

# EXPERIENCE WITH LIGHT DYNAMIC PENETRATION IN A LANDSLIDE LOCALITY

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## ABSTRACT

Because of vital prevention and redevelopment measures in problem localities affected by slope instability, geotechnical investigations must be carried out. One of the applicable methods is Light Dynamic Penetration (LDP). Although it was designed for easy field investigations in planning line structures to identify parameters, such load bearing capacity, and compactness, its use proves to be much wider. Using LDP it is possible to detect the interfaces between the discrete layers, potential slip surfaces, or groundwater level. However, it is important to note that the results of LDP are always related to one point only and to investigate a whole area, a complementary survey is needed. In the paper we report research where we used a geophysical method of Electrical Resistivity Tomography (ERT) to validate the results rendered by Light Dynamic Penetration in a redeveloped post-mining locality characteristic of landslides. The results of both measurement methods were unified for better interpretation and clarification to find out whether LDP is suitable to investigate a landslide locality. It shows that LDP provides relevant information on the mass structure in a given locality, but as opposed to other geophysical methods LDP informs only about one point only. The authors thus recommend carrying out surveys in landslide areas combining LDP and ERT as complementary measurements of groundwater level in the openings made using LDP. Mutually combining these two methods, it is possible to obtain a number of valuable information on landslide conditions (depth and course of shear plane, groundwater level, structure of layers, etc.) and physical-mechanical properties of soils.

**Keywords:** Light Dynamic Penetration, Slope instability, Electrical Resistivity Tomography

## 1 INTRODUCTION

Environmental hazards in the form of landslides or slope deformations are some of the serious problems in the building industry and opencast mining of mineral resources. However, landslides and slope deformations have been natural parts in the development of the earth relief since the very beginning. Instabilities occur not only due to anthropogenic interference, but are common on natural slopes constituted of soils or rocks. In both cases, processes that activate instabilities may last from several seconds to long time periods, when stability conditions deteriorate gradually. All slope movements arise due to the effect of gravity that influences soils and rocks in a slope. Movements occur when the stability conditions, given by the balance of forces, are disrupted. The first acting force in the steady state is shear resistance, which prevents the slope to move. On the contrary, the second force, the so-called shear stress, generates the movement of the slope body and acts in the direction of landslide. The gravity manifests here as the so-called gravity force, which acts under the slope angle and decomposes into normal force (perpendicular to the slope) and circumferential stress (parallel to the slope). This implies that when shear stress exceeds shear resistance, slope movement occurs. The factors that have negative influence on slope stability are those that either increase shear stress (e.g. slope inclination, vibrations, slope load, water pressure, etc.), or those that reduce shear resistance (e.g. weathering, changes in the structure, water uplift, etc.) [1].

These physical-mechanical properties of soils constituting a slope are the input data for stability calculations. Due to vital safety precautions in problem localities, it is important to improve the accuracy of geotechnical investigations via testing new methods.

This paper focuses on Light Dynamic Penetration in the context of landslides and slope movements, which are some of the most serious hazards in the building industry and opencast mining. Although Light Dynamic Penetration (LDP) and its application has been reported in [2,3,4], the research on the use of LDP is still needed and must be verified in contrast with other methods.

## 2 STUDY LOCALITY

The study locality where the measurements were carried out is situated within the redeveloped locality of Most Lake, the Czech Republic. The locality is characteristic of recognizable manifestations of slope instability. In total, 15 penetrations were systematically executed in 3 profiles. The first profile includes points 1–5, the second profile includes points 6–10, and the last profile, which is reported in this paper, includes points 11–15. The study locality and the distribution of the different points and profiles are seen in Figure 1.

