Engineering Physical Factor Considerations for Specifying Dam Type During Memve’ele Dam Construction (South-Cameroon).

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Abstract

This paper presents the results of engineering investigations used to select a best design for the Memve'ele dam. The selection of Memve'ele dam type has been based on consideration of physical factors such as topography, climate, availability of construction material, geology, geotechnical and foundation conditions and the selection of optima alternative between three dam types. According to these factors, Memve'ele valley is very wide and situated in the warm climate zone with dry and rainy seasons favorable to embankment type dam; the geology reveals very good conditions with Ntem formations and residual deposits as foundation materials and the dam site is not influenced by earthquake; this behavior is confirmed by geotechnical data and further indicates that this site is favorable to a composite dam type (embankment and concrete dams or connecting concrete structures) and the construction materials found within or near the dam site are suitable for usage. These characteristics have contributed retaining three dam types. The alternative of these three dams is a composite dam type option including homogeneous earth dam and rock fill dam with central core link by concrete structures. Engineering geological map and general layout of Memve'ele's dam highlight the important role plays by engineers. The main dam that is observed actually in the Memve'ele dam site is composed from left to right of left connecting dam section, flushing sluice, main spillway section, riverbed dam section, auxiliary spillway section and right bank dam section.

1-introduction

Engineering works occupy a main place in the civil application. The application field of engineers is very wide. They operate in many sectors and steps such as planning, design, construction, maintenance and operation for all type of system infrastructures. The selection of dam type is one of the major concerns in dam engineering. Selecting the type of dam is largely dependent of engineer geologist studies on physical factors in the dam site. Dam as levees are water retaining structures constructed across a stream, river or waterway to fulfill specific functions such as water supply, flood control, irrigation and hydroelectric power generation (Novak et al. 2001). Embankment dam and concrete dam are two types of dam which are most present in the World. Embankment dam can be classified into six types of structures including homogeneous earth fill dam, rock fill dam, impervious core type rock fill dam, facing type rock fill dam, roller compacted concrete (RCC) embankment dam and blasted rock fill dam. Types of concrete dam are represented by arch type dam, buttress type dam, concrete gravity type dam, masonry dam and trapezoidal-shaped cemented sand and gravel (CSG) dam (Kutzner, 1997). Selecting the type of dam among of major two types of dam, during construction, requires consideration of several physical factors such as site condition, topography, geology and foundation conditions, material available, environmental and economic (USACE, 2004). Usually, the final choice of dam type is based on comparison between dam types previously recommended after factor studies mentioned above. Protection from spillway discharges, limitations of outlet works, the problem of diverting the stream during construction, availability of labor and equipment, accessibility of the site, the purpose of the dam, and dam safety all affect also the final choice of the type of dam but, these factors are beyond the scoop of this paper. In this study, only physical factors and comparison between dam types previously retained are discussed in order to select the best dam type suitable for Memve'ele site. This paper also further illustrates the planning dam recommended by engineer geologists and displays the link between geology and civil application during infrastructures constructions. Memve'ele's dam is situated in Ma'an division at about 175 km southwest of Ebolowa city in the south region of Cameroon. Five dam sites alternatives have been previously selected, but only one was judged better to study because of its advantages (Table 1). The dam axis (Fig. 1) is located at 2 km river reaches from the Ntem river ferry near the Nyabessan village to the Memve'ele's waterfall. The coordinates of reference control points of main dam axes are presented in the table 2. The spatial distribution of control points suggests the dam curves (Fig. 2).

2-geological Settings

The banks of the mainstream (Ntem river) run from north latitude 3° to west longitude 13° through with a flow direction from east towards west. This river crosses in Cameroon, Gabon and Equatorial Guinea with the length cover of 61%, 32% and 7% respectively. Ntem river with its tributaries cover an area of 31000 km^2 which belongs to the Ntem complex (Fig. 3, Owona et al, 2011; Ntomba et al., 2020) which represents the northwestern corner of the Congo craton. Thus, it is the Archean igneous province which is made up of intrusive tonalite, trondhjemite and granodiorite type rocks and banded plutonic rocks represented by charnockites, charno-enderbites and enderbites (Toteu et al., 1994; Shang et al., 2004b; Tchameni et al., 2001, 2004; Pouclet et al., 2007). Paleoarchaean (3266 Ma) magmatic activity, including charnockitic plutonism is known in this region (TallaTakam et al., 2009).The igneous plutons contains exposures of volcano-sediment large xenoliths rocks interpreted as remnants of greenstone belts. These greenstone rocks were dated by Pb-Pb zircon evaporation technique at ca. 3100 Ma (Tchameni et al., 2004) and intruded by late k-rich granitoids (2.73 Ga; Tchameni et al., 2000).The deformation of Archean rocks that are exposed in the Ntem Complex is much discussed. Studies show that these rocks are constituted of juvenile lithosphere and blocks of older material that were stacked during three phases of deformation from about 3.1 to 2.7 Ga. The first phase is dated to 3.1 Ga by Sm/Nd method (Toteu et al., 1994), the second phase age spanned from 2.9 to 2.8 Ga and the third phase is dated at 2.7 Ga (Owona et al., 2011). Other studies show that these rocks have recorded two phases of deformation (Maurizot et al., 1986). The first phase at the Mesoarchean times consists on the successive diapiric emplacement of both TTG and charnockite suites (Tchameni et al., 2000). The second phase is marked by the sinistral or dextral shear zones that cross high and low grade mylonites whose orientations vary from N-S to ESE-WSW (Tchameni et al., 2010). However, the Archean igneous rocks of this complex are traditionally known as derived from arc magmatism (Shang et al., 2004a; Ntomba et al., 2016). The dam site is exposed in the Memve'ele's shear zone (MSZ) in northeast direction (Fig. 3c, Ntomba et al., 2020), at upstream of the waterfalls. Above of Ntem complex, there are red or yellow, acid; highly desaturated and ferrallitic soils (Vallerie, 1995). These soils are composed by a very thick regolith, more or less thick indurate layer above this is found kaolinite combined with hematite and goethite (Nguetnkam et al., 2006).

3-material And Method

For this study, geotechnical investigations have been performed by many exploratory methods, such as geological mapping, core drilling, geophysical survey, shaft test pit and trench excavating field and laboratory testing. The mapping includes the study of geomorphologic features, assessment of soil materials, rock types and the ground water level. The geological surveys include a study of surface conditions (terrain excavation and transportation condition), distribution of usable and unsuitable layers, ground water level of quarry and borrow areas to evaluate the availability of required natural construction material combining with the results of testing. Many cross sections have been made along the studied dam axis and in the borrow areas (Fig. 10) coupled with airborne techniques using drone at few meters above the dam site at the aim to realize geological map (Fig. 4) and high quality image captures (Fig. 17). These airborne techniques particularly have led to do quantitative description and statistical distributions of discontinuities of Ntem Formations. The reserve in the borrow areas is estimated by using both parallel section and mean thickness methods. Cores of borehole, exploratory shafts and test pits were logged following by Engineering Geology Field Manual, 2001. Sampling and packer tests have been performed as directed by the Engineer. Laboratory tests of embankment material, rock and soil samples have been performed at National Central Material Testing Laboratory, Cameroon. Geological data were obtained by field works, through scan line at the dam site (ISRM) and thin observations. The petrographic analysis was carried out in a thin observation with an electronic microscope. Scan line at the dam site is done by airborne technique using drone at few meters above of soil. The sand has been mined by grab boat. Granular samples from studied soils were collected to use for mechanical test. The geotechnical studies were carried out in detail including core drilled data and in situ testing. Many boreholes were drilled by drilling rig to assess the geological and geotechnical of the Ntem formation where is located the dam foundation. The liquid limit (LL) was measured by the method of the dish of Casagrande and the plasticity limit (PL) by the method of the roller both according to NF P94-051 standard. The specific gravity of the materials is measured according to NF P94-054 standard. The compressive strength test is measured after NF P94-420 standard. The permeability tests include rock quality designation (RQD) and Lugeon water. The RQD index consists to degree of jointing and the water absorbed quantity in the 10 cm of borehole drilled on total drilling. The rock is distributed after RQD class (0–25, very slightly, 25–50 slightly, 50–75 moderate, 75–90 good, 90–100 excellent (Deere and Deere, 1987). The Lugeon values express the permeability of rock samples. This parameter is measured in the Lugeon scale (0–1 Lugeon impervious, 1–5 Lugeon low permeability, 5–10 Lugeon medium permeability, 10–15 Lugeon high permeability and > 15 Lugeon very high permeability). The determination of earthquake coefficient is based on the relation between intensity felt at the site as shown in table 4 and frequency of occurrence (Nc) in the period for 100 years and 250 years by ISC method, Japan Meteorological Agency (JMA) method and Munich Reinsurance (M.R.) company. Noted that intensity $I = 8.0 + 1.5M - 2.5\ln r$ (Cornell, 1968) and $\log Ah = 0.014 + 0.30I$ (Trifunac and Brady, 1975). I is intensity, M corresponds to Magnitude assumed, r represents distance from the epicenter of earthquake to the dam site in kilometer and Ah is acceleration in cm/s^2 theoretically calculated. Additional data used for evaluating and selecting the appropriate dam type option during Memve'ele dam construction include meteorological data and the concrete tests (Table 3). The meteorological data is not obtained directly in the dam site. Therefore, we have used meteorological data during 1996–2005 (Sinohydro, 2012) observed at Ambam station in Ntem river basin which have been collected daily and average of each month has been calculated. Parameters such as mean monthly temperatures, humidity and winds have been obtained considering cumulated year of each one of parameters respectively.

