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CO-OPERATIVE RESEARCH PROJECT

REPORT

Final activity report

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Flood disasters account for about a third of all natural catastrophes throughout the world (by number and economic losses) and are responsible for more than half of the fatalities. Trend analyses reveal that major flood disasters and the losses generated by them have increased drastically in recent years. For this reason it is important to take appropriate steps without delay. On the one hand, the efforts that are being taken to combat climate change must be stepped up, while on the other hand we must pay more attention to flood protection and loss minimisation or prevention. These disasters could be significantly attenuated by improved technical flood protection. One main part of flood protection is the dike rehabilitation of existing dikes (some of them were built more than 150 years ago) as the majority of existing dikes do not fulfil the existing safety standards. Existing dike rehabilitation techniques are quite often expensive with a limited field of application. The proposed ProDiCon system will target this problem as it intends to develop a universal dike rehabilitation technology applicable to all types and states of dikes. The ProDiCon technology is an innovative and economical technology for dike rehabilitation due to the on-site and in-situ preparation of the novel dike sealing material. By applying the ProDiCon technology during dike rehabilitation transport processes can be minimised significantly. Beside the material development the ProDiCon project aims to develop a novel technique for the application of dike sealing material. The novel technique can also be applied to wetted and softened dikes where the usual technologies must fail due to heavy construction machines – this could be seen very impressive during and after the recent flood disasters.

Whithin the first period, the ProDiCon project focused on information search regarding typical dike characteristics, building materials, construction and rehabilitation methods as well as on the development of a novel sealing material on the basis of the MTG-I material for a lasting dike sealing. Based on this, the second period focused on the assessment of the novel material in respect of required material properties, processing parameters, appropriate environmental sustainability and resistance against natural impacts.

In the beginning of the first project year the partners carried out a description of typical dikes in their respective country incl. division according to different types, allocation, type of used materials, techniques sizes and dimensions. An investigation and evaluation of different dike constructions as well as methods and techniques for building and rehabilitation of dikes was performed. To finalise the definition of basic requirements for dikes, the different techniques defined in the previous task were evaluated economically to identify economical criteria, against which the new ProDiCon process will be compared.

Rehabilitation techniques applied in the different states concerned have been studied, classified and described, taking into account their advantageous and disadvantageous features/characteristics from technical and economical point of view.

An investigation and evaluation of the fundamental definition, composition and properties of dike building materials and sealing materials, summary of the bases for the using of MTG und modified MTG for the building of dikes was performed by the ProDiCon consortium.

The ProDiCon partners carried out an investigation and evaluation on possible and suitable additives, such as locally available clay materials, additives to change rheological properties, additives for strength development. Additives were selected and material samples analysed.

All partners provided their ideas on possible application areas for the ProDiCon system, i.e. where and under which conditions it would be possible implement newly developed ProDiCon technology in their region, country.

Available additives for dike construction, which seem to be suitable for application in the PRODICON process, were prepared to be blended with the MTG samples to obtain the material for future tests.

The MTG samples were analysed regarding mode of action and the installation behaviour of the MTG, inferences for the modification of the material system. MTG will be defined and adjusted. The material composition will be optimised with respect to the base material within the samples.

On the basis of the MTG-I-material a sealing material will be developed which meets the requirements of a qualitative dike sealing. The novel material shall have the required material properties, the processing parameters as well as an appropriate environmental sustainability and resistance against natural impacts.

Work on the mathematical model for the dike material (the natural soil and the modified one) and for the dike structures have been almost completed; necessary adjustments to the FEM program have been already made and they require some verification yet. Parametric studies for some typical dike cross-sections, before and after dike rehabilitation, and for assumed flood recordings are now in progress.

For the development of the novel sealing material MTG-II bench-scale tests are needed in order to prepare field tests under realistic conditions and to allow for the necessary optimisation.

Objective of these tests is to test different injection methods with different materials and to gain first results regarding the material characteristics of the different MTG-II materials inside the soil and the injection characteristics of the materials in connection with the available basic conditions.

The preparations of the bench-scale-tests are completed by the PRODICON partners. The execution of the tests begins in November.

Identification of seepage coefficient for soils modified by a sealing material was proposed with the aid of triaxial testing apparatus. Detailed analyses concerning real bench scale dikes will be made after receiving of the experimental.

The project web site (www.prodicon.eu) was established in the first project months and is continuously updated with information, deliverables, reports and other achievements.

The second period of the ProDiCon project started in October 2007 with the completion of the mathematical model for the dike material (the natural soil and the modified one) and for the dike structures by partner no. 9: Politechnika Krakowska (PK). Simulations of dike stability regarding material requirements, material characteristics and influences of material variations were assessed as well as requirements of material before, during and after the injection defined. These investigations enabled PK to perform parametric studies for some typical dike cross-sections, before and after dike rehabilitation, and for assumed flood recordings.

