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# ENGINEERING GEOLOGICAL SURVEY FOR RAILWAY EXTENSION IN THE NILE VALLEY

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## Abstract

Egyptian National Railway (ENR) called for a tender for doubling the railway line Edfu/ Aswan in the mountainous terrain. The engineering geological works were carried out by the authors for MÁVTI Co. Ltd. The study includes two parts El Serag and El Gaafera sections having a length of 6.5 km. One side of the railway track is bordered by steep sandstone cliffs of 30 – 40 m in height that forms the edge of rugged low relief topography often dissected by wades. The other side is on the right bank of the Nile where a narrow flood plain is cultivated and covered by dense vegetation. Several alternatives were studied for the second rail track including tunnel open cut, rock excavation, land bridge and gabion versions. ENR chose the rock excavation version. As a consequence the cliff wall geometry, joint system and rock formations were studied in details. By using these data the necessary rate of rock excavations, the schedule of works, machinery, safety conditions and excavation methods – blasting, swelling cement – were prepared. Finally swelling cement was used by Egyptians. No Hungarian expertise was used during the construction phase.

*Keywords:* engineering geology, petrophysics, sandstone, structural geology.

## 1. Introduction

The Egyptian National Railway (ENR) called for an international tender for the study of doubling the railway line Edfu/Aswan in the mountainous terrain of Serag and Gaafera. The Hungarian Design Office of Railways (MÁVTI Co. Ltd) won the tender in summer of 1994. The authors were invited as experts in the preparation of engineering geological study for the different track versions and their design and construction plans. The drilling works and riverbed soundings were carried out by the consulting company (The Nile Engineering Consulting Office) of Dr. F. El-Kadi from Cairo. The engineering geological site survey and design were prepared in two phases.

## 2. General Description of the Study Area

The study area is located along the river Nile and includes two mountainous railway sections in a length of 6.5 km. El Serag section is 80 km while El Gaafera section is 20 km *N* of Aswan.

### 2.1. *Topography*

The area is in the transition zone of Nile valley and Eastern desert. The present rail track is on the right bank of the Nile at a distance of 20 to 130 m from the river bank. The 'desert' often ends in steep up to 20 – 30 m high cliffs that are as close as 3 – 5 m to the railway track. The altitudes vary between 80 and 160 m asl. Despite this low topographic difference the bare surface looks like a rugged mountainous area since it is dissected by wadis and includes unstable cliff sections.

### 2.2. *Geology*

The rock formation on the surface is the Nubian Sandstone that is mainly of Cretaceous in age (*Fig. 1*). The sandstone is ochre yellow, brownish rarely violet having well sorted but poorly rounded particles in calcareous cement. This often cross-bedded sandstone shows great variety in the rate of cementation in the thickness of beds, but as a rule four major types were distinguished:

- thick-bedded ferruginous to silicified very rigid sandstone
- massive well cemented sandstone banks
- thin-bedded medium cemented sandstone with frequent ripple marks
- thin-bedded loosely cemented pulverising sandstone.

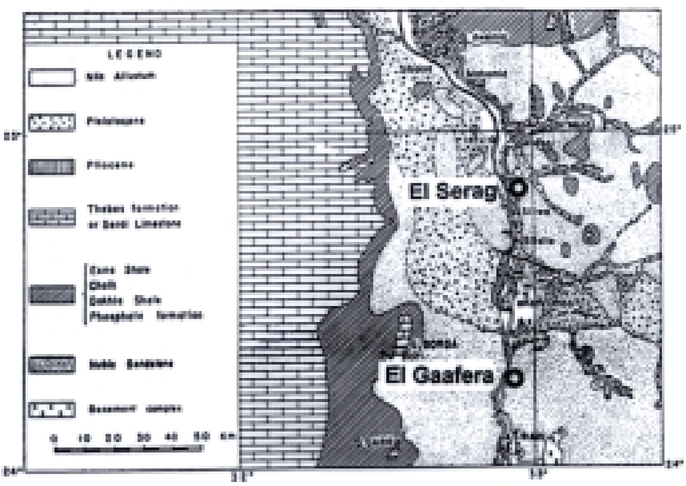


*Fig. 1.* Geological map of the Nile valley between Esna-Aswan (after the Atlas of Egypt)

The sandstone types alternate within the sections and often contain greenish grey laminated to foliated silty clay intercalations (*Fig. 2*). In the kaolinitic clay gypsum and anhydrite also occur. The cover beds are 'variegated shales' that concordantly evolves from the Nubian sandstone. These cover beds were only found at one site far from the railway line on a hill South of El Serag. Recent dark grey muddy alluvial sediments form terraces along the Nile in the river banks or bays. Bottom of the wadis is covered by recent fanglomerates – silt with rock fragments – which are related to rare rainfalls or by drift sand.

