River Nile bank protection – German-Egyptian cooperation in analysis, design and quality control

Protection des berges de la rivière du Nil - coopération germano-égyptienne sur analyse, conception et contrôle de la qualité

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ABSTRACT

As the banks of the River Nile in Egypt were endangered by severe erosion in several locations, a river bank protection scheme consisting of a fill and a stone revetment was planned as a countermeasure. In the first project phase, protection work was carried out without soil testing and without site-specific design. This measure halted the erosion, but in several locations the protected banks were severely damaged after a very short period of time. In the second project phase, as part of a German-Egyptian cooperation project, a procedure for analysis, design and quality control for the river bank protection work was developed. For the new locations soil investigations were carried out to determine the relevant soil parameters. Then site-specific stability analyses and site-specific filter design were carried out. The requirements of the design process agreed upon between the German and the Egyptian partners are presented and design examples are given. Part of the agreement was also the execution of thorough quality control measures during the construction process. A design concept for river bank protection works adapted to Egyptian conditions was developed. This concept led to very satisfying results and was used as a model for similar following projects in Egypt.

RÉSUMÉ

Les berges du Nil en Égypte ont été à plusieurs endroits menacées par une grave érosion. En tant que contre-mesure, une protection des berges composée d’un remblai et d'un revêtement de pierres a été prévue. Dans une première phase du projet, le travail de protection des berges a été effectué sans sondage et sans conception spécifique pour le site. Grâce à ces travaux, l'érosion a été arrêtée, mais les protections ont été gravement endommagées à plusieurs endroits dans un laps de temps relativement court. Lors d’une deuxième phase du projet, dans le cadre d'une coopération germano-égyptienne, des procédures d'analyse, de conception et de contrôle de la qualité des travaux de protection des berges ont été élaborée. En travaillant sur de nouveaux sites, des études de sols ont été effectuées pour en déterminer les différents paramètres. Avec ces paramètres, des analyses de stabilité et des conceptions de filtres spécifiques à chaque site ont été effectuées. Les conditions concernant le processus de conception convenue entre les différentes parties allemandes et Egyptienne sont présentées et des exemples sont donnés. Une partie de l'accord a également concerné l'exécution de mesures minutieuses pour contrôler la qualité pendant le procédé de construction. La conception de travaux de protection des berges adaptées aux conditions égyptiennes a été développée. Ce concept a abouti à des résultats très satisfaisants et a été utilisé comme modèle pour de futurs projets similaires en Égypte.

Keywords : River Nile, erosion, river bank protection, design concept, stability analyses, filter design

1 INTRODUCTION

As a consequence of the erection of the High Aswan Dam in southern Egypt in the 1960s, the banks of the River Nile between Aswan and Cairo were subject to severe erosion in several locations. In the late Eighties the Egyptian authorities established that along approx. 242 km of the 2,033 km total length of river bank significant erosion had occurred, with annual land losses of between 0.5 and 3 m, or even more in some locations. A schematic sketch of a typical cross section of an endangered river bank is given in Fig. 1. In most cases, the erosion caused by the river water in the lower part of the almost vertical banks, plus the overflow of irrigation water from the top of the bank, led to a dislodgement of large sections of soil.

As part of a pilot project from 1989 to 1991, about 3 km of river bank were protected by a stone revetment founded on a stone toe. Using the experience gained, about 20 km of river bank were stabilized in a follow-up project in 1992. These measures temporarily halted the land loss. However, after only two or three years and in some cases after only a few months significant damage to the river bank protection was observed. In some locations the stone toe had slipped, followed by the stone revetment. In other locations the stone revetment had locally settled due to the erosion of backfill and filter material caused by irrigation water running over the slope. In addition, in several cross sections large deformations and cracks were observed, indicating that the overall stability of the river bank protection construction was insufficient.

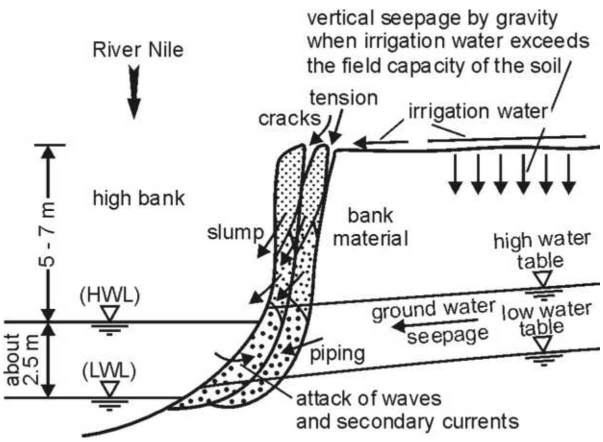

Figure 1. Factors affecting bank failure on the River Nile (NRI 1992).

