Development of an appropriate mortar for sustainable rain water cisterns

Raphael Breiner\textsuperscript{a,}\*, Thorsten Heid\textsuperscript{a}, Harald S. Müller\textsuperscript{a}

\textsuperscript{a}Institute of Concrete Structures and Building Materials (IMB), Karlsruhe Institute of Technology (KIT)
Gotthard-Franz-Straße 3 / Am Fasanengarten, 76131 Karlsruhe, Germany

Abstract

The knowledge of the rheological properties of cement-based building materials is of outstanding significance for their workability and applicability. However, it usually takes extensive efforts to optimize those materials as their rheological properties may differ in a wide range depending on the physical properties of the selected source materials. By means of a case study, the successful implementation of a rheologically optimized cement-based mortar for the construction of rain water cisterns is presented in this paper. The material was developed within the scope of a German-Indonesian joint project, funded by the German Federal Ministry of Education and Research (BMBF), where the storage, distribution, and treatment of water has to be assured by durable concrete structures. Comprehensive rheological investigations are presented which provide the database for the optimization of the mortar with regard to its intended range of application. For the selection of the source materials, special emphasis was placed on the ready availability at low cost. The rheological properties of the fresh mortar allow an easy workability by hand while the hardened mortar shows a durable and tight appearance at the same time. The developed rehabilitation mortar can be used as a coating for walls, floors, and ceilings of cisterns. The future multiplication of the project results within the region was assured by a local capacity building when the material concept was applied in practice in Indonesia for the construction of sustainable rain water cisterns in Gunung Kidul.

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\* Corresponding author. Tel.: +49-721-608-47781; fax: +49-721-608-48400.
E-mail address: breiner@kit.edu
1. Motivation and objectives

The sound knowledge of the rheological properties of cement-based building materials is of outstanding significance for their workability and applicability. However, it usually takes extensive efforts to optimize those materials as their rheological properties may differ in a wide range depending on the physical properties of the selected source materials.

Against this background the present paper deals primarily with the development and rheological optimization of an appropriate mortar for the rehabilitation or even reconstruction of sustainable rain water cisterns. The main objective of the works described in the following was to minimize water losses due to cracks and to guarantee the secure and durable long time operation of the cisterns.

2. Field study

Within the scope of a German-Indonesian joint project, funded by the German Federal Ministry of Education and Research (BMBF), a hydropower plant with an underground concrete barrage (see Fig. 1) was initialized, designed and built during the years of 2002 to 2008.

During the dry season, it provides an urgently required water supply for the karst region Gunung Sewu in Central Java, Indonesia [1,2]. The basic conception and the predesign of the concrete barrage were accomplished by the Institute of Concrete Structures and Building Materials (IMB).

Within an on-going German-Indonesian follow-up project funded by the BMBF, the hydropower plant is currently embedded into the frame of an “Integrated Water Resources Management” (IWRM), which couples all aspects of water supply, distribution, usage and treatment in an overall concept [3]. One major aspect is to rehabilitate and enlarge the existing water storage and distribution system in the project region in order to handle the additional water supplied by the new hydro power plant.

Fig. 1. Sketch of the structure of the hydropower plant (longitudinal section, without hydraulic components) with the functional elements cofferdam, flood relief line, barrage and platform with valve chamber [4].
The Institute of Concrete Structures and Building Materials (IMB, Subproject 5) of the Karlsruhe Institute of Technology (KIT) focuses in particular on the serviceability of durable watertight and functional hydraulic constructions. The project includes amongst others the development of a concept for sustainable rain water cisterns in the village of Pucanganom located in the karst area of Gunung Sewu.

Pucanganom near the city of Wonosari was chosen within the IWRM-Project as a pilot village where the developed measures of the different subprojects are implemented to prove their applicability and to support a future multiplication in the region. Initially contact was made to the authorities in Pucanganom responsible for construction activities. They facilitated the detailed determination and evaluation of the current condition of the cisterns with regard to their tightness, structural design, materials used as well as rehabilitation requirements.

During a heavy earthquake in May 2006 many domestic water cisterns were damaged or even completely destroyed. In the following years new cisterns with a volume of 9 m³ were built by local village people who were trained within the scope of international and national aid programmes. Two trained workers supported by 6 unskilled workers are able to build a cistern within 4 days.

