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Effects of Excavation Damage on the Electrical Properties of Rock Mass

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Abstract

Electrical and electromagnetic (EM) methods have been used for characterisation of Excavation Damage Zone (EDZ) in conjunction with long-term safety evaluation of geological disposal of spent nuclear fuel. Physical properties of the rock have been tested in laboratory to characterise the property changes related to EDZ. EM research has focused around Ground Penetrating Radar (GPR) utilizing GPR EDZ method, developed for excavation quality control in means of EDZ extend. For 20 specimens, resistivity, relative dielectric permittivity (ε_r) as well as high frequency scattering parameters (electrical conductivity and ε_r) were measured. Induced Polarization (IP) values were calculated from resistivity data. Resistivity, IP and ε_r, was produced to support the use of GPR image analysis and the GPR EDZ method. Results were analysed to reveal links between ε_r and conductivity, and to analyse possible depth dependencies. A positive association between electrical conductivity and ε_r was observed. Changes in the electrical properties linked to shallow depths and visual EDZ features were observed, which seems to validate the theoretical basis of the GPR EDZ method. Electrical property data allows further modelling, development and assessment of the GPR EDZ method.

Keywords

Excavation damage, scattering parameters, electrical resistivity, electrical conductivity, induced polarisation, relative dielectric permittivity, network analyser

Introduction

Excavation damages the rock in the tunnel vicinity and this weakens the rock mass. Formed damage zone in the tunnel vicinity, microscopic as well as open fractures, are referred to as Excavation Damage Zone (EDZ). Understanding the formation and physical characteristics of excavation damage is critical for the long-term safety evaluation of deep geological disposal of spent nuclear fuel. More intense and deeper the EDZ penetrates, the higher is the risk for formation of pathways for the radio nuclides to the organic nature. As the EDZ is seen as a long-term disposal safety issue, it has to be controlled. Methods for controlling EDZ are Drill and Blast (D&B) method related (drilling, charging and workmanship, e.g.) but a measurement method for EDZ is needed as well. The Finnish company Posiva has been developing high frequency Ground Penetrating Radar (GPR) method for the task since 2008, resulting in a GPR signal frequency content analysing method called GPR EDZ method (Kantia et al., 2012; Kantia et al., 2013; Kantia et al., 2016a). It appears that the GPR EDZ method can be used in EDZ characterization (Heikkinen et al., 2010) as well as in EDZ extent measurements (Kantia et al., 2016b). In this work, electrical properties of intact and damaged rock specimens were determined to verify the feasibility of the GPR EDZ method and allow theoretical modelling of the GPR signal in the rock mass.

Excavation damage zone

Terminology used in EDZ investigations is based on a paper by Dinis da Gama and Torres (2002) which defines several levels of distinctly different damaged zones: (1) zone of crushing, (2) zone of radial cracking, (3) zone of extension and expansion of fractures and (4) elastic zone where no cracks are formed (Figure 1). Siren et al. (2014) separate the most important formation mechanisms of EDZ as (1) EDZ_{CI} - Construction induced excavation damage zone, which is instantly formed by the construction method and (2) EDZ_{SI} - Stress-induced excavation damage zone, which is consequence of the redistribution of the stress field in the rock (Figure 2). EDZ influences the physical and mechanical properties of the rock mass and EDZ effects are different in different rock types. For example, granitic pegmatoid (PGR) with intense micro fracturing differs from veined gneiss (VGN) characterised by clear individual fractures that penetrate deeper.

