Česká geotechnická
společnost **ČSSI**

ZAKLÁDÁNÍ STAVEB
FOUNDATION ENGINEERING

BRNO 2017

13.-14. 11. 2017

45. konference se zahraniční účastí
45th Conference with international participation

Sborník příspěvků / Proceedings

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APPLICATION OF DYNAMIC COMPACTION FOR SOIL STRENGTHENING UNDER A LARGE HALL FLOORS

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Application of dynamic compaction for soil strengthening under a large hall floors
In this paper is presented soil strengthening using DC technology. The soil improvement works of 28 000m^2 floor area were performed in Havirov, in 2015/2016. Dynamic compaction was used there as an alternative to stone columns. Apart of this type of soil improvement, also another two types of technologies were executed: dynamic replacement and bi modulus columns. Both are also shortly described in present paper.

Key words: dynamic compaction, soil strengthening, soil improvement

1. INTRODUCTION

Designing structures' foundation and floors on anthropogenic soils is one of the most common problems during design process of warehouses localized on old industrial areas. According to obligatory standards, this type of existing soils conditions cannot be used to directly foundation. Therefore, many of designers use piling systems to foundation building structures on that type of soils. Piling is, of course, technically proper solution, but economically it increases costs of whole budget of investment. On the other hand, piling solution works only as a second-foundation in layers of well-capacity soils, which transfers whole reactions from structure to deeper part of ground. Piling solution works only punctual, instead of soil improvement propositions, which can improve conditions under whole area of warehouse and/or structures pillars.

Geotechnical market can offer huge range of soil improvement solutions. On areas with industrial soils, one of typical design proposition is executing dynamic compaction, especially under slabs, dynamic replacement as a soil improvement for footing or plates, where also the bi-modulus columns also can be used with success.

In the article those three technologies will be shown based on realization in Havirov, on investment as follow: Nová Továrna na Výrobu Zdravotních Setů – Procedurepak, executed by Skanska CZ.

2. DESCRIPTION OF TECHNOLOGIES

Three techniques were used as soil improvement in the investment as in above. Firstly, the dynamic compaction (DC) and dynamic replacement (DR) were executed. After dynamic technologies execution, bi-modulus columns (BMC) were realized.

DC technology is a simple dynamic technology, used for improve loose non cohesive soil or anthropogenic soils with lack of silt and organic parts. Invented in 60s of 20th century, patented in Menard company, is still very popular technique for reinforcement those types of grounds. Main assume of this technique it to improve weak subsoil by high energy transmission during dropping the pounder. As a result, compaction of subsoil depending on its basic condition, structure and depth is achieved. Dropping energy is transferred to subsoil by multiple impacts with properly shaped steel pounder, with weight ranging from 10 up to 40 tons, freely falling from height between 5 to 40 m.

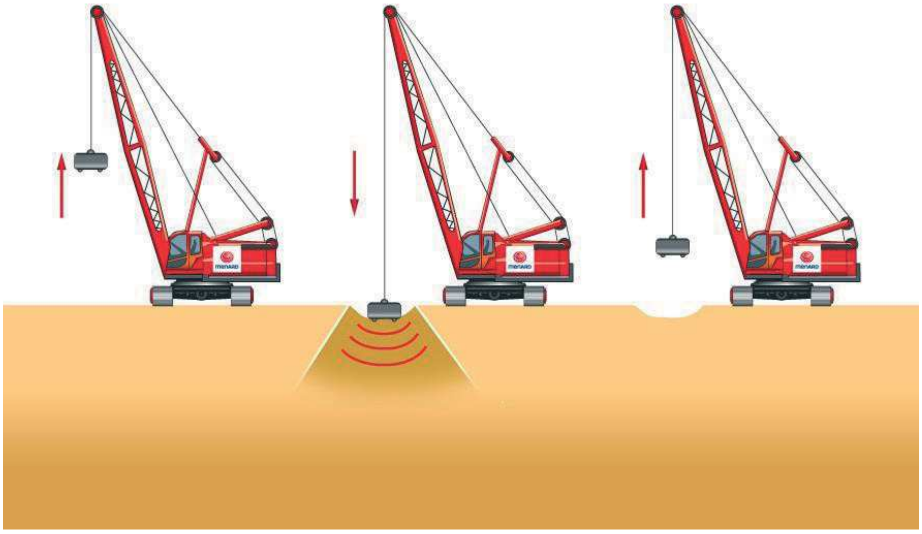


Fig. 1: Dynamic Compaction (DC).