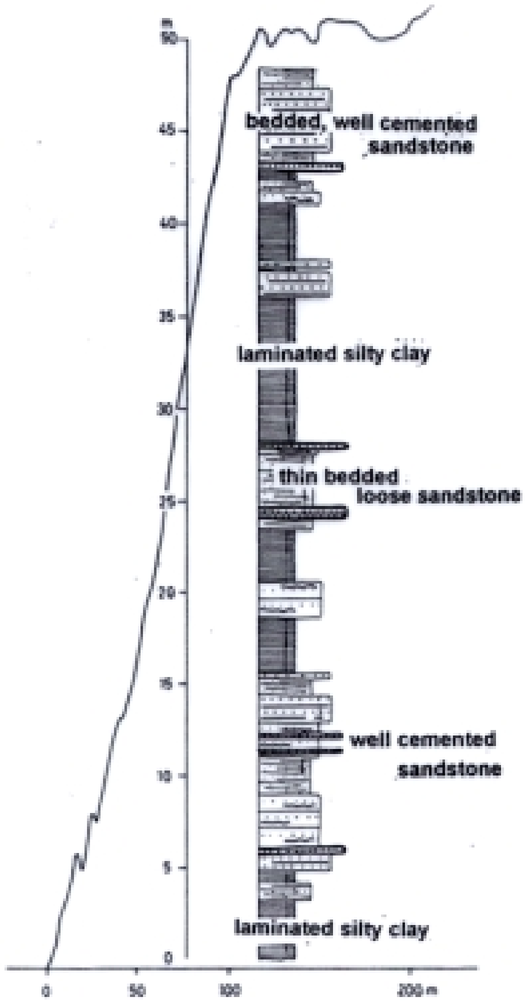


*Fig. 2.* Typical geological cross-section of the El Serag section

### 2.3. Structural Geology

The river bed of the Nile was formed in a structurally preformed valley. The bedding of the Nubian Sandstone is subhorizontal on both sections having a dip of 6 – 8°. In contrast, the sandstone beds and banks are densely jointed and often fractured. The tectonics related joints and discontinuities show a very characteristic orientation. In the El Serag section the $NE - SW$, while in the southern section at El Gaafera $ESE - WNW$ strikes are typical. These directions have primary importance in the preformation of wadis and thus wadis are perpendicular to the railway track. Less frequently, transversal $NNW - SSE$ oriented fractures are also found.

### 2.4. Hydrology

The major stream of the area is the river Nile that has a regulated discharge since the construction of Aswan Dam, thus, no floods occur. Other permanent streams or lakes are not found on the study area. The climate is arid typical of desert with great diurnal temperature changes. The mean annual rainfall is less than 10 mm. At the same time the exceptional but usually heavy rains result in intense erosion of the uncovered, barren surface. No water culvert was found at the studied railway sections.

## 3. Engineering Geological Evaluation of Railway Track Versions

The construction of the second railway track was already in progress on the plains between Edfu and Aswan during the engineering geological site survey. Thus it was very urgent to choose the best alternative and design the second track in the mountainous areas. Two major points were considered for the track selection during the primary site survey:

- If the new track is located farther from the present railway track, the construction works do not influence significantly the rail traffic. Two versions were analysed:
  - tunnel and
  - open cut
- If the new track is simply the extension of the present line, the foundation, the telecommunication signalling and locking system are less costly. Three versions were studied:
  - rock excavation,
  - land bridge and
  - gabion

### *3.1. Tunnel Version*

The tunnel version was the one that has been proposed as the first alternative for both areas by MÁVTI Co. Ltd. In the El Serag section (792+300 – 794+600) it would be necessary to have a 1150 m long tunnel to have the necessary track curve. The outcrops showed that the tunnel of 10 m in diameter would be in medium or high quality sandstone. At the entrance zone thin bedded sandstone and laminated silty clay intercalations occur. The geodetical survey showed that the area was much more dissected than estimated. The crossing wadis are deeply cut and as a consequence it would be necessary to stabilise the coverbeds, and artificial wadi bottoms have to be constructed (*Fig. 3*).