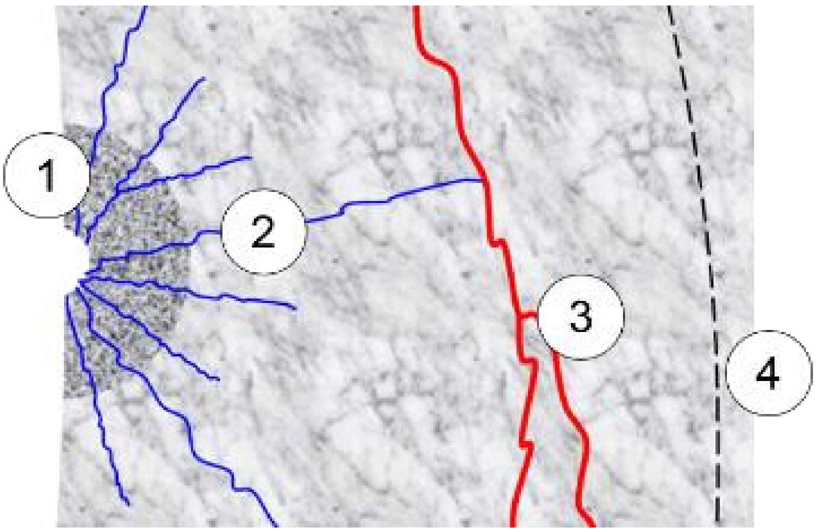

Figure 1: *Schematic presentation of different type of damages near the blasting hole and tunnel surface as classified by Dinis da Gama and Torres, 2002: (1) zone of crushing, (2) zone of radial cracking, (3) zone of extension and expansion of fractures and (4) elastic zone, where no cracks are formed. Adapted from Kantia et al. (2016).*

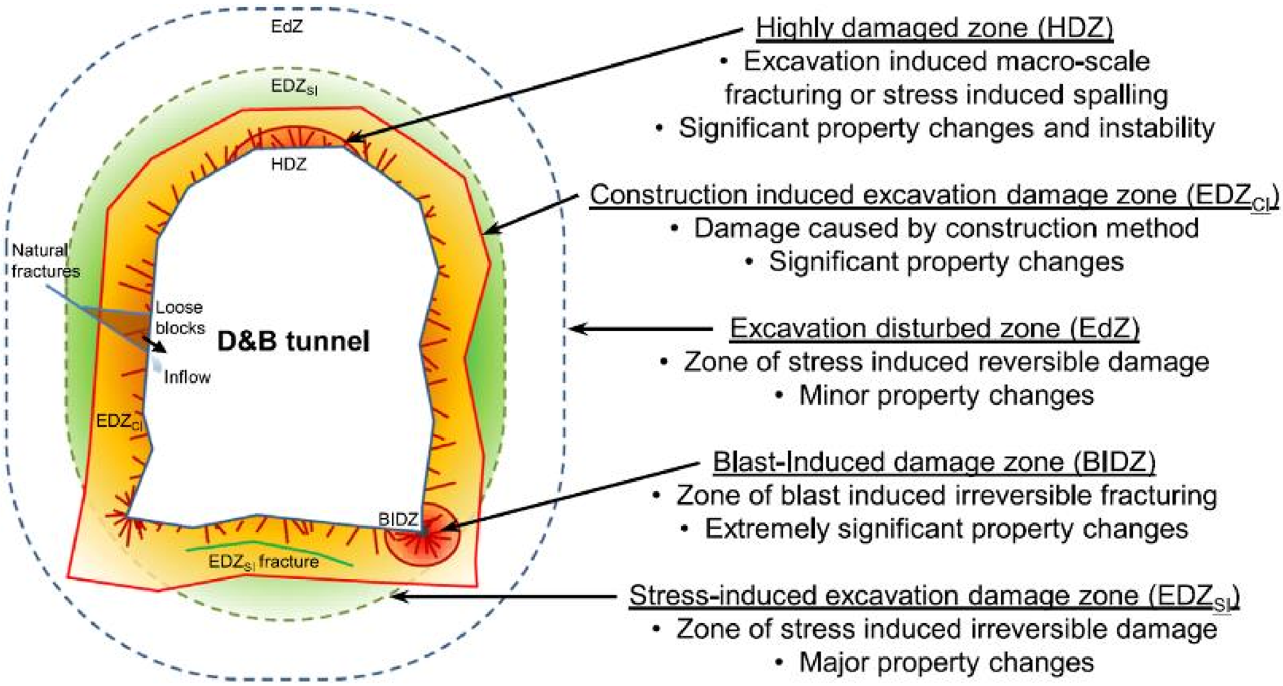

Figure 2: *Definitions of the different damage zones used in this work. Modified from Siren et al. (2014)*

