REUSE OF LOCAL MATERIALS IN ARID AREAS THE CASE OF THE SKHOUR RHAMNA – MARRAKECH HIGHWAY

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ABSTRACT

The highway Skhour Rhamna-Marrakech (84km), located in an arid area, with a hot and dry climate, is mostly embanked and required about 4 Mm^3 of local materials of loan. The materials issued from excavation or borrow pits are in a very dry state (1 to 2% water content) and their percentage of thins (gravel with diameter < 2 mm) becomes very high after extraction, which does not allow their use in embankments, according to current technical norms and guides. The humidification or the search for "skeletal" materials was technically necessary. The rare ground waters had to be saved for the local population, and the impact on the landscape was to be minimized (limitation of depots and borrow pits). The remote transportation of 1,5 Mm^3 of water was economically unjustified.

The protection of the environment, as well as the absence of any adaptable reference, led to the construction of 10 Mm^3 of embankments in unseen technical conditions : thins placed in the core, and protected with lateral layers composed of skeletal elements (providing stability and protection against erosion) ; and minimization of water infiltrations in the embankment with a water-tight central reservation.

The minimization of the environmental impacts seems to be achieved, and the construction costs and deadlines respected.

1. PROJECT PRESENTATION

The SETTAT – MARRAKECH highway is part of the grand axis AGADIR – MARRAKECH – CASABLANCA – TANGIERS – EUROPE & "Trans-Maghrébine" highway. This connection will place Morocco at a crossroad between the different North African countries and Southern Europe.

This grand axis is also part of the "Schéma d'Armature Autoroutier National" (S.A.A.N, National Scheme for Highway Framing), and constitutes a link between two strategic regions of the country, the Center and the South.

The segment SKHOUR RHAMNA – MARRAKECH completes the segment SETTAT – SKHOUR RHAMNA, which is being built in parallel.

During construction, the segment SKHOUR RHAMNA – MARRAKECH was subdivided into three sections :

Section 3 : SKHOUR RHAMNA – BENGUERIR (31,100 Km-long)
Section 4 : BENGUERIR – PK 30 (30,000 Km-long)
Section 5 : PK 30 – MARRAKECH (22,700 Km-long)

The construction of this infrastructure will essentially allow :

- The integration of the Center provinces and the rural areas to the rest of the Kingdom.

- The participation to the industrial and touristic development of the region of Marrakech, currently in progress.

The construction started mid 2004, with an objective to open the highway to traffic in the beginning of 2007.

Concerning the earthworks, the global quantities are as follow : :

« Table 1 – Earthworks' quantities »

Category	Unit	Amount
Excavations	M^3	8 900 000
Embankments	M^3	9 500 000
Borrows	M^3	4 500 000
Deposits	M^3	2 500 000

2. PRINCIPLES USED DURING DESIGN PHASE

2.1 Geological and geotechnical overviews

During the design phase, and for the earthwork needs, a series of geotechnical tests (by corings and boreholes) were made in order to :

- determine the nature of the local materials
- define how to use the materials issued from excavations, and especially determine the evolution of the thin fractions
- improve the project in consequence of the previous information (search of a balance between excavations and embankments)
- define the needs in borrowed materials
- identify a strategy to apply for the completion of the project and the FCF(Firm's consultation files).

2.1.1 Sections Skhour Rhamna/Benguerir and Jbilet/Marrakech

These two sections are respectively the first part (30 km) and the last part (17 km) of the project. The type of material in these areas is metamorphic schist sometimes punctuated with quartzite and dolerite. They are covered with deteriorated and loose schist.

In their natural state before extraction, these materials are classified as R62 and R63 according to the GTR [1].

2.1.2 Section Benguerir / Jbilet :

The type of material found in this section (central part, 37 km-long), is constituted of calcareous rocks, marno-calcareous rocks punctuated with tuffs.
There can be often found a calcareous crust alternated with hard calcareous rocks and tuff-like limestone.

