# Muram and Decomposed Rock as Construction Materials for Earth Dams

## Emploi du «Muram» et des roches décomposées dans la construction de barrages en terre

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### Summary

The residual soils prevailing at Konar I Dam site are found to be suitable construction materials as they combine a good shearing resistance with a low permeability. The grain size characteristics remain practically unchanged whether the soils are treated mechanically or chemically. The permeability of the materials is lower than is to be expected from their appearance and grain size characteristics. This is due to the rough surface of the grains, the materials having disintegrated in situ. The standard proctor curve of the materials is flat, so that a wide range of moisture content is allowable. The unfavourable influence of mica content can be eliminated to a considerable degree by rolling the materials with sheepsfoot-roller on the dry side of the optimum moisture content. A stable dam foundation is provided by a sufficiently dense ground. The perviousness, however, is increased by joints and weathered pegmatite intrusions, so that precautions have been taken against the possibility of piping and uplift. The borrow areas become very extended, as the material to be excavated by shovel is only a 10–15 foot layer on the surface.

### Sommaire

Les matériaux trouvés dans les environs du barrage de Konar I – actuellement en construction – présentent une bonne résistance au cisaillement et une faible perméabilité, qualités qui permettent leur utilisation pour la construction d'un barrage en terre. La granulométrie reste pour ainsi dire inchangée après traitement soit mécanique, soit physique; la perméabilité est inférieure à ce que la granulométrie laissait à prévoir, ce que nous expliquons par le fait que la surface des grains est irrégulière, le matériau s'étant désintégré en place. La courbe obtenue par les essais Proctor étant plate, une forte variation de la teneur en eau est donc présumable. L'influence défavorable du mica peut être en grande partie éliminée en passant le rouleau à pieds de mouton et en restant dans la partie sèche de la courbe de teneur en eau optimum. Le sol est suffisamment compact pour former une assise stable pour le barrage. Toutefois, la perméabilité est accrue par la présence de fentes et par des infiltrations de pigmatite décomposée, de sorte qu'il a fallu prendre des dispositions pour remédier à une sous-pression éventuelle. Les carrières sont très étendues car les matériaux ne peuvent être extraits autrement qu'à la pelle mécanique et jusqu'à une profondeur de 10 à 15 pieds seulement.

### Introduction

The Konar I Dam on the Konar River in Bihar, is at present under construction for the Damodar Valley Corporation at Calcutta, India. When completed, it will maintain a reservoir of 262,000 acre-feet of water, which will serve for the storage of cooling water for the thermal power station at Bokaro as well as for flood control. The dam, with a maximum height of 150 feet, is of earth with a central concrete spillway. It has a length of 12,650 feet and contains 5.5 million cubic yards of earth and rockfill and 420,000 cubic yards of concrete. (Fig. 1.)

### Properties of the Materials in their Natural State

*Geology and surface features.* The geology of the reservoir area shows throughout the same characteristics and the same sequence of strata. The different layers of materials met with are various stages of weathering in situ of the same Archaen rock, of the Gondwana formation, a micaceous gneiss with intercalations of pegmatite veins.

The landscape of the reservoir area is that of a peniplain—open country, with low rounded hills formed by river meanders. The vegetation consists of natural jungle and this is interspersed by villages, pastureland and cultivated fields. Rice is grown in the depressions into which clay has been, in course of time, washed in from the slopes.

