

SECTION 3 : ENGINEERING GEOLOGY

3.1 INTRODUCTION

The engineering geological investigation for the pre-feasibility study comprised a site visit between 22nd and 24th January 2003, a study of available information and the interpretation of laboratory tests performed on disturbed samples. No field tests were carried out during this visit.

Four alternative sites have been investigated during the site visit, all four being situated upstream of the falls. An additional alternative site (Site 5) was later added to the study. The condition at this locality was inferred from investigation results at the nearby Site 4.

3.2 METHODOLOGY

For this pre-feasibility investigation the available information such as reports, geological maps, aerial photographs and local information were obtained. The four sites (excluding Site 5) were visited to evaluate the founding conditions and to study possible available construction material sources. Contractors and construction companies were contacted to determine the availability and quality of construction materials.

Laboratory tests were conducted on disturbed samples retrieved from various locations in the vicinity of the sites. Four indicator, two California Bearing Ratio, one consolidated undrained triaxial and two permeability tests were performed. The results of these tests are given in **Annexure 1** in **Volume 2** of this report.

3.3 AVAILABLE INFORMATION

A 1:1 000 000 geological map, dated 1980, based on the 1:1 000 000 map (1978 Edition) published by the Surveyor-General, Windhoek.

A preliminary feasibility investigation report by Hydroconsults, dated August 1969.

A report: "Earthquake hazard in Southern Africa", published by Geological Survey of the Republic of South Africa, 1979.

Aerial photographs

An unpublished rainfall map of Namibia indicates that the annual mean rainfall in the project area is between 600 mm and 700 mm.

3.4 GEOLOGY

The entire area is covered by Tertiary to Quaternary deposits of the Kalahari Group, consisting of sand, calcrete and gravel. Calcrete terraces and red, partially consolidated dune deposits of the Namib desert are also present. The 1:1 000 000 geological map is the only map available. It shows no geological features/structures of any description, except the covering of Tertiary deposits and a quartzitic sandstone rock outcrop at the Falls. Below these partially consolidated Tertiary deposits, which are visible in the riverbed, is the quartzite (or quartzitic sandstone) of the Nosib Group of the Damara Sequence (Damara Supergroup).

Rock outcrops are very sparse and were only noticed in the riverbed of the Okavango River and on hills located in the vicinity of Sites 3, 4 and 5.

As far as the geological information on the available map is concerned, there are no distinguishing features regarding geological structures whatsoever indicated in the region concerned. A study of the airborne laser mapping and the aerial photos of the area, however, indicated a NE-SW trending linear feature across the river midway between sites 4 and 5. This feature could represent a dyke or a structural feature such as a fault. The study of the contour maps also revealed vague indications of three possible geological lineaments directly upstream on the left flank of Site 4, striking more or less north-south. These are somewhat conjectural at this stage and do not warrant a degrading of Site 4 as a possible alternative, particularly if read in conjunction with section 4.6, where it is highlighted that the dam sites are not in a high risk area as far as seismicity is concerned. The seismicity of the sites needs to be further investigated during the detailed feasibility phase, as discussed in Section 3.6.

Similar linear features may be present at or close to the other sites but are not noticeable due to the presence of unconsolidated materials which cover these features. The full extent and orientation of the features should be investigated by geophysical methods such as EM (electromagnetic), resistivity and/or magnetometer surveys during the detailed feasibility

phase. The results of the geophysical surveys should be used to plan the position(s) of boreholes to investigate the geological conditions of these features.

3.5 CONSTRUCTION MATERIALS

The construction materials required for a weir structure, consisting of a concrete section in the centre and with earth embankments on the flanks, are coarse and fine aggregate, fill materials, rip-rap, filter and core materials. If mass gravity wall sections are considered for the flanks, then only fine and coarse aggregate would be required.