These clusters are covered with coarse alluvium and quaternary-age deposits in the form of muddy gravels.

The deteriorated schist are buried very deeply and are not reachable in the excavations of the highway layout. However, they can be found at a depth of only 4 or 5m in a borrow pit in this section.

The calcareous materials before extraction are classified as R21 and R22 according to the GTR [1]. The majority of the materials extracted with a ripper or explosives are classified as CiBi.

2.2 Climate

The highway between Skhour Rhamna and Marrakech goes through a region with sub-Saharian climate, with precipitation levels of 300 mm, sometimes 200 mm, mostly during the cold season (from September to May), and high evaporation (cf. table 2).

The heat differences are important, with an average annual temperature of about 20°C and extremes ranging from -3°C to +48°C.

Moreover, the ground waters are very deep (sometimes > 120m-depth) with very variable flows that cannot meet the needs in watering and in humidification of the multi-million cubic meters of embankment material. One should also note that the first section (31km-long) does not intercept any ground water and that only a major one is found at the end of the second section, but at a depth of over 40m.

« Table 2 – Summary of precipitations from 1985 to 2004 in the area. »

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**TOTAL**
MONTHLY TOTAL	**610**	**547**	**825**	**527**	**173**	**108**	**7**	**45 ,5**	**153**	**370**	**581**	**545**	4494
MONTHLY AVERAGE	**30,5**	**27,4**	**41,3**	**26,4**	**8,7**	**5,4**	**0,3**	**2,2**	**7,6**	**18 ,5**	**29**	**27,3**	224,7

2.3 Measures taken

After taking these geotechnical and climatic aspects into consideration, and even though the materials at hand are in a very dry state, it was decided to use them in their initial state.

In the absence of any technical referential and conclusive previous experience, the technical prescriptions had to be made specifically for this project.

Indeed, this was a question of applying to an arid area, and to a highway infrastructure, a technique previously used in a desertic zone for embankments of small height in standard roads.

- In Morocco, the results of past experiences were published in

  ”Routes en milieu désertique – l’expérience marocaine – titre 3- chapitre2.1”.

This project was of course more problematic, since the average height of embankments is of 8m, with sometimes a height of 20m. The need for specific technical measures led to making experimental trial tests in true scale for the compaction of dry materials extracted locally, during the study phase. These measures are mostly about :

- Concerning the materials classified R62 and R63 :

- the compaction without humidification (dry and very dry state) of layers with small thickness, limited to 40 cm in embankments and to 25 cm in the PST (upper part of embankment)
- the application of intense compacting energy, in the way of the GTR

- the restriction of the material diameter to 0/250 mm in embankments and 0/150 mm in the PST
- the restriction of the fraction of thin material to 30 %
- a thickness of 80 cm for the PST, which last layer (25 cm) is made of water-insensitive material, compacted at “m” state (humid)

These measures were determined following an experimental trial test made with materials of class R6, extracted by mining the “déblai 1” (excavation site 1) in the first section.

The application of these measures is to be confirmed with trial tests in the beginning of construction.

- Concerning the other types of material:
  - their use in their natural state provided that a trial test set the conditions of compaction
- The slopes are set to 2H/1V for embankments > 10m et 3H/2V for the others.