4-results And Analyses

4-1-Environmental context and local geology

The dam site lies at Memve'ele's island in the southern plateau area of Cameroon, at where the ground generally descends from north towards south, at an elevation varied between 400 m and 700 m above the sea level. The river course at the ferry is expanded of about 300 m wide with both the gentle riverbed and elevation of about 381-382 m. The upstream topography is gentle and the water flow is slow, while at the dam axis and its downstream, a ground elevation is of about 382-387 m. The ridges on the left embankment and on the right embankment have elevations of about 420 m and 400 m respectively. The bank slope on the left embankment is relatively steep and the natural side slope is about 35° whereas, on the right embankment, the natural bank slope is relatively gentle of about 5-10°. The dam site belongs to the equatorial warm climate zone. The air temperatures vary from 16.5 °C to 39.5°C with an average annual of ~ 27.7°C. The wind speed is ranged between 1.5 and 25 m/s with average annual of 3.64 m/s. This area is covered with dense rain forest, featured by four seasons divided in two dry seasons and two rainy seasons. The average annual rainfall is 2294.4 mm. The first rainy season falls in March to June, relatively frequent rainfall with moderate intensity accounting for about 27% of the annual rainfall. The first dry season falls in July to September. The second rainy season falls in mid-September to mid-December, very frequent rainfall with high intensity accounting for 55% of the annual rainfall. The second dry season falls in mid-December to February with high temperature (tab. 7 and fig. 11). The river is divided into the left and right stream with twists and turns, distributed with several curved branches and three relatively big islands (fig. 1). The Ntem river flows through the quaternary deposits including alluvial deposits; lacustrine/swamp deposits and residual deposits which are found above of lower Precambrian Ntem formations (fig. 4 and 5a; Bisso et al., 2020). The quaternary deposits display clay content between 21.3 and 59.7%, plasticity index ranged between 24 and 36, permeability coefficient between 1.77E-6 and 8.44E-9 cm/s and natural water content between 8 and 33% (table 6). The Ntem formations are mainly composed of migmatite, gneiss, and limestone to magnetite which are intruded by granite, garnet bearing amphibolites, diabase, granodiorite and orthogneiss with pyroxenes (fig. 5), distributed both downstream and upstream of the Memve'ele dam site. These formations were originally of sedimentary rocks of argilla-calcareous and sandstone having vast geosynclines. However, rocks derived from igneous origin are present. These formations have been metamorphosed in the Mesoarchean (2927± 8.9 Ma, U-Pb/Zrn, unpublished data) and folded in generally NE-SW direction. The foliation is variably oriented NE-SW, E-W and N-S mainly (fig. 5b), and consists both to an oblique and a steep dips (fig. 5e) in widespread directions. Mineral lineation is outlined by aggregate boudinaged amphibole and quartz while stretching lineation is illustrated by stretched quartz. A fault is observed along the river course of the Ntem in the downstream of the waterfalls. Precisely in 120 m line distance away from the powerhouse area. Two movements of this fault are observed including the northeast side of the fault line is sunk and the southeast side of the fault is raised, also the northwest side of the fault is raised and the southwest side is sunk. These features suggest a hinge fault. The Ntem river course is linearly running along the fault line through the Ntem trough or gorge (fig. 5i) at the Ntem downstream of the waterfalls whereas, its course of the upstream is meandering to the northeast direction (NE-SW to ENE-WSW, fig. 3c), due to developing depression zone here by fault movements. However, no sense of shear indicators could be associated with these fractures. The conglomerate or breccias near and along the fault line is well consolidated and matrix is tightly cemented (fig. 5h and j) due by the fault activity. It is inferred that the conglomerate might be formed in Mesozoic to Palaeogene time. As seen during field investigations, notably both in the waterfall and near the powerhouse areas, Ntem fault is composed of many brittle normal and horizontal faults and display polished surfaces or slickensides printed on epidotes (fig. 5f). The brittle normal faults generally strike NE30°~ 40°, dip northwesterly at a moderate to steep angles of 50° ~ 80°. Densely jointed zones are found at rocky outcrops, dominantly striking NE30°~ 40° and E-W with moderate to steep dipping angles (fig. 5j, k and l), indicating an outline sub-parallel for all tectonic features (gneissosity, shear zone, fault and jointed rocks). Overall these behaviors of tectonic features imply local deformations. The microscopic features of petrographic and tectonic elements are shown in the figure 6. An earthquake can obviously have catastrophic effects on the dam if it is not designed accordingly (Seed et al., 1975; Narita 2000). From table 9, the calculation of earthquake coefficient (k = gal/980) is resulted as k = 0.0006, say k = 0.01 for the return period of 100 years and k = 0.03 for 250 years respectively. The value of k = 0.01 is the proposed earthquake coefficient for the Nachtigal among hydropower project locating some 250 km northeast of Memve'ele site. Operating Basic Earthquake (OBE) is an earthquake that can reasonably be expected to occur with 50% probability of exceedance during the service life (ER 1110-2-1806, American regulation for operation basic earthquake (OBE)). This corresponds to a return period of 144 years for a project with a service life of 100 years. For conservative design, OBE is recommended to be 0.03 g which corresponds to a return period of 250 years and MCE to be double of OBE for Memve'ele hydroelectric project (0.06 g).

4-2-Geotechnical conditions

Three borrow areas including borrow areas B1 and B2 on the right bank and borrow area B3 on the left bank (fig. 8) have been used. These borrow areas are composed by two main strata including quaternary deposits at upper and Mesoarchean Ntem formations at lower level (fig. 9b and 10). The results of mechanical tests of residual soil in these borrow areas are presented in the table 5. The specific gravity values vary from 2.60 to 2.76. Wet and dry densities in the studied soils vary from 1.51 to 1.61 g/cm^3 and 1.23 to 1.55 g/cm^3 respectively. Porosity values are ranged between 0.700 and 1.190 %. Liquid limit values vary between 58.4 and 76.2 wt. % (tab. 5). Plasticity limit values are ranged between 28.3 and 40.1 wt. % (tab. 5). The deformation modulus values vary between 2.7 and 37.4 MPa with an average of 8.6 MPa. The coefficient of permeability varies between 3.60E-04 and 8.27E-06 cm/s averaged 2.21E-04 cm/s. The breakdown of soil deposits increases the percentage of the particle size smaller than 0.005 mm. As per the exploration well, the reserve estimations are 43.71 x 10^4 m^3, 86.66 x 10^4 m^3 and 52.01 x 10^4 m^3 respectively. Natural sand is to about 30.000 m^3.

5-discussions

5-1-Embankment dams with concrete structures

5-1-1-Physical considerations

The type and size of dam constructed depends on the topography and geology of site, stream morphology and the construction materials that are readily obtainable near the site (Emiroglu, 2008). Topography allows determining the first choice of the dam type. In this study, the dam site is a broad valley where embankment dam with central core can be constructed (Emiroglu, 2008, USACE 2004). However, the stream morphology is complex as shown on figures 1 and 2. This behaviour allows combining two concrete (fig. 7) spillways including main and auxiliary spillways with 85 and 102 m of length respectively and embankment sections into one structure (Golze 1977; Goldin and Rasskazov 1992). The dam site climate character well defined wet and dry seasons, thus it may be practicable to construct an earth fill dam only during two dry seasons. This option, if it is considered allowing of extend the construction season. However, a rock fill dam can be constructed during all the time (Fell et al., 1992). These site conditions are favourable to a composite dam including earth and rock fill dams according to the influence of climate (EM 1110-2-2300) and foundation conditions (Edris 1992; Fraser et al., 2001) with soil deposits and Ntem formations respectively as foundation materials. The geological cross sections and borehole analyses display geological units which are mainly composed of two strata namely upper quaternary deposits and lower Precambrian Ntem formations (fig. 10 and 12). The thickness of quaternary deposits increases from left toward right bank (from 1~3 to 13 m; fig. 10a and 10b (from E-E' to H-H')) and particularly, this thickness is weak on the river island. After stripping these upper alluvial deposits on the river islands, Ntem formation can emerged (fig. 13). These conditions of site with rocks and alluvial deposits as dam foundation materials (Fraser et al., 2001) can support embankment dams such as rock fill and homogeneous earth dams respectively (EM 1110-2-2300). The Ntem formations appear slightly weathered to fresh rock at depth where are low permeable. Moderate weathered zone in the valley section is only several meters thick generally. Thus, consolidation grout must reach down 5 m deep to enhance foundation rock quality and lower seepage (Edris 1992). Fulfilling this requirement allows that rock fill dam rests on the Ntem formations (EM 1110-2-1901). Based on distances between epicenters (79 - 280 km, tab. 4) and dam site, the dam site is located in an area not very prone to earthquake. This result is further confirmed by field investigations where evidence of intense fault activities was not seen. Consequently, concrete dam is not priority. However, a composite dam with concrete structure is recommended due to good quality and availabity of rocks. It is noteworthy that the river section is situated in the equatorial warm climate zone; in the wide valley area which provides a competent rock and alluvial deposit foundations and also this site provides suitable sand and gravel; thus composite dams or embankment dams such as homogeneous earth dam, rock fill dam with central core, rock fill dam with inclined core with concrete spillways can be constructed in this site.

5-1-2-Mechanical considerations

Previous studies on Ntem formations have revealed that they are good as construction materials (Bisso et al., 2020). This trend is further shown on geological cross sections and borehole analyses that display RQD values between 56 and 100%, weathering grade between high weathered to fresh rock and lugeon values are ranged between 1.99 and 2.90 Lu (fig. 12). These results indicate that Ntem formations require enhancement before to be used as foundation materials. However, the availability of suitable rock (Bisso et al., 2020) and enhancement foundation processes may favour a rock fill dam (Golze 1977; Bureau of Reclamation 1984; USACE 2004; EM 1110-2-2300).

As shown in table 5, the specific gravity values indicates that the soil deposit materials are good to excellent performance in the civil application works (Nwaiwu et al., 2006; Paige-Green et al., 2015; Onana et al., 2016). Wet and dry densities values are lower than those obtained in Yutiao and Da'ao dams (Hao-Feng Xing et al., 2006). This result indicates that soil deposits are medium density. Soil deposits display a low porosity character. Liquid limit values are higher than those obtained on lateritic gravels from northern Nigeria (Chuka Osadebe et al., 2011). Plasticity limit values display that soil materials are classified from low plasticity to plasticity according to Casagrande scale. Liquid limit values in the borrow areas are above 40% (table 5), indicating that soil materials were qualified “erosion resistant”. The deformation modulus values are higher than those (0.5-1.5 MPa) proposed by Messou (1980) and those obtained in lateritic gravels in Burkina-Faso (1.26 MPa; Millogo et al., 2008) and Cameroon (0.88-1.27 MPa, Onana et al., 2015 and 2016). In addition, this result further indicates the relatively clay contents in the soil deposits. The coefficient of permeability displays higher values than those obtained in Kiri dam (from 1.5E-08 to 1.00E-6 m/s; Ahmed Bafeto et al., 2019) and recommended values of 7.00E-10 to 1.00E-06 m/s. This result indicates that studied materials are lesser ability to allow the passage of seeping water if they are used as embankment materials. The breakdown of soil deposits increases the percentage of the particle size smaller than 0.005 mm. This result indicates that the studied soil materials are well-graded particle-size distribution and easy compaction so that they can be used as construction material during dam construction (Hao-Feng Xing et al., 2006). The plasticity index and the clay content of soil from three borrow areas are on the high side with an exception in the borrow area 3 where the clay content roughly met the requirement (tab. 6). However, these soils can be used in the civil application, notably in the base layer of dam and also constitute the transition, cushion and filter materials. In borrow areas B2 and B3, the natural water content is higher than the optimum water content (the investigation period fall within local rainy season), while in the borrow area B1, the natural water content is lower than the optimum water content (the investigation period fall within local dry season). These behaviours show that the studied soil materials are sensitive to water content variations. Overall, the studied Ntem formations and soil materials are good to be used as foundation and embankment materials. Thus, these site conditions may favour an embankment dam as previously retained above.

The total reserve of soil deposits is 182.39 x 10^4 m^3. Natural sand is to about 30.000 m^3. The excavated quantity of rock material from the structure foundation is nearly 300 x 10^4 m^3. In the borrow area B3, the thickness of upper residual soil is weak (fig. 10c3) and consequently, this borrow area has been also retained as quarry area after excavating the upper residual soil. The reserves of underlying Ntem formations in this borrow area B3 has been estimated to 237.37 x 10^4 m^3. These results indicate that materials are abundantly available on the dam site and may be used for an embankment dam construction such as homogeneous earth and rock fill dams linked to concrete structures (Golze 1977; Bureau of Reclamation 1984; EM 1110-2-2300). Elastic modulus, Axial compressive and tensile strengths increase with concrete grade whereas poisson’s ratio and linear expansion coefficient remain stable (tab. 3). These results suggest that Ntem formations can be used for processing the concrete aggregate; rip rap materials and crushing rocks (Emiroglu 2008; Bisso et al., 2020). Thus local supply of concrete aggregate, sand and riprap contributed to propose concrete structures associated with a rock fill dam (Golze 1977; Bureau of Reclamation 1984; Ghafoori et al., 2011).