For the construction of the cisterns in Pucanganom a mortar with a relatively high cement content is used. Sand and cement are mixed together, two parts to one, and water is added until the desired workability is reached, corresponding to a non-site water/cement-ratio of approximately 0.45. The mixing itself is done by hand in-situ (see Fig. 2). No ingredients other than sand and cement are added to the mortar. In particular no commercially available concrete additives are used. The cement is ordinary Portland cement (OPC) or a puzzolanic Portland cement (PPC), depending on availability. The sand is a raw volcanic sand with a squared shape and grain size diameters of up to 4 mm.

![Fig. 2. Mixing of the mortar in-situ.](image)

The construction always follows the same appropriate principle. On the first day a base-course for the foundation of the water cistern is assembled which consists of raw and crude limestones assembled similar to prepacked concrete.

The aggregates generally have a medium diameter between 100 and 200 mm and show a very high porosity due to their karst origin. They mostly originate form karst limestone quarries near the site or are even collected directly from the surroundings. On this base-course a round foundation is modelled with a simple mortar consisting of four parts of sand and one part of cement (see Fig. 3(a)).

On the second day, the reinforcement cage of the water cistern is tied together with smooth reinforcement steel having a diameter of 6 mm and 8 mm respectively. The whole reinforcement cage is wrapped with a wire mesh fence (chicken wire) and a bamboo mat, which acts as formwork for the application of the mortar on the inner side of the cistern.
The reinforcement cage is put on the foundation, which has been treated at the beginning of the third day with a screed on a layer of old cement bags to assure a decoupling of the construction in case of a future earthquake (see Fig. 3(b)).

After all necessary pipe and drainage installations are made the inner mortar layer is applied by hand on the cistern walls (see Fig. 3(b)). After the hardening of the inner mortar layer, the bamboo formwork is removed on the beginning of the fourth day. Consequently, the outer mortar layer is applied (see Fig. 4(a)). The mortar layer on the ceiling is made against a layer of old cement bags which are installed from inside the reinforcement cage (see Fig. 4(b)).

During the construction works it became evident that from a technical and economical point of view, the controlling of the rheological behaviour of the mortar is the key factor to achieve the best possible imperviousness of water cisterns. It would be desirable to have at one’s disposal a practical guideline of how to compose the mortar according to its intended range of application.
3. Materials

Based on the experiences gained during the field study described above as well as a literature survey, the source materials for the investigation were selected and carefully characterized considering their usage as mortar ingredients. The main restriction for planning and construction was to use only locally available source materials. Their selection and their properties are discussed shortly in the following.

3.1. Cement

Numerous cement plants exist in Indonesia being controlled by worldwide operating cement producing companies. However, in practice only Portland cements (OPC Type I) and so-called Portland puzzolanic cements (PPC) are used. Preliminary experiments and investigations at the IMB substantiated to favour an OPC Type I produced by the Gresik company for the mortar optimization in Pucanganom. It has a Blaine-value of 3690 cm²/g and a density of 3.09 g/cm³. The cheaper PPC held a substantial amount of indissoluble components, had a lower grinding fineness, and was consequently excluded.

3.2. Sand

During the exploration of numerous digging and excavation facilities for sand and gravel, as well as concrete plants in the region of Yogyakarta, important information for the selection of concrete aggregates in Indonesia was gained. The sand used for construction measures in Yogyakarta and the Gunung Sewu exclusively comes from the Merapi area. It can be described as raw volcanic sand with a comparatively high dry density of 3.17 g/cm³.

3.3. Additives and admixtures

Superplasticizers (SP) were not intended to be used in the mortar mix in order to ensure its economical composition. However the commercially available product SIKA ViscoCrete 1050 was investigated as a reference. SIKA ViscoCrete 1050 is a universal and highly effective superplasticizer based on polycarboxylatether polymers especially developed for ready-mix concretes. It has a density of 1.06 g/cm³ and shows a long-lasting efficiency. It was examined to what extent the water/cement-ratio of the cement suspension could be lowered by replacing the superplasticizer, a comparatively expensive chemical product, with a low priced saccharose (local retail sugar).

Admixtures like fly ash do not exist in Indonesia, or are available as expensive import products only. Locally available ashes from the hillsides of the Merapi volcano and further a rice husk ash (abu sekam padi) were investigated but unfortunately did not show any hydraulic properties, which were necessary for a qualified use in the mortar mix.