3. ADJUSTMENTS MADE DURING CONSTRUCTION

3.1 Complementary geotechnical studies :

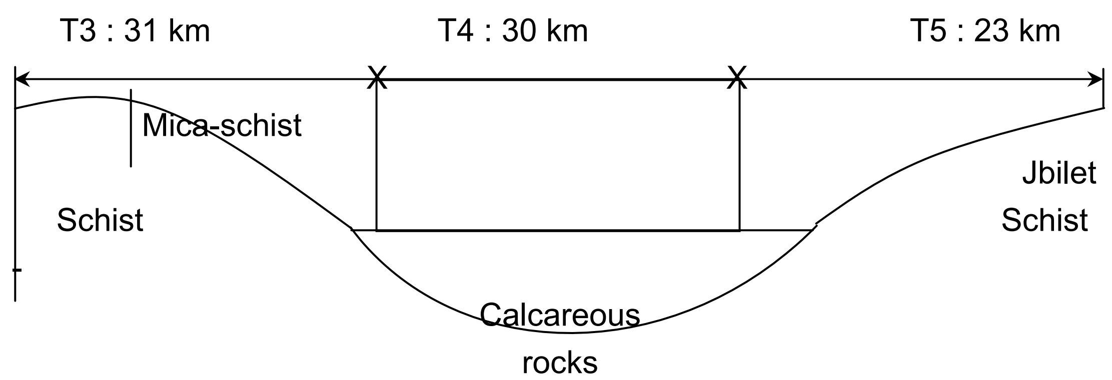
At the start of construction, during the preparation phase, a series of complementary geotechnical tests were made in order to :

- make sure of the compatibility between the materials and the measures set by contract and by the studies.
- make sure of the possibility of their re-use in the conditions set by their technical specifications.
- establish a project of earthworks.

The clusters found were conform to the results of the initial geotechnical study, except between the kilometric points 10 and 31 in the section 3 (Skhour Rhamna – Benguérir), where crumbly mica-schist can be found, as well as red clay and tuffs deteriorated by the mica-schist.

All materials found are in a dry to very dry state (1 to 3%) and are for the most classified as C1B5 after extraction, and sometimes even C1Ai.

The geotechnical profile can be summarized as follow :



« Figure 1 – Geotechnical profile»

3.2 Trial tests for compaction

Many trial tests were made in order to define the objectives of maximal densification in compacting the embankments, and the setting of a Q/S as a reference for the realization of highway embankments.

The principle of execution of the trial test consists of compacting the materials by applying the compacting energy of the closest and most similar case, in terms of the GTR classification of the material in question.

The compaction energy is then increased in successive stages of two passes until the materials reach their maximal compaction level, which translates into either a drop the bearing EV2, or a weak evolution of the bearing in spite of the increase of the compaction energy.

The evolution of the bearing is considered to be weak when the average of the measured bearings between three successive compaction energies increases of less than 10 % when you pass to the next and superior compaction energy.

3.3 Results of the trial tests

The trial tests were made with a thickness of 1,20m (1,50m non-compacted), subdivided into three successive layers of 0,40m, using a V5 vibrating cylinder.

The maximum diameter of the materials cannot exceed 250 mm. To achieve this, several experimental tests were made with different meshes (or filters) to reduce the dimensions of the blocks.

3.3.1 Material identification before compaction

The results of the identification tests of the materials before compaction can be summed up as follow : (example of materials issued from excavation sites D1 and D8)

« Table 3 – Material identification before compaction »

Type: schist from D1	**Diameter size**				**VBS**	**Wnat**	**GTR class**
	% < 0,08 mm	**% < 2 Mm**	**% < 50 Mm**	**Dmax Mm**			
1st layer	12,2	28,5	61	240	0,18	3	C1B5
2nd layer	14,7	31,5	58	220	0,18	2,2	C1B5
3rd layer	13	27,3	77	250	0,23	2,1	C1B5
Average	13	29,1	65	–	0,2	2	C1B5

Type: mica-schist from D8	**Diameter size**		
	% < 0,08 mm	**% < 2 Mm**	**% < 50 Mm**
Avant compactage	2 à 6	6 à 23	50 à 68

3.3.2 Follow-up of bearings

The bearing measures were made for each layer and each tested energy.