5-2-Memve’ele’s composite dam type: types of embankment dams selected

5-2-1-Comparison, advantage and disadvantage of dam types

Three dams including homogeneous earth dam, rock fill dam with central core and rock fill dam with inclined core (fig. 14) have been selected previously on the base of factors such as topography, geological, geotechnical and foundation conditions, availability of construction materials (Hunter 1979; Emiroglu 2008). However, the comparison between them is required in order to fully select dam types.

General characters of dam types

The dam crest of the earth rock section is 1260 m in length, 10 m in width, and 13.5 m in average height, suggesting that Memve’ele’s dam is classed among high dams (ICOLD). The dam foundation is located on the Ntem formations and soil deposits. The reinforced concrete wave wall has a top elevation of 396.2 m and a dam crest elevation is of 395 m. Except homogeneous earth dam, the dam facing materials are available from the excavation of foundation pit or exploitation of borrow areas (DS-13, 2011).

Characteristics and discrimination of each dam type

Homogeneous earth dam

The upstream and downstream side slopes of earth dam have such a gradient of 1:3 (fig.14a). The upstream dam slope is of dry-laid masonry revetment, and a dry-laid masonry has a thickness of 80 cm, under which the thick transition layer and inverted filter are laid; the downstream dam slope features, 30 cm transition material for protection, slope toe lays upon the arris of body drainage (ICOLD 1989).

Advantages of the homogeneous earth dam consist in singular material, simple construction procedure and dry disturbance; large thickness of impervious part of dam body and relatively small seepage gradient is conductive to stabilize seepage and reduce seepage flowing through the dam body (EM 1110-2-1901; Brian 1989); the impervious treatment measures of dam foundation can be simplified because of long contact seepage path between dam body and dam foundation, and that between bank slope and concrete structure. This dam type can be adapted to a weak foundation such as quaternary deposit soils (EM 1110-2-2300).

Unfortunately, this dam type has some disadvantage aspects including the shear strength of soil aggregates which is less than that of rock aggregate, graves, sands used for the other dam types, so its upstream and downstream dam slopes are gentler than those of other dam types, and the filling quantity is relatively large; the dam body construction is affected by weather and rainfall, which may result in effective workdays and extension of construction time.

Rock fill dam with central core

The clay core wall is arranged on the upstream side of the dam axis, with the horizontal width of 5.0 m on the top, and a bottom connected to the bed rocks of dam foundation. Upstream and downstream side slopes of the clay core wall have a gradient of 1:2 and 1:1.8 (fig. 14b) respectively. On the upstream side of the core wall is the 1.5 m thick inverted filter and the transition layer. On the downstream side thereof is 1.5 m thick inverted filter and the transition layer (Narita 2000). The dam facing is filled using Ntem formation block stones (Golze 1977).

The core-wall lies in the middle of the dam body without relying on the permeable dam facing (Brian 1989), with its dead weight passing to the foundation in itself, safe from sedimentation of dam facing. The core wall depends on the dead weight of core wall filling earth to enable the contact surface between core-wall and foundation to produce a relatively big contact stress, which helps to strengthen the connection between core wall and foundation and improve the permeable stability of contact surface along the dam foundation. In case of drop reservoir level, the water contained in upstream dam facing will be discharge rapidly, conductive to the stabilization of upstream dam slope and homogenizing the upstream dam slope gradient of clay core wall dam or steepen the slope core wall. In view of the relatively low seepage line of the downstream dam, the downstream dam slope can be designed to be relatively steep (ICOLD). Under the condition of the same impervious effect, the clay core-wall dam consumes less earth aggregate than that the sloping core dam does, and the climate has a little impact on construction. It is relatively easy to connect the core-wall on the dam axis to the bank slope and the concrete structures (Golze 1977).

Because the earth aggregates of core-wall and the permeable materials are on the same horizon, different from the sloping core dam, the dam facing of the clay core-wall dam cannot be filled to meet the schedule in the case that the climate has an adverse impact on construction.

Rock fill dam with inclined core

The top of sloping core-wall has a horizontal thickness of 5.0 m, and the bottom thereof is connected to the bedrocks of the dam foundation with 5 rows of consolidation grouting. The upstream and downstream side slopes have a gradient of 1:3 and 1:1.5 (fig. 14c) respectively, filled with inverted filter and transition layer. The dam facing is filled using Ntem formation block stones (Golze 1977).

Where there is difficulty in filling in rainy seasons, the clay sloping core dam is employed, and the permeable materials of the downstream dam facing shall be first filled to meet the schedule. The relatively low seepage line of the downstream dam facing is conductive to the stabilization of the downstream dam slope (ICOLD).

Given the fact that the clay sloping core wall relies on the permeable dam facing, the too much sedimentation of dam facing will lead to the crack of the core wall. The connection between the clay sloping core dam and the bank slope and concrete structures is not easy as that between the core wall dam and the bank slope and concrete structures. The contact stress between the sloping core wall and the foundation is less than that between the core wall and the foundation. Additionally the conditions of connection are not as good as that of core wall dam.

The homogeneous earth dam, the dam with inclined core and the dam with central core have total quantity of impervious material of 675,000 m^3, 307,000 m^3 and 198,000 m^3 respectively, of which the dam with central core has the least filling quantity, and the homogeneous earth dam has the most filling quantity. In view of the impact of rainfalls in rainy seasons upon filling progress and quality of earth and rock fill dam, it is better to reduce the quantity of impervious material as possible (Emiroglu 2008) so the dam with central core is priority to be selected.

The homogeneous dam or dam with central core, which leads easily to junction of embankment with concrete structures such as main/auxiliary spillways (EM 1110-2-2300, Golze 1977) while the dam with inclined core is to join with the concrete structures through a transition zone of homogeneous dam. In such case it seriously interfering the construction.

Comparing with the dam with inclined core, the dam with central core provides higher contact pressure between the core and foundation to prevent leakage and greater stability under loading (EM 1110-2-1901).

Overall, a composite dam including homogeneous earth and rock fill with central core dams linked at concrete structures (fig. 16) has been selected for Memve'ele dam.

5-2-2-Engineering plan map of the Memve'ele main dam

Assuming that the dam axis is topographically flat and the river is divided mainly into the left and right stream (fig. 15). Each stream section is occupied by weak thickness of alluvial deposits very fine sand overlying moderately weathered granitic gneiss of Ntem formation as it is the same in the island river (fig. 1). These behaviours are suitable for arrangement of main spillway, flushing sluice, auxiliary spillway on the right and left side of the main river course upon the weathered granitic gneiss. The geometrical characteristics of Memve'ele main dam are shown in figure 16. The layout of dam axis has both a curved shape with radius of about 400 m and a right line (fig. 16 and fig. 17). The dam has about of 20 m height with design reservoir storage of 1.3 x 10^8 m^3 and effective storage of 0.08 x 10^8 m^3. From right to left banks, the general layout of Memve'ele is main spillway, flushing sluice, rock fill dam with central core (MD 1+695.511 to MD 0+438.283), auxiliary spillway (MD 0+438.283 to MD 0+332.283) and homogeneous earth dam (MD 0+332.283 to MD 0+000.000) (fig. 16). In the figure 16, engineers have provided for that homogeneous earth dam rests on weaker foundation at the left bank and have lower length than rock fill dam with central core. All these suggest that the erosive action of water flow is limited and the large quantity of construction materials was never used respecting economic factors and safety of entire dam (Emiroglu 2008). This plan has been adopted and is materialized actually by the dam structure (fig. 17).

6-conclusion

(1)-The application of airborne as new investigation techniques coupled with field works of dam site have been allowed to realize a geological map and a high quality image captures have been done by drone. These approaches may have application in other areas

(2)-A composite dam (homogeneous earth dam + rock fill dam with central core) option was found to be the best solution to retain water for hydroelectric purposes

(3)-The engineering geologist and design engineer work together while dam planning. The results from this study show their contributions to supply a general layout of main dam.

Declarations

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Tables

Table 1: The characteristics of alternative dam sites.

Alternative check items	Dam site 1	Dam site 2	Dam site 3	Dam site 4	Dam site 5
Utilization of water	Ntem water river only. Deversion scheme shall be needed.	Ntem water river only. Deversion scheme shall be needed.	Ntem water river only. Deversion scheme shall be needed.	Ntem water river only. Deversion scheme shall be needed.	All the river water.
FSL/Tailrace Cross Head	390 m/355 m (55 m).	388 m/355 m (53 m).	389-390 m/355 m (54 m).	390 m/355 m (55 m)	390 m/355 m (55 m)
H : Probable dam scale L :	10 m (maximum) 2,200 m.	8 m (maximum) 2,300 m.	10 m (maximum) 1,900 m.	10 m (maximum) 2,000 m.	15 m (maximum) 4,200 m.
Dam type	Earth fill	Earth fill	Earth fill	Earth fill	Earth fill
Topographic conditions • Right bank	Very good	Fair (Complicated topographic condition)	Good	Very good	Fair (Complicated topographic condition)
• River bed	Rock exposed (470 m wide)	Medium (water depth, 3-5 m)	Rock scattered	Medium	Poor (water depth 3-5 m)
• Left bank	Long and flat (low)	Long and flat (low)	Long and flat (low)	Fairly good	Long and flat (low)
Geological conditions	Two depression zones to be acrossed lowered the rock line at the right bank. Thick soil at the right bank.	One depression zone to be acrossed. Rock line of the right bank is elev.383 m.	One depression zone to be acrossed. Rock line of the right bank is below elev.390 m.	One depression zone at the 100 m upstream of the axis. Rock line lowered at the right bank (El. 375 m).	Fault problem (active or stable) should be clear. Very thick laterite at the right half of the axis.
Local communication	Expected to improve	Expected to improve	Not change	Not change	Change to inconvenient
Impact to Memve'ele's water falls	Not serious	Not serious	Not serious	Not serious	Not serious
Recomandations	To be abandoned	To be abandoned	To be abandoned	To be studied	To be abandoned

Table 2: The geographically coordinates of main dam axes.

Control points	North	East
MD-01	266424.797	654006.309
MD-02	266266.582	653984.153
MD-03	266136.773	653857.476
MD-04	266060.910	653783.443
MD-05	265442.038	653179.497
MD-06	265022.675	653302.567
MD-07	264991.200	653326.479
MD-08	264945.173	653369.995

Table 3: Main characteristics of concrete.

	Concrete grade						
Value	C10	C15	C20	C25	C30	C35	C40
Axial compressive strength (N/mm^2)	4.8	7.2	9.6	11.9	14.3	16.7	19.1
Axial tensile strength (N/mm^2)	0.64	0.91	1.10	1.27	1.43	1.57	1.71
Elastic modulus (N/mm^2)	$1.75*10^4$	$2.2*10^4$	$2.55*10^4$	$2.8*10^4$	$3.0*10^4$	$3.15*10^4$	$3.25*10^4$
Poisson's ratio	0.167						
Linear expansion coefficient ($C^{\circ-1}$)	9.0*106						

Table 4: Calendar of earthquake near the dam site (Ambrasey and Adams, 1986).

Date	Epicenter	Magnitude	r (distance)	I(intensity)	Ah (acceleration)
1903/06/10	3N10.0E	4.4	79.4	3.7	13
1911/03/26	3.1N11E	5.7	119.3	4.6	24.8
1913/10/09	3.8N12.3E	5.1	280	1.6	3.1

Table 5: Geotechnical properties of quaternary deposits in the dam project area.

