QUASI–2D-EXPERIMENTS - VISUALIZATION OF IMPACTS ON EMBANKMENTS

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An experimental configuration is described, which allows quasi-2D-impact tests on small scale model embankments considering the rotation of a bloc too. With a high speed camera and the Particle Image Velocimetry the displacement field due to an impact can be visualized and analyzed. This gives rise to a better understanding of the impact process and the evolution of the impact disordered area. Finally the results of the research project will lead to an improvement in the design of rockfall protection embankments.

Keywords: rockfall protection embankments, impact disordered area, Particle Image Velocimetry (PIV), displacement field, basic principles for design, influence of rotational impact energy, overrun of protection embankments

INTRODUCTION

The present course of action for dimensioning rockfall protection embankments does not agree with the circumstances of an impact of a bloc onto an embankment. Up to now the design in Switzerland is based on the equivalent force method by using a formula which was developed for rock sheds and is described in the FEDRO-guideline "Exposure of rock sheds due to rockfall" [1]. But there are significant differences concerning the geometry as well as the boundary conditions in the two cases "rock shed" and "rockfall protection embankment".

In the recent past several approaches have been presented for the structural analysis of a rockfall protection embankment under impact. The proposed methods vary from analytical methods based on simple shapes for the impact disordered area, e.g. [2], [3], to numerical methods like Finite Element Method (FEM), e.g. [4], [5] or Distinct Element Method (DEM), e.g. [6], [7] to simulate the impact and its consequence on the embankment. Even though some of those approaches are supported by experiments, little is known concerning the real disordered area and the displacement field created by an impact of a boulder on an earth dam.

Blovsky [8], for example, shows illustrations in his thesis, which are very similar to those usually used to describe base or slope failure. But because he used a pendulum for the small scale impact tests, there is a restricted guidance of the impacting body. Additional, due to the pendulum system, the influence of the rotational energy of an impacting body could not be taken into account in those tests.

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Hofmann & Mölk [3] have done small scale tests with a sphere. Three different impact velocities have been used in the tests. They described the impact disordered area of an earth dam as an “activated embankment volume”, which may achieve 5 to 6 times the sphere’s diameter. But the definition of their “relative impact energy”, which is used in the calculations, is based on a simple 2D-cross section and not on a volume. Additional only the translational part of the energy is used in their model.

Plassiard & Donzé [6], [7] used DEM to simulate the impact of a sphere onto an embankment. With that numerical method it is possible to calculate the displacement field created by an impact inside the embankment. To calibrate their model and determine input parameters, back analysis of triaxial tests as well as free-fall tests have been used, but no tests with impacts on embankments had been done.

Real scale tests have been done by Peila et al. [4]. They made tests with 4 embankments, but only one of them was without geogrid reinforcement. The impact body was accelerated by a ropeway. This experimental arrangement leads to only negligible rotation of the block. Therefore the influence of the rotational energy during the impact could not be studied. Back analysis has been done by FEM, but only for embankments with geogrid reinforcement.

Because there are different current available statements concerning size and shape of the disordered area created by an impact on one hand and information is missing about the role of the rotational energy in the impact process on the other hand, a research project was established to investigate these questions.

EXPERIMENTAL COMPOSITION OF QUASI-2D-TESTS

A quasi-2D-experiment is an experimental arrangement where physical processes can be observed in a plane. But because in real life there is always a 3rd dimension, an experimental arrangement has to be used, where the influence of the 3rd dimension should be as low as possible. This may be realized by using a slice of an embankment and a cylinder as the impacting body instead of a sphere. To produce this embankment slice it has to be constructed between two walls with smooth surfaces. One of these walls has been made of acrylic glass to observe the impact of the cylinder onto the embankment slice. It can be assumed that the friction between soil and the smooth wall surface is lower than within the soil. The height of the cylinder is smaller than the thickness of the embankment slice to avoid contact with the two walls. So, when the cylinder hits the embankment slice, the deformation due to the impact will be the same upright to the cylinder’s axis.

The experimental equipment for the small scale quasi-2D-impact tests consists of (Fig. 1)

- a construction box, where the embankment slice can be built,
- a guide rail to accelerate the cylinders,
- different cylinders resp. cylinder related bodies for the impact tests,
- a high speed camera with a light barrier and a pulse generator,
- a triaxial acceleration sensor mounted in a hollow cylinder and integrated in a wireless sensor network and
- a computer to collect the data.