3.5.1 COARSE AND FINE AGGREGATE

Concrete aggregate is a scarce commodity in the Okavango area. The nearest rock quarry is a quartzite quarry approximately 50-60 km from Popa Falls towards Rundu. There are some concerns regarding the flakiness of the aggregate. This could be attributed to a poor crushing process and may thus be remedied if attention is given to the process or a new crusher is established. The quality and quantity of the available material should be investigated further.

The indicator test result of the sample "Site 4 River Sand" (refer to **Annexure 1 of Volume 2** of this report) shows the sand to be suitable for use as fine aggregate. Initial indications are that sufficient fine aggregate should be available along the river. If necessary this can be blended with crusher dust from the quarry.

3.5.2 FILL MATERIALS

Material which may be suitable for fill in an embankment can be found just downstream of the Popa Falls towards the Malaria Control Camp. An indicator test on the sample "Mosquito BP Red Gravel" shows the soil to be suitable for the outer zones of an embankment. The consolidated undrained test indicates that the soil represented by sample 03/217 will have sufficient strength for the outer zones of the embankment. The total volume of material available has, however, not been established and it is uncertain if sufficient material will be available to construct the outer zones of the embankments. Further detailed investigations are necessary to determine how widespread the occurrence of this material is.

3.5.3 RIP-RAP

The moderately to highly weathered sandstone, which is present on the sites, may be suitable for use as rip-rap. Alternatively it may be obtained from the quartzite quarry mentioned above.

3.5.4 CORE MATERIALS

The indicator test result for the "Site 2 clay" sample (appended to the report) suggests that this particular source is marginally suitable for a conventional core. Relatively high seepage rates are to be expected. The indicator and permeability tests gave conflicting results; with regards to the suitability of sample 03/221 as a core material, the indicator test showed a poor grading, while the permeability test gave an acceptable value ($5,341 \times 10^{-6}$ cm/s). More testing of this particular source is thus required.

A possible alternative source of core material could be the Omuramba Omatoko which is, however, located some 120 km from Divundu towards Rundu. No samples were taken of this material, with the result that it is not possible to comment at this stage on its suitability as core material.

In the event that earth embankments prove to be the most economical alternative, and in the event that the material found in the Omuramba Omatoko is found to be unsuitable for use in a clay core, then consideration should be given to utilising a concrete lining or an asphaltic core for the embankments.

3.5.5 FILTER MATERIAL

For a filter in an embankment structure, a relatively clean sand is required. Large quantities of sand are available and some samples have been taken for laboratory tests. The results given in **Annexure 1** of this report, indicate that "Site 4 River Sand" could also be used as the filter material.

As an embankment is likely to be constructed using semi-pervious materials, it should be borne in mind that a special filter design is required to accommodate the seepage rates associated with these materials.

3.5.6 ROAD BUILDING MATERIAL

For road building purposes the “Dimbare Youth Centre Red Sand” is of G7 quality and can be used for the Selected Layer, whilst the “Mosquito BP Red Gravel” which is of G4 quality is suitable as base course material (Guidelines for Road Construction Materials, Committee of State Road Authorities of South Africa). In the possible absence of suitable sub-base material (Quality grades G5 or G6), consideration would need to be given to using base course material.

Road building materials would be required in cases where the existing district road D 3402 would need to be relocated to above design flood levels.

3.6 FAULTING AND SEISMICITY

A study of aerial photos of the general area of the sites has indicated the presence of a linear feature trending approximately north-east – south-west across the river midway between Sites 4 and 5. This feature is possibly a dyke.

Three minor linear features have also been noticed directly upstream of site 4 on the left flank. One of the features crosses the dam site on the left flank near the full supply level.

The origins of these features are unknown and will need to be investigated further if either site 4 or 5 is considered for the detailed feasibility study. The investigation will need to consist of geophysical surveys and drilling.

It is likely to be found that these features will not pose a severe threat to the stability of the proposed structures.

A study of the geological map of the area has not revealed the presence of significant faulting, although it should be borne in mind that the majority of the solid geology of the area is obscured by sand.