Below the 1–2 feet of topsoil of organic origin,—not always present—the first 3–6 feet thick geological layer is to be found. The soil is coloured and known in India as "Muram". It is plastic and contains grains of every size, from clay up to coarse gravel. The coarse part of the material is mainly quartz,

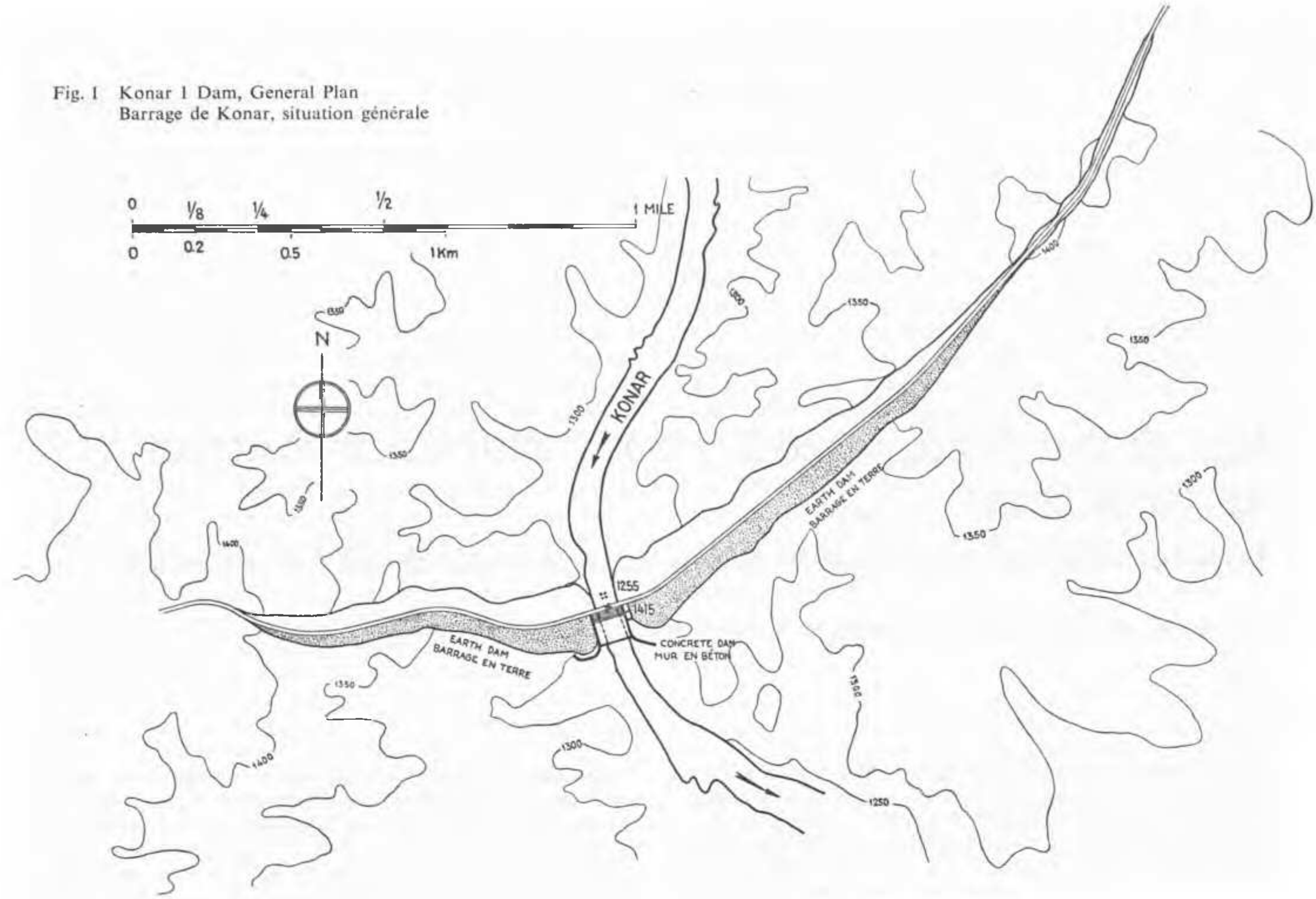


Fig. 1 Konar 1 Dam, General Plan
Barrage de Konar, situation générale

which has best resisted disintegration. Muram is the decomposed residue of a much thicker and older rock formation.