		Physical properties						Atterberg limits				Consolidation (Sat.)		Quick shear	
S/N	Depth (m)	NWCW (%)	Specific gravity	Wet densi-ty (g/cm^3)	Dry density (g/cm^3)	Degree of saturation (%)	Poro-sity	LL (%) W_L	PL (%) W_P	PI I_P	LI I_L	Coef. $av_{1\text{-}2}$ MPa^{-1}	Modulus $Es_{1\text{-}2}$ MPa	Cohe. C Kpa	Fric. °
TJB07	1.5	18.1	2.64	1.64	1.39	53.03	0.90	29.3	13.0	16.3	0.31	0.78	2 .3	25.0	
TJB08	2.0	17.4	2.65	1.68	1.43	54.13	0.85	31.3	14.8	16.5	0.16	0.46	3.7	13.6	
TJB13	1.5	17.3	2.63	1.65	1.41	52.32	0.87	29.2	14.5	14.7	0.19	0.41	4.3	3.3	
Borrow area 1															
TBJ 101	3.0	23.6	2.76	1.65	1.33	61.02	1.07	71.6	38.0	33.6	-0.43	0.50	4.0	55.3	28.8
TBJ 102	3.2	20.0	2.71	1.64	1.37	55.14	0.98	58.4	28.3	30.1	-0.28	0.56	3.0	23.1	35.1
TBJ 103	4.0	20.0	2.72	1.51	1.26	46.83	1.16	76.2	35.1	41.1	-0.37	0.20	9.9	2 .2	41.9
TBJ 104	3.2	23.1	2.69	1.65	1.34	61.71	1.01	75.8	36.5	39.3	-0.34	0.18	10.8	0.7	40.1
TBJ 105	3.9	17.2	2.75	1.69	1.44	52.14	0.91	76.9	40.1	36.8	-0.62	0.79	2.7	54.0	26.9
TBJ 106	2.5	9.2	2.63	-	-	-	-	64.2	35.7	28.5	-0.93	0.05	37.4	-	-
TBJ 107	3.5	12.0	2.66	1.70	1.52	42.42	0.75	69.9	34.7	35.2	-0.64	0.73	2.8	39.2	28.8
TBJ 108	3.3	8.1	2.70	1.62	1.50	27.28	0.80	71.9	39.9	32.0	-0.99	0.57	3.5	32.6	34.5
TBJ 109	3.0	9.2	2.63	1.69	1.55	34.60	0.70	64.2	35.7	28.5	-0.93	0.56	3.0	18.3	39.0
Number		9	9	8	8	8	8	9	9	9	9	9	9	8	8
Max.		23.6	2.76	1.55	1.55	61.71	1.16	76.2	40.1	41.1	-0.28	0.79	37.4	55.3	41.9
Min.		8.1	2.63	1.26	1.26	27.28	0.70	58.4	28.3	28.5	-0.99	0.05	2.7	0.7	28.8
Average		15.8	2.69	1.41	1.41	47.6	0.92	69.9	36.0	33.9	-0.61	0.47	8.6	28.2	34.4
Borrow area 2															
TBJ 201	3.2	33.0	2.68	1.63	1.23	74.52	1.19	66.9	34.0	32.9	-0.03	0.77	2.8	18.0	27.2
TBJ 202	4.0	30.5	2.68	1.62	1.24	70.53	1.16	70.4	38.6	31.8	-0.25	0.80	2.7	13.3	33.3
TBJ 203	3.0	24.5	2.69	1.77	1.42	73.87	0.89	62.8	30.9	31.8	-0.20	0.43	4.2	74.0	30.4
TBJ 204	3.5	21.0	2.69	1.75	1.45	65.69	0.86	52.1	27.6	24.5	-0.27	0.28	5.9	17.0	50.1
TBJ 205	3.5	25.0	2.69	1.64	1.31	64.03	1.05	83.6	43.5	40.1	-0.46	1.00	2.2	14.0	38.0
TBJ 206	3.8	22.9	2.68	1.80	1.46	73.96	0.83	68.0	36.4	31.6	-0.43	0.35	4.8	65.0	38.2
TBJ 207	3.0	26.9	2.60	1.66	1.31	70.82	0.99	80.2	40.3	40.5	-0.33	0.33	5.1	50.0	39.0
TBJ	4.5	28.4	2.61	1.61	1.25	68.54	1.08	63.9	36.4	27.5	-0.26	0.82	2.7	9.7	39.7

208															
TBJ 209	4.0	23.1	2.60	1.62	1.32	61.56	0.98	74.0	37.0	37.0	-0.38	0.75	2.8	40.0	43.2
Number		9	9	9	9	9	9	9	9	9	9	9	9	9	9
Max.		33.0	2.69	1.80	1.46	74.52	1.19	83.6	43.5	40.5	-0.46	1.00	5.9	74.0	50.1
Min.		21.0	2.60	1.61	1.23	61.56	0.83	52.1	27.6	24.5	-0.03	0.28	2.2	9.70	27.2
Average		26.1	2.60	1.68	1.33	69.28	1.00	69.1	36.1	33.1	-0.29	0.61	3.7	33.5	37.7
Borrow area 3															
TBJ 401	4.0	22.7	2.60	-	-	-	1.02	44.5	27.5	17.0	-0.28	0.23	8.8	-	-
TBJ 402	3.5	17.8	2.64	1.56	1.32	47.30	0.99	69.9	32.3	36.6	-0.40	0.52	3.6	11.1	37.1
TBJ 403	3.0	25.6	2.60	1.64	1.31	67.15	0.99	74.4	41.2	33.2	-0.47	0.26	6.9	40.1	33.1
TBJ 405	3 .2	24.4	2.65	1.70	1.37	68.85	0.94	66.4	30.4	36.0	-0.17	0.41	4.8	48.8	21.6
TBJ 406	3.5	29.6	2.69	1.61	1.35	52.81	1.00	68.9	32.3	36.6	-0.07	0.53	3.8	42.1	35.1
Number		5	5	4	4	4	5	5	5	5	5	5	5	4	4
Max.		29.6	2.69	1.70	1.37	68.85	1.02	74.4	41.2	36.6	-0.07	0.52	8.8	48.8	
Min.		17.8	2.60	1.56	1.31	47.30	0.94	44.5	27.5	17.0	-0.47	0.23	3.6	11.1	
Average		24.0	2.64	1.63	1.34	59.03	0.99	64.8	32.7	31.9	-0.28	0.39	5.6	35.5	

Table 6: Comparison between quality index with test index in the borrow areas.

Borrow area B1					
S/N	items	Quality index		Test index	
		Homogeneous material	Impervious soil	Range value	Average value
1	Clay content	10%~30%	15%~40%	35.9%~59.7%	49.5%
2	Plasticity index	7~17	10~20	24~36	31.2
3	Permeability coefficient	< $1*10^{-4}$ cm/s after compaction	< $1*10^{-5}$ cm/s after compaction	$6.90*10^{-5}$ ~$8.44*10^{-9}$ cm/s	$1.03*10^{-5}$ cm/s
4	Natural water content	Close to the optimum water content		8.1%~23.6% 15.8% Optimum water content of 18%~24.9% average water content of 21.9%	
Borrow area B2					
S/N	items	Quality index		Test index	
		Homogeneous material	Impervious soil	Range value	Average value
1	Clay content	10%~30%	15%~40%	23.1%~48.5%	40.4%
2	Plasticity index	7~17	10~20	25~36	31.2
3	Permeability coefficient	< $1*10^{-4}$ cm/s after compaction	< $1*10^{-5}$ cm/s after compaction	$1.77*10^{-6}$ ~$2.03*10^{-9}$ cm/s	$3.55*10^{-7}$ cm/s
4	Natural water content	Close to the optimum water content		21%~33% 26.1% Optimum water content of 11.7%~25.1% average water content of 22.3%	
Borrow area B3					
S/N	items	Quality index		Test index	
		Homogeneous material	Impervious soil	Range value	Average value
1	Clay content	10%~30%	15%~40%		
2	Plasticity index	7~17	10~20	27~35	30
3	Permeability coefficient	< $1*10^{-4}$ cm/s after compaction	< $1*10^{-5}$ cm/s after compaction	$1.59*10^{-6}$ ~$3.04*10^{-9}$ cm/s	$5.21*10^{-9}$ cm/s
4	Natural water content	Close to the optimum water content		17.8%~25.6% 24% Optimum water content of 11.8%~25.6% average water content of 12.9%	

Table 7: Climatic data of 2005 year from Ambam station.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.
Precipitation (mm)	39.9	67.9	158.9	196.1	202.9	148.3
Temperature (°C)	27	29	31	27	26	24.5
Month	Jul.	Aug.	Sep	Oct.	Nov.	Dec.
Precipitation (mm)	64.3	81.7	212	293	166.4	48.2
Temperature (°C)	18	21	23.5	25	25	26

Table 8: The mechanical properties of construction materials.

Lithology	Density	Shear strength			Compression modulus	Deformation modulus
	(g/cm^3)	f	f’	c’ (MPa)	(MPa)	(GPa)
Residual soil	1.66	0.35~0.40	-	0.015~0.025	3.5~4.5	-
Completely weathered granitic gneiss	1.9	0.40~0.42	-	0.010~0.015	6~8	-
High weathered granitic gneiss	2.65	-	0.55~0.65	0.10~0.20	-	1~2
Moderately weathered granitic gneiss	2.75	-	0.85~0.9	0.75~0.8	-	5~5.5
Slightly weathered granitic gneiss	2.75	1.20~1.25	-	1.55~1.60	10~11	-
Densely jointed zone	2.65	-	0.55~0.65	0.10~0.20	-	1~3

Lithology	Allowable bearing force (MPa)	Permeability coefficient	Allowable seepage gradient	Slope 1 : x	
		(cm/s)	(at seepage exit)	(Above water)	(Under water)
Residual soil	0.15~0.20	1~5E-05	-	0.75	1.25
Completely weathered granitic gneiss	0.18~0.22	5~7E-05	0.5~0.7	0.75	1.25
High weathered granitic gneiss	0.50~0.60	3~5E-03	0.4~0.5	0.50	0.75
Moderately weathered granitic gneiss	3.5~4	3~5E-04	0.4~0.45	0.30	0.50
Slightly weathered granitic gneiss	5~6	2~4E-05	-	0.20	0.30
Densely jointed zone	1~1.5	3~5E-03	-	0.50	0.75

Table 9: Calculation of earthquake coefficient.

Return period	ISC method*	JMA method**	MR
100 years	2.5 (=5.8 gal)	I – II (=25 gal)	- - -
250 years	4.0 (16.4 gal)	III (=14 gal)	5 or below (< 32.7 gal)

*LogAh = 0.014 + 0.30I (I : intensity in ISC scale)

**a(gal) = $0.45*10^{S/2}$ (S: intensity in JMA scale)

Figures

Figure 1

As viewed near the ferry station (on the right bank), the front of dam axis.

