacity increase	Modulus E_{v2} [MPa]	Bearing capacity increase
I	welded geogrid	15 cm	11.38	1.22	11.38	1.13
		30 cm	23.65	1.07	22.06	1.13
II	non-woven geotextile	15 cm	9.08	no benefit	9.94	no benefit
		30 cm	22.74	no benefit	17.43	no benefit
III	unreinforced (referential)	15 cm	11.13	1.00	10.11	1.00
		30 cm	22.21	1.00	18.18	1.00

Table 3 Measurement on Subgrade with Bearing Capacity of 7 MPa

Testing space	Geosynthetics	Layer thickness	Modulus E_0 [MPa]	Bearing capacity increase	Modulus E_{v2} [MPa]	Bearing capacity increase
I	unreinforced (reference)	20 cm	17.90	1.00	unexecuted	N/A
		40 cm	69.16	1.00	53.66	1.00
II	woven geotextile	20 cm	23.23	1.30	unexecuted	N/A
		40 cm	63.76	no benefit	56.51	1.05
III	rigid Geogrid A	20 cm	24.89	1.39	unexecuted	N/A
		40 cm	62.08	no benefit	55.41	no benefit

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Table 4 Measurement on Subgrade with Bearing Capacity of 15 MPa – 1st Series

Testing space	Geosynthetics	Layer thickness	Modulus E_0 [MPa]	Bearing capacity increase	Modulus E_{v2} [MPa]	Bearing capacity increase
I	Woven geotextile	20 cm	32.35	no benefit	25.17	no benefit
		30 cm	43.75	no benefit	33.28	no benefit
II	rigid geogrid A	20 cm	31.90	no benefit	29.79	no benefit
		30 cm	47.06	no benefit	34.06	no benefit
III	unreinforced (reference)	20 cm	31.74	1.00	28.43	1.00
		30 cm	47.35	1.00	34.20	1.00

Table 5 Measurement on Subgrade with Bearing Capacity of 15 MPa – 2nd Series

Testing space	Geosynthetics	Layer thickness	Modulus E_0 [MPa]	Bearing capacity increase	Modulus E_{v2} [MPa]	Bearing capacity increase
I	rigid geogrid B	20 cm	32.98	no benefit	25.94	no benefit
		30 cm	46.48	no benefit	35.19	no benefit
II	welded geogrid	20 cm	32.80	no benefit	27.87	no benefit
		30 cm	47.38	no benefit	35.54	no benefit
III	unreinforced (reference)	20 cm	38.33	1.00	29.26	1.00
		30 cm	52.48	1.00	37.74	1.00

Table 6 Measurement on Subgrade with Bearing Capacity of 15 MPa – 3rd Series

Testing space	Geosynthetics	Layer thickness	Modulus E_0 [MPa]	Bearing capacity increase	Modulus E_{v2} [MPa]	Bearing capacity increase
I	flexible geogrid A	20 cm	31,16	no benefit	27,18	no benefit
		30 cm	47,92	no benefit	34,82	no benefit
II	flexible geogrid B	20 cm	29,99	no benefit	29,79	no benefit
		30 cm	42,26	no benefit	37,06	no benefit
III	unreinforced (reference)	20 cm	33,36	1.00	28,43	1.00
		30 cm	49,95	1.00	39,89	1.00

Various kinds of woven and non-woven geotextiles, and welded, flexible and rigid geogrids were used for the experiment. All of them are products of well-known producers and are certified for highway and railway usage.

Discussion of results

Table 2 displays measurement results for welded geogrid and non-woven geotextile on a very weak subgrade of 5 MPa of bearing capacity. Measured data shows that there is no benefit from non-woven geotextile on bearing capacity increase. However, welded geogrid demonstrated 22 % and 13 % (railway and highway

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modulus measurement methodology) bearing capacity increase on a 15cm thick sub-base layer in comparison with unreinforced structure, and 7 % and 13 % bearing capacity increase on a 30cm thick sub-base layer.

Table 3 displays measurement results of woven geotextile and rigid geogrid A on a very weak subgrade of 7 MPa of bearing capacity. Measured data shows that woven geotextile yields bearing capacity increases of up to 30 %, and rigid geogrid A up to 39 % on a 20cm thick sub-base layer; however there is no significant bearing capacity increase on a 40cm thick sub-base layer.

Tables 4, 5 and 6 display measurement results obtained for woven geotextile, rigid geogrid A, rigid geogrid B, welded geogrid, flexible geogrid A and flexible geogrid B placed on weak subgrade of 15 MPa of bearing capacity. All results show that there is no significant bearing capacity increase on a 20cm and 30cm thick sub-base layer either.

Outcome

The performed experiments imply that the influence of selected geosynthetics on the bearing capacity increase of weak subgrade is very limited. Measurement shows geosynthetics are able to increase the bearing capacity of very weak soil (a subgrade with bearing capacity expressed by deformation modulus of 5 MPa or 7 MPa), namely in relation to a relatively thin sub-base layer – up to 20 cm. As such a weak subgrade is not useful for highway or railway foundation, it would be useful only for the temporary subgrade improvement of roads on such a weak subgrade. Improvement of weak soil (bearing capacity 15 MPa) by geosyntetics was not shown, in contradiction to the claims in the trade publications from the geosynthetic producers.

