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論文題目	Performance of sandy soil mixed with calcium-magnesium composite as attenuation layer for geogenic contaminants		

One strategy currently being explored in the development of a technically simple, economical, and practical countermeasure when reusing excavated soils and rocks that contain geogenic heavy metals as fill materials in an embankment, is the installation of a compacted layer of a base material of sandy soil mixed with stabilizing agent underlain the contaminated pile. A key issue related to its design is the selection of a suitable base material and agent to achieve the desired permeability, attenuation, and pH buffering function, considering the commercial availability, ease of use, suitability for several heavy metals, compliance with regulations, and so on. This study proposes the use of sandy soil (natural soil) mixed with calcium-magnesium (Ca-Mg) composite as the attenuation layer. Geoenvironmental reliability of this composite was investigated considering its arsenic (As) attenuation, pH buffering, and water retention characteristics, as a function of the different particle sizes of this agent and acid (H_2SO_4) concentrations.

From batch-type tests, it was found out that natural soil has a capacity to increase pH and to reduce metal concentrations from solution. This function plays an important role because the attenuation layer can be heterogeneous in attenuation performance and maybe cracked due to earthquakes and static deformation with time, during long-term services. Freundlich parameter, K – a good index for quantifying the contaminant attenuation property of solid material – was estimated to be 11 cm^3/g. By introducing the Ca-Mg composite into the soil matrix, the attenuation function and capability to buffer pH of the natural soil became more effective, but in the order of decreasing particle size (i.e. coarse$<$fine$<$powder). Highest As retention by the solid materials was noted in the soil-powder agent composite, where K reached 535 cm^3/g which is about 50-times higher compared to that of the natural soil. The soil-agent composite was capable of raising pH to alkaline conditions and retain more As with more acid input which might be due to more negative-surface charge and/or precipitation reactions. However, when the pH of the soil-agent composite suspension decreases below the precipitation pH (about pH=5), reduction in the amounts of As retained by the soil-agent composite is expected.

Using column tests, it was found out that the composite could lower concentrations of As-applied to values below the acceptable limit; for many flow volumes and different pH conditions. Removal ratio (*Rr*) was generally >95%, and As concentrations were under the allowable limit of 0.01 mg/L. This suggests that by lining possible acid-generating materials on top of the attenuation layer constructed using this composite, we can expect it to reduce As in leachate to negligible amounts for a long period/volumes of flow. Also, although this agent offers a higher pH buffering property, this feature decreased over time with continuous permeation due to the leaching of carbonates from the agent with more volumes of flow. Presence of Ca and Mg carbonates (from agent) in the soil increases the extent of precipitation mechanism, and precipitation of calcium arsenate is expected, which is less mobile and toxic, and stable over a wide pH range.

By adding powder agent to the soils, the air-entry value (ψ_a) and residual saturation (S_{rf}) were increased, and the highest S_{rf} is expected for the granite soil-powder agent composite; but not verified due to the small range of applied air pressures. Considering silica sand (of ψ_a=0.9 kPa), adding 5% powder agent increases ψ_a to 1.5 kPa. Also, although the coarse agent reduced ψ_a of the

soil due to its particle size, the soil-coarse agent composite still exhibited a higher S_{rf}. Taking granite soil-coarse agent composite (of ψ_a=0.7 kPa) as an example, S_{rf} reached 63%, which is much higher than that of the natural soil. This shows that Ca-Mg composite does not only enhance the attenuation function of soil, but also can improve the water retention properties of sands, especially for a well-graded soil. Poorly graded sandy soils like silica sand may not be suitable base material, for they drastically become impermeable (hydraulic conductivity, $k=1\times10^{-14}$ m/s) from small changes in negative pressures. When permeability is too low, infiltrate water cannot pass through the layer, and saturation degree (S_r) in the embankment will increase, which risks its stability.

In conclusion, although powder agent offers a better improvement to the attenuation, pH buffering, and water retention properties of a natural soil, coarse agent which is cheaper to produce and offers better material handling, can be applied as a material for the attenuation layer. Less, but long-term reactivity expected when using this particle size of agent.