According to a published map by Fernandez and Guzman (1979)⁶⁾ (Preliminary map of natural seismic hazard (100 years)), the site lies in an area where there is a 90 per cent probability of a seismic intensity of 6,2 (modified Mercalli scale) not being exceeded during a period of 100 years, and a 90 per cent probability of a seismic intensity of 7,0 not being

exceeded during a period of 500 years. The dam is thus not in a high risk area and due to the low height of the wall it is anticipated that no special earthquake design requirements will be necessary. This aspect will, however, need to be investigated more closely during the detailed feasibility study phase.

The risks that need to be assessed during the detailed feasibility study will include the following:

- **Embankment dam**

- Liquefaction of the material in the dam or its foundation.
- Collapse due to movement at a slip surface in the slope or through the foundation.
- Loss of freeboard.
- Development of uncontrolled leakage through cracks or at interfaces with structures or abutments.
- Spillways and hydraulic controls to be damaged to the extent that dangerous conditions develop.

- **Concrete dam**

- Sliding on its foundation or at the abutments.
- Opening of joints or cracks to the extent that uncontrolled leakage takes place, or failure due to local crushing.
- Blocks or sections to be displaced.
- Spillways and hydraulic controls to be damaged to the extent that dangerous conditions develop.

The assessment of the abovementioned risks would involve, in broad terms, two stages: namely the assessment of the hazard and the degree of shaking due to the earthquake and the translation of these effects into parameters which constitute the input for stress analyses.

The first step in the assessment of the seismicity would be the collection of relevant data. This will include, as already mentioned, the published map by Fernandez and Guzman and analyses of more recent studies by seismologists. (Prior to this report Dr Andrej Kikjo at the Council for Geoscience had telephonically informed us that he can report on the seismic risk of the area, but at a cost of several thousand Rand – thus a study which should be included in the detailed phase.) Such studies should include assessments of the regional geological structures, the fault systems and past seismic activity. In particular, the linear feature

between sites 4 and 5 should be assessed for its potential as an active fault. An estimate would then have to be made of, *inter alia*, the intensity of the earthquake at the site, utilizing site specific attenuation curves. The site intensity must be converted to a design parameter such as the ground acceleration.

After a study of the abovementioned data, a decision will have to be made on the level of the structural analyses necessary. Sophisticated software is available for analysis in both the frequency and time domain to calculate stresses and displacement. These would require, *inter alia*, detailed statements of the input ground motion, such as frequency content, amplitudes and duration, as well as the non-linear stress-strain relationship of the soil materials involved. Approximate models to gauge factors of safety, probability of failure and displacement are also available.

Once the detail or approximate analysis results are available, mitigation measures can be designed. These may range from deep compaction of the sands on site (to avert liquefaction) and/or special structural designs, or merely flattening of design slopes.

As mentioned earlier, the area does not appear to be in a high risk area. Correlation data by Trifunac and Brady (1975)¹⁴⁾ indicates that the 6,2 Modified Mercalli Intensity, mentioned above, translates to a ground acceleration of 0,037g, whilst the intensity of 7,0 gives an acceleration of 0,066g. Should these values be substantiated by the detailed study, it is expected that very few, if any, special design features will be required to mitigate against earthquake effects.

3.7 ENGINEERING GEOLOGICAL INVESTIGATION

For a map showing the position of the different weir sites refer to **Figure 3-11** in **Section 3** of this report. This section provides a description of the geotechnical conditions present at each weir site. A fully integrated discussion of each weir site is provided in **Section 7**.

3.7.1 SITE 1

3.7.1.1 Locality

The site is located approximately 1,5 km upstream of the Popa Falls and corresponds to Site B identified in the 1969 study. The alignment of this site passes over a relatively large island with pristine vegetation.

3.7.1.2 Site Description

The site is located in a section of the river where the valley is relatively flat. Although the site visit took place in the low flow season, only minor rock outcrops were visible in the river bed. It was, however, evident from the shallow water depth that rock is likely to extend across the full width of the riverbed.

