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SUMMARY OF DOCTORAL THESIS

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Title: Study on the Improvement of the Serviceability Performance of Earth Hydraulic Structures by using High Performance Fiber Reinforced Cementitious Composites

複数微細ひび割れ型繊維補強セメント複合材料による土構造の水利施設の使用性の向上に関する研究

This study investigated the effectiveness of High Performance Fiber Reinforced Cementitious Composites (HPFRCC) in improving the serviceability performance of earth hydraulic structures through repairing with a thin layer of the cementitious material. The HPFRCC employed in this study was Engineered Cementitious Composites (ECC) and regular concrete was used as a comparison. The target application was the repair of earth hydraulic structures such as earth dams and earthen or unlined canals. Earth dams and unlined canals are prone to deterioration due to exuberance of weeds and other deteriorative forces and hence require regular maintenance. Moreover, restricting crack widths within serviceability limits is critical for ensuring water tightness and maintaining serviceability performance. The costs associated with complete removal of weeds may be prohibitive and other engineering solutions are necessary to control deterioration. In some cases, repair of earth structures by cementitious materials may be necessary to improve durability and strength. The effectiveness of this solution hinges on the durability of the repair material. The use of materials with poor durability results in repair structures with poor durability which may constantly require repairs. Such a cycle of repairs increases life cycle costs and hence need to be controlled. Whilst regular concrete has been ubiquitous in construction for over 175 years, inherent deficiencies related to its brittle behavior and production of through cracks of unlimited widths adversely affects both the short and long term durability of related concrete structures. On the other hand, ECC has high strain capacity is ductile and hence can restrict deformation to surface fine cracks of widths less than 0.1mm.While it has been elucidated that ECC is more effective than concrete in repair of concrete structures, applications in earth hydraulic structures is yet to be clarified.

Therefore, investigations were carried out in this study to clarify the effectiveness of ECC in the repair of earth embankments, durability when exposed to organic acid containing weed sap, surface deformation of canal linings and cost effectiveness. In the investigation for the repair of earth embankments, the aim was to curtail the re-emergence of weeds and consequent impairment of durability after application of a repair layer. ECC and concrete were monitored for crack development and penetration of light which supports photosynthesis and consequent growth of weeds. It was observed that while ECC developed fine surface cracks of width less than 0.1mm which prevented the penetration of adequate light to support the photosynthesis and consequent growth of weeds, concrete developed through cracks of unlimited width through which adequate light to support growth of weeds could penetrate. It was therefore concluded that ECC was more effective than regular concrete in curtailing the re-emergence of weeds on the surfaces of earth embankments. Moreover, the through crack produced by concrete is susceptible to further expansion due to differential settlement of earth embankments and therefore can also host flying seeds from other weeds which can sprout and grow. This leads to further expansion of the crack and loss of serviceability integrity of the entire water supply facility.

The hydration process in cementitious materials is prone to modification by external substances and since exposure of fresh construction material to organic acids from the sap of lacerated weeds is inevitable during maintenance or construction, an investigation to assess the durability of ECC and concrete in corrosive environments was carried out. In this investigation, the effect of organic acids on hydration of the cementitious materials was carried out. The setting time of the fresh materials as well as compressive and flexural strength of the hardened materials were monitored. It was observed that while organic acids tend to retard the setting time of all cementitious materials by the neutralization alkali-acid reaction or through adsorption of particles on the surfaces of the hydrating cement particles, the severity of the retardation depends on the composition of the cementitious material. It was found that the retardation in the setting time of ECC was less severe than in regular concrete since the chemical additives in ECC moderated the pH of the material and enabled ECC to stiffen and gain strength within the expected period. However, the retardation of the setting time of concrete by the organic acid impinges the short term durability and resistance to deteriorative agents thus weakening and also depreciating long term durability.

It is known that surface roughness of canals affects the velocity and quantity of flow and hence it is desired that a lined canal surface remains smooth throughout its lifetime. An investigation was undertaken to clarify the effect of the ductility of ECC under non-uniform loading on the levelness of ECC lining surfaces. It was found that non-uniform loads caused undulations on the surface of ECC and hence increased roughness. The magnitude of the deformation and consequent significance of the roughness was relative to the magnitude and source of the non-uniform loading. Moreover, the inclusion of geo-textiles as separators moderated the deformation.

Since the use of high cost of the ECC material is currently limiting its widespread applications, the effect of reducing the volume of material as a cost cutting measure was investigated. In this investigation, the effect of thickness of ECC elements on crack distribution was monitored. It was observed that the thickness of plates has no significant effect on the crack width and crack distribution of ECC. This enables smaller thicknesses of ECC elements to be applied where structurally possible, thereby reducing the material volume and subsequently lowering overall material costs. The ductility of ECC, production of fine surface cracks as opposed to the brittleness and production of through cracks by plain cementitious material and ability to restrict crack widths to less than 0.1mm despite reduction in thickness from 30mm to 10mm makes ECC a more durable and economically viable repair material than traditional concrete.

Through this study it was clarified that ECC is a more durable repair material than traditional concretes in earth hydraulic structures applications. This means the use of ECC in repair works can minimize the cycle of repairs and improve the serviceability performance of earth hydraulic structures. Moreover, despite the relatively high initial cost of the material, improvement of the serviceability performance and curtailment of the cycle of repairs imminent with traditional concretes decreases the Life Cycle Costs (LCC) of earth hydraulic structures.