To perform an effective Dynamic Compaction executing, the lattice - boom cranes are used, obtaining sufficiently high impact energy.

Dynamic Compaction method consist of two pounding phases: in first phase the deep layers are compacted, in the second stage intermediate ones. After those two stages execution, surface compaction (so-called “ironing”), is carried out within whole improved area.

To confirm designing assumption, before executing DC technology the test plot is normally preceded. The grid spacing and impact energy (weight, shape of pounder and height of its drop) needed to achieve designed parameters is checked there.

DR (Dynamic Replacement) technology consist on executing big diameter aggregate columns in cohesive soil. It is an amplification of DC technology, with using aggregate fraction till 125 mm. The columns are formed by a heavy pounder 15 up to 30 tons weight, dropped from height ranging from 10 up to 30 m. A single column is formed by a few series of pounding. The pounding process is commenced in a shallow excavation filled in with mineral or recycle aggregate. In first series of pounding, crater in subsoil is formed, and then filled in with a backfill material. Subsequent stages of aggregate adding to the excavation and of pounding are repeated till the moment when DR column is formed according to the previously elaborated design. Often the end of the column forming is indicated by a thud combined with a sudden reduction of the pounder penetration value. Large diameter columns (ranging from 1.6 m up to 3.0 m) are driven to a depth ranging from 2.0 m up to 5.0 m. More information about this technique can be found in [1] and [2].

The BMC (Bi-Modulus Columns) soil improvement technology consists of several stages. The BMC core is made in the same way as the CMC (Controlled Modulus Column) column. A specially designed displacement auger installed on a machine equipped with a high torque and static vertical thrust head displaces the soil horizontally towards the hole centerline. When the displacement auger reaches the required depth the injection grout based on a concrete mixture is pumped under pressure to the hole. The pumped concrete flows through the auger pipe. The concreting process is performed under a pressure which does not cause any damage to the hole walls and prevents from mixing the soil with the injection grout.

A BMC head is formed applying the SC technology in a point of construction of the CMC core. By a specially designed downhole vibroprobe installed on the equipment assembly the BMC head is formed in three basic stages: vibroprobe driving, aggregate backfill and compaction.

3. DESIGN ASSUMPTIONS

Project in those three – DC, DR and BMC –technologies, were executed in November and December 2015 in Havirov - Nová Továrna na Výrobu Zdravotních Setů Procedurepak. General Contractor was Skanska. DC technology were used to improve subsoil under the slab, except 10 m width area nearby sewage system, where BMC columns were executed. DR columns were performed under tanks, nearby to main hall (figure 2).

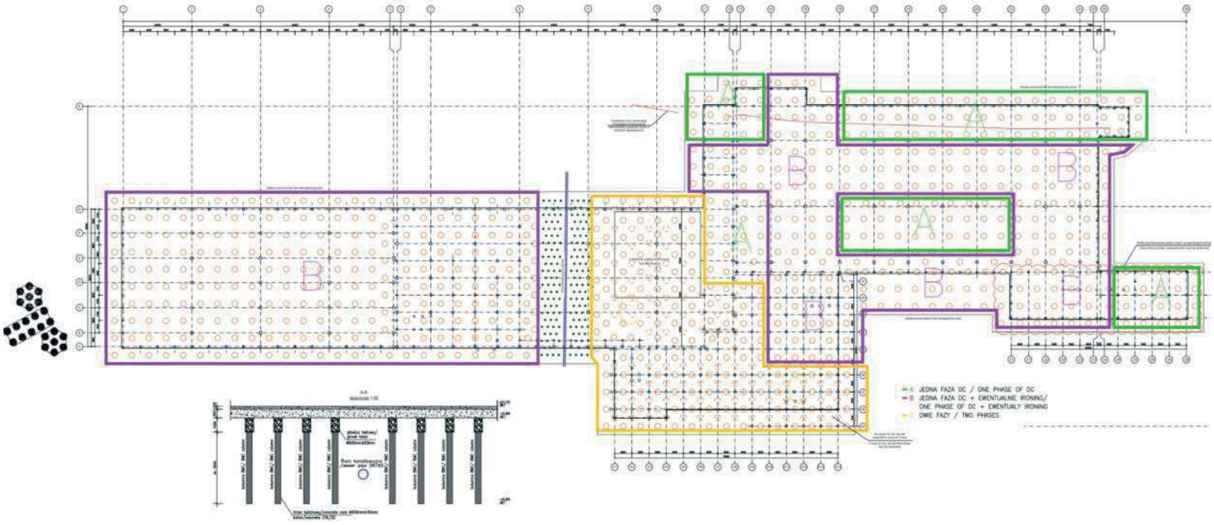


Fig. 2: Plan of soil improvement on Havirov – Procedurepack.