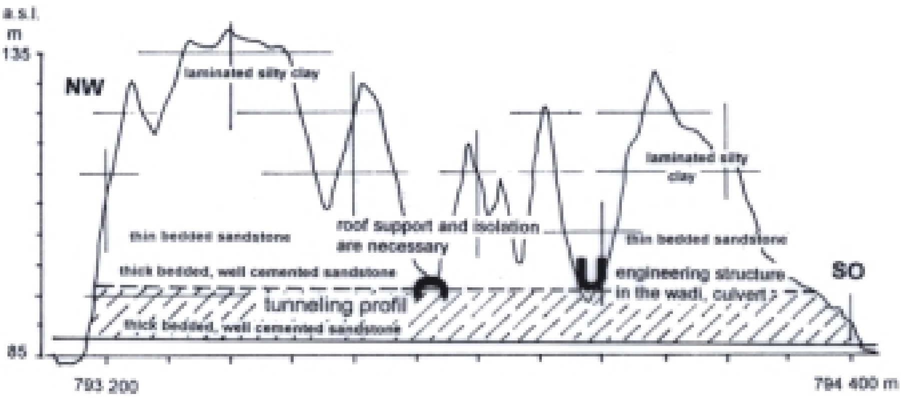


*Fig. 3.* Simplified cross-section of the tunnel version, el serag section

In the El Gaafera – El Aakaba section (852+000 – 856+000) the tunnel version would be an alternative because landslides were recorded in the section 853+800 – 854+400. The tunnel would be 500 m long and would cross the 140 m high hill. The 11.5 m high tunnel would penetrate mainly into high-quality thick-bedded sandstone and subordinately in medium-quality sandstone. The thickness of the cover beds would be between 11 and 33 m. The northern entrance zone would be in a former ancient quarry, while the southern entrance zone would be in a densely fractured unfavourable sandstone (*Fig. 4*). In the meantime the ENR dropped the tunnel version for security reasons.

### *3.2. Open Cut Version*

This version was proposed by the ENR. Its advantage is that by excavation blasting and earthwork can be rapidly executed. In the El Serag section this version has the highest diversion (maximum 300 m) from the present railway track. In very variable rock conditions and strongly dissected surface a 30 – 40 m deep and 750 m long

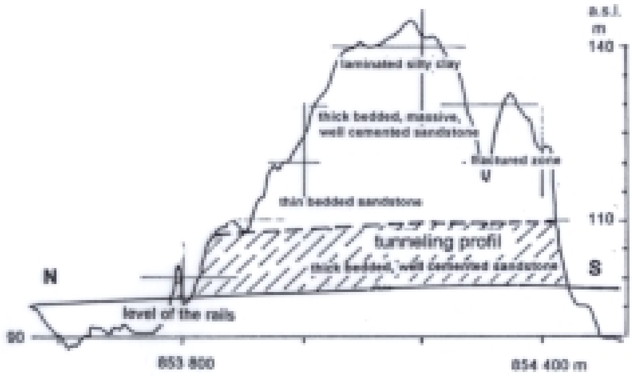


*Fig. 4.* Simplified cross-section of the tunnel version, El Gaafera section

open cut would be needed. Therefore a two-stepped terraced version with slope angle of 72° was proposed (*Fig. 5*). On the terraces rock fall protection should be provided in the form of protecting grid or wall and there would be no need for net cover of the slopes. For safety reasons the assessment of the bottom width of the cut is recommended.

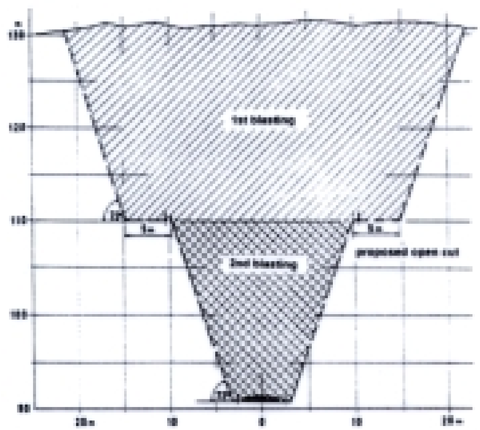


*Fig. 5.* Cross-section of the open cut version

In El Gaafera section the open cut also would be longer than the tunnel version and would have a larger curve in a length of 750 m. For the construction of double rail track about 1000 $m^3$/m of stone material should be removed just like to the El Serag section. The two-stepped section would be finalised by blasting and footwall support. Since the top of the slope would expose thick laminated siltstone and clay net protection of the slope would be necessary to avoid rock falls and slides.