With regard to the control of the sedimentation behaviour the clay mineral bentonite is used to stabilize cement suspensions by increasing the suspension’s thixotropy. Furthermore, bentonite binds free water due to its stratification structure, preventing bleeding. Consequently, a locally available bentonite mineral was examined. It could be identified by means of x-ray diffraction analysis as sodium-bentonite. It has a density of 2.71 g/cm³. In addition, its quantitative composition was determined together with the Institute of Mineralogy and Geochemistry (IMG) using x-ray fluorescence analysis.
4. Rheological investigations

Rheological investigations were performed to determine the flow behaviour of the pure cement suspension phase of the mortar and to judge the influence of the different additives and admixtures. A measuring system consisting of a high-end rheometer (Haake MARS) combined with a measuring cell especially developed for cement suspensions, was used (see Fig. 5).

The measuring cell consists of a cylindrical vessel with an adjustable wall serration to account for different grain size diameters and to overcome sliding of the cement suspension in the contact face to the wall. The cell filled with cement suspension is installed into the rheometer and defined shear stresses are consequently applied with a paddle-shaped rotor to determine the rheological properties.

The water/cement-ratio of the tested cement suspensions amounted in each case to 0.5. Measurements were performed 5 minutes, 15 minutes, 30 minutes and 60 minutes after the addition of the water. Table 1 summarizes the mix compositions for the rheological investigations.

<table>
<thead>
<tr>
<th>w/c [-]</th>
<th>sugar [% by mass of cement]</th>
<th>superplasticizer [-]</th>
<th>bentonite [-]</th>
<th>rice husk ash [% by mass of cement]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.05</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>0.50</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>-</td>
<td>0.20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>0.05</td>
<td>-</td>
<td>0.50</td>
<td>-</td>
</tr>
<tr>
<td>0.5</td>
<td>0.05</td>
<td>-</td>
<td>-</td>
<td>5.00</td>
</tr>
</tbody>
</table>

Rheological measurements were carried out to judge the effectivity of the sugar (sac.) to replace the tested superplasticizer (SP). For this purpose the cement suspensions were mixed with graded dosages of sugar and superplasticizer and were consequently rheologically characterized. Measurements were performed 5, 15, 30 and 60 minutes after the water was added to the dry cement at atmospheric pressure and at a constant temperature of 20°C. In Fig. 6 the influence of the sugar and the superplasticizer on the flow behaviour of the cement suspension is illustrated over the whole shear rate range.
It can be clearly observed that yield stress and dynamic viscosity decrease with increasing sugar content. It should be noted that a sugar content of 0.05 % by mass of the cement already leads to a significant drop of the flow curve similar to the addition of the superplasticizer by 0.2 % by mass of the cement.

Fig. 6. Influence of sugar (sac.) and superplasticizer (SP) on the flow behaviour of the cement suspensions with a water/cement ratio of 0.5 15 minutes after addition of the water at atmospheric pressure and a temperature of 20 °C.

In addition, the influence of bentonite (ben.) and rice husk ash (rha.) on the flow behaviour were examined. For this purpose the cement suspensions were mixed with previously determined amounts of rice husk ash and bentonite and were consequently rheologically characterized. Like before, measurements were performed 5, 15, 30 and 60 minutes after the water was added to the dry cement at atmospheric pressure and at a constant temperature of 20 °C. Fig. 7 shows the change of the flow properties of the cement suspensions over the whole shear rate range depending on the respective addition.

Fig. 7. Influence of sugar (sac.), rice husk ash (rha.) and bentonite (ben.) on the flow behaviour of the cement suspensions with a water/cement ratio of 0.5 15 minutes after addition of the water at atmospheric pressure and a temperature of 20 °C.

The addition of bentonite to the pure cement suspension resulted in an increased yield stress and dynamic viscosity. When sugar was added, yield stress and viscosity dropped below even the values of the pure cement suspension. Furthermore, the addition of rice husk ash as a puzzolan to a sugared cement suspension reduced the effect of the sugar. However, yield stress and viscosity were still lower compared to a pure cement suspension. Fig. 7 shows these experimental results 15 minutes after the addition of water.
5. Fresh mortar experiments

Following the investigation of the flow behaviour of the cement suspensions with the rheometer, the consistency of different mortar mixtures was examined with conventional methods and compared with the results of an industrial mixture for drinking water cisterns in Germany and was in accordance with the Indonesian reference mixture.