Measured electrical properties and observed changes

For 20 specimens, electrical resistivity, induced polarisation (IP effect, describes chargeability of the material) and relative dielectric permittivity (describes attenuation of an electromagnetic wave in the material) values as well as high frequency scattering parameters (electrical conductivity and relative dielectric permittivity) were determined. Resistivity was first measured at 0.1 Hz, 10 Hz and 500 Hz using a proprietary measurement system developed by the Geological Survey of Finland. From the measured resistivity values, IP effects (0.1 Hz / 10 Hz and 0.1 Hz / 500 Hz) were calculated. Relative dielectric permittivity was measured using an Adek v.7 percometer operating in the 40 – 50 MHz range (for 19 of the 20 specimens). Description of the resistivity, IP effect and relative dielectric permittivity measurements can be found in Kiuru (2017). High frequency scattering parameters (electrical conductivity and relative dielectric permittivity) were measured for all specimens both saturated and dry at 2 GHz and 3 GHz using an Agilent network analyser. Results are shown in Table 1.

Results were analysed to reveal associations between electrical parameters and their possible depth dependencies. A general increase in relative dielectric permittivity was observed with increasing resistivity (Figure 3), while scatter of the observed values also increases. At the low frequencies (0.1 Hz, 10 Hz and 500 Hz) resistivity is generally higher in the first 20 cm of the excavated surface, and shows higher variation than deeper (Figure 4, left). A similar effect was also observed at higher (2 GHz and 3 GHz frequencies), if not as pronounced (Figure 4, right). Relative dielectric permittivity shows higher values and variation near the excavated surface as well (Figure 5). Changes in the electrical properties linked to shallower depths could in some cases also be linked to visually observed EDZ fractures in core samples (Kiuru et al., this publication), which seems to validate the theoretical basis of the GPR EDZ method.

Table 1: *Results from the measurements.*

Sample	Rock type	Depth	Porosity	Resistivity					Permittivity		
				R0.1	R10	R500	2G	3G	ε_r	$\varepsilon_r'^1$	$\varepsilon_r'^2$
		m	%	Ohm.m							
ED123	VGN	0.054	0.81	11900	11200	10200	67.0	47.4	6.30	6.65	6.58
ED124	VGN	0.135	0.60	18200	16700	14500	114.9	87.3	6.44	6.15	6.10
ED131	VGN	0.115	0.24	34600	31300	27300	188.0	151.8	6.17	5.53	5.51
ED132	VGN	0.170	0.25	21500	20100	18400	264.8	247.5	6.35	5.19	5.17
ED141	VGN	0.590	0.45	8540	7810	7080	118.7	103.1	6.40	6.28	6.19
ED142	VGN	0.645	0.55	7190	6990	6640	87.8	71.6	6.26	5.99	5.91
ED144	PGR	0.200	0.41	5050	5190	5140	200.5	189.6	5.32	5.39	5.34
ED145	PGR	0.255	0.36	6010	6450	6340	155.9	142.1	5.28	5.28	5.24
ED146	PGR	0.310	0.27	14600	14300	13700	107.9	93.9	5.81	5.51	5.43
ED147	PGR	0.365	0.32	9850	9470	9060	105.9	94.5	5.71	5.47	5.41
ED152	PGR	0.530	0.32	8100	7990	7740	189.7	179.8	5.59	5.31	5.26
ED153	PGR	0.585	0.40	5920	5740	5480	180.4	166.3	5.61	5.35	5.31
ED154	PGR	0.640	0.26	7370	7240	7000	184.7	170.4	5.22	5.41	5.38
ED165	PGR	0.115	0.31	4780	4640	4500	199.2	190.9	5.56	5.23	5.20
ED166	PGR	0.170	0.28	6260	6150	5960	180.8	169.8	5.48	5.30	5.26
ED170	PGR	0.390	0.41	9900	9500	8910	188.0	181.3		5.28	5.24
ED172	VGN	0.055	0.22	16400	15300	13800	214.6	173.9	5.99	5.59	5.54
ED173	VGN	0.110	0.23	24000	21800	18500	87.7	65.8	6.31	7.02	6.95
ED174	VGN	0.165	0.26	36300	31500	25800	117.7	91.5	6.38	6.52	6.47
ED175	VGN	0.220	0.20	38700	34300	28900	210.7	179.1	5.85	5.54	5.50