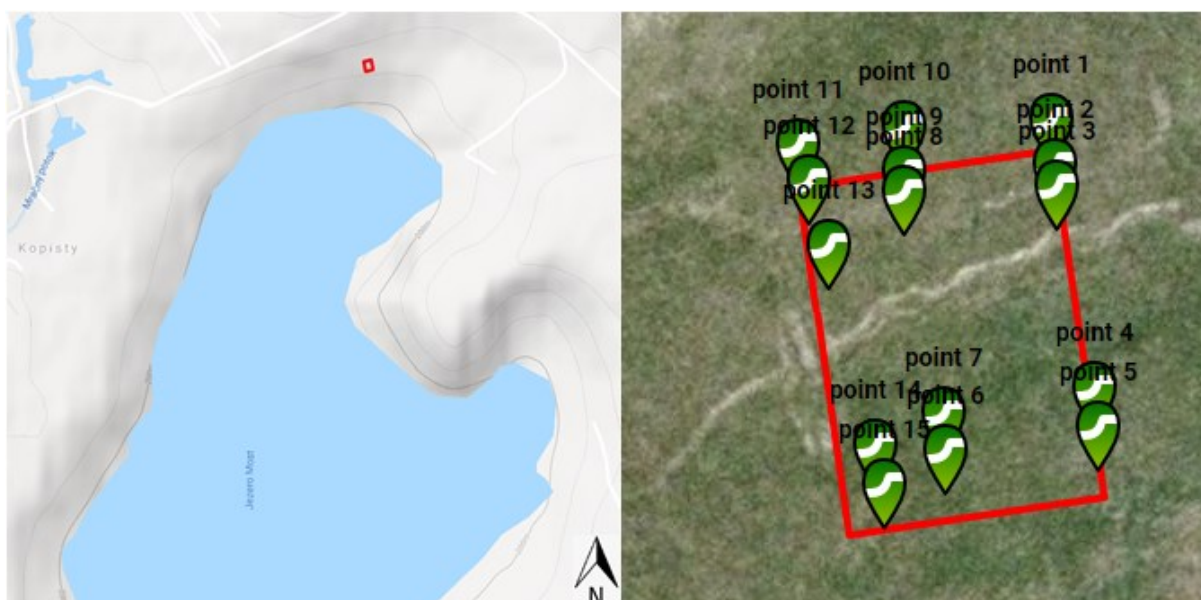


Figure 1. Study locality and the points of penetration

### 3 METHOD

The principle of LDP is to determine the resistance of soils or weak rocks to the penetration of the probe. This test is done in-situ. The so-called constant impact force is used for the penetration, which is reached by a drop rammer of a known weight falling from a constant height to an LDP anvil. The penetration resistance is defined as the number of rammer blows needed to drive a cone into a given depth (10 cm in Light Dynamic Penetration).

When evaluating LDP results, it is important to keep in mind that the number of blows per 10 cm is of a reference value only. For this reason, we do not account for parameters such as the weight of penetration probe rods in dependence on the depth, or it ignores the friction due to possible clamping of rods in the massif under investigation. The so-called Dynamic Penetration Resistance  $q_{\text{dym}}$  was introduced, which contains all factors affecting the penetration results. The value is obtained based on the formulas below [5]. Table 1 gives an outline of the different quantities.

$$r_d = \frac{E_{\text{theor}}}{A \cdot e} = \frac{m \cdot g \cdot h}{A \cdot e} \quad (1)$$

$$q_d = \left( \frac{m}{m+m'} \right) \cdot r_d \quad (2)$$

Table 1. Outline of quantities and values

designation	name	unit
$r_d, q_d$	resistance	[Pa]
$E_{\text{theor}}$	theoretical energy due to impact	[J]
$A$	cone base surface area	[m <sup>2</sup> ]
$e$	average penetration per blow	[ - ]
$m$	rammer weight	[kg]
$m'$	rods weight	[kg]
$g$	gravity acceleration	[m/s <sup>2</sup> ]
$h$	rammer drop height	[m]

To verify the results rendered via LDP, we carried out a geophysical investigation in the profile by means of constant separation resistivity method – Electrical Resistivity Tomography (ERT). It is a frequently applied method in geophysical investigations of landslides [4, 6]. In this case, we applied the method using the ARES 200E instrumentation. The obtained data were processed using a special-purpose software by Geotomo Software – RES2DINV.

#### 4 RESULTS OF LIGHT DYNAMIC PENETRATION IN PROFILE 3

As an example, we report the evaluation of Profile 3, which is represented by points 11–15, in Figures 2 to 6 below. In this profile, the reference method applied was ERT. The interpretation of ERT results are given in Figure 7.