After mixing the mortars in a Hobart-mixer, the slump values of all mixtures were determined 5, 15, 30 and 60 minutes after the addition of water to the dry ingredients according to [6]. Furthermore the flow behaviour of the mortar when applied to an inclined plane was evaluated with a so-called slip-test 10 and 40 minutes after water addition. The test setup was developed in 2002 by KIT students for testing and optimisation of mortar workability [7]. The individual steps and exemplary results for a stiff and a smooth mixture are illustrated in Fig. 8.

The mortar is applied with a thickness of 5 mm in a flat formwork with an edge length of 10 cm. It is mounted with an angle of 75° to the horizontal surface in a metal frame and positioned on a Hägermann table to be stressed with 15 impacts. The maximum value of the mortar slip is taken as criteria for the application behaviour of the mortar in-situ.

71 fresh mortar experiments were performed in total. Initially the water/cement-ratio and the sand/cement-ratio were varied as main parameters of the mortar composition to figure out the overall limits of workability. Afterwards, the effects of the addition of different amounts of commercial superplasticizer and stabilizer as well as local sugar, bentonite, cassava flour and rice husk ash were studied. A description of all results and their detailed analysis can be found in [8].
The best results were gained with a mixture comprising a lowered water/cement-ratio of 0.4, a higher sand/cement-ratio of 2.5 and the addition of both saccharose with a content of 0.05 % by mass of the cement and bentonite with a content of 0.5 % by mass of the cement. Fig. 9 illustrates the behaviour of the slump value over the processing period.

![Slump value over the processing period](image)

**Fig. 9.** Slump value over the processing period for the new mixture compared to an industrial reference (Pagel TW 20) and the common mixture.

The new mortar mixture shows a good workability, reaching the aimed slump range during the whole processing period. Compared to the industrial reference mixture (Pagel TW 20) and the common Indonesian mixture, the slump values tend to be a little higher, which favours easier workability. However, its applicability, i.e. its ability to be applied on vertical surfaces and even on ceilings, was not endangered at any time. This can also be seen in Fig. 10, where the rheological behaviour of the new and the common mixture is compared.

![Shear stress and viscosity](image)

**Fig. 10.** Shear stress and viscosity over the shear rate of the new mixture (green) and the common mixture (black).
The new mixture has a similar yield stress of about 19 Pa compared to 17 Pa of the common mixture. Furthermore, its viscosity is somewhat lower due to the addition of sugar which favours the workability. The applicability (“stickiness”) was still similar due to the addition of bentonite, which stabilizes the mixture. The material composition and its main rheological properties are summarized in Table 2.

<table>
<thead>
<tr>
<th>parameter</th>
<th>new</th>
<th>common</th>
</tr>
</thead>
<tbody>
<tr>
<td>cement</td>
<td>634 kg/m³</td>
<td>698 kg/m³</td>
</tr>
<tr>
<td>water</td>
<td>254 kg/m³</td>
<td>314 kg/m³</td>
</tr>
<tr>
<td>sand</td>
<td>1355 kg/m³</td>
<td>1262 kg/m³</td>
</tr>
<tr>
<td>w/c-ratio</td>
<td>0.4</td>
<td>0.45</td>
</tr>
<tr>
<td>s/c-ratio</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>saccharose</td>
<td>0.05 %</td>
<td>-</td>
</tr>
<tr>
<td>bentonite</td>
<td>0.5 %</td>
<td>-</td>
</tr>
<tr>
<td>yield stress</td>
<td>17 Pa</td>
<td>19 Pa</td>
</tr>
<tr>
<td>viscosity</td>
<td>0.38 Pas</td>
<td>0.65 Pas</td>
</tr>
</tbody>
</table>

6. Hardened mortar properties

Based on the results from the rheological investigations on cement suspensions and the fresh mortar experiments, the mechanical properties were finally determined on hardened mortar specimens.

Prismatic specimens with a length of 160 mm and a square cross-section of 40 x 40 mm were produced according to [9]. The prisms were wrapped in foil and stored for one week under humid jute. Until the time of testing after 28 days, the prisms were stored unwrapped in a climate chamber at a temperature of 20 °C and a relative humidity of 65 %. Table 3 summarizes the mix compositions for the investigations on the hardened mortar properties.