The results of averages obtained from the measures were registered in the following table:

« Table 4 – Follow-up of bearings »

Type: schist from D1	**6 passes**		**8 passes**		**10 passes**	
	EV2 (MPa)	**K**	**EV2 (MPa)**	**K**	**EV2 (MPa)**	**K**
1st layer	117	3,23	136	2,89	107	2,8
2nd layer	135	2,27	106	3,4	116	4,2
3rd layer	124	2,34	90,2	2,8	96	3,1
Average	125	2,6	111	3	106	3,4
Type: mica-schist from D8	**6 passes**		**8 passes**		**10 passes**	
	EV2 (MPa)	**K**	**EV2 (MPa)**	**K**	**EV2 (MPa)**	**K**
Average	37	2,3	38	2,37	35	2,9

We should note that the values of EV2 obtained for 8 and 10 passes are relatively similar, with a weak drop in bearing, which leads to keeping 8 passes. Considering the state of the top of the compacted layer (formation of a film of thins), the measure of K is not significant.

3.3.3 Material identification after compaction

Three trenches are opened after making a trial test. These trenches help in making sure of the compaction of the material, and in making samples for identification.

The results of the identification tests are reported in the following table:

« Tableau 5 – Material identification after compaction »

Type: schist from D1	Diameter size				VBS	GTR class
	% < 0,08 mm	% < 2 mm	% < 50 mm	Dmax Mm		
1st trench	17,3	38	66,3	240	0,22	C1B5
2nd trench	15,6	36,5	63,5	250	0,24	C1B5
3rd trench	16,9	29,5	66,1	270	0,3	C1B5
Average	16,4	34,7	65,3	–	0,25	C1B5

Type: mica-schist from D8	Diameter size		
	% < 0,08 mm	% < 2 mm	% < 50 mm
After compaction	9 to 13	32 to 42	75 to 80

Considering these results, we can notice a small evolution of the diameter size of about 3% for gravels with diameter <= 0,08mm and of 6% for the 2mm sieve, in the case of schist from excavation site D1.

In the case of mica-schist, we can observe even more evolution, of about 7 % for gravels with diameter <= 0,08mm and of 25% for the 2mm sieve.

3.3.4 Conclusions

- The mined schist, compacted at a very dry state, present good results for bearing for ordinary embankments, and a small evolution in diameter size.
- The compacted material presents a good tightening (which could be observed after opening trenches).
- The number of passes to apply is 8, using a V5 vibrating cylinder and a layer thickness of 40cm (Q/S obj = 0,06 m^3/m^2).
- The mica-schist present a strong evolution in diameter size, and weak bearing levels.

« Photo 1 – Mica-schist during extraction in section3 »

« Photo 2 – Sound schist from section 3 in embankments »

« Photo 3 – Mica-schist from section 3 in embankments »

3.4 Technical problems met

Dry compaction of very dry materials presents technical problems in terms of embankments stability, if humidified after opening to traffic. The possible risk varies depending on the quality of the materials (especially on the proportion of elements under 2mm) and the height of the embankment.

3.4.1 Land data :

Section 3 :

- The mined materials issued from excavation sites in the beginning of this section are mostly schist classified from C2B4 to C2B5, with a percentage of materials with diameter under 2mm inferior to 30%, and thus of skeletal type with a granular-like behavior.
- The other excavated materials are crumbly mica-schist extracted by means of a ripper. Their proportion of elements under 2mm is above 30%, which makes them non skeletal materials with thin-like behavior, and make them evolve a lot with compaction.

Section 4:

- With the exception of the calcareous rocks from the lutecian-age and the marno-calcareous rocks, this section does not contain reusable material.
  The quaternary-age clusters are gravelly clayey silts, sometimes with a tuffy layer (which makes them hard to reuse in their dry state because they do not cement, and because the compacting energy tends to loosen them instead of tighten them).

Section 5:

- Most of the embankments were built with mined schist having a percentage of materials under 2mm < 30%, and thus classifies them as skeletal materials.

3.4.2 Risk analysis

The compaction of materials at a very dry state has three main risks when in contact with water :

- Collapse or inflation of the embankment.
- Instability of the embankment slopes (surface sliding and erosion due to water and wind).
- Loss of bearing in the surface of the earthworks.