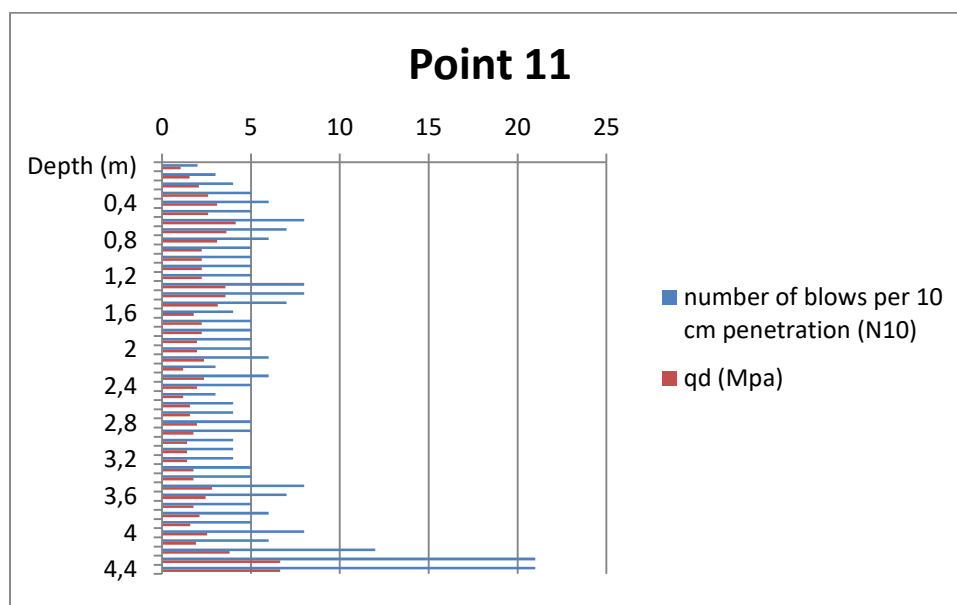


Figure 2. LDP results for point 11 (HPV=1.6m)

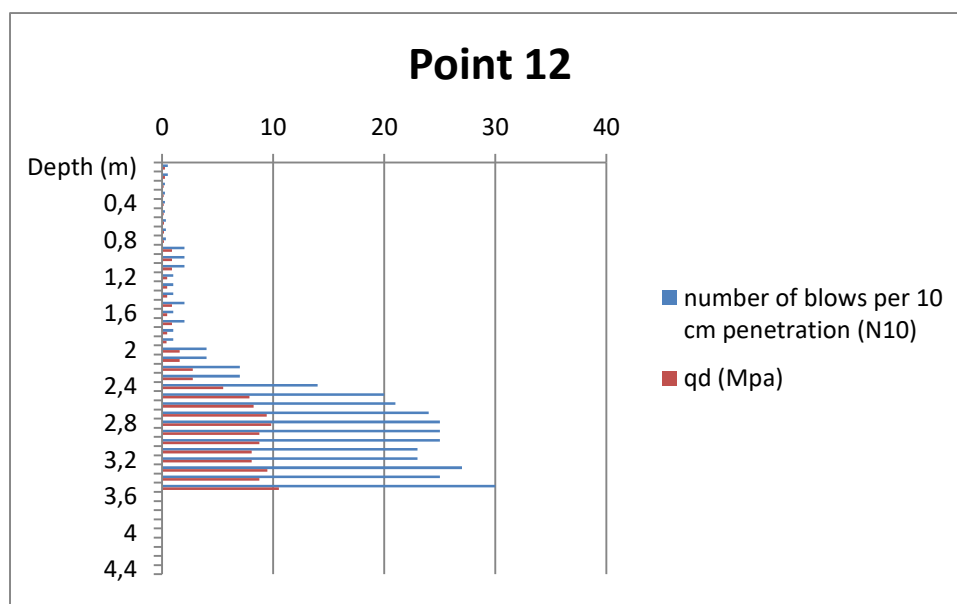


Figure 3. LDP results for point 12 (HPV= 0.2 m)