<table>
<thead>
<tr>
<th>Name</th>
<th>w/c</th>
<th>s/c</th>
<th>sac. [% by mass of cement]</th>
<th>rha. / ben.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ref 2</td>
<td>0.45</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M1</td>
<td>0.4</td>
<td>2.5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>M2</td>
<td>0.4</td>
<td>2.5</td>
<td>0.05</td>
<td>-</td>
</tr>
<tr>
<td>M3</td>
<td>0.4</td>
<td>2.5</td>
<td>0.05</td>
<td>0.5 ben.</td>
</tr>
</tbody>
</table>

The compressive strength and the flexural tensile strength of the hardened mortar were determined according to [9]. Further the pore volume and the pore size distribution of the cement stone were given by mercury intrusion porosimetry according to [10]. After 28 days the water absorption of the mortar specimens under atmospheric pressure and under a pressure of 150 bar were determined according to [11]. Finally the density according to [12] and the total porosity according to [13] were examined. The results of the investigations on the hardened mortars are presented in Table 4.

The results of the investigations on the hardened mortar specimens showed both a high compressive strength and a high flexural tensile strength for all mixtures. Due to the high cement content, the common Indonesian mixture Ref2 showed the highest strength values.
Table 4. Results of the investigations on the hardened mortars

<table>
<thead>
<tr>
<th>Name</th>
<th>$f_{cm}$ [MPa]</th>
<th>$f_{c,6}$ [MPa]</th>
<th>density [g/cm³]</th>
<th>Hg-porosity [%]</th>
<th>Water absorption [%]</th>
<th>Total porosity [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1 bar</td>
<td>150 bar</td>
</tr>
<tr>
<td>Ref 1</td>
<td>69.4</td>
<td>9.3</td>
<td>2.3</td>
<td>17.2</td>
<td>7.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Ref 2</td>
<td>80.3</td>
<td>12.0</td>
<td>2.6</td>
<td>16.3</td>
<td>9.2</td>
<td>10.8</td>
</tr>
<tr>
<td>M1</td>
<td>73.0</td>
<td>11.2</td>
<td>2.5</td>
<td>12.7</td>
<td>7.9</td>
<td>9.4</td>
</tr>
<tr>
<td>M2</td>
<td>74.8</td>
<td>10.6</td>
<td>2.5</td>
<td>13.8</td>
<td>8.2</td>
<td>9.8</td>
</tr>
<tr>
<td>M3</td>
<td>71.6</td>
<td>10.4</td>
<td>2.5</td>
<td>13.6</td>
<td>8.4</td>
<td>10.1</td>
</tr>
</tbody>
</table>

The commercially available mortar Ref1 showed the lowest strength value. However, no detailed mixture composition was available to judge this behaviour. The low water/cement-ratio of mixtures M1, M2 and M3 of 0.4 resulted in a high compressive strength as expected. The inclusion of sugar did not seem to affect the compressive strength negatively. Also, the effect of bentonite was still in the scattering band. The reduction of the water/cement-ratio aimed to reduce the porosity of the mortar as low as possible to guarantee a high durability. A German regulation [14] suggests for cistern mortars a HG-porosity lower than 12 % by volume. This was almost reached by all mixtures M1 to M3 (see Table 4) which showed a mean porosity of 13.4 %. The mixture M2 with the addition of sugar had a slightly higher porosity than M1. However, the increase was still in the scattering band and the effect of the sugar on the porosity was therefore excluded. All mixtures showed a favourable pore size distribution with a small percentage of capillary pores (see Fig. 11).

Compared to the requirement of porosity lower than 12 % according to DVGW W 300 (2005), the porosity values of mixtures M1 to M3 are acceptable, while the Indonesian reference mixture Ref2 had a higher porosity of 16.3 % due to its higher water/cement-ratio. Surprisingly, the industrial reference mixture Ref1 showed the highest porosity of 17.3 % and, in addition, the highest share of capillary pores (see Fig. 11). The determination of the water absorption under atmospheric pressure and under a pressure of 150 bar produced similar tendencies. Mixture Ref2 showed higher porosities than the optimized mixtures M1 to M3. However, mixture Ref 1 had a lower porosity in...
this case, which must be attributed to its unknown mixture composition. It could be possible that further chemical agents are admixed to enhance the sealing behaviour.