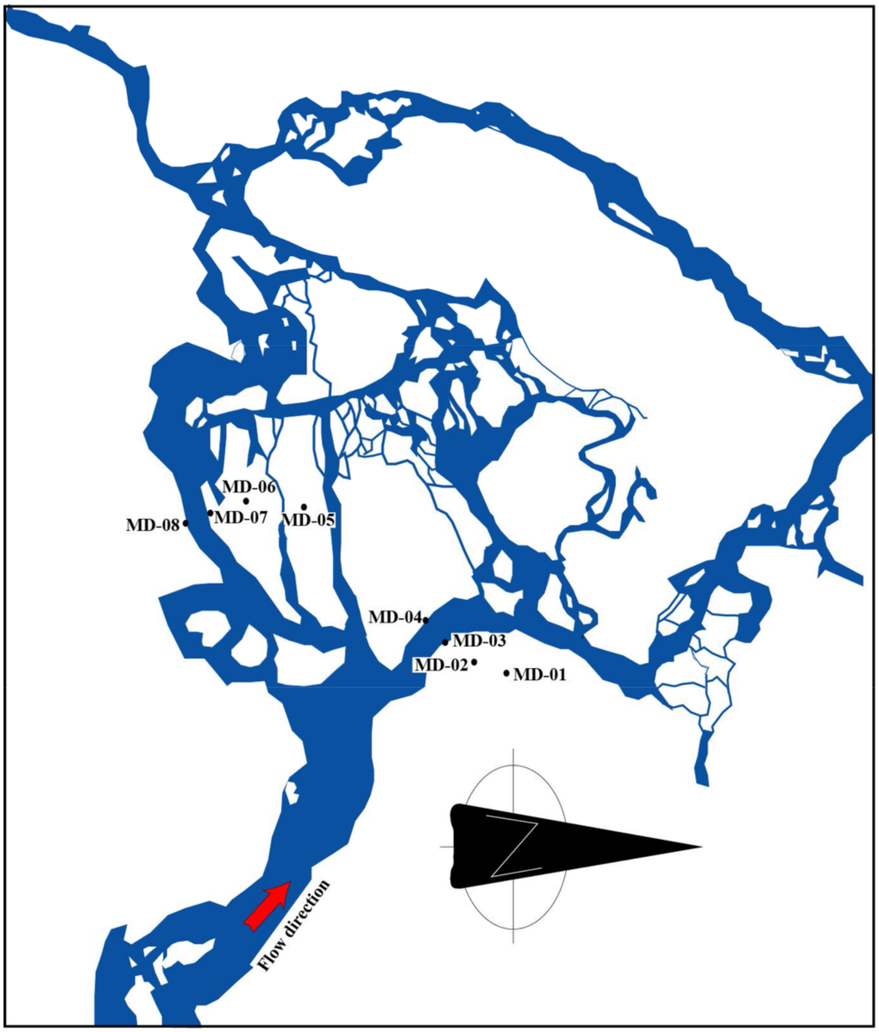

Figure 2

The spatial distribution of control points showing the delineate of dam axis. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

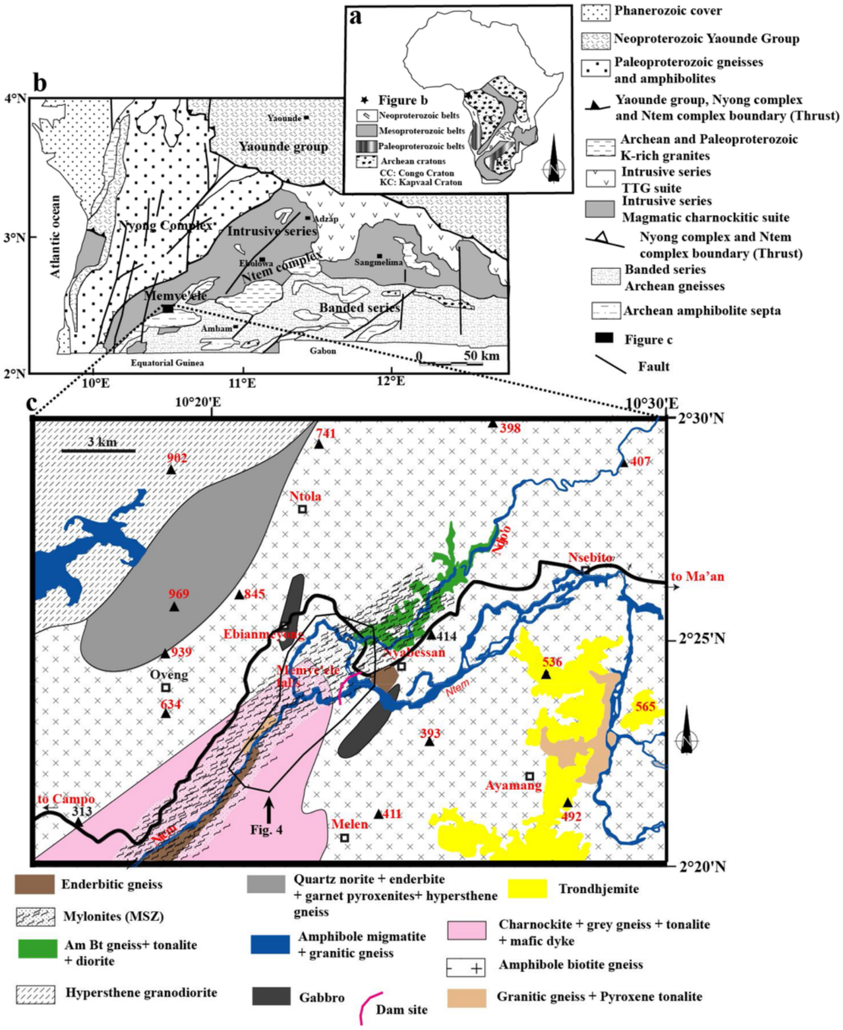

Figure 3

a-Geological map of the Ntem complex, Southern Cameroon (Pouclet et al., 2007); b-Precambrian belts of Central and South Africa (Pouclet et al., 2007) and c-Geological map of the Memve'ele area (Ntomba et al., 2020) showing the dam site. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

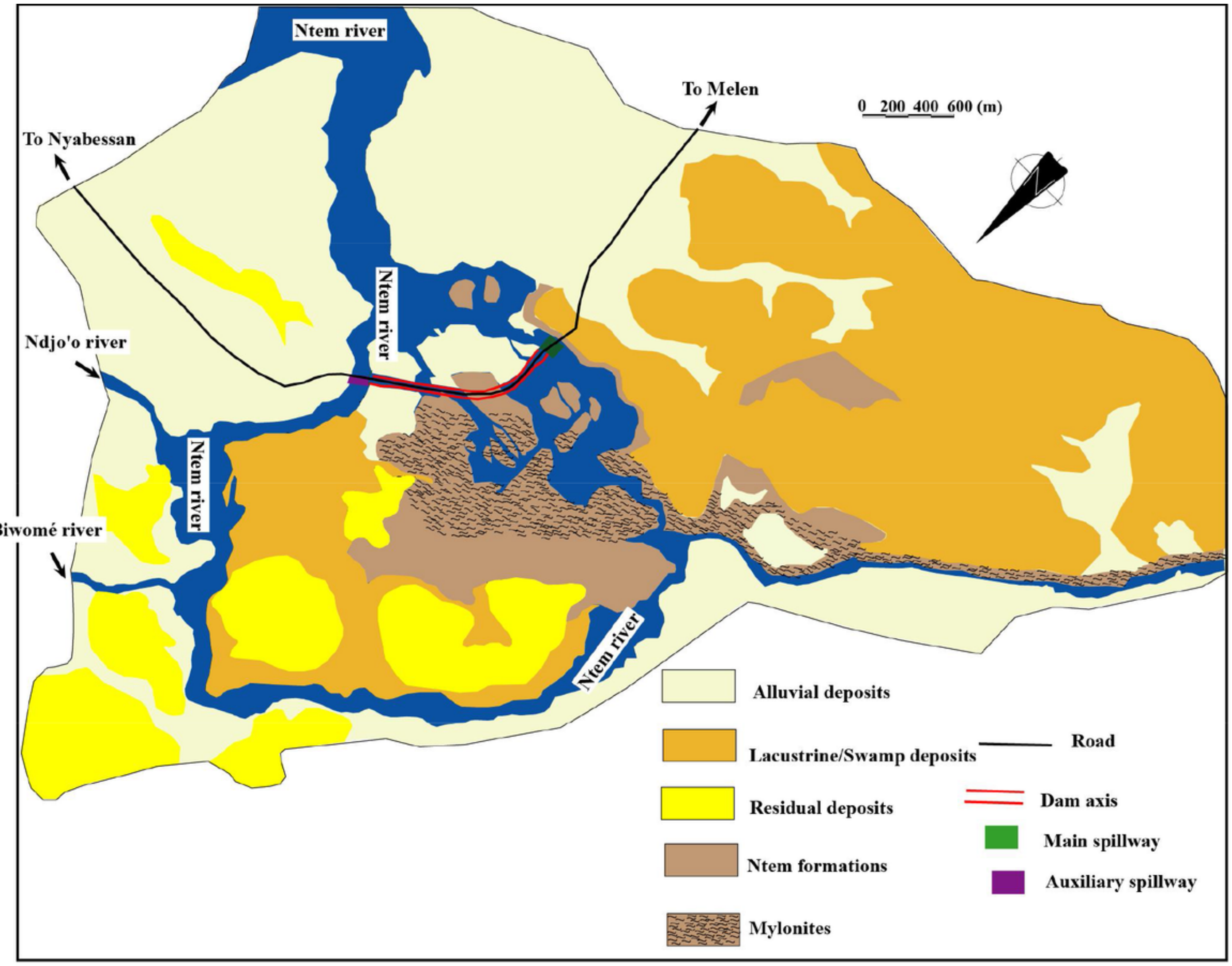

Figure 4

Engineering geological map of dam project area (Bisso et al., 2020). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

