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Ultrasonic surface measurements at the Porta Nigra, Trier, and the Neptungrotte, Park Sanssouci Potsdam

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Ultrasonic measurements along profiles at the surface of an object are well suited to characterize non-destructively weathering of natural stone near the surface. Ultrasonic waveforms of surface measurements in the frequency range between 10 kHz and 300 kHz are often dominated by the Rayleigh wave – a surface wave that is mainly sensitive to the velocity and attenuation of S-waves in the upper 0.3 cm to 3 cm. The frequency dependence of the Rayleigh wave velocity may be used to analyze variations of the material properties with depth. Applications of ultrasonic surface measurements are shown for two buildings: the Roman Porta Nigra in Trier from the 3rd century AD and the Neptungrotte at Park Sanssouci in Potsdam designed by von Knobelsdorff in the 18th century. Both buildings belong to the world cultural heritage and restorations are planned for the near future. It is interesting to compare measurements at these two buildings because they show the applicability of ultrasonic surface measurements to different natural stones. The Porta Nigra is made of local sandstones whereas the facades of the Neptungrotte are made of Carrara and Kauffunger marble. 71 and 46 surface measurements have been carried out, respectively. At both buildings, Rayleigh-wave group velocities show huge variations. At the Porta Nigra they vary between ca. 0.4 km/s and 1.8 km/s and at the Neptungrotte between ca. 0.7 km/s and 3.0 km/s pointing to alterations in the Rayleigh- and S-wave velocities of more than 50 % due to weathering. Note that velocities of elastic waves may increase e.g. because of the formation of black crusts like at the Porta Nigra or they may be strongly reduced due to weathering. The accuracy of the ultrasonic surface measurements, its reproducibility, and the influence of varying water saturation are discussed. Options for the analysis of ultrasonic waveforms are presented ranging from dispersion analysis to full waveform inversions for one-dimensional and two-dimensional models of the outermost layers of the object under investigation. Furthermore, results of non-destructive ultrasonic surface measurements are compared to results of destructive investigation techniques.