7. Discussion

Rehabilitation mortars may include, besides the main ingredients cement, sand and water, various organic or mineral additions, which influence the mortar properties. As commercially available additions are quite expensive and hardly available in the local region of Gunung Kidul, alternative additives and admixtures were chosen to be examined. The main focus in this regard was on the investigation of local retail sugar as an alternative for liquefying additives. Further cassava flour (not dealt with in detail here) and bentonite were tested as alternatives for commercial stabilisers. Moreover an Indonesian rice husk ash (abu sekam padi) was treated with different methods and their influence on the puzzolanic reaction was determined.

Starting with a sand/cement-ratio of 2.0, the sand content of the rehabilitation mortar was increased to minimize the costs as well as the shrinkage tendency. At the same time, the water/cement-ratio was reduced as low as possible to enhance the durability of the construction material. This logically resulted in a clear deterioration of the mortar workability, which was balanced with the addition of sugar in a dosage of 0.05 % by mass of the cement. Negative effects were detected neither on the strength values of the mortar, nor on its porosity.

The usage of stabilisers to prevent a bleeding of the mortars was not mandatory due to the low water content of the mortars. However, the objective was rather to enhance the applicability (“stickiness”) of the mortar with higher sand content with cost-effective measures. At the beginning, the use of cassava flour as organic substance in the rehabilitation mortar was excluded also because of its high price. The clay mineral bentonite was investigated in detail and finally added to the mortar in a dosage of 0.5 % by mass of the cement. Although it resulted in a slight reduction of the workability, the applicability was positively influenced.

The usage of rice husk in the rehabilitation mortar was abandoned, as it notably reduced the workability while its beneficial effects on the puzzolanic reaction could not be proven clearly within this study.

The optimal mixture regarding a favourable compromise of fresh and hardened mortar properties was achieved with a mixture containing a water/cement-ratio of 0.4, a sand/cement-ratio of 2.5 and both saccharose with a content of 0.05 % and bentonite with 0.5 % by mass of the cement. It shows a high strength and a low porosity with only a small share of capillary pores. By increasing the sand content, the higher cement content due to the lower water/cement-ratio was compensated. Compared to the Indonesian reference mixture, even a reduction of the cement content of 10 % was achieved while maintaining the known workability. This means that the former size of the cisterns of 9 m³ could be enlarged to 10 m³ while keeping the material costs constant.

During the construction works it became evident that from a technical and economical point of view, the in-situ rheological behaviour of the mortar is the key factor to achieve the best possible tightness of water cisterns. Therefore, the methodology of how to compose the mortar according to its intended range of application was summarized in a comprehensible practical guideline.

The guideline was translated (German – English – Indonesian) and handed over to the villagers as an important part of the capacity development. The basic concept was already discussed in detail and field-tested with the local persons being responsible for construction activities during preceding stays in Pucanganom (see Figs. 2 to 4). The joint construction of the first cistern revealed valuable knowledge regarding the construction procedure and the material behaviour in-situ which were used to further adapt the concept to the local situation. The revised concept was successfully implemented with the joint construction of a second cistern in May 2013 (see Fig. 12).
8. Conclusion and outlook

By means of a case study the successful development and implementation of a rheologically optimized cement-based mortar for the appropriate construction as well as rehabilitation of rain water cisterns in Indonesia is presented in this paper. In the process the effects of different source materials on the rheological properties of pure cement suspensions were examined while the actual workability of the hydraulic materials was verified with fresh mortar experiments. Finally, the mechanical properties were determined on hardened mortar specimens.

The developed material can be used as a coating for walls, floors and ceilings of cisterns, for the local rehabilitation of damaged areas only, or even as a construction material for complete new cisterns. For the selection of the source materials, special emphasis was placed on a ready availability and low costs. The rheological properties of the fresh mortar allow an easy workability by hand while the hardened mortar shows a durable and tight appearance at the same time.

During March 2014, the tightness and serviceability of the cisterns build up to that point were verified during a field investigation and discussions with the local users. It was apparent that due to the close cooperation with the local persons being responsible for construction activities, the adapted concept for cistern construction was very well accepted by the inhabitants of the village.

Due to the positive feedback, the joint construction of further cisterns is planned. However in this case, only a consulting support is foreseen, which should on the one hand encourage the personal responsibility of the local population, while on the other hand verify to what extent the concept is really adopted and continued independently in the future.

Acknowledgements

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