Geologically, the subsoil is built as anthropogec soil till about 4-6 m under the terrain. Below some clays and silts, and silty sands are formed till the end of investigation – 25 m below the terrain level. Details are shown in figure 3.

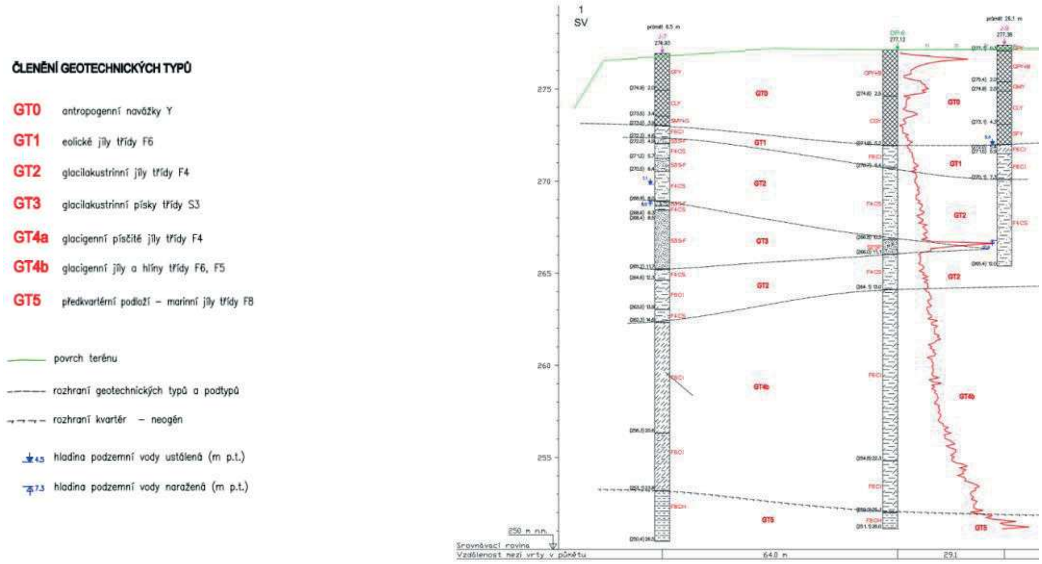


Fig. 3: The typical cross-section of soil investigation for Procedurepack on Havirov.

As a design solution, the following assumption were made:

1. Technologies:
    a. DC – under floors;

   b. BMC – along sewage system (φ700);
   c. DR – under tanks.
2. DC technology
   a. Average relative density to the depth of 5m: $I_D \geq 0{,}50$; $E_{def} \geq 45$ MPa;
   b. Average relative density to the depth of 8m: $I_D \geq 0{,}45$; $E_{def} \geq 40$ MPa;
   c. Drop points spacing: 6,0 m x 6,0 m – square net

Before starts of executing whole works for flooring test area was planned and executed.

4. TRIAL AREA

The test field in dimensions 30,0 m x 30,0 m was done to verify the design assumption and to make eventually corrects in designed solution. The scheme of test field with phases section is shown below on figure 4a. On "part A" the orange points indicates first phase drop point, the green one the second phase. On the other site (part B) violet dots indicates drop points for phase 1 and 2 (drops of second phase in the same points as phase 1). Location of dynamic probing DPM points is shown in drawing 4b. During the test the pounder was dropped from the height 10-15m, 8 times on each point. Only during heave test the drops were different: 4x10m, 4x12m and 4x15m. To perform the soil strengthening pounder which weight was 9 and 14 tones was used. Dimension of the pounder base was 2x2m and 1,5x1,5m respectively.