These problems occur mostly with materials which fraction of thins increases with compaction, to the point where it becomes the main factor in the global behavior of the material.

Moreover, the drying and wetting cycles of the embankment slopes can also cause problems (traction fissures, … etc).

3.4.3 Complementary investigations :

Loads tests were made on site, in order to check the behavior of the embankments.
These tests consist in applying a known constraint on the embankment with a metal plate (Ø 75cm), increase it to saturation, and then examine the resulting deformations.

The results of these investigations can be summed up as follow :

- The embankments made of schist with less than 30% of materials under 2mm, a Dmax < 250 mm, and a height < 7m have very small deformations. They do not show any problems.
- The embankments made of mica-schist : the materials are very thin (Dmax about 63mm), and fraction under 2mm about 50%. They tend to swell up when height H>3m, in the higher part of the embankment and its slopes. In addition to that, the risk of erosion is high because of its low plasticity.
- The thin materials and coarse alluviums (gravelly silts) having a fraction under 2mm above 30% and a Dmax around 100mm have the same results as the mica-schist : the height of the embankment should not exceed 3m.
- The tuff materials tend to shrink with small heights.

To evaluate these risks, expert assessments and complementary studies were made, and they led to the following measures :
- The schist used at the beginning and the end of the section (for 26km) : no special measure was to be taken, the specifications of the CCTP were adequate and do not require technical additions.
- Concerning the central part of the section (about 58km, which represents 70% of the project's total length) : new measures had to be taken, like the use of skeletal materials that would "frame" the embankment and diminish the impact of the fraction of thins.

These materials called "skeletal" must have a "granular-like" behavior, expressed by the following characteristics after compaction :

- Continuous and uniformly spread diameter size on the 0/D.

- Dmax ≤ 250mm for normal embankments and Dmax ≤ 150mm for the PST.

- Fraction of thins (under 2mm) inferior to 30% on the 0/D.

In addition, the materials found in this part of the project (mica-schist in section 3 from PK6 to PK31, and the calcareous silts and coarse alluviums in section 4 from PK0 to PK30) require the following measures :

- The embankments shall be made of :

Skeletal material for the entire height, or non-skeletal materials issued from excavation, in the upper 3m, protected with a 3m-wide layer of skeletal materials (what is left of the embankment built with skeletal materials).

Concerning the embankments already built (but not completed) with non-skeletal materials, their sides (or shoulders) should be replaced by skeletal materials for a width of 3m. What is left in height should be built with skeletal materials, if height H>3m.

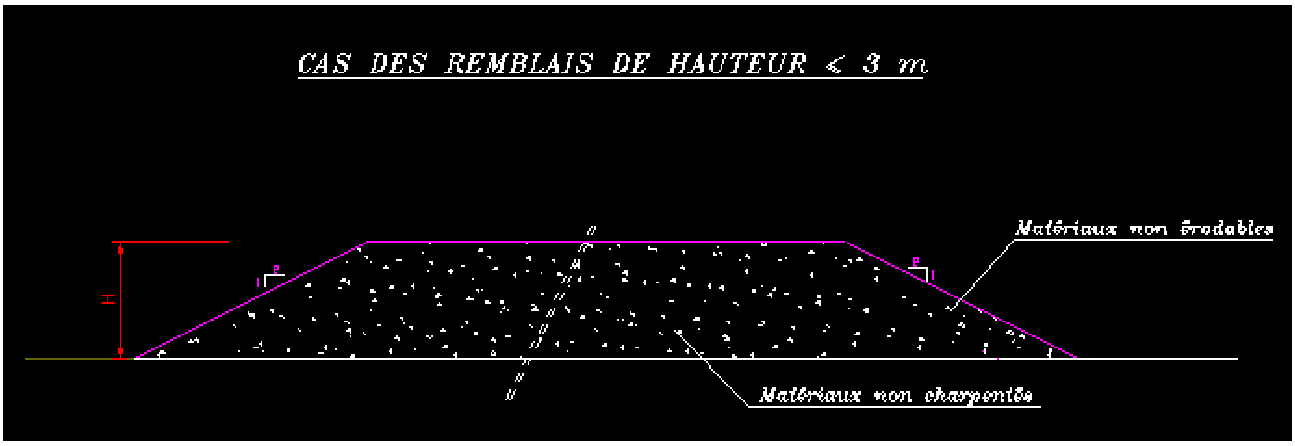
- The side layers made of skeletal materials shall be anchored into the ground.