R0.1 is measurement at 0.1 Hz, R10 at 10 Hz and R500 at 500 Hz
2G is the measurement at 2 GHz and 3G at 3 GHz
ε_r is the measurement at 40-50 MHz, $\varepsilon_r'^1$ at 2 GHz and $\varepsilon_r'^2$ at 3 GHz

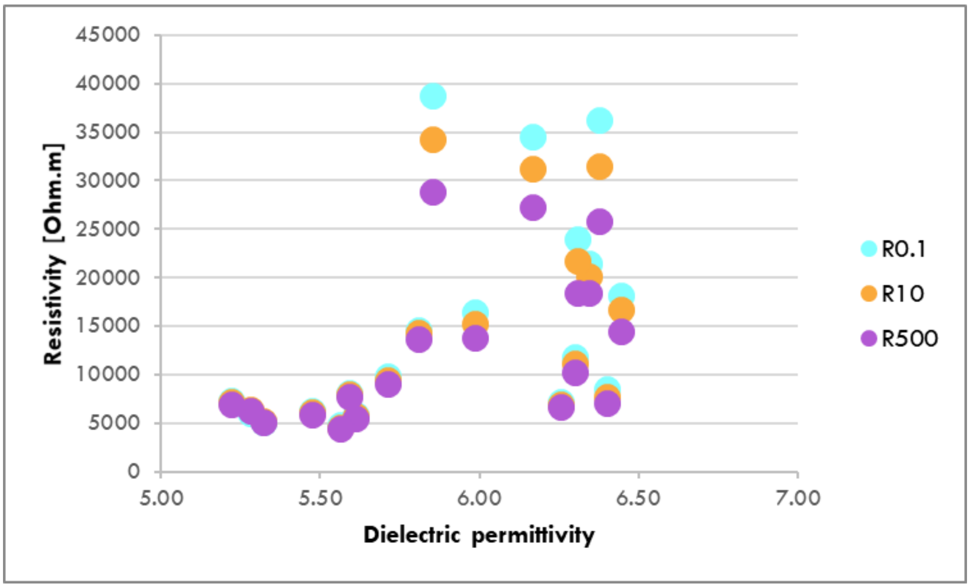

Figure 3: *Relative dielectric permittivity appears to increase with increasing resistivity. R0.1, R10 and R500 correspond to measurements at 0.1 Hz, 10 Hz and 500 Hz, respectively.*

