Abstract

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論文題目	Mechanical and leaching characterization of inert waste landfills for safe and sustainable management		

Inert wastes such as construction and demolition waste, rock, glass, metals, plastics, woods etc. are disposed at the inert waste landfills in Japan. Presently, the inert waste landfills follow the design instructions of the municipal solid waste (MSW) landfills because of the unavailability of design instructions for inert waste landfills. The MSW design instructions are considered as too conservative for the inert waste landfills because the composition of the inert waste is different than the MSW. A better understanding of composition, physical characteristics, mechanical characteristics, leaching characteristics of inert wastes is needed to check the waste fill stability, embankment stability and leachate chemistry. In this thesis, the test and design methods for safe and sustainable inert waste landfills are discussed. This entire research is broadly divided into three parts namely- (a) In-situ and laboratory mechanical tests for mechanical characterization of inert waste, (b) Lysimeter, laboratory column, and laboratory batch leaching test to understand the leaching behavior inert waste, and (c) Slope stability analysis with centrifuge model test and FEM dynamic analysis.

(a) In-situ and laboratory mechanical tests for mechanical characterization

The composition of an inert waste landfill is important from the geotechnical point of view because the concrete and rock wastes help in increasing the bearing capacity of the landfill and the fibrous fractions can act as reinforcement by providing tensile resistance to increase the volume of the inert waste landfill. The physical and mechanical characteristics were examined at inert waste landfills in Japan, aiming at establishing a safe and cost-effective design method specific to inert waste landfills. Composition analysis, basic physical properties, angle of repose, CASPOL impact value test, and in-situ direct shear test were conducted. Wide variety in composition was found for three main components which were: fibrous content with a range of 3.6 to 54%, granular content from 13 to 45%, and soil-like content from 43 to 74%. Water content increased and percentage air voids decreased with an increase in fibrous content and age after reclamation. Impact value, an indicator of bearing capacity, increased with the increase in dry density. For the direct shear test, cohesion (c) and internal angle of friction (φ) were found within the range of 2–21 kN/m^2 and 22–59^o respectively. The shear stresses obtained from these c and φ values were higher than the municipal solid wastes, particularly for landfills having fibrous fractions ranging from 14 to 30% and under the normal stress of 25.55 kN/m^2. 'c' increased and 'φ' decreased with increase in dry density, age

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after reclamation, and impact value. The correlation calculated for c and φ with impact value for inert waste landfill were $c = 4.10\ I_a - 21.32$ and $\varphi = -4.61\ I_a + 82.37$. Laboratory direct shear test and laboratory triaxial tests were also conducted with inert waste collected from the landfill sites to check the effect of fibrous fractions on shear strength characteristics and to compare the results with the in-situ shear strength tests. In laboratory direct shear tests, four samples of inert waste with 3, 6, 11 and 16% fibrous content were tested. The internal friction angle first increased, then decreased with an increase in the proportion of fibrous fractions to a certain extent and the cohesion first decreased and then increased. In laboratory triaxial test conducted with inert waste having 0, 0.5 and 1% fibrous contents, deviatoric stresses increased with increase in confining pressure and fibrous content. With an increase in axial strain under confining pressures of 60 and 90 kPa, the volumetric change of 0% fibrous content showed similar behavior as dense sand and that of 1% fibrous content was similar to loose sand. For 0.5% and 1% fibrous content under high confining pressure, deviatoric stress increased after a certain axial strain, indicating inert waste with fibrous content may show higher shear resistance under high axial strain condition.