2. SELF-COMPACTING CONCRETE (SCC)

A very important operation carried out in case of monolithic concrete constructions and during the production of prefabricated elements is the compaction of the concrete mixture. Compaction is there to ensure both the required density of the concrete, its homogeneity, and also infilling of all the specified room with the concrete mixture, so that the synergism of the concrete with the reinforcement is ensured too. A number of compaction methods and compacting devices can be used for this purpose achievement. Especially nowadays when more and more subtle constructions with high reinforcement degree are being designed, the execution of the compaction process is becoming more demanding, as it is difficult to ensure optimum compaction of all parts of the future construction or of the prefabricated element. This can then cause cavities, gravel nests or other non-uniformity signs or anisotropy, which may degrade the visual effect, allow

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reinforcement corrosion or endanger statistic or possibly even dynamic characteristics of the whole construction. A modern solution to the problem described is using such a concrete mixture that will fill in the entire volume of the construction, thanks to its own gravity effect, and at the same time completely coat up the reinforcement - all this without any need of a compaction operation. The material of such characteristics is called the Self-Compaction Concrete (SCC). But together with the SCC technology being introduced to the civil engineering practice a number of other problems that didn't used to be so important in the past when using traditional concrete technologies become now topical. Mixtures for self-compaction concrete must show high level of mobility at appropriate viscosity (a mixture is supposed to fill in the entire designated space spontaneously), there can be no segregation of the coarse components in the mixtures caused by the effects of the components mobility or by blocking the reinforcement, etc. However, compliance with these requirements often affects the fundamental concrete parameter, which is its strength.

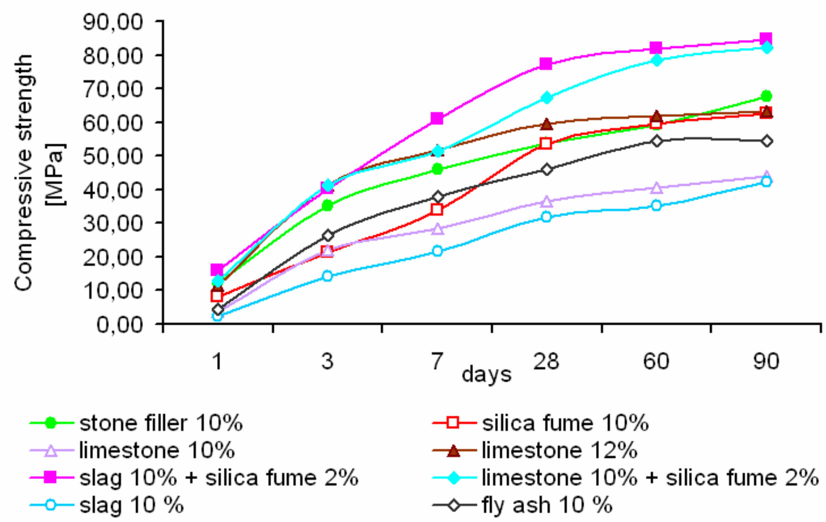

Fig. 2 – Development of the compression resistance increase of various SCC in relation to time

One of the means for reaching the required characteristics of the mixture is making use of the new generation surface-active substances, i.e. super-plastificators adjusting the mixture mobility, and also by the means of higher volume of fine particles proportion in the filler, ensured by the addition of micro-fillers. Industrial by-products can be used as the micro-fillers (e.g. silica fume, fly ash, finely grained slag or limestone, stone fillers, etc.). The SCC technology is therefore important

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also from the view of utilising waste materials and thus contributing to the environment protection.

The SCC technology development has been known since the last decade of the 20^{th} century, so it is a rather new technology. However, CDV infrastructure laboratories have been carrying our surveys concentrated on monitoring the effects of concrete mixture composition on the characteristics of self-compaction concrete already since the year 2000.

Our tests have proved significant behavioural changes of concrete mixtures in relation to their type and volume of the used micro-filler. Similarly, the results of tests on the matured concrete prove a significant dependence of their mechanically-physical parameters on the formulation of the used concrete mixture, see for example the graph in fig. 2. The conclusions of some experimental tests have already been published [9, 10, 11]. Further tests are currently taking place and their results will be gradually announced to the specialists.

3. NON-DESTRUCTIVE TESTS OF BRIDGE CONSTRUCTIONS

The analysis of the central bridge registration on the roads of the CR shows that from the total number of 15 650 of road bridges only 5 823 conform or conditionally conform (i.e. almost don't conform), which is more than a third (37%). From the mentioned number further 1 360 bridges are dilapidated (in a state of disrepair). 19 of these bridges have their span bigger than 100 m, 97 of bridges have span 30 - 100 m, etc. Almost the same can be said about the conditions of bridges in other European countries.