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The main reasons were that a relatively steep inclination of the revetment of 1:1.5 had been chosen and that no soil investigations and no site-specific analyses and stability calculations had been carried out for the project. The project had been executed without such measures, because maintenance work is relatively cheap in Egypt compared to Western Europe and so minor damage had seemed acceptable. However, the damage observed gave rise to considerations about modifications of design and construction work in order to keep anticipated damage within reasonable limits.

Between 1995 and 1998 another approx. 90 km of River Nile banks were protected against erosion as part of the River Nile Bank Protection Project, Phase II. This project was financed by the German government, represented by the KfW Bank. In a cooperation between a German consultancy team, the Nile Research Institute as the Egyptian authority commissioned with planning and design works, and a General Project Management representing the Egyptian Ministry of Public Works and Water Resources, a concept for analysis, design and quality control was developed for this project. This concept and the work carried out are described in the following.

2 PREVAILING CONDITIONS FOR THE PROJECT

The hydraulic-hydrological conditions at the River Nile sections to be considered are relatively moderate. The maximum flow velocity is about 1.5 m/s and wave height does not normally exceed 0.5 m.

The water levels are regulated by the Nile barrages located between Aswan and Cairo. Over the year, there is a low water level phase between November and April. From April on the water level rises, reaching a high water level between June and August which is about 2 to 3 m higher than the low water level. Because of this, the period of construction of the river bank protection was limited to the low water phase between November and April.

In Phase I of the river bank protection project a stone revetment 50 cm thick, consisting of at least two layers of stone, was built with an inclination of 1:1.5 to a height of 1 m above the highest water level. Below the revetment a 10 cm thick filter layer was placed in order to avoid erosion of the backfill material below. At the lower end of the revetment a stone toe was placed with the upper edge at the low water level.

Since the river bank protection with a stone revetment was proved to be suitable in principle, it was also decided to use the general design in Phase 2, but with adaptations to improve durability and to minimize the damage potential of the construction. Another important point was that the costs for wages should be at least 30% of the total costs. Thus, the aim of protecting the river banks would be combined with social measures to improve the living conditions of the local, relatively poor people. Also for this reason, the use of mineral filter layers was chosen rather than geotextile filters, which would have to be imported from abroad.

For Phase 2 of the project, the maximum inclination of the stone revetment was agreed to be 1:2. To stabilize the stone toe and to protect it from scour, a 3 to 5 m long protection layer in front of the toe consisting of stones or alternatively of sandbags was planned. The stone toe itself was to be placed on a filter layer of sandbags to prevent erosion of the river bed below it.

Moreover, a main agreement was that for each location a site-specific design should be carried out, including field and laboratory soil investigations and, based on this, stability analyses and filter design. The characteristic cross section, which was agreed upon to be the basis of the plans for Phase II of the river bank protection project is shown in Fig. 2.

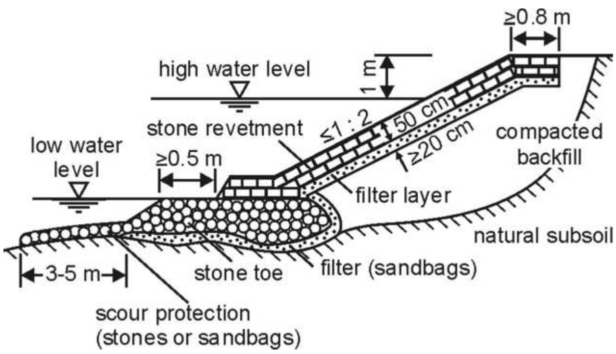

Figure 2. Characteristic cross section of the river bank protection.

3 GUIDELINES FOR SITE-SPECIFIC DESIGN

Taking the prevailing conditions and also the experience of the Nile Research Institute gained in the foregoing projects, design guidelines were drawn up for Phase 2. The main aspects of these design guidelines were as follows:

- Regarding soil explorations, borings with a diameter of at least 100 mm were planned at maximum distances of about 200 m. The boring depth should be adapted to the site conditions and usually lie between 6 and 12 m. The extraction of soil samples should be combined with Standard Penetration Tests (SPT) in order to obtain data to assess the relative density or, in general, the strength and stiffness of the soils.
- The soil parameters were to be determined by laboratory tests. In particular, grain size distributions for the assessment of filter stability and direct shear tests for the determination of shear parameters were required.
- The stone revetment, 50 cm thick and with a maximum inclination of 1:2, should consist of hand-laid and overlapping stones in at least two layers.
- For the filter layer underneath the stone revetment a minimum thickness of 20 cm was stipulated. The filter material was to be chosen taking the type of backfill material into account, so a filter design based on geometric criteria was required. The use of non-cohesive backfill material was recommended, but not compulsory.
- For the stone toe, a maximum inclination of 1:1.5 and a scour protection layer at least 3m long was required. The stones used should weigh between 20 and 50 kg.
- Stability calculations should be carried out for the most unfavourable cross sections at a maximum distance of 50 m. An overall factor of safety of at least 1.5 was required. Based on the experience of the Nile Research Institute, the water level difference between groundwater level and high and low water level, respectively, was assumed to be 1 m.