3.7.1.3 Site geology

Some rock outcrops were noticed in the river bed. Site 1 is covered by an alluvial sand deposit. The transported material covers the hard rock geology which consists of quartzite of the Nosib Group of the Damara Sequence.

There are no noticeable adverse geological conditions.

3.7.1.4 Founding Conditions

Only minor rock outcrops were visible in the river bed. The rock could not be inspected and the founding conditions are therefore based on the conditions observed at the other sites.

The riverbed rock, being sandstone /quartzitic sandstone, is probably moderately to highly weathered and may be classified as a weak rock. The rock is probably also highly fractured. However, as it is likely that the weir will not exceed a height of 10 m, relatively low bearing pressures will be exerted on the bedrock. A concrete spillway section at midstream can therefore be founded on the sandstone/quartzitic sandstone rock provided the loose, soft rock, and severely fractured sections are removed.

Final recommendations regarding founding conditions and grouting requirements can only be made once the geophysical testing, rotary core drilling and Lugeon testing have been carried out during the detailed feasibility phase.

3.7.1.5 Slope Stability

The entire area at the site and within the dam basin itself is very flat with the result that slope stability problems are not foreseen. If slope failures should occur they would be small and localised failures which will not have any influence on the stability of the weir.

3.7.1.6 Conclusions

From an engineering geological viewpoint, the visual inspection of the site and the available information indicate that the site is suitable for the construction of a low (± 10 m high) weir structure. The bearing pressures of the proposed structure are low. The structure can be found on weathered rock without compromising the stability, however, a bedrock profile will need to be determined during further investigative work. This would include seismic refraction surveys, rotary core drilling and the excavation of deep test pits.

3.7.2 SITE 2

3.7.2.1 Locality

Site 2 is located only a short distance upstream of Site 1. The left flanks of Sites 1 and 2 meet on the left bank whilst on the right bank the flank of Site 2 is located approximately 800 m upstream of Site 1. The alignment of this site also passes over a small island which is, however, only exposed during low flow periods and is insignificant.



View of Site 2 looking from the right bank towards the left bank.

3.7.2.2 Site Description

The valley is also very flat at this site, which has a wide river section (± 400 m). Although no rock was exposed at the time of the inspection, shadows under the water indicated that there was probably bedrock. It can also be assumed that the small island is probably rock with some sediments that have been deposited on its surface which allow the growth of reeds.

3.7.2.3 Site Geology

The geological conditions encountered at this site are similar to that of site 1. Substantial alluvial deposits overlie the quartzite of the Nosib Formation. No rock outcrops were visible. Possible structural geological features such as faults and dykes have been covered by transported material. No adverse geological conditions were noticed during this study.

3.7.2.4 Founding Conditions

Although the Okavango was at low flow during the site visit, no rock outcrops could be seen in the river section other than the dark shadows under the water. The flanks are covered by unconsolidated material, mostly sand and a local resident also confirmed that there were no rock outcrops in the area.

The sandstone/quartzitic sandstone is covered by unconsolidated material. The depth to moderately weathered bedrock is, however, unknown. Comments on founding conditions can only be made after more detailed studies and investigations such as drilling and geophysical surveys are carried out.

It is expected that the rock would be of similar quality as at Sites 1 and 3.

3.7.2.5 Slope Stability

As for the other sites, the area is flat and no slope stability problems are foreseen. Any failures are likely to be small and should not have any effect on the stability of the dam.

3.7.2.6 Conclusions

This site is similar to the other sites, except that no rock outcrops were visible at the time of the site visit. It is expected that founding conditions are similar, but this can only be verified

after a geophysical survey and drilling have been done. Further investigative work at this site will include the excavation of deep test pits, seismic refraction surveys and the drilling of rotary core boreholes to determine the depth and quality of bedrock.

3.7.3 SITE 3

3.7.3.1 Locality

The site is located immediately upstream of the Divundu bridge.