Such poor bridge conditions are caused partly by the lack of financial means for their maintenance, but also by the absence of adequate, relatively quick and cheap monitoring method which would enable us to detect their defects in early stages, allowing us simple a and financially not very demanding maintenance. One of such possible solutions could be a method based on the principle of acoustic emission (AE). Diagnostic methods using AE belong to the group of non-destructive passive methods and use gradual wave pulses. The signals of acoustic emissions accompany the dynamical processes in the material and then come through as gradual elastic wave motion. The source of such wave packages are sudden energy releases in the material. This process is followed by deformation, fracture or phase changes in the material.

CDV is, together with the Physics Institute of Faculty of Civil Engineering, Brno University of Technology, the solver of the grant of the Czech Ministry of Transport "Methodology of the reinforcement corrosion process determination of reinforced and prestressed structures". The aim of this project is to produce

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technical guide that will codify the acoustic emission (AE) method as a method for routine use in the bridge management system.

The survey began by a detail study of survey results of other prominent research centres. It was realised that the task given by the Ministry was with its approach to the point of issue entirely new and that now other research centre had ever specialised in such a project. So from this point of view, the survey is quite unique, on the border of basic research and applied survey. And even though the AE principle has been know for several years, it has never been quite verified whether the corrosion process in the reinforcement can come through in the frequency spectrum of the construction.

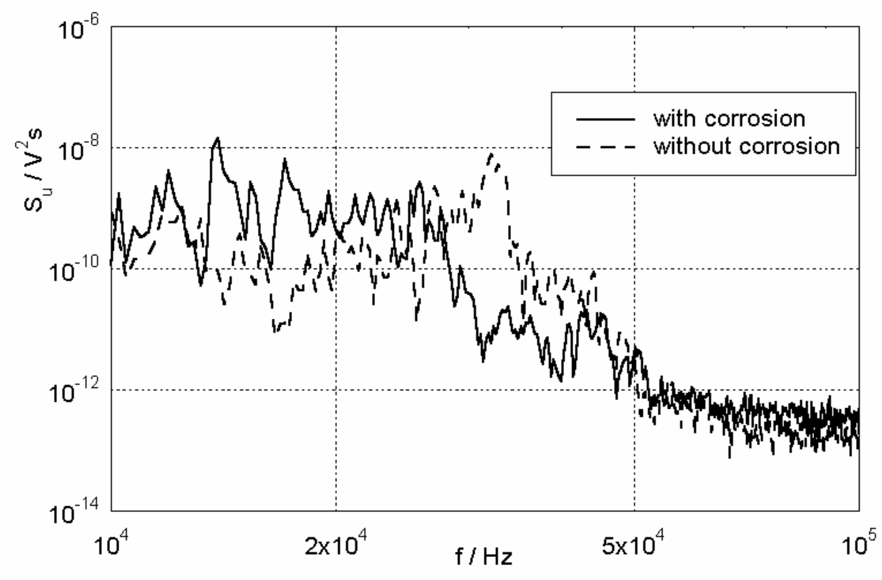

Fig. 3 – Comparison of spectra of supports with corroded and not corroded reinforcement

Another part of the survey was dedicated to finding a device that would be suitable for reading the AE signals both in laboratories and in real conditions. Firstly, a two-channel device was constructed which was later extended into a four-channel one. So now we can measure a signal read by four indicators placed at different parts of the construction at the same time. First measuring was carried out on iron-concrete samples of the size of 10x10x40 cm with built-in corroded and not corroded steel reinforcement of 8 and 10 mm in diameter.

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Fig. 4 – Testing on bridges

The AE impulses have been induced by hits with special hammer onto the surface of the concrete samples, later induced with dynamic loading in a loading presser, which complies better with the real conditions. From the analysis of signals gained when using the Fourier transformation we can see the difference of frequency characteristics between samples with the corroded reinforcement and samples with non-corroded reinforcement, see for example fig. 3.

The laboratory tests were followed by tests on real bridge constructions. The tests have so far been carried out on 5 bridges at different places of the Czech Republic. The AE signals have been induced by driving a dumping car Tatra over a wooden 15 cm high sill. The indicators have been placed on the bridge ceiling, see fig. 4. The results of the research are being continuously published, e.g. [12, 13].

4. CONCLUSION

The activity description of CDV in the field of the transport infrastructure technology mentioned in this article is obviously not complete, due to the limited extent of this article. So let me allow to give at least a simple list of other CDV activities. CDV currently or recently is or was working on other research projects: together with companies PONTEX, Motorway structures Prague (Dálniční stavby Praha) and SMP Construction, on a project of the Ministry of Transport (MD) “Cement concrete pavements on bridges”, see for example [14], and also on various projects of COST 343 – Reduction in Road Closures by Improved Pavement Maintenance Procedures, COST 344 – Improvement to Snow and Ice Control on European Roads and Bridges, COST 347 – Improvement in Pavement Research with Accelerated Load Testing, COST 351 Water Movement in Road Pavements and Embankments, COST 353 – Winter Service Strategies for European Road Safety, COST 354 – Performance Indicators for Road Pavements, TREE – Transport Research Equipment in Europe, etc.

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