Fig. 1 Experimental equipment for small scale quasi-2D-impact tests, a) testing facility, b) construction box with model embankment, c) impact bodies

QUASI-2D-TESTS

For the construction of the embankment slice a sand–fine gravel mixture has been used. The grain-size distribution has been chosen approximately to that one which was presented by Blovsky [8] for his tests. The moisture content of the soil was determined after the impact tests and was found to be between 3.5% and 8.5%. Up to now tests have been done with two different embankment shapes (Table 1).

Tab. 1 embankment shape

type	crest width [cm]	uphill side		downhill side	
A	19	62.6°	approx. 2:1	37.3°	approx. 4:5
B	9.5	62.6°	approx. 2:1	37.3°	approx. 4:5
D	2.5	62.6°	approx. 2:1	37.3°	approx. 4:5
A	20	47.8°	approx. 1:1	47.8°	approx. 1:1
B	13	47.8°	approx. 1:1	47.8°	approx. 1:1
D	5	47.8°	approx. 1:1	47.8°	approx. 1:1

To measure the particle velocity inside the soil behind the acrylic glass during the impact and to visualize the displacement field the method of Particle Image Velocimetry (PIV) is used. Pattern recognition between 2 pictures is done with PIV utilizing the color difference of the sand grains. Because the impact process is a very quick process the high speed camera is used with a frame rate of 500 Hz that is 1 picture every 2 x 10^{-3} s.

The evaluation of the experiments is still in progress, but some remarkable results are already available. Fig. 2 shows as an example the maximum displacement fields due to an impact of a rotating cylinder named G respectively a very slow rotating body with an octagon cross section named OKT. The cylinder G has a weight of 7.44 kg, the impactor OKT a weight of 6.77 kg. The translational velocities before impact are v_G = 6.1 m/s resp. v_{OKT} = 6.5 m/s. The rotational velocities before impact are ω_G = 74 s^{-1} resp. ω_{OKT} = 3.4 s^{-1}. So the translational energies just before the impact are nearly the same (G: E_t = 139 Nm, OKT: E_t = 141 Nm), but the difference in rotational energy is very significant (G: E_r = 65 Nm, OKT: E_r = 0.1 Nm).

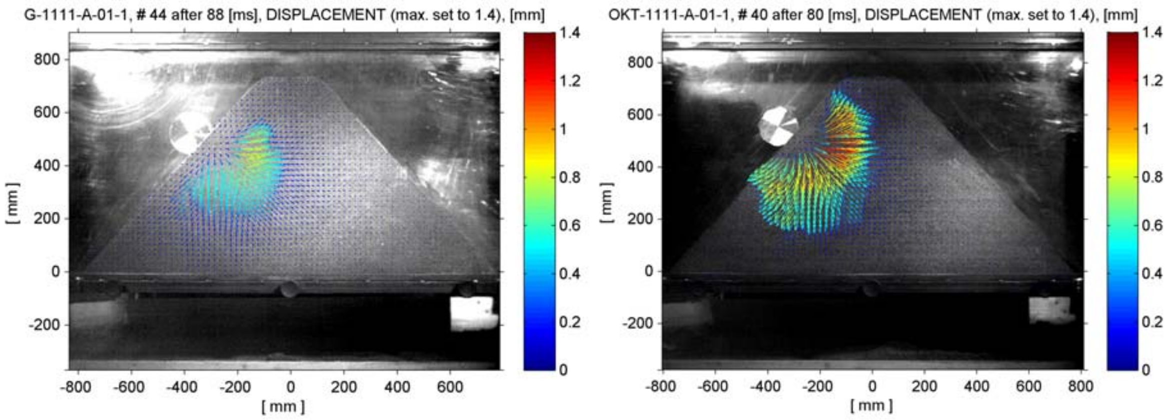

Fig. 2 Maximum displacement fields due to an impact of a rotating cylinder respectively a very slow rotating body with an octagon cross section. The translational energy in both cases is nearly the same. Embankment with 47.8° slope at uphill side as well as downhill side.

Even though the total energy of the cylinder G is approximately 44% higher than the total energy of the impactor OKT and the translational energy of both is nearly equal, the displacement field inside the embankment shows the larger displacements for the impactor OKT with nearly no rotation (Fig. 2). This example seems to affirm that rotation has an important effect on the impact process and the displacement field inside the embankment.

CONCLUSIONS

With the quasi-2D-impact tests on a small scale embankment model and the PIV method it is possible to visualize the displacement field due to an impact. Large deformation inside the embankment may be interpreted as compaction zones, while large deformations at the crown's downhill side may point to a loosening zone. The tests which have been evaluated up to now seem to affirm, that rotation has an important effect on the impact process and the resulting displacements. Additional even for the steep uphill slope of the embankment an uprolling of the bloc has been observed. In some cases the embankment was vaulted by the bloc.

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