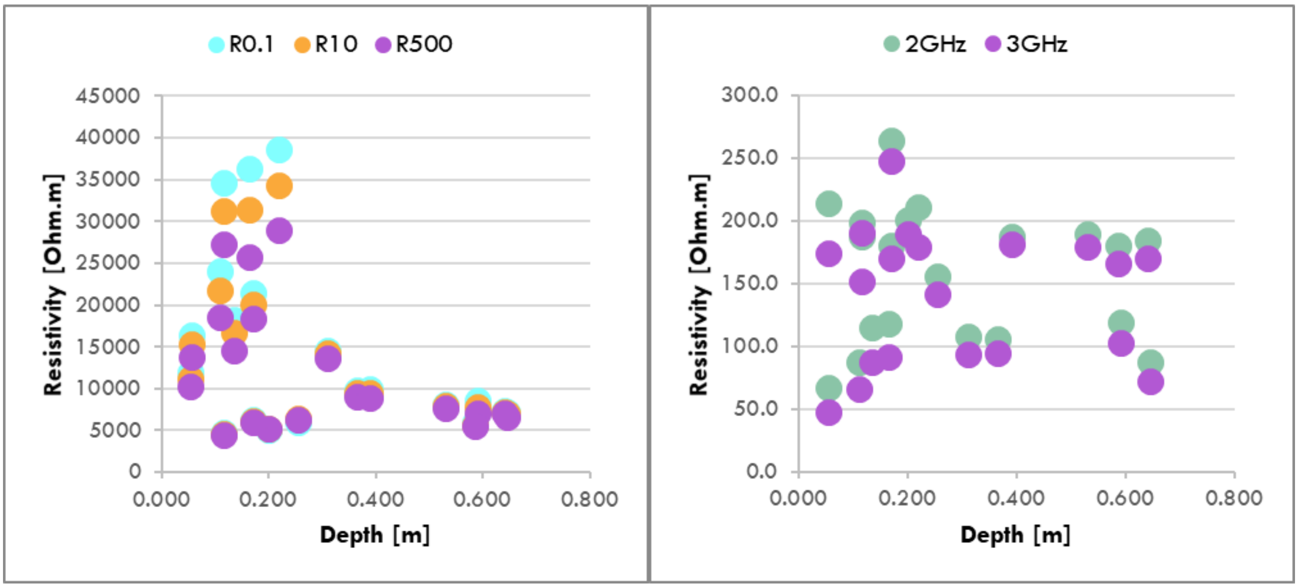

Figure 4: *Resistivity vs depth from excavated surface. At low frequencies (0.1 Hz, 10 Hz and 500 Hz, left figure), resistivity variation within the first 20 cm is much higher than deeper from the excavated surface. R0.1, R10 and R500 correspond to measurements at 0.1 Hz, 10 Hz and 500 Hz, respectively. Similar effect is observed with high (2 GHz and 3 GHz) frequencies as well (right figure).*

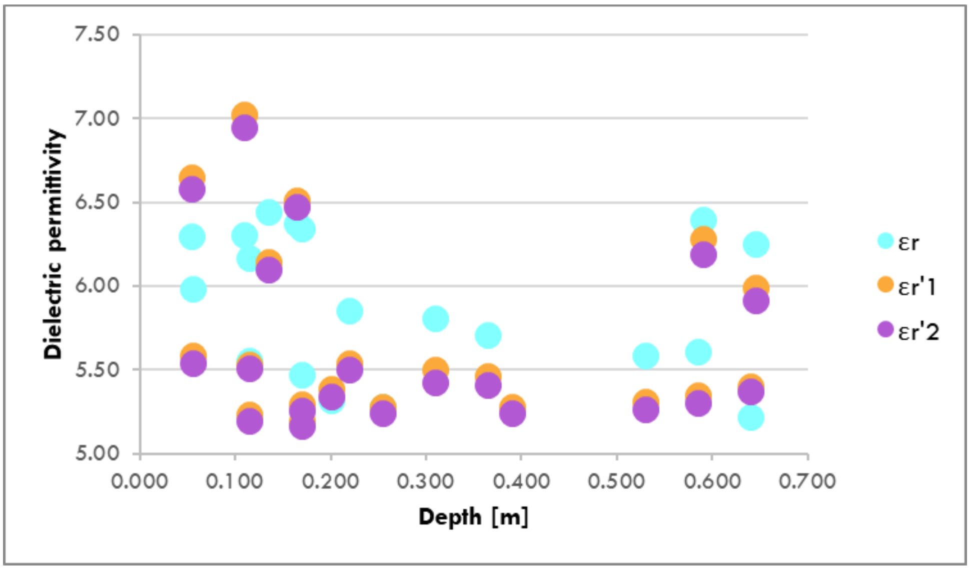

Figure 5: *Higher relative dielectric permittivity is observed in the surface layer, regardless of the measurement frequency.* ε_r *is the measurement at 40-50 MHz,* $\varepsilon_r'1$ *at 2 GHz and* $\varepsilon_r'2$ *at 3 GHz*

Conclusions

Changes in the electrical properties linked to shallow depths and visually observed EDZ features were observed, which seems to validate the theoretical basis of the GPR EDZ method. Knowing the electrical properties of intact as well as damaged rock allows assessing the feasibility of the method and enables theoretical modelling of the GPR signal behaviour in the site-specific rock mass. Improved understanding of the correlation between the geophysical and mechanical parameters of the rock mass provides better capability to detect and model the development of the excavation damage zone with help of the GPR EDZ method.

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