After the Muram layer follows a layer of decomposed rock, the thickness of which varies from 6–10 feet. The colour of this material is yellow, brown or grey, and varies from place to place. It has almost no plasticity. It contains grains of every size from clay up to coarse gravel, although the clay content is very small. The structure of the material in situ is still the same as that of the original gneiss.

The decomposed rock changes slowly into hard rock as depth increases. The indefinite interface usually occurs about 40–60 feet below ground level. Sometimes parts of the unweathered hard rock extend to the surface and appear as outcrops.

All the soils found, Muram and decomposed rock, are micaceous. The mica content varies considerably from place to place. Sometimes the soils contain sheets of mica, sometimes they contain a large amount of mica in powder form, often however the mica content is not appreciable. (Fig. 2.)

*Density of the materials in situ.* The borrow areas were explored by test pits, and the dam foundation, consisting of the same sequence of strata, by test pits, dry density tests and soundings by means of a small driving rod and drillings.

The test pits were opened by manual labour and carried down to 10–15 feet below ground level. At this depth the material was so hard that it was difficult to excavate further by this method.

Dry density tests showed an increase of density with increasing depth. Whereas at 8 feet below ground the dry density was found to be about 120 lbs./cu.ft., it reached values of more than 145 lbs./cu.ft. at a depth of 200 feet.

Soundings with a driving rod driven by a weight of 66 lbs. dropped from a height of 8 in. already showed a reasonably resistant surface at a depth of 7–10 feet, having a driving resistance of more than 80 blows per 8 in. penetration, or a specific driving resistance of more than 3,400 lbs./sq.in.

The results of the drillings, made with diamond bit, indicated a sound rock surface at about 40–60 feet below the ground level, above which there was only a little core recovery.

*Permeability of the materials in situ.* The permeability of the material in situ was determined by permeability tests in the drill holes carried out every 5–10 feet down the drill holes from top to bottom. In the surface layer up to about 50 feet the losses varied between 0.001 and 0.1 gall./ft./min., corresponding to a permeability between $10^{-6}$ and $10^{-4}$ cm/sec. The losses in the bedrock exceeded the value of 0.1 gal./ft./min. in a few cases.

The surface material in situ is intersected by decomposed pegmatite veins and this accounts for the particularly high permeability values. Furthermore the bedrock is jointed by a set of horizontal and roughly vertical cracks which may have been caused by temperature changes in geological times. Frequently, however, these joints were found filled with fine material.

## Characteristics of the Soils in the Laboratory

*General.* The grain size distribution of the soils was determined by sieving down to No. 200 mesh (0.074 mm). The percentage of grains finer than 0.074 mm was determined by pipette analysis after adding caustic soda solution to the soil suspended in water. It was found that the Muram layer