The evaluation of dynamic resistance in the profile implies that the dynamic resistance values vary considerably (from about 0.1 to 12MPa) and likely depend on the soil consistency (water content in the soil). A decrease in the values followed by a soaring value may be related to the localisation of a slip surface. The lowest values were reported in points 12 and 13, and using the water level meter NPK G10, groundwater level was measured to be closest to the ground surface in these two points. In general, very low values of dynamic resistance occurred in all points, which corresponds to a water-bearing horizon above a slip surface. This was confirmed by a liquid level indicator and by geophysical investigation. A rather fast increase in the dynamic resistance from about 2 m below the ground surface was reported in point 12, which could indicate a crown of more solid or impermeable rocks. This was confirmed by the geophysical investigation, and a similar result was reported in Profile 1 too.

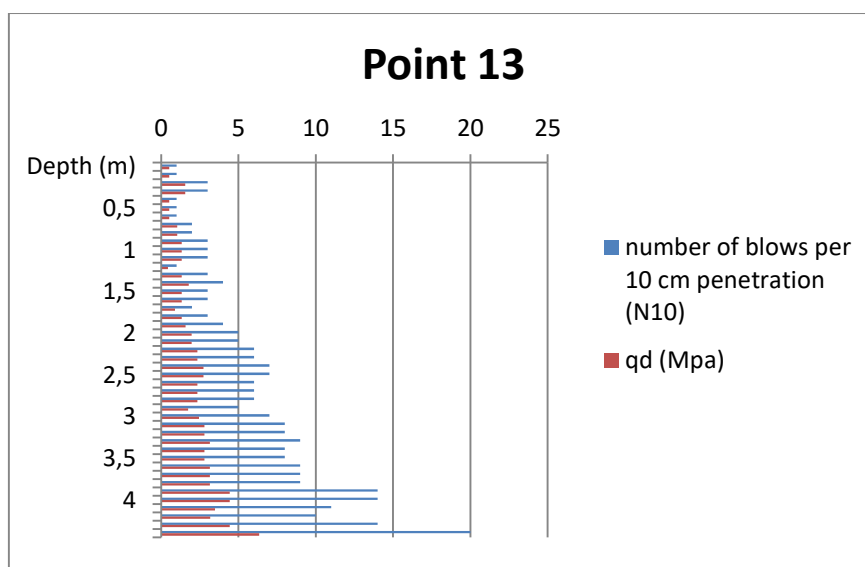


Figure 4. LDP results for point 13 (HPV= 0.1 m)

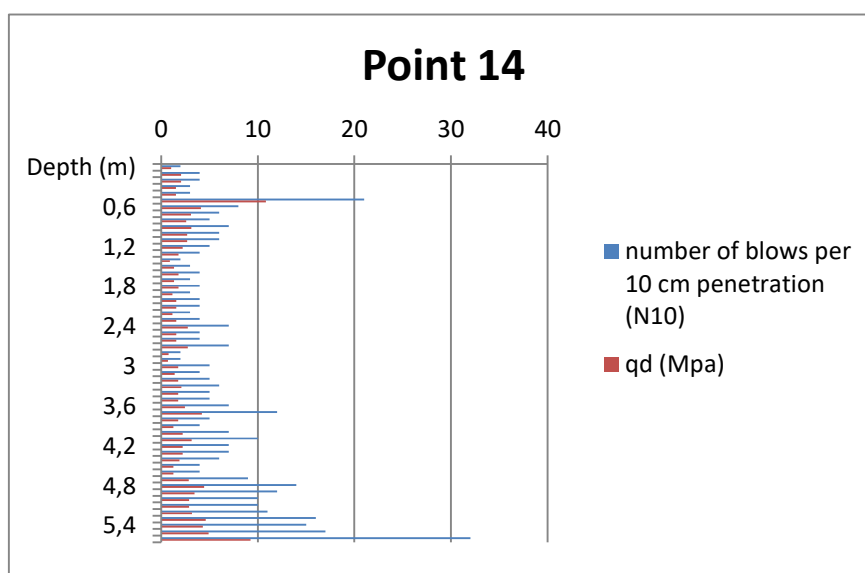


Figure 5. LDP results for point 14 (HPV= 0.6 m)