View looking upstream from the Divundu Bridge towards Site 3 : Left photo shows both river banks and the right photo is a view on to the steep left bank

3.7.3.2 Site Description

The left bank is steep and rock is visible on the surface whilst the right bank is very flat. Rock outcrops are abundant in the riverbed and also on the right bank. The rock is overlain by white, loose sand and alluvium. The visible rock is very fissured with many cavities indicating a high degree of weathering. The degree of weathering is, however, not worse than that found on the other sites visited, where rock was encountered.

Whilst the left flank of a weir at this site would be short compared to other sites, the right flank is longer as it needs to reach high ground.

3.7.3.3 Site Geology

Rock outcrops are visible at this site on the left flank, in the riverbed and some rock outcrops are visible on the right flank although they are generally covered by alluvium. The rock is

weathered quartzite of the Nosib Formation which has been largely covered by alluvial deposits.

3.7.3.4 Founding Conditions

The concrete section of the weir structure can be founded on the sandstone/quartzitic sandstone rock. The rock can be described as light grey to black, medium to highly weathered, highly fractured, medium grained quartzitic sandstone.

The upper layer of weathered rock will need to be removed before an adequate founding horizon will be exposed. On the left flank, however, a detailed investigation will need to be carried out to establish the condition of the rock into which an embankment would have to be tied.

The envisaged dam structure is relatively low and will exert low loads on the founding horizon. The upper loose and fractured material must be removed before placement of the foundations can be undertaken.

3.7.3.5 Slope Stability

As for Sites 1 and 2, this site is also very flat and no slope stability problems are foreseen. Any failures which may occur, are likely to be small and will not have an influence on the stability of the dam.

3.7.3.6 Conclusions

Numerous rock outcrops are visible on the flanks and in the river bed. The sandstone rock outcrop will serve as a good founding medium for a small weir structure. The fact that the rock is fractured and that numerous cavities are present indicates that some form of foundation preparation such as grouting may be required.

This site is considered to be most favourable from an engineering geological point of view due to the presence of abundant rock outcrops. The river channel is also relatively narrow at this position. Rock outcrops are present on the left flank, and the fact that the river channel is narrower here than at other sites indicates that the materials on the flanks are also more resistant to erosion. No prominent linear features which may indicate the presence of faulting or dykes have been noticed.

3.7.4 SITES 4 AND 5

3.7.4.1 Locality

Site 4 was visited on the occasion of the field investigations but Site 5 was added subsequently as a possible alternative and was thus not investigated during the site visit. From inspection of available maps and subsequent field trips, it was found that large and extensive rock outcrops are present at both sites, as attested to by the rapids in the river section where the average gradient of the river bed is approximately 10 times greater than at Sites 1, 2 and 3.



Photographs of Site 4 looking upstream (left photo) and downstream (right photo) showing rock outcrops

3.7.4.2 Site Description

The right bank of Site 4 rises gradually, necessitating a longer embankment than on the left bank, which rises rapidly from the riverbed. On the left there is a hill which rises rapidly from riverbed level. However, there is a side channel which passes around the northern side of the hill which can be utilised, in the first instance, as a diversion channel during construction. After the weir in the main river course has been completed, the valley will be closed with an auxiliary embankment incorporating a fuse plug which would breach when a flood occurs with an intensity greater than the design flood.

Site 5 is located approximately 1 km downstream of Site 4. This site has a narrow valley with relatively steeply rising left and right banks. A secondary valley is located further northwards

which has an elevation of some 4,5 m lower than the hill between the main channel and the secondary valley. This valley would need to be closed with an embankment.

3.7.4.3 Site Geology

Quartzite rock outcrops of the Nosib Formation are present on both sites 4 and 5. Alluvium consisting mainly of sand overlies the bedrock in places. A linear feature with a NE-SW strike can be noticed just upstream of site 5 on the aerial laser mapping and the aerial photos. This linear feature could represent a dyke or a structural feature such as a fault. Available information, however, indicates that the seismic risk of the area is low, as discussed in section 4.6.

Another three small linear features are also present directly upstream of site 4. All three features have a N-S strike. These lineaments may, however, not be indicative of structural features. The significance of the structures will need to be investigated further if these sites were to be considered.