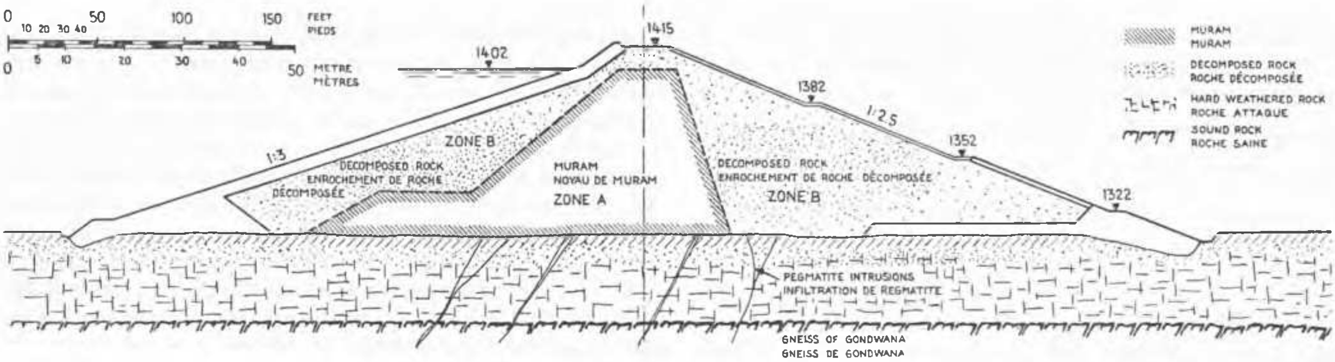


Fig. 2 Typical Cross-Section of the Earth Fill
Section type

| *Material Matériaux* | *Dry density reached in the field lbs./cu.ft Poids du matériel sec mesuré sur le terrain* | *% of maximum standard proctor compaction Degré de compactage en % d'après proctor* | *OMC for standard proctor compaction Teneur en eau optimale d'après proctor* | *Moisture content placed Teneur en eau du matériel mis en place* | *% passing No. 200 mesh Pourcentage de grains passant le tamis No 200* | *Permeability cm/sec. Coefficient de perméabilité* | *Cohesion lbs./sq.ft Cohésion* | *Tangent of friction angle Tangente de l'angle de frottement* |
|---|---|---|---|---|---|---|---|---|
| Muram | 117 | 94% | 11.1% | 9.5% | 16.5% | $2.6 \times 10^{-6}$ | 1.150 | 0.420 |
| Decomposed Rock Roche décomposée | 116 | 95% | 11.7% | 9.8% | 12.7% | $6.5 \times 10^{-6}$ | 0.600 | 0.750 |

contains about 16–25 % fines passing No. 200 mesh, while the decomposed rock contains only 12–16 % fines. On the average the Muram layer contains 3–5 % more clay and silt than the decomposed rock. The higher cohesion and plasticity of the Muram is not however due only to a higher percentage of grains passing the No. 200 mesh but also to the higher clay content. (Fig. 3.)

As these soils have originated by decomposition in situ, and have not been transported and ground together, the size of

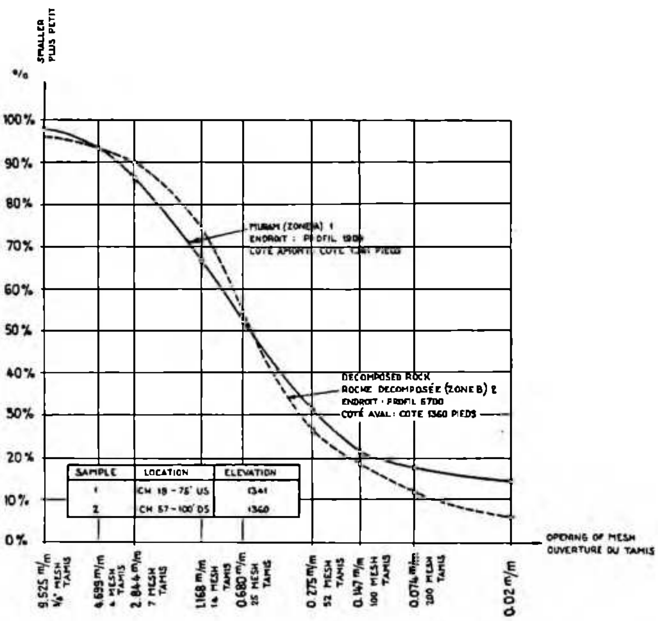


Fig. 3 Typical Grain Size Distribution Curves
Courbes types de la répartition des grains

the grains is still indefinite. It may therefore be expected that removal of overburden, excavation and compaction, as well as contact with moisture and air, will all change the grain size characteristics.

Mechanical treatment during excavation and compaction, was found to have no appreciable influence on the grain size characteristics. Keeping the soil submerged for one month was also found to have a negligible effect. Chemical treatment of the soils with hydro-chloric acid caused only a slight increase in the fraction of fines. The soluble salt content of the materials is 1–3 %. The specific weight of the grains was found to be between 2.63 and 2.71 g/cc.

*Compaction.* The standard proctor compaction test gave an optimum moisture content of about 11 % for Muram and 12 % for decomposed rock, and maximum dry densities of about 124 lbs./cu.ft. and 119 lbs./cu.ft. respectively.