- The embankments made of non-skeletal materials, completed but without the PST layer, shall be ripped for a depth of 50cm; that depth shall be replaced with skeletal material.

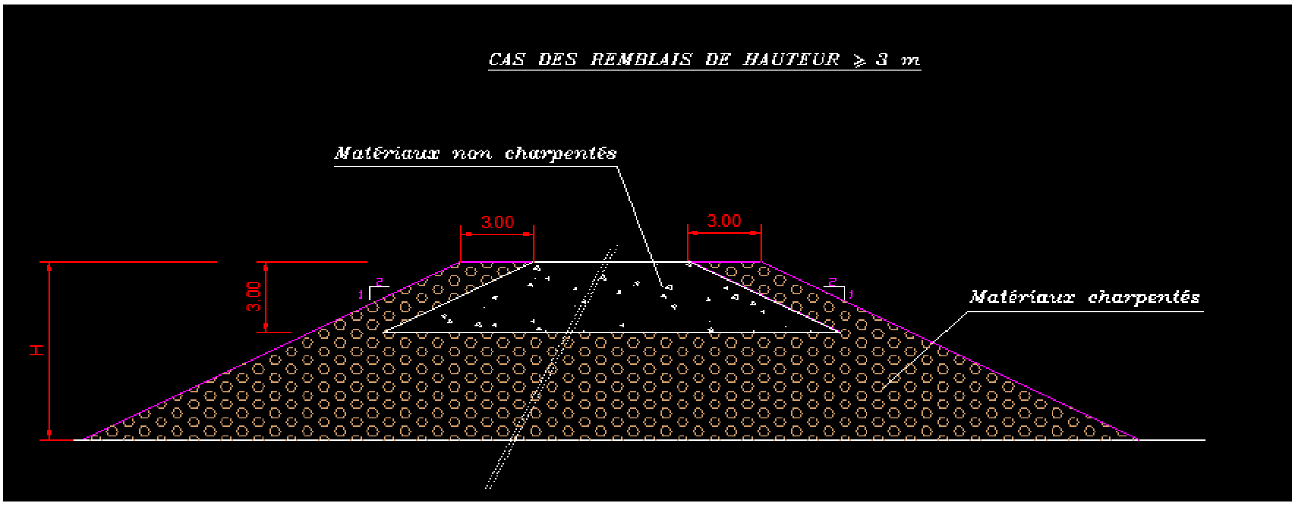
- The PST layer in contact with non-skeletal materials shall be humidified for a depth of 50cm to increase gripping between the two.

- The bottoms of the excavations made of mica-schist shall be replaced by skeletal materials.

At last, it is necessary to make sure that the materials used in the protective layers in the sides are resistant to erosion, by having a PI (plasticity index) > 10% and a fraction under 2mm < 40%.



« Figure 2 – Construction of embankments with H < 3 m »



« Figure 3– Construction of embankments with H > 3 m »

3.4.4 Retained construction measures

The application of these recommendations led to the definition of complementary construction measures adapted to the actual state of the earthworks and other important factors such as :

- The minimization of the environmental impact : the protection of water resources in the region; the minimization of embankment dismantling (which could have led to the creation of multiple spoil areas along the entire project); the minimization of borrow pits (which would have led to the creation of multiple pits with depth > 6m, spread along the entire project).
- Reduce the impact on the deadlines : what was already built had to be as much preserved as possible by limiting dismantling; and the measures taken had to be applied as quickly as possible.
- Reduce the impact on the project cost (increase in depots and borrow pits) and ensure its contractual processing.