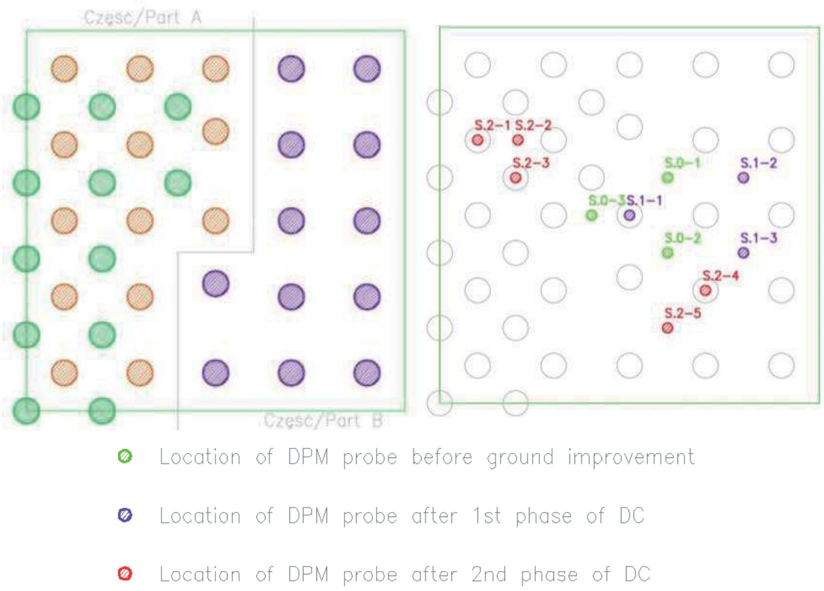


Fig. 4: a) Phases section during the test field, b) DPM tests points.

The test field was carried out to check main aspects of work:
- Soil compaction after works (dynamic probing DPM)
- Ground lowering after the works (survey measurements)
- Working parameters (no of drops, no of cycles, drop height checked by "heave test")

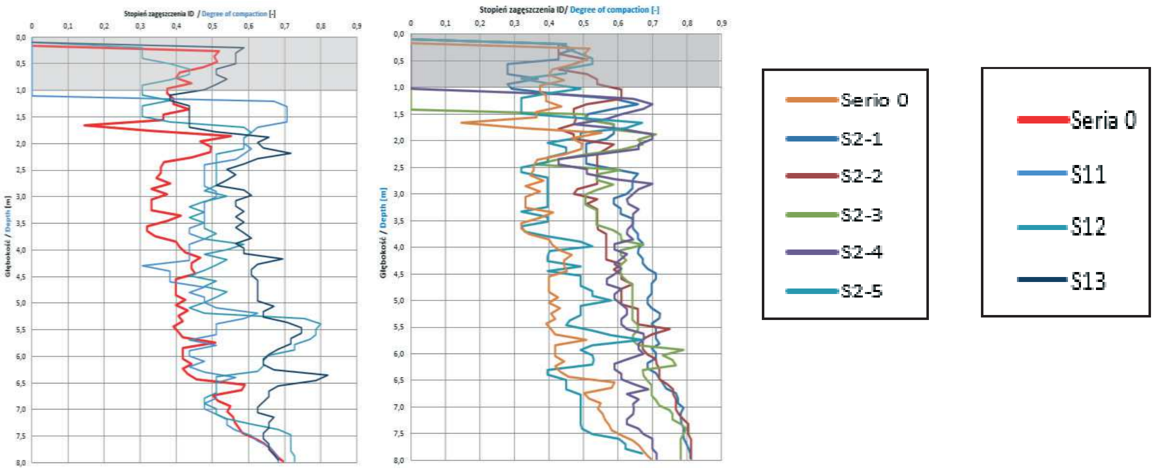


Fig. 5: The DPM probes results from trial area after 1 and 2 phase.

Considerable increase of degree of compaction after the DC is shown at the graphs above. Therefore the technic of soil strengthening as DC was an appropriate choice. The main soil improvement should be carried out with the same rules as on the A part of the test field. At almost all of the probes made after the 1st phase and after the 2nd phase of DC, the degree of compaction till 5 meters under the terrain is above 0,5. Also till the depth by 8 m under the terrain there was no demonstrated to found the degree of consolidation less than 0,45 in any points.

Another part of the quality tests on trial area was so called "heave test". The Heave test consists on determining the uplifts of ground nearby the pounder's drop point by the geodetic measurements of control picket rising. Crater dimensions were also checked during the tests. The Heave test was made after the 1st and the 2nd phase of DC. During the first phase of pounder drops (12 times) no heave were measured. Tests results from the second phase are shown below on figure 8. The soil uplift was getting higher from the drop no 8 which can be assumed as the last to be performed. Based on the measurements ground level lowering was possible to estimate. The estimated ground settlement was 17 cm after first phase and next 15 cm after the second phase.

Based on leveling measurements (by surveyor) of the test field it was obtained that the soil surface settled about 15,0cm after first phase. Generally average value of settlement was about 30 cm. The decreasing is accordant to the expected by the Menard Polska during the designing the Technological Project.