Furthermore the moisture compaction curve was found to be fairly flat. Even where material is compacted at 3 % less than the optimum moisture content, the compaction reached is greater than 95 % of the maximum. A wide range of moisture content during placing can therefore be tolerated.

*Permeability.* The permeability in the laboratory, determined by falling head permeameter for maximum standard proctor compaction, was found to be 2.6 ft./year for Muram and 6.5 ft./year for decomposed rock. These values are low considering the small clay and silt content of the materials and this is a typical fact for such soils. Another reason is the irregular surface of the grains which have not been ground by transport. (Fig. 4.)

*Shear resistance.* The shear resistance of the materials was determined in the direct shear apparatus, supplemented by triaxial shear tests carried out in the undrained state, after the sample had been saturated and consolidated under an all-round consolidation pressure in the drained state. On comparison it appeared that the friction angles obtained in the direct shear apparatus were to be reduced. The results obtained are as follows:

| | | |
|---|---|---|
| Muram | $c = 1{,}150$ lbs./sq.ft. | $\tan \varphi = 0.420$ |
| Decomposed Rock | $c = 600$ lbs./sq.ft. | $\tan \varphi = 0.750$ |

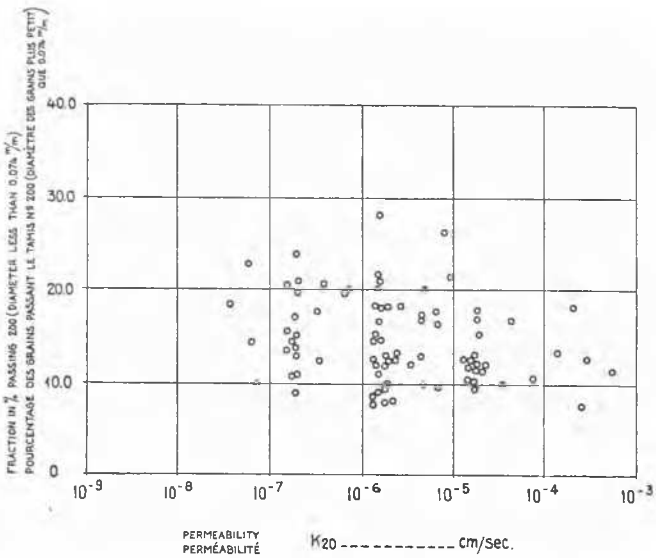


Fig. 4 Permeability of the Soils as Function of the Content of Fines
Perméabilité des matériaux en fonction de la teneur en grains fins

## The Cross-Section of the Dam

As it appeared that the uppermost Muram layer is richer in silt and clay than the underlying decomposed rock, the dam cross-section was divided into two zones, a central zone A, of surface Muram richer in fines, and a zone B. of decomposed rock, on either side. The central zone A is extended toward the upstream side as a horizontal blanket so as to lengthen the seepage path through the dam foundation.

The upstream slope, protected with a 4 foot dumped riprap, is inclined at 1 vertical to 3 horizontal, while the downstream slope, covered by sodding, has an inclination of 1 vertical to 2,5 horizontal.

Due to joints and weathered pegmatite intrusions, the dam foundation possesses a higher average permeability than the embankment, and precautions had to be taken against uplift and piping from heave or subsurface erosion. This was effected by constructing a drainage blanket of sand, gravel, and stones, on the downstream side thus releasing the seepage water under sufficient pressure of overburden. No core trench and in general no foundation grouting have been provided. It will however be necessary, after the completion of the dam and the first filling of the reservoir, to watch carefully for any springs occuring beyond the downstream toe of the dam. Meanwhile it is expected that the whole earth dam foundation will be tightened after some years by the introduction of silt carried in from the river.