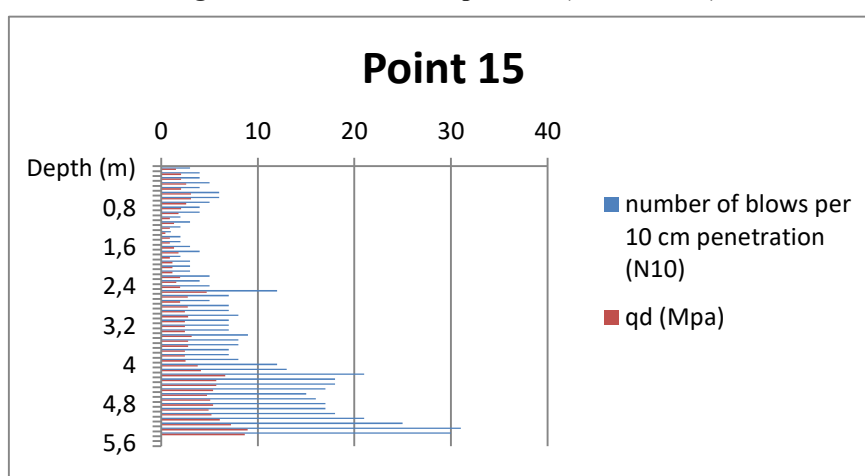
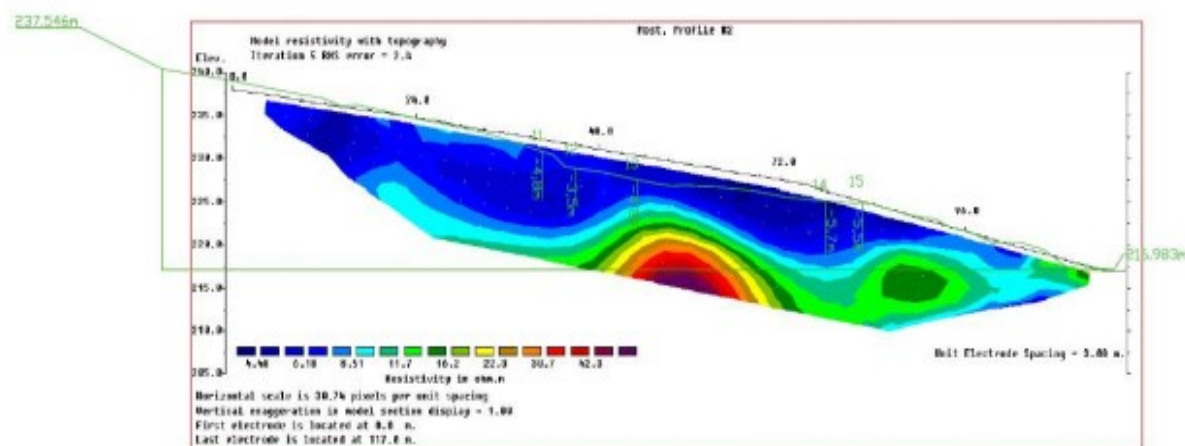


Figure 6. LDP results for point 15 (HPV= 3.6m)

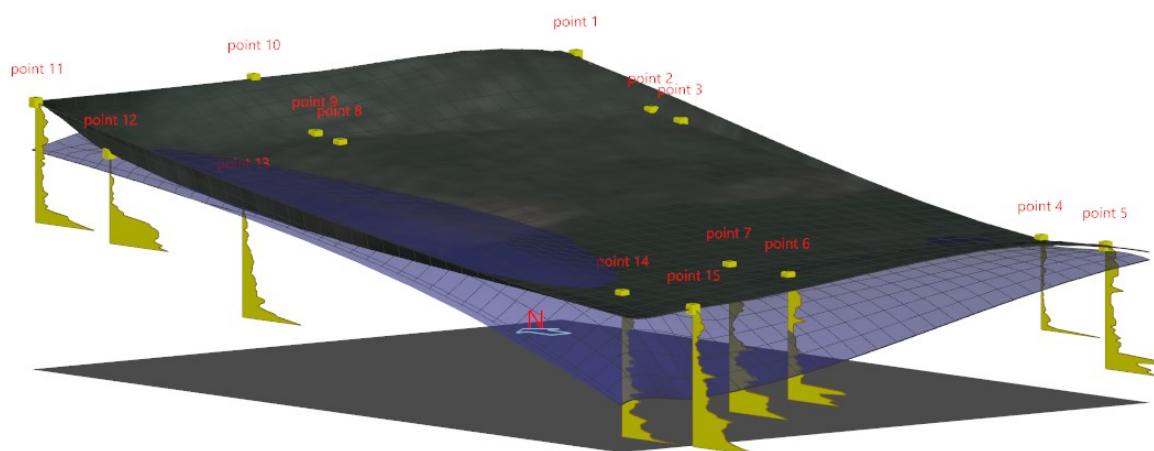
Figure 7 gives a graphical interpretation of results from ERT. It must be pointed out that the cross section geometry to interpret the ERT method is simplified and corresponds to the general slope inclination. The course of real slope is plotted in green. Figure 7 also shows points where Light Dynamic Penetration was carried out. The