For the development of the novel sealing material (MTG-II) bench-scale tests were required in order to prepare field tests under realistic conditions and to allow for the necessary optimisation. The objective of these tests was to try different injection methods with different

materials in order to assess the material characteristics of the different MTG-II materials inside the soil and the injection characteristics of the materials under various conditions.

The design and scheduling of the bench-scale tests on the test site in Laußnitz near Dresden (Germany) included pre-analyses of the sealing material (i.e. flow characteristics) and of the injection technology (i.e. distance and location of tubes). Test ditches were installed with supplied soils, using coarse-grained and mixed-grained soil so as to simulate the generally low compression ratio of old dikes. In doing so, the workability and injection ability of the injection materials were evaluated for soils with a homogenous, low compactness. Because of the homogeneity of the different types of soil within one test ground the comparability of the different experimental series was assured.

The injection of varied MTG suspensions at bench-scale, was executed in December 2007 by means of tube-à-manchette injection. After the excavation of numerous injection bodies in January 2008, laboratory tests were carried out and the results were evaluated against the overall aim of the ProDiCon project which was the development of an innovative method for an effective and cost efficient rehabilitation of damaged dikes. Therefore, injection ability, water permeability as well as erosion and shearing resistance were tested and evaluated. The laboratory tests revealed that the injection material dispersed well into the voids of the coarse grained soil and that it penetrated from the dense soil into the less dense soil consistently. The results of the percolation tests revealed a decrease of the water permeability by a factor of 4 for both the coarse-grained and the mixed-grained soils. However in the mixed-grained soil, the water permeability (k_f) still was at $2.5 \cdot 10^{-8}$ m/s which did not entirely meet the partners' requirements of $k_f \leq 1.0 \cdot 10^{-8}$ m/s as for a perfect sealing effect. The subsequent field tests on proper dikes therefore focused strongly on this factor.

Based on the results of the bench-scale tests, the ProDiCon partners designed and scheduled two field tests on proper dikes in order to test the ProDiCon technology under the conditions of regular dike rehabilitation efforts. In so doing, appropriate modifications and improvements of the method could be considered in direct response to problems and mistakes. Before the actual field performance, the environmental acceptance of the developed sealing material was evaluated by means of Environmental Impact Assessment to certify its environmental harmlessness.

The first field test on a dike without actual dike function in Dessau-Roßlau (Germany) started in May 2008. The constructive and technological preparation of the damaged dike section also included the detailed examination of the dike's present soil characteristics using geo-radar and geo-physics. After the evaluation of these examinations and the sampling of the dike's ground materials, the respective mixtures of the sealing materials for injection were defined and the actual injection works prepared.

Within the field test, three different sealing materials were installed by means of the tube-à-manchette and the medium-pressure (MDI) method using original MTG material and two modified MTG suspensions. Abort criterion for each injection was the leakage of sealing material out off the dike crest. It is therefore to assume that the upper covering was as well injected with sealing material.

On-site examinations by means of geo-radar and small percussion drillings showed clearly that loose areas, voids and defects within the respective ground present before the injections were filled and stabilized. Laboratory analyses of excavated soil samples after the injection regrading grain size distribution, flow and plastic limit, water permeability, proctor density, compression ratio, fading rate confirmed the method's sealing effect. The water permeability

of a dike decreased by at least 10^{-3} m/s and the injection columns created a completely vertical sealing layer within the dike through overlapping injection columns. The determination of the shearing parameters confirmed that the overall dike stability was improved significantly by both injection methods.

In November 2008, the ProDiCon partners performed a second field test on a functional dam in Vysoké Veselý (Czech Republic) with similar material characteristics and installation parameters. Due to the site conditions, injections were undertaken on the embankment which was to be rehabilitated, by using only the tube-à-manchette injection technique.

The sealing effectiveness of the injections was then assessed by means of observation well and geo-radar before and after the injection works. The examination of the rehabilitation site before the injection works clearly identified multiple water leakages out off the embankment. Before the rehabilitation, the water level was at about 3.32 to 3.35 m under top ground surface which complied with the water leakage out off the embankment. Directly after injection on March 13, 2008 the water level decreased to 4.82 m under top ground surface. Within the following weeks, the water line again rose due to environmental condition (e.g. rain, snow) but levelled off at about 3.92 m under top ground surface. The leakage off water out of the landside embankment was stopped permanently. Geo-radar scans mapped before and after the injections confirmed these results. The scans clearly showed a consistent, homogenous sealing wall within the dam. The grouting of the newly developed material created an effective sealing wall against percolating water so that damaged dam sections were rehabilitated. Hence, the effectiveness and applicability of the ProDiCon material and method was proven on a proper dam even under load.

Summarizing the above, the injection of the innovative MTG material by means of tube-à-manchette and medium pressure injection fully succeeded. A very good inter-mixture of the injected material and the in-situ soil was realised and damaged dike sections were stabilized. As both field tests finished with such convincing results, the ProDiCon technology is now ready for commercial launch and further application on different damaged dikes and dams.