## 3.3. Rock Excavation Version

The first version proposed by us after the site survey was the rock excavation version. In the El Serag section 30% of the track line is bordered by steep and high (15 – 35 m) sandstone cliffs. The cliffs have variable geological composition and are densely jointed. As a consequence even if only the original track is used the stability of the cliff faces has to be checked. For doubling the railway line excavation and protecting measurements are needed and thus a too-stepped excavation is proposed. The protection and angle of slope is identical to the one of the open cut. The El Gaafera section is more varied, and 35% of the track is bordered by cliffs. The critical part of the section is 853+800 – 854+400 where there was a significant landslide in 1991 that affected the road also. In that section thick clay is intercalated in the sandstone (for details see chapter 4).

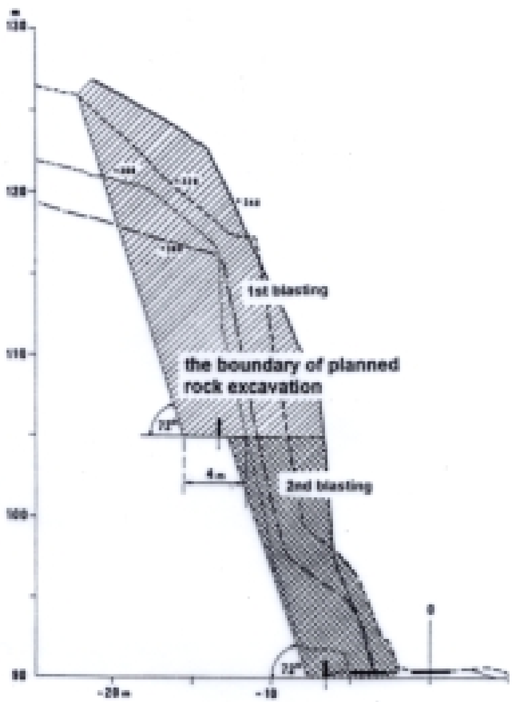


*Fig. 6.* Cross-section of the rock excavations

### 3.4. Land Bridge Version

The designers suggested this version as a second choice. The new track would be on the side of the Nile with land bridges of 18 m each having SOIL MAC foundation with piles of 1 m in diameter. The engineering geological data for the design is very limited. Sandstone rarely occurs on the riverside of the track. In most cases it only occurs as debris and Nile terrace or clayey muddy alluvial deposits are found (*Fig. 7*). The access is difficult, the costs of the survey are high and thus no drillings were performed. The vegetated zone between the Nile and the track also needs protection.

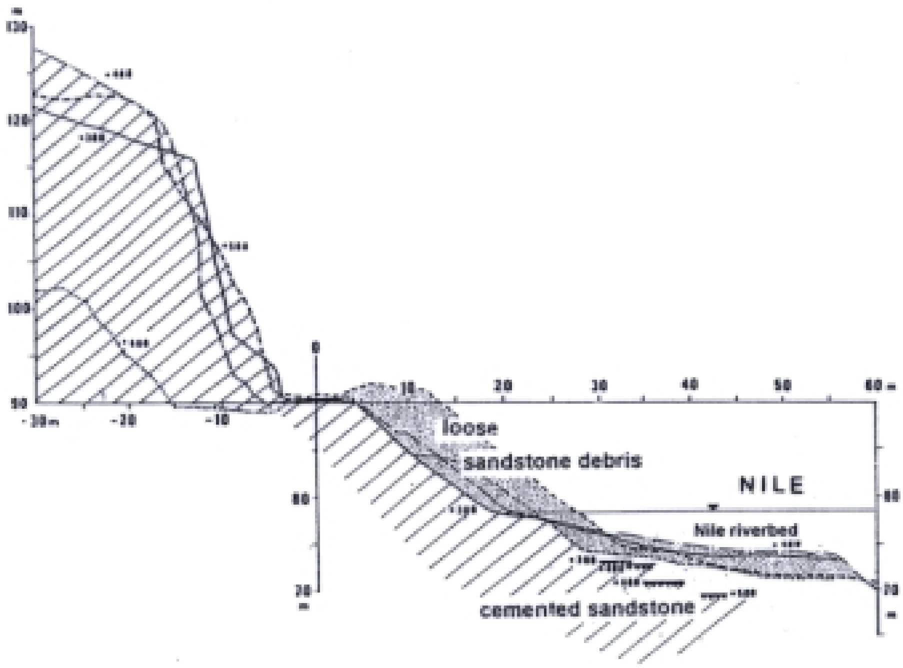


*Fig. 7*. Geological cross-section of the cliff foot zone by using the data of dynamic sounding and sonic sounding (after NECB)