In Fig. 3 the result of the analyses carried out with respect to the design guidelines stated above is shown for an exemplary cross section.

In a few locations, it was found that the desired factor of safety could only be reached by greatly increasing the amount of stone and backfill material, leading to a significant cost increase. It was thus agreed upon that in such special cases factors of safety lower than 1.5 were acceptable. This seemed reasonable in view of the regular inspections of the river banks by the Nile Directorate authorities and to the relatively low costs to be expected for maintenance measures.

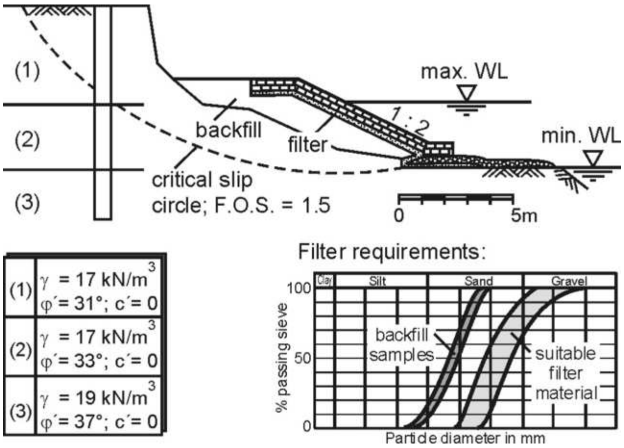

Figure 3. Exemplary cross section of the bank protection, designed in accordance with the guidelines.

4 EXECUTION, QUALITY CONTROL AND COSTS

Figs. 4, 5 and 6 show details of the construction of the river bank protection.

Both the stones of the stone toe and the sandbags serving as a filter layer underneath were constructed by dumping in the water or, if possible, by hand-laying (Fig. 4). Subsequently, the section behind the toe was backfilled. The backfill material was usually taken (with the landowners` permission) from soil material stemming from the fields behind the river bank. It was placed in layers about 25cm thick and compacted either by hand tamping or by vibratory plates.

Subsequently, the filter layer was installed with the desired inclination. The stones of the revetment were placed on top of the filter layer (Fig. 5).

Besides the design guidelines, extensive measures for the quality control of the construction work were also agreed upon. The following controls were carried out with random testing by site engineers employed by the Nile Directorates responsible or commissioned by them:

- assessment of the suitability of the stones delivered from quarries,
- checks on the size of the stones and comparison with the requirements,
- checks on the backfill and filter materials used, by taking samples and determining grain size distributions,
- carrying out of compaction control measures.

During the whole construction period the work was supervised by the site engineers.

On several visits, the German consultancy team and experts from the Nile Research Institute and the General Project Management assessed the quality of the work. Overall for the three construction periods, a very high standard was attested for the work carried out.

The average costs of the river bank protection work in Phase 2 were approx. 700,000 L.E./km. These costs were considerably higher than the costs spent in phase I. Besides the costs of soil investigation and design, the main reason for the increase in costs was of course the lower inclination of the bank and the greater amount of stone used on the stone toe and the scour protection layer. However, the result was a river bank protection with increased durability and reduced vulnerability.

5 CONCLUSIONS

The authors believe that the project described here is a model for good technical cooperation between two states. Expertise brought in from both sides led to a concept of analysis, design and quality control which has been proved to be suitable for the special construction measure taking Egyptian conditions into account. In the sequel of the project, the concept has also been used in other bank protection projects.

Figure 4. Stone toe atop sandbags under construction.

Figure 5. Detail of the stone revetment atop gravel filter layer.

Figure 6. Partly completed river bank protection.

Figure 7. River bank protection two years after construction.

The results of the project were very satisfactory. On a final visit two and a half years after the start of the construction work it was found that the river bank protection was in very good condition on the whole (Fig. 7). Only at a few sites was a need for minor maintenance works identified, since some stones of the revetment had loosened and moved. However, this was not a result of erosion or sliding, but of the intensive usage of the banks by the local people. It was possible to repair the damage easily and at little cost.

REFERENCE

Nile Research Institute (NRI) 1992. River Nile Protection and Development Project, River Nile Bank Protection Guidelines. Ministry of Public Works and Water Resources, Water Research Center, Egypt.