As the decomposed rock used in the outer sections of the dam has a low permeability, high porewater pressures are expected to develop in the upstream slope after the yearly drawdown of the reservoir. The provision of a highly permeable section consisting of dumped rockfill, on the upstream side, was considered as a possible means of reducing these porewater pressures. The rockfill, however, would have considerably increased the cost of the embankment. Under these circumstances it was decided by the owner of the work not to use this method and to be satisfied with lower factors of safety.

Konar I Dam is situated close to one of the most violent earthquake centres. Within the last 50 years Northern India has suffered 5 major earthquakes. The design of the earth dam was therefore made taking into account a horizontal earthquake acceleration equal to 12 % of gravity. Using this figure for the upstream slope of the dam for an earthquake with reservoir empty gives a value of 0.95 for the safety factor. For this value the possibility of slip has here been provided against.

Table 1 Safety Factors

| *Slope* | *Condition* | *Safety factors* |
|---|---|---|
| Downstream | Reservoir full no earthquake | 1.70 |
| | Reservoir full Earthquake 12 % | 1.30 |
| Upstream | Reservoir empty no earthquake | 1.35 |
| | Reservoir empty Earthquake 12 % | 0.95 |

## Behaviour of the Materials during Construction

*Excavation.* The materials are excavated by 2½ cyd. shovels, which permit excavation to a depth of 10–15 ft. The excavation is done in two steps. The uppermost 5–7 feet are placed in the centre part of the dam, while the underlying 5–8 feet are placed into the two outer parts.

*Placing and compaction.* The materials are spread in layers of 8 inches and rolled by sheepsfoot-rollers exerting a pressure of 250 lbs./sq.in. The range of moisture content allowed during placing is up to 4 % dry from the optimum moisture content as determined by the standard proctor compaction test. The degree of compaction reached in the field is 95 %.

*Influence of mica content.* When construction was started, the effect of the mica content upon compaction and mechanical properties of the materials was not exactly known. It was expected that the blade-like mica grains would favour horizontal stratification but that the sheepsfoot-roller would prevent such stratification to a large extent. In the laboratory the strength and compaction of the micaceous materials were satisfactory. The compaction of highly micaceous materials had a tendency to be less than that of other materials.

Subsequently, in a series of layers consisting of highly micaceous materials placed and compacted at excessive moisture content, it was observed that under heavy loads, such as the wheels of the haulage equipment, horizontal slickensides developed, spaced about 2–3 inches from one another. The slickensides had a soapy polish consisting of blade-like mica grains in powder form.

Undisturbed samples taken in the area for shear tests showed that the cohesion of the materials was greatly reduced in a direction parallel to the plane of the slickensides, whilst the friction angle was roughly maintained.

When the material placed was dryer than the specified optimum moisture content, no formation of slickensides was normally observed. It may therefore be concluded that micaceous material is to be rolled well on the dry side of the optimum moisture content. The sheepsfoot-roller then prevents any marked horizontal stratification. If the material is rolled too wet, horizontal slickensides occur, due to over-compaction.

*Permeability of the compacted materials.* The actual permeability of the embankment was checked by field tests. The discharge was measured in an open pit, filled with water. The permeability determined in the field was 10–20 times higher than in the laboratory. As the surface of the embankment is not representative of the interior of the dam, subject to consolidation pressure, the laboratory permeability value was used for the design of the embankment.

*Strength of the compacted materials.* The strength reached in the embankment was found by quick bearing tests and by soundings with a small sounding rod.

The bearing capacity tests were performed with a circular in slab of 4 in. diameter. After saturating the soil, a bearing capacity of 24,000 lbs./sq.ft. (= 12 kg/cm$^2$) for both Muram and decomposed rock was obtained, a value which agrees well with the results obtained in the laboratory. The results of these tests are considered to be on the safe side, since here also the surface cannot be representative of the behaviour of the soil within the body of the embankment, for no consolidation pressure has acted on it, and during saturation the soil will swell.

Soundings performed in the same way as for the dam foundation indicated a sounding resistance in the embankment between 950 and 1,300 lbs./sq.in.

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