### 3.5. Gabion Version

In the third version of the design plan the track would be the same as in the former version. The same signalling and safety system should be used and thus it is an economical version. The method is based on simple techniques, it is environment friendly and there is no need for special foundation. Difficult access and protection of vegetated zone are also important factors (*Fig. 8*). Engineering geological survey has not been performed.

*Fig. 8*. The railway track is bordered by steep cliffs to the *W* and by narrow vegetated land on the riverside of Nile to the *E*

## 4. Engineering Geology of Cliff Faces

The ENR chose the rock excavation version for both sections, El Serag and El Gaafera, in the first phase of the tender. For the study of cliff faces 1:20 000 scale topographic maps and cross-sections (in every 20 m) of the track line were provided. The sites of drillings were also discussed with NECB. The main problems of cliff faces even in the present single track version are as follows:

- the cliffs have a height of few tens of metres and are located alongside the track,
- cliffs are densely dissected by joints that are mostly perpendicular, subordinately parallel to the cliff face,
- bedding parallel discontinuity surfaces are significant being horizontal or having a dip of 6 – 8°,
- the cliffs are composed of heterogeneous rocks: massive – thick-bedded – thin bedded – laminated types having varied strength parameters (*Table 1*) and high porosity (5 – 23 V%),
- due to the low strength and dense joints – 1027 joints were identified – the sandstone rock bodies are of poor quality (*Fig. 9*).

*Table 1.* Petrophysical properties of sandstones (air dry state)

| Petrophysical properties | | Sandstone | | | |
|---|---|---|---|---|---|
| | | Yellow compact fine sand tone | Yellowish-brown thick-bedded fine sandstone | Yellowish-brown fine sandstone with ripple marks | Light grey laminated fine sandstone |
| bulk density | $kg/m^3$ | 1950 | 1890 | 1900 | 1875 |
| open porosity | V % | 8.2 | 23.1 | 21.5 | 19.7 |
| uniaxial compressive strength | MPa | 30.0 | 19.1 | 18.8 | 17.5 |
| modulus of elasticity | MPa | 32100 | 8900 | 23000 | 15500 |
| tensile strength | MPa | 2.4 | 1.3 | 2.5 | 1.2 |

Petrophysical tests were carried out at the Department of Engineering Geology, Technical University of Budapest

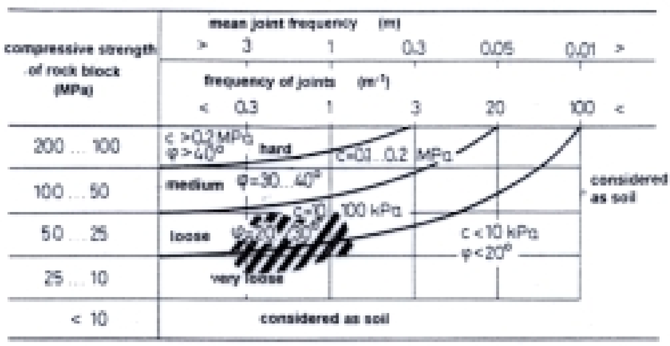


*Fig. 9.* Quality categories of sandstone rock bodies based on compressive strength and joint frequency (after BIENIAWSKI, 1980)

### *4.1. El Serag Design Section (792+300 – 794+600)*

In the El Serag section the 30 – 40 metre high cliffs follow the railway track. The rock excavations which are needed for the new track can be divided into three units:

In the section **792+000 – 792+980** several smaller zones must be excavated

(000-060, 200-420, 480-500, 940-980). The cliff face has a height of 30 m within the sections 300 – 400, but it is relatively far from the railway track. A wide, rock debris covered slope is between the cliff and the track. The thick sandstone banks and the clay beds with sandstone blocks of this hill slope must be removed. The removal of the hill slope foot has a horizontal extent of 3 – 6 m, and a vertical one of 5 – 8 m.