The information obtained from the test field allowed the final arrangement of impact point and selection of other technical parameters to be made.

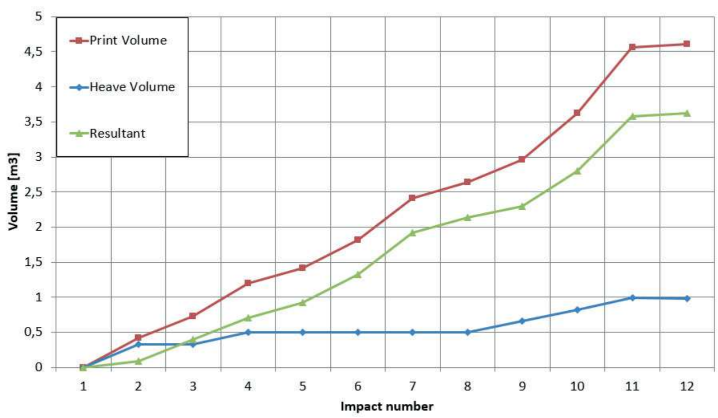


Fig. 6: Ground heave and crater depth during second phase of ramming on trial field.

5. SOIL STRENGTHENING EXECUTION

While DC is a technique based on trials, successfully lead trial area enable to estimate working parameters which were applied during execution. During the one phase works the pounder was dropped from the height 5-18m, 5-10 times on each point. The works were executed within 6 weeks. This include 28 000 m^2 of soil strengthening under floors, DR pillars execution under tanks and BMC piles as well. DC execution were divided on three main areas (see figure 2): A (green) – area of one DC phase; B (violet) – area of one phase of DC and ironing; C (yellow) – two phases of DC. As DC is technique which is based on trials the design was adapted to the works on site. After the first phase of ramming (weight drop) quality check were done. After analyzing the results another one phase or even two were run. So called "active design" must always be performed during work execution with this recurrent technique. Picture from the execution stage is shown below (fig.7).

Fig. 7: Soil strengthening execution on the described project.

The application of the Dynamic Replacement and Dynamic Compaction technology involves the generation of a shock wave which may have a negative impact on the surrounding civil structures; therefore, it is recommended to monitor the impact of vibrations on the civil structures while performing the Dynamic Replacement method works at a distance lower than 50 m from the structure. During the works on 3 areas vibration measurements on neighboring structure was carried out. The measurements results confirmed that the works did not influence the technical stage of the building. Additionally to vibration measurements cracks on the nearby building were measured – they did not extend after the works. The results were really satisfying while the building was in technically bad condition and the distance to nearest point of strengthening was about 25m. On figure 8 the building nearby the site is shown, additionally typical vertical acceleration graph is shown.

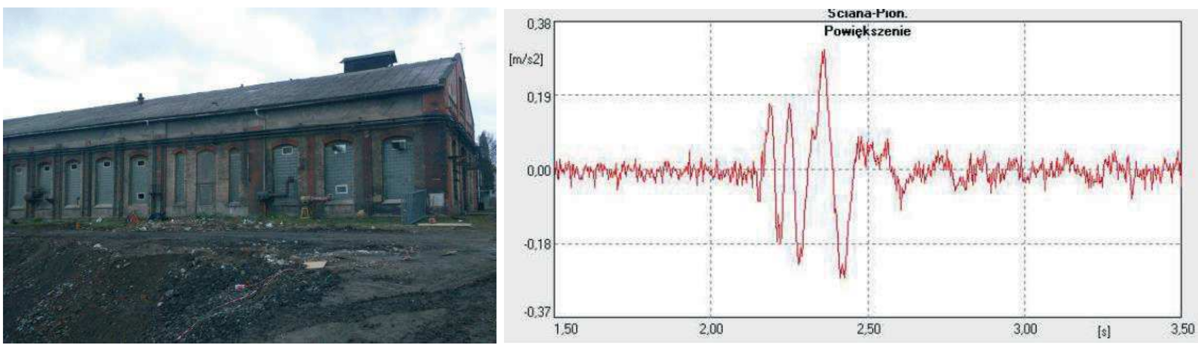
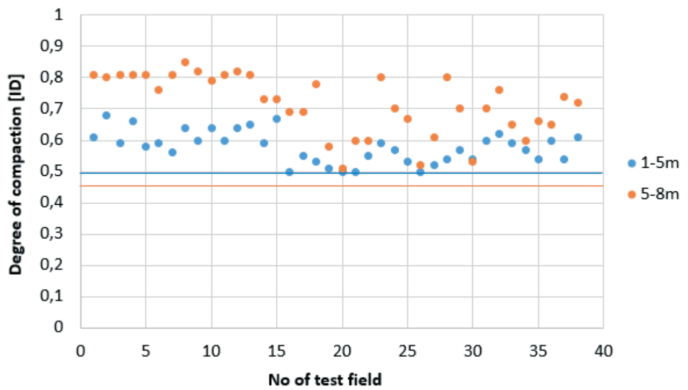