So, for all parts of the project concerned by these problems, in addition to the recommendations of experts, the following complementary measures were taken :

- Modification of slopes into 1V/2H instead of 2V/3H.

- Possibility of reuse of non-erodable thins for embankments of H<=3m, without the protective side layers made of skeletal materials.

- Reduction of the width of the central reservation to 3m, its coating with a layer of asphalt concrete, and the removal of the central drain-pipe. This sole measure reduced the needs for borrow pit materials by 600 000 m3 in section 4.

- Adoption of a roof-like profile for the PST instead of W-like profile.

- Coating of the BAU (emergence lane) with a layer of asphalt concrete.

These last three measures decrease water infiltration into the embankments during rain seasons, and thus reduce all risks of road distortion while in service. They also reduce the effect of evaporation by blocking infiltrated waters during the dry season, effect that could cause a loss of bearing of the surface of earthworks.

3.5 Measures relative to work execution

The adoption of the previous measures required a close follow-up of earthworks and a lot of pragmatism in order to better apprehend the reuse of materials, which quality and size fluctuated depending on the soil nature, the reached depths and the conditions of extraction, loading and compaction.

Continuous amendments of the extraction and reuse modes were essential; they led to the adoption of technical dispositions, like :

- Extracting materials with diggers at excavation sites and borrow pits, instead of using bulls, as initially planned.
- Avoiding mixing materials when charging and transporting them to reduce their evolution and the increase in the fraction of thins.
- Mining the excavations as soon as extraction becomes difficult with digger or bulldozers, under the condition of checking the economical impact of the operation.
- Aim for Dmax > 250mm at extraction for skeletal materials to avoid excessive increase in thins and keep its skeletal condition.
- Eliminate the big residual blocks found after compacting the embankments.
- Keep the excess meter (of skeletal material), when an embankment is made of mica-schist, as an additional measure to reduce erosion in slopes.
- Protect the bottom of excavation sites, until the next layer is placed, to avoid the drop in load bearing due to erosion of the materials and ground drying and attrition.

4. EXPERIENCE OUTCOME

To conclude, this was the first experience in embankment compaction using materials in a very dry state, and for which no actual referential exists, especially when the height exceeds 3m.

A close follow-up will be made in the future to detect as soon as possible any sort of local evolution, such as cracks (which leads to water penetration and loss in bearing), erosion of slopes, etc.

This follow-up has to take into consideration the changes in temperatures and rain levels, the nature of materials, the important of road traffic,… and will be followed with treatments such as the fixing of cracks, local purges, asphalt concrete maintenance, slope protection (especially in areas with possible floods) ,…

As a whole, and taking into consideration the bearing and densification results as well as all the other measures applied during works, this experience help set a method for massive reuse of local materials in their initial state and without any major modifications, but with some technical amendments to respond to the requirements in quality for highway infrastructures.

This experience mostly helped save the environment from being disfigured, save the rare water resources of the region, avoid the transportation of millions of cubic meters of water to moisturize the dry materials, but also and most importantly reduce the project costs.

The efforts of ADM [2] shall also be noted, whether during the study phase or during works, as well as the efforts of all actors in this operation, to quickly find solutions to these problems to leave initial objectives intact (save the environment and the water resources), instead of leaning towards easier issues such as humidification of materials (as recommended by the GTR).

We will finally and most importantly keep in mind that this experience was one big trial test, that will help set a new method to be used in other regions of the world where reuse of local materials in their initial state is a necessity when confronted to the rarity of natural resources.

RÉFÉRENCES

1. Guide technique – Réalisation des remblais et des couches de forme – LCPC/SETRA - September 1992.
2. Autoroutes du Maroc (Highways of Morocco).