3.7.4.4 Founding Conditions

From the visual inspection held at the time of the field inspections it would seem as though founding conditions would be good, relative to the low bearing pressures to be expected below the weir. The weathering pattern is generally the same as on the other sites, which would require removal of the loose soft rock and severely fractured sections near the surface. It is hoped that, with the removal of rock to founding level of the concrete section, good founding conditions will be found. This will have to be substantiated by core drilling and geophysical surveys before a final decision can be taken.

Although Site 5 has as yet not been visited, large scale maps indicate that rapids also exist at this site with substantial exposure of rock. The comments made in respect of Site 4 are therefore also deemed valid for Site 5.

3.7.4.5 Slope Stability and Conclusions

Although both banks rise more rapidly than at the other sites, no slope stability problems are anticipated at either of these two sites.

3.7.4.6 Conclusions

Rock outcrops are present on both sides. The foundation of the structure can be placed directly on rock. Loose and jointed material will have to be removed. Further investigative work on these sites will include:

- Geophysical surveys such as seismic refraction surveys to determine the depth and quality of bedrock, electromagnetic, magnetic and/or resistivity surveys to determine the type, orientation and conditions of the linear features,
- Rotary core drilling and Lugeon Testing,
- The excavation of deep test pits,
- Sampling of materials and laboratory testing.

3.8 CONCLUSIONS

- Five alternative sites have been investigated during this study. At Sites 3, 4 and 5, rock outcrops are visible, which at least give an indication of the founding conditions and expected founding level. No rock outcrops were noticed at Site 1 and very little at Site 2.
- The quartzitic sandstone present at the sites is moderately to highly weathered. Potholes are present and the rock is highly fractured. It is expected that grouting will be required to fill the fractures and to improve founding conditions.
- Based on this visual study and from a founding point of view, Sites 3, 4 and 5 are considered the most suitable for this project. The slightly narrower river channel at Site 3 may indicate more favourable rock conditions than at Sites 4 and 5.
- Construction materials are scarce. Aggregate is available approximately 50-60 km away. Sand is available on site for concrete and filter materials. The clayey sand on site for possible use as core material is only marginally suitable. An asphaltic core or concrete lining should be considered. Material suitable for the outer zones of the embankment is locally available.

- From this study it is evident that the geological conditions have been described based on a visual inspection. The quartzite rock is in most cases not visible as it is covered by alluvial deposits.

3.9 RECOMMENDATIONS

- Sites 2, 4 and 5 are likely to be feasible from an engineering geological viewpoint. These sites, commencing at Site 5, should be investigated by means of a seismic refraction survey, followed by rotary core drilling (including Lugeon testing and SPT's) and the excavation of deep test pits to determine founding conditions. Investigations at Sites 4 and 2, in that order, should only commence if Site is found to be unsuitable.
- Laboratory tests on the core should include UCS, point load tests, durability and water absorption testing and a mineralogical analysis.
- The electromagnetic method should be used to determine the position of any structural features such as faults and/or dykes. The conditions, extent and orientation of these features should be investigated using the resistivity method. The linear features at sites 4 and 5 should be investigated by means of the resistivity method.
- Locally available and existing construction material sources should be extensively sampled and tested. Tests for the various construction material types should include the following:

Coarse concrete aggregate

ACV

10% FACT

Alkali aggregate reaction

Durability

Fine concrete aggregate

Grading

Durability

Flakiness Index

Unit weight

Rip Rap

Water absorption tests

Sulphate soundness tests

Rockfill

Durability testing

Earth fill

Unified classification

Permeability

Dispersiveness

Shear strength

Filter material

Grading analysis

Core

Grading analysis

Permeability

Dispersiveness

Shear strength

- New potential material sources should also be investigated by adequate sampling and testing. The potential sources must be identified on the available maps and then investigated in more detail. Sampling should be done by excavating test pits either by hand or with a backactor (TLB).