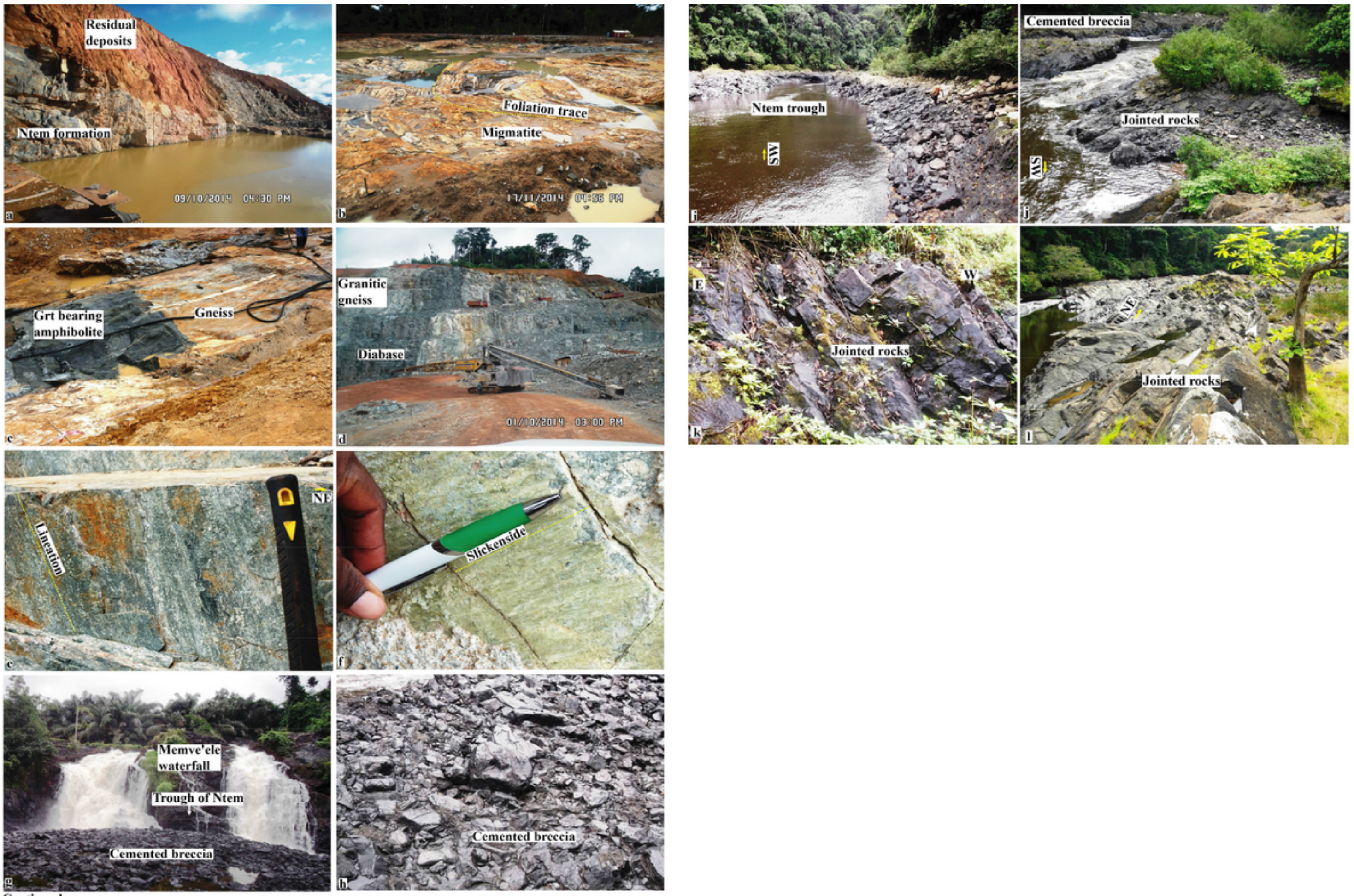

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Figure 5

a-Geological units in the dam site; b-curved foliation trace on the migmatite formation; c-contact between gneiss and garnet bearing amphibolites; d- contact between granitic gneiss and diabase; e- steep dipping foliation plane showing a stretching lineation; f-fault plane with strickenside lineations; g-Memve'ele waterfall in the Ntem river at downstream of Dam; h-cemented breccias/conglomerates; i-Ntem trough or fault line at downstream of waterfall; j-Jointed rocks and cemented breccias in the fault zone; k-jointed rocks in opposite front of waterfall along the east-west direction; l-jointed rocks parallel to fault line along the northeast-southwest direction.

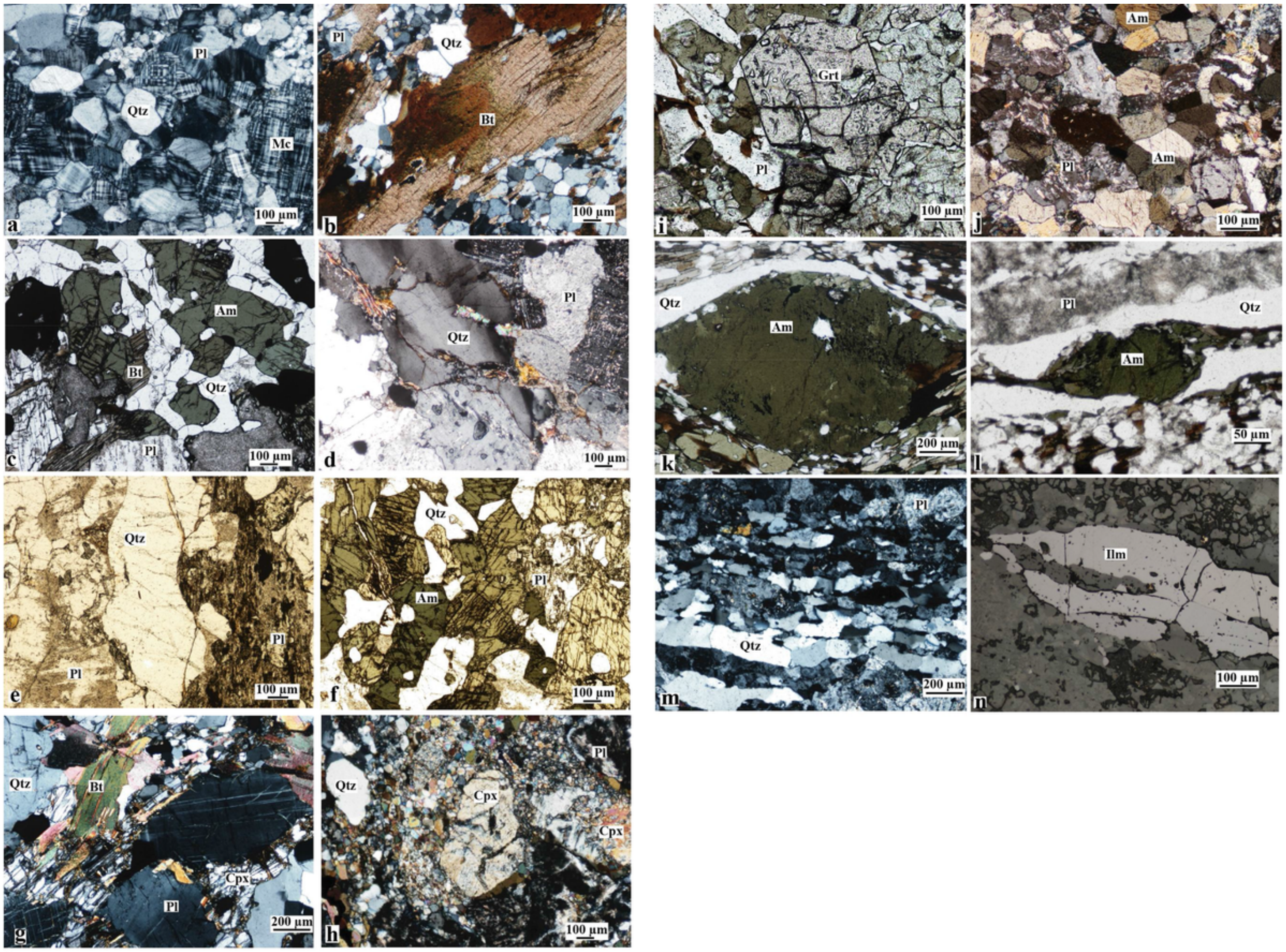

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Figure 6

Microscopic aspects of rocks: a-heterogranular texture in the feldspar rich granitic gneiss, b-foliation trace outlined by phenocrystal biotite in the granitic gneiss; c-amphibole crystal surrounded by quartz indicating partial melt in the granodiorite noted the presence of biotite kink band; d-old phenocrystal quartz displaying sub grain boundaries in the gneiss; e-leucosome of migmatite composed mainly of quartz, plagioclase and sericite; f-mesosome of migmatite mainly composed by amphibole as ferromagnesian crystal and leucosome pockets of quartz and plagioclase; g-granular texture in the charnockitic rock; h-heterogranular texture in the diabase noted the presence of secondary amphibole at the lower part of pyroxene; i-well-formed of garnet in the diabase; j-amphibole rich and plagioclase pockets in the amphibolites, noted the presence of straight boundaries between amphibole crystals indicating high grade metamorphism; k-symmetrical amphibole grain surrounded by tiny quartz ribbon and biotite in the mylonitic area; l-dissymmetrical amphibole grain within the quartz ribbon and displaying the shear movement in the mylonitic area; m-ribbon quartz with curved sub grain boundaries in the granitic gneiss suggesting a low temperature grade; n-phenocrytal grain of ilmenite stretched in the mylonitic area.

Figure 7

Main spillway (concrete structure) under construction.

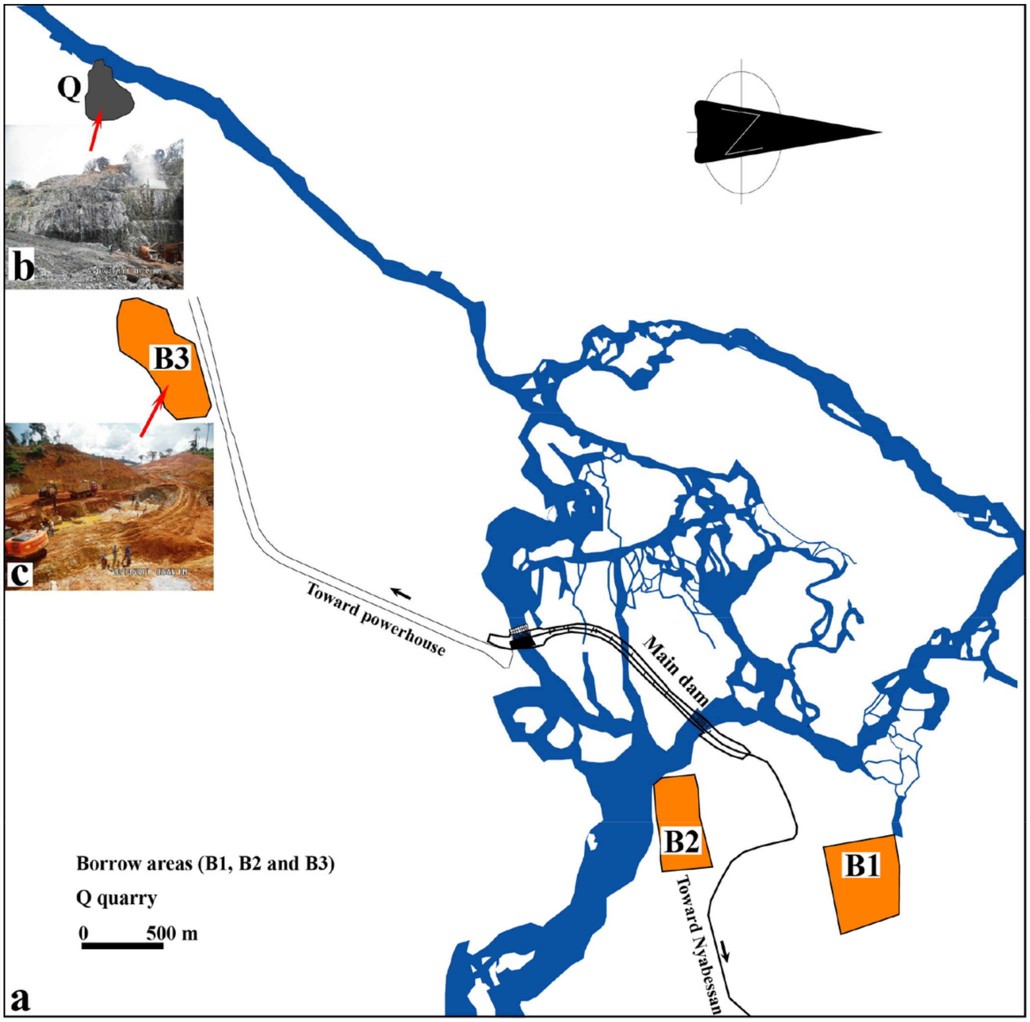

Figure 8

a-The dam site maps showing borrow areas, b-Quarry site and c-borrow area B3. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