cross section clearly shows an area with considerably lower resistivity values (in blue), which is likely to represent areas with increased water content. This corresponds to the results obtained via LDP. Deeper there is a clear area with increased resistivity (red to brown), which forms a certain crown in one place. It may be an area of more solid, impermeable soils, e.g. claystone, which forms a natural dam for groundwater. During increased precipitation, the groundwater level rises over the 'crown' and spills over to lower places, where it may act as an active force due to pressure. This way, it lowers the slope stability.



**Figure 7. Final resistivity values in the Profile 3 and marked LDP points**

Next, the measured locality was modelled (Figure 8) in GEO5 – Stratigraphy programme. This programme is used for geological modelling and production of geological cross sections, but may also be used to evaluate field tests, such as LDP. A 3D model of the situation was made, into which all 15 penetration points were imported and evaluated. As clear from Figure 8, the discussed points 12 and 13 were located in waterlogged terrain in the real conditions of the locality.



**Figure 8. 3D model of the study locality in GEO 5 programme**

However, the LDP results from GEO 5 programme, seen in the 3D model, only depict the dependence of the required number of blows to reach the required depth, in contrast to Figures 2 to 6, where the values were already recalculated based on the used formula into the values of dynamic penetration resistance  $q_{dym}$ .

The software GEO 5 is able to export the records from the different measured points in the form of a graphical output - see Figure 9.

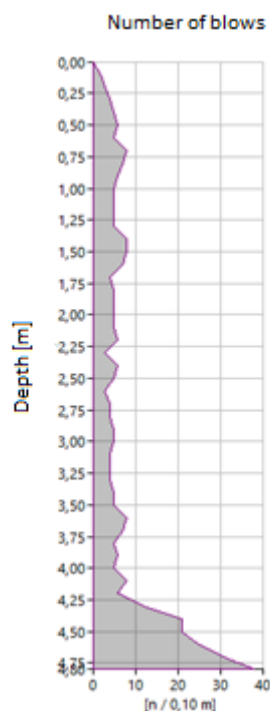


Figure 9. Example of final value of point 11 from GEO 5 programme

## 5 CONCLUSION

The paper described experience with the application of Light Dynamic Penetration as a tool to investigate instable localities and to identify potential sub-surface water and surface slips. To verify the suitability of LDP, we also used geophysical investigation, namely using Electrical Resistivity Tomography, and measured the groundwater level using an electro-contact water level meter.

The existing measurement results show that Light Dynamic Penetration may be used for the geological investigations of slope instabilities. Using LDP, it is possible to locate water bearing horizons, which have strikingly lower levels of dynamic resistance. A significant increase in the dynamic resistance points at the boundary between saturated and unsaturated soils, e.g. a potential slip surface.

In conclusion, we must emphasize that despite the fact the method is able to identify the boundary between layers, potential slip surfaces and groundwater levels, the interpretations are done only for single points. To obtain a complex idea of the layer sequence, or slip surfaces, it is advisable to do complementary investigations, for example, using Electrical Resistivity Tomography. With regard to the low price of LDP and its simplicity, LDP shows as suitable for the initial surveys or a complementary method for extensive landslide areas, where other methods cannot be applied because of time or cost intensity.

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