The **793+200 – 793+720** section involves two cliffs: 200 – 540 and 620 – 720 but it needs similar rock excavation technology. The 35 – 40 m high cliffs are nearly vertical having an irregular morphology, which is related to the frequent joints. In the elevated zones the clayey siltstone beds are common, therefore a slope with less than 70 – 72° – which are the general values for the design – is proposed. Numerous steep (80 – 85°) fractures are found in the southern zone of the long cliff (520 – 540 section). These fractures are perpendicular to the track and therefore endanger the stability of the cliff face. As a consequence special attention is needed during rock excavations and the modification of the designed slope profile is possible during the works (*Fig. 10*). Because of the 25 – 40 m height of the cliff by the rock excavations a two to three stepped slope profile has to be constructed in a width of 8 – 20 metre (*Fig. 11*). The southern shorter cliff is also very fractured perpendicularly to the rail track. At the foot of the cliff fallen sandstone debris lies. Here also a slope profile with two benches is feasible.

*Fig. 10*. Detail of the densely jointed cliff face. The joints are parallel to the railway track, 793+520 section

The most densely fractured section is the **793+980 – 797+220** (*Fig. 12*). In the elevated zones the cliff has a height of 35 – 40 m, while at its ends it is only 10 – 15 m high. The bulk of the rock material is a thick bedded sandstone (sandstone banks), while in the middle of the cliff face silty laminated clay and sandstone occur. The numerous fractures are not only perpendicular but parallel or oblique to the railway track, consequently there is a risk of rock falls (*Fig. 13*). Thus a two-stepped 5 – 10 m wide excavation is proposed.

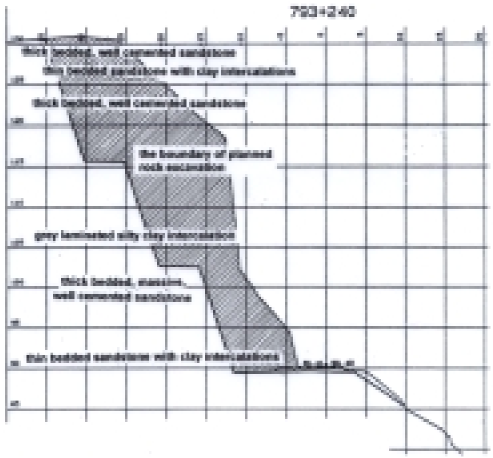


*Fig. 11*. Three-stepped excavation profile of the cliff face in the section 793+240 (after BOHUS, G.)

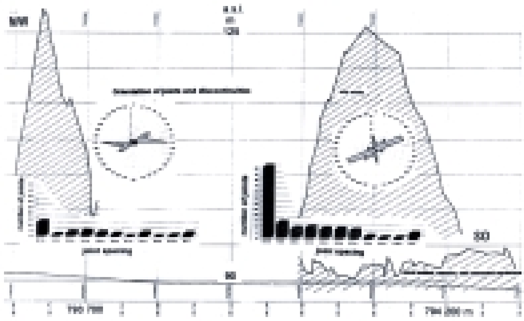

*Fig. 12*. Distribution of joint spacing in the southern part of the El Serag cliff section

### *4.2. El Gaafera – El Akab Section*

In the El Gaafera – El Akab section the cliff is somewhat lower and is located slightly far from the present track. The rock excavations are needed in three units:

**853+220 – 853+500** part of the section starts with gentle slopes to the North and the major excavations are only necessary at its southern part. The bulk of the hills is composed of thick sandstone banks. The surface is locally covered by the damp material of the former sandstone quarrying. The planned extent of the rock excavations: 5 – 35 m in width and 5 – 25 m in depth, is feasible, although the subhorizontally bedded sandstone is densely jointed.

The **853+720 – 854+380** section is the most problematic part of the whole area.