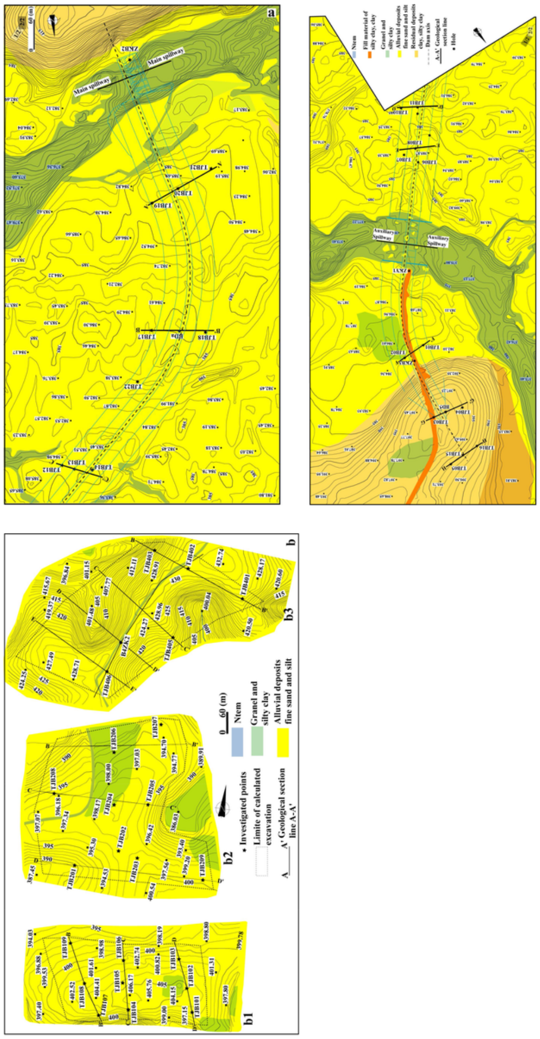

Figure 9

Geological maps: a-in the dam site; b-in the borrow areas (b1-borrow area B1, b2-borrow area B2 and b3-borrow area B3). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

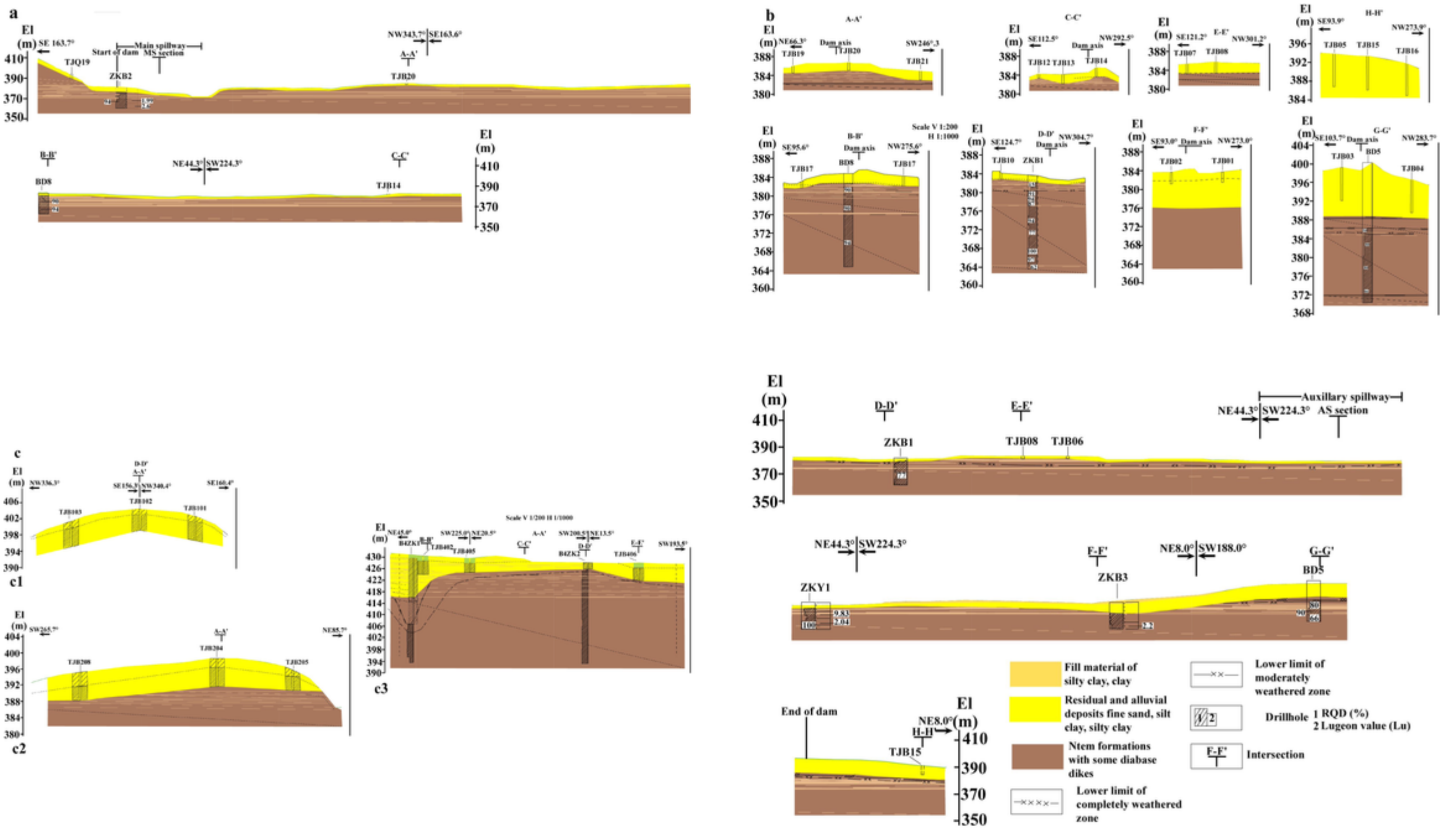

Figure 10

Geological cross sections: a-longitudinal section of dam; b-transversal section of dam; c-geological section in the borrow areas (c1-borrow area B1, c2-borrow area B2 and c3-borrow area B3).

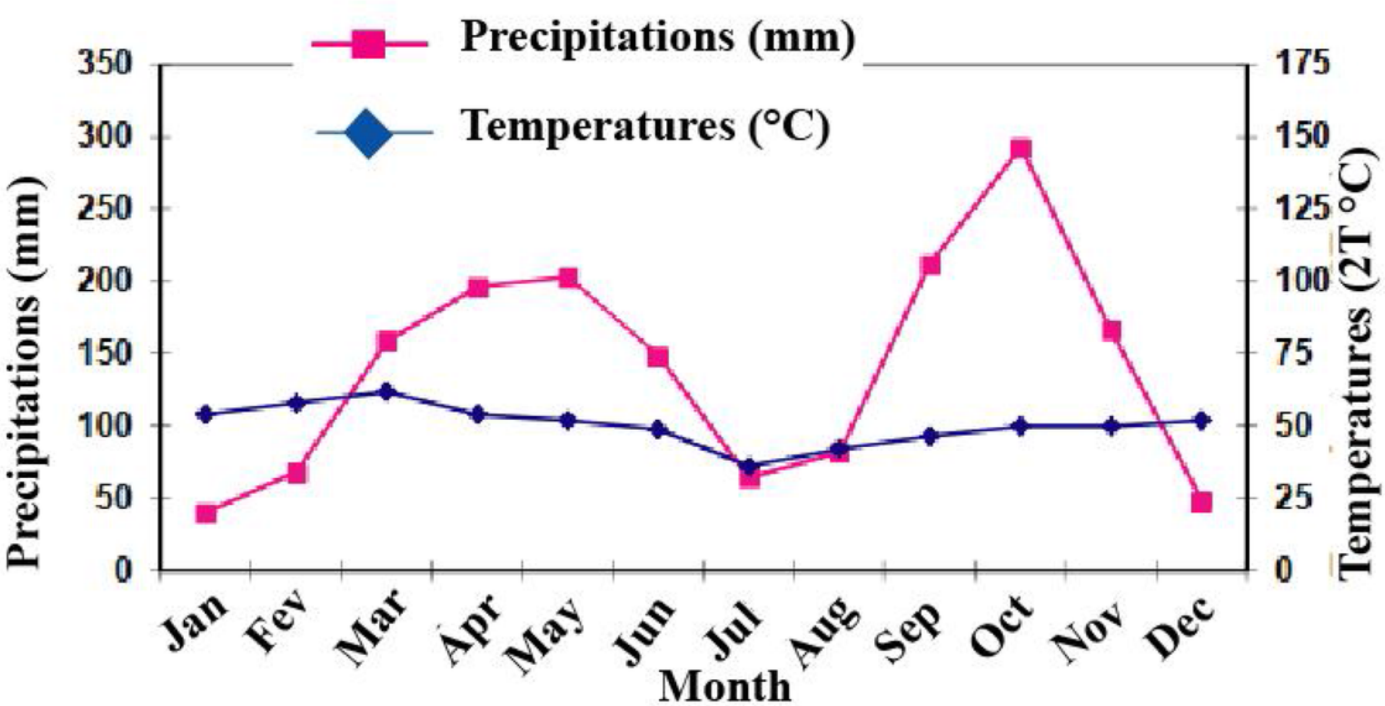

Figure 11

Ombrothermic diagram of 2005 year from Ambam station.

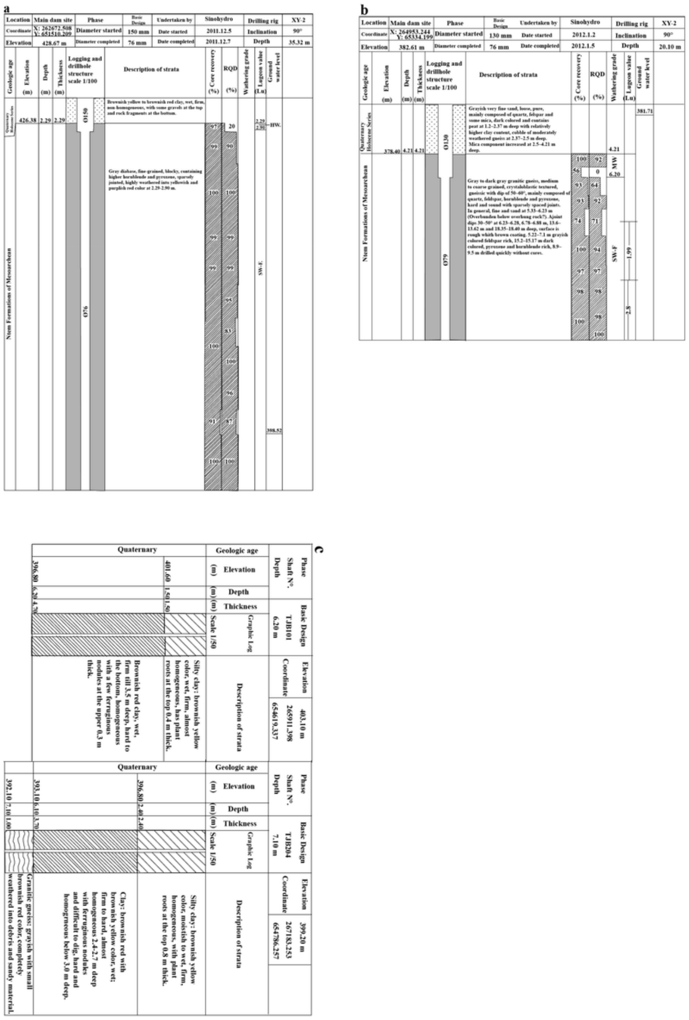

Figure 12

Geological stratigraphic chart: a-borehole B4ZK2; b-borehole ZKB2 c-shaft of TJB101 and TJB204 respectively.