Fig. 8: Building on which vibration measurements were taken and examplary acceleration graph.

6. QUALITY CONTROL

Due to quality control needs the terrain was divided into 38 a[illegible] vas strengthened separately and on each area quality control dynamic [illegible] vas performed. In case of performing more than two phases also two quality check tests were performed. In the graph below (fig. 9) the final results are shown.



I_D	E_{def}
0,40	34
0,45	40
0,50	45
0,55	51
0,60	56
0,65	62
0,70	68
0,75	74
0,80	79

Fig. 9: Reached copaction degree and values of calculated E $_{def}$ parameter.

In the described case as usually when using this technique the reached ground parameters were quite homogeneous. It was noticed that in this area where soil was already compacted the improvement was not visible (see figure 10a on the depths 4-8m). However in most of points the improvement was significant like on exemplary area 23 (see figure 10b). What is needed to be mentioned – the quality tests were carried before the heavy roller compacted the top 1m of the soil. This range of depths is usually not compacted in DC technique and needs to be improved later with use of roller. The dynamic replacement columns performed under the tanks were also checked. The DPM sounding were performed in the middle of the columns. On fig. 10c one of the tests results is shown. It can be clearly seen that the column length was about 4m. The stiffness of the soil under the column was stress dependent (increasing with the depth).

a) b) c)

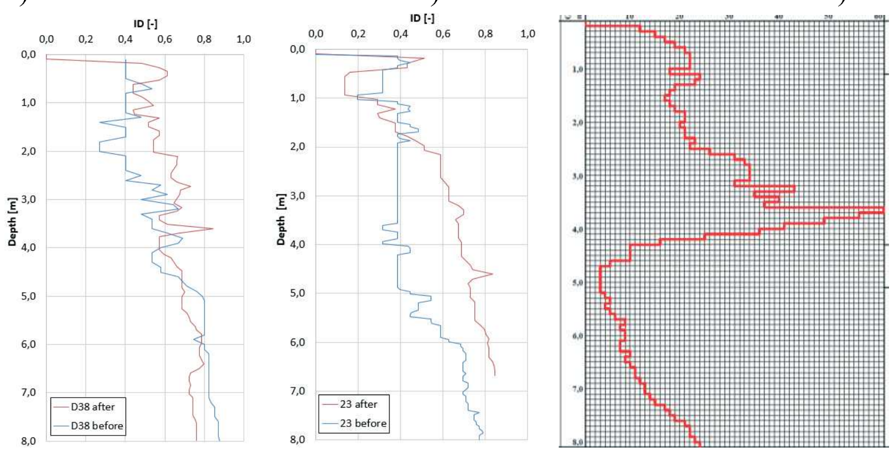


Fig. 10: Quality control DPM tests results.

7. CONCLUSIONS

On the turn of the year 2015 and 2016 soil strengthening under the hall NOVÁ TOVÁRNA NA VÝROBU ZDRAVOTNÍCH SETŮ PROCEDUREPAK was performed. During DC/DR/BMC performance, all needed tests were made: trial field with all necessary tests, dynamic probing on areas where DC was performed, dynamic probing in DR columns and tests of adverse dynamic effects on the neighboring structures. Tests results made on trial field affirmed the validity of using dynamic compaction to strengthen the soil on the main area of the hall. Tests results are considered as satisfied.

After analyzing the dynamic probing results it was established that on all tested areas necessary compaction (strengthening) was achieved. On some areas the required parameters were achieved after second or third phase of compaction. However it do not change the fact that soil parameters after strengthening works are quite equal. Dynamic probing in DR columns prove their high stiffness. Vibration measurements on neighboring structure prove that strengthening works do not caused any damage to them.

The achieved results are proven that dynamic compaction method can be seen as recurrent technique to improve anthropogenic soils (made ground) with vary degree of compaction.

8. ACKNOWLEDGEMENTS

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