*Fig. 13*. Tectonised unstable cliff face at the ‘Nubian village’, section 794+220

*Fig. 14*. Rail ‘curtain’ and reinforced concrete retaining wall at the landslide area for stabilising the highway, 853+900 section of the railway track

This part of the section is affected by fossile landslides to a great extent. In 1991 an active landslide developed at the highway (*Fig. 14*). The top of the cliffs is mainly covered by laminated silty clays and thin bedded sandstones, meanwhile the major part of the cliffs is composed of thick sandstone banks of good quality. The most striking fact is the abundance of green, variegated clays. In the landslide zone and south of the landslide the clay, which has a thickness of some metres, incorporates sandstone blocks (*Fig. 15*). It is also remarkable that on the top of the cliff 30 – 40 cm wide fissures appear. These fissures are almost always filled with clay, which

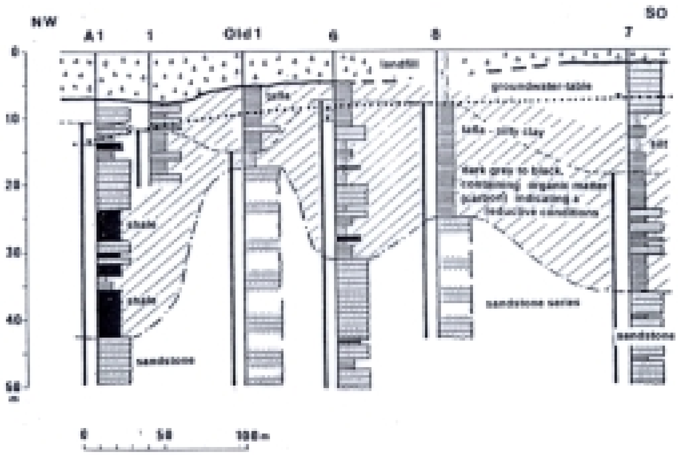


*Fig. 15*. Simplified cross-section along the Nile in the landslide area of El Gaafera (the section was compiled by using the drillings of NECB)

*Fig. 16*. A huge sliding sandstone block above the railway track, section 853+950

can evoke a risk when those are soaked by rain or from other sources. A large slided sandstone block reminds of that risk (*Fig. 16*). Therefore it is recommended to shift the new track away from the landslide by 30 – 45 metre toward the cliff. Thus by removing huge mass of sandstone the load can be decreased and the new track will be located outside of the zone of the sliding surface (*Fig. 17*). Continuous supervision and readjustment of the design is necessary during the constructional works (*Fig. 18*).

The **854+600 – 855+960** section is divided into two units; 854+060 and 854+180 – 854+960. In this section only minor excavations are needed, with the

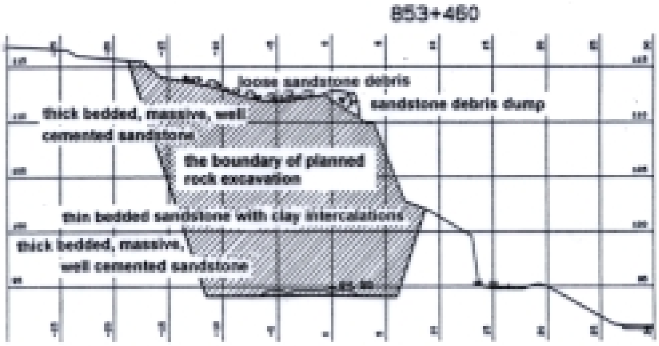


*Fig. 17*. The proposed excavation profile of the cliff, landslide area El Gaafera section 853+460

*Fig. 18*. Railway track perpendicular joints in the cliff of the section 854+300

removal of hill foot or with construction of open cuts. The land surface is covered by some metres thick sandstone debris (dump of former quarries) (*Fig. 19*). Since this debris on the steep slopes is not stable its removal is necessary. Part of this sandstone can be used as a construction material for the railway embankments. The bare rock of the hills consists of thick sandstone banks, while at the hill foot grey or variegated clays with sandstone blocks are exposed. The maximal extent of the proposed excavations is 3 – 15 m in width and 3 – 8 m in height.

## 5. Conclusions

The construction of the second railway track in the 6.5 km long sections of El Serag and El Gaafera is difficult due to the steep cliffs that border the railway line. For

*Fig. 19.* Sandstone debris form steep slopes alongside the railway track, section 855+500

finding the economical and safe solution several track versions were proposed. By using the engineering geological data ENR chose the rock excavation version.

Detailed geodetic and engineering geological surveys were carried out in the second phase of the studies. Based on these data detailed plans were prepared for the scheduling excavations and for safety conditions during these works.

Detailed plan and economic calculations were performed for the large-scale rock excavations – blasting brings several safety problems thus ENR decided to use swelling cement for the excavations. With swelling cement 6% of linear expansion is calculated and its reaction and consolidation last for 6 hours in Egyptian climate. The steep, high, densely fractured and often rock fall prone cliffs can be only excavated by continuous supervision.

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