Figure 13

The foundation pit of dam under construction.

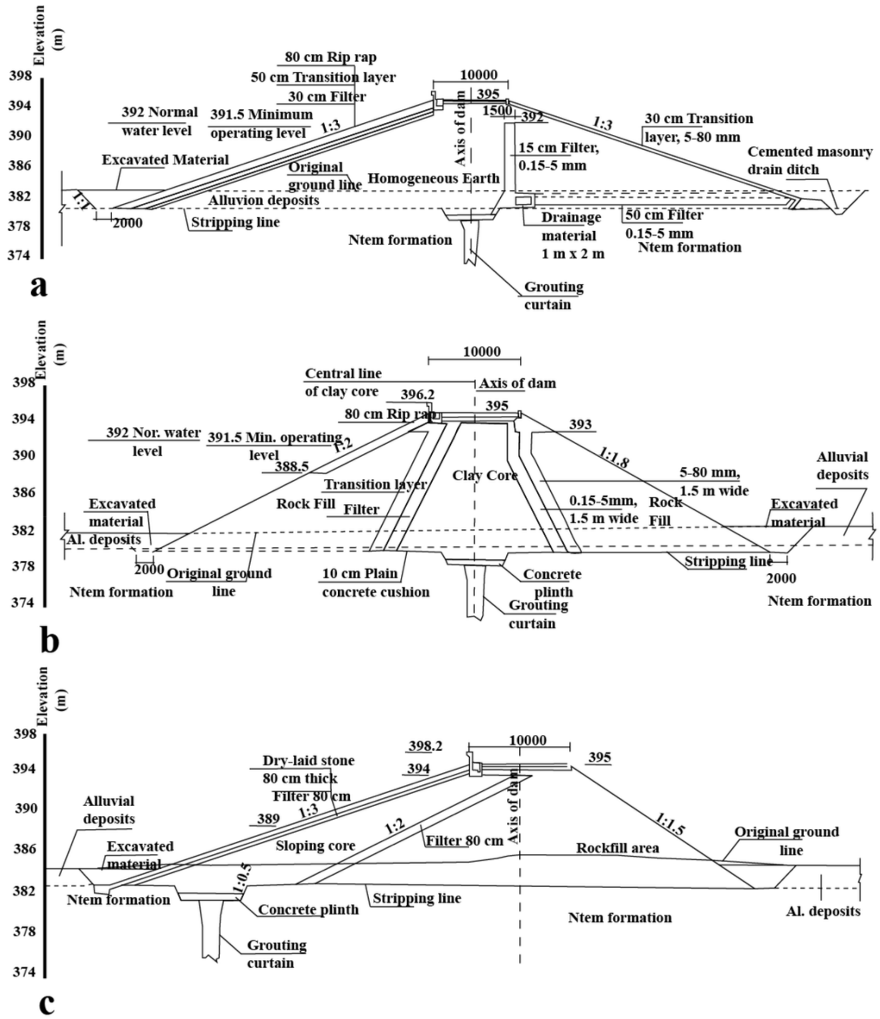

Figure 14

Typical cross sections of dam types primarily selected according to physical factor considerations; a-homogeneous dam; b-rockfill dam with central core and c-rockfill dam with inclined core.

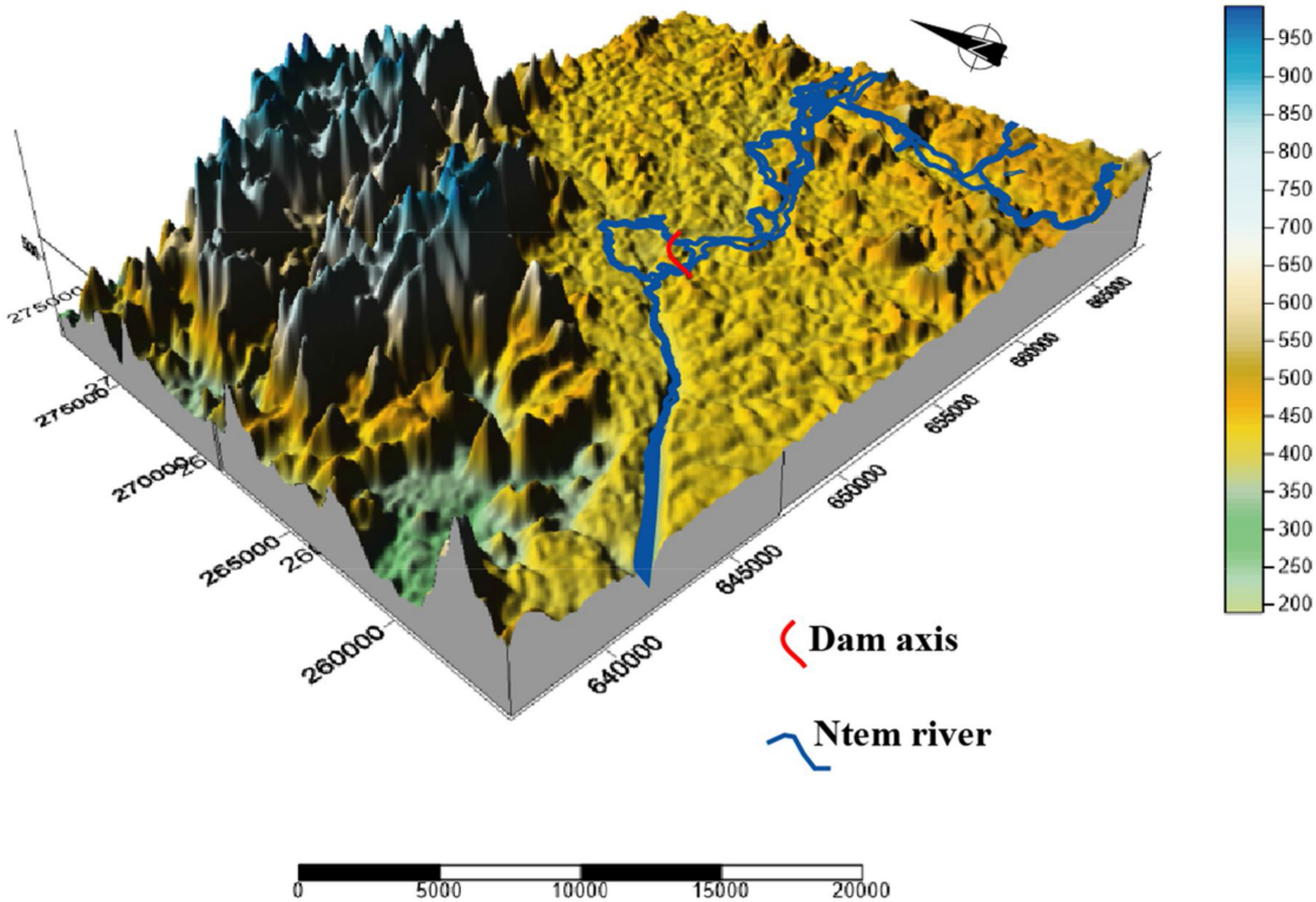

Figure 15

Topography of dam site.

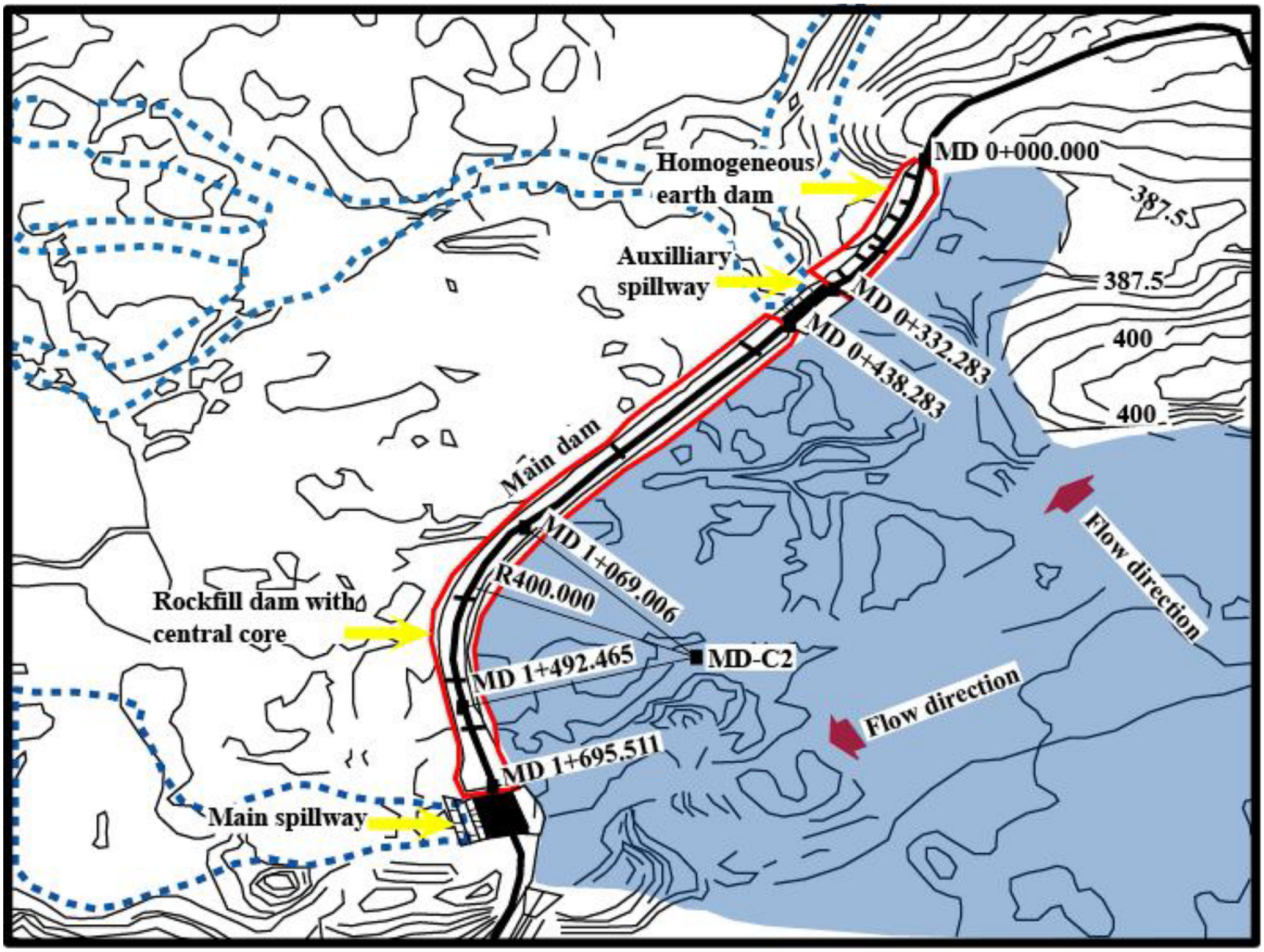

Figure 16

Engineering sketch map showing the layout of main dam. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 17

a-As viewed near the main spillway (on the left bank), the Memve'ele main dam, b-as viewed from downstream position, the secondary spillway (structure concrete) on the right hand of the Ntem stream.