(b) Lysimeter, column and batch leaching tests on inert waste materials

The presence of fibrous fractions in inert waste may cause storage of water inside the inert waste landfill and there are also some possibilities of the presence of toxic and degradable matters in the inert waste materials. In this research, lysimeter tests were carried out with various configurations to check the leaching of contaminants and to determine a better reclamation method. Lysimeter drainage results showed that the retention property of leachate was dependent on the reclamation method. Sorption of dissolved toxic materials present in the leachate by the soil was confirmed. Although an increase in the concentration of chemical parameters or metals in the leachate was observed from highly compacted reclamation, the concentrations were found within the standard limits. In the laboratory column leaching test, the change in the leachate behavior was observed due to variation in fibrous contents of 2% and 10% in the inert waste. The water storage and dissolved parameters were found lower for the column with 10% fibrous content than that of 2% fibrous content. TOC was found higher for 2% fibrous content, but the values were found to be within the standard limit. With high fibrous content, the density became lower, thus increasing the drainage and decreasing the water-waste contact time. Soil layer installation seemed to be an effective solution for sorption of heavy metals etc. and buffering capacity. From the column leaching test, it was confirmed that the higher fibrous content in the waste materials does not store leachate if they

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are smaller in size. Batch leaching test was also conducted before the column leaching test. The batch leaching test was conducted to have a quick estimation of the amount of heavy materials present in the leachate. The results of the batch leaching test can also be used as an alternative for lysimeter and laboratory column test, but the results obtained may not be very precise as it is a quick leaching test.

(c) Slope stability analysis with centrifuge model test and dynamic analysis

The strength parameters obtained from the in-situ test were used in slope stability analysis. Centrifuge model test and dynamic analysis on landfill models under small and large earthquake conditions were carried out. In the centrifuge model test, models of landfills with 1:1 gradient slope were made of silica sand mixed with and without fibrous content and input acceleration were applied within the range of 100-400 gal. For lower values of acceleration (100-200 gal), landfills and embankments were stable, but for higher values (300-400 gal), remarkable damages of slopes were observed. In case of rigid embankments (made of cement improved soils), slope failure occurred with a slide of embankment due to change in earth pressure from passive to active condition (passive failure mode). Without fibers, a complete slide of upper and lower embankment occurred. In case with landfill model with fiber, overburden pressure in the lower layer was larger than the upper layer and fibers contributed to tensile resistance; thus, little damage was observed. Significant slide was observed in the upper embankment for landfill models with fiber for higher values of acceleration (300-400 gal) because of heavy transmission of shaking force from lower (fiber reinforced) rigid landfills. One case of centrifuge model was also made by compacting the top layer from 60% relative density to 90% relative density, but complete resistance to sliding of embankment could not be achieved. In-situ density, water content, and shear wave velocity were used as input parameters for dynamic analysis. In dynamic analysis, models of landfills with embankments of cement improved soil or cohesive soil were tested with and without fiber. Three models were selected with slope gradients of 1:1, 1:1.5, and 1:2. For cement improved (rigid) condition, small earthquake (L1) showed smaller non-linearity of the embankment and waste layer, and integral behavior of the slope; however, for larger earthquake (L2), non-linearity predominated to non-integral behavior and embankments acted against the earth pressure. Damage of upper embankment can be repaired easily but this phenomenon should be considered in the design of landfill slopes. From static and dynamic slope stability analysis, the possibility of making a steeper

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slope than the existing inert waste landfill was confirmed. The dynamic analysis demonstrated the failure condition of slopes during a heavy earthquake.

In conclusion, within a specific limit, the fibrous fractions present in the inert waste improved the shear strength of the waste and showed improvement in the slope stability during earthquake condition. The leaching test confirmed the safety of the quality of the leachate generated in the inert waste landfills. Possible storage of leachate in large fibrous fractions inside the inert waste landfill can be reduced by using fibrous fractions of 10-15 cm size. Therefore, in place of the existing slope, a steeper slope can be recommended to increase the storage capacity of the inert waste landfills. Steeper slopes can reduce the burden of finding more land areas for the construction of new inert waste landfills. Moreover, if mechanical tests confirm the high bearing capacity and slope stability of the inert waste landfill, then after closure of the landfill, the area can be reused to construct some new facilities. Appropriate land use and reuse of inert waste landfills can reduce the negative impacts on the environment and encourage sustainability.