MANAGEMENT OF THE RISK OF FLOODING AND WATER EROSION ON MOTORWAYS IN MOROCCO

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The risk of flooding and soil erosion is rising because of the impacts of climate change: period of heat waves and drought are prolonged and extreme rainfall events are becoming more intense and frequent. This worsening of climate conditions increases the vulnerability of transport infrastructure, the risk of undesirable movements of land and soil and the risk of flooding.

With the research project conducted concerning the assessment and modeling of the risk of water erosion on highways in Morocco under the effect of climate change, an overall map of the risk of erosion in Morocco was developed. With this high-resolution modeling, the quantities of displaced materials (erosion / deposition) under the effect of precipitation specific to each region can be evaluated.The simulations were carried out using the 3D model, which shows through physical laws the process of runoff formation and erosion for each given precipitation event.

In addition to the erosion risk overview map, medium-scale simulations were carried out in three potential-risk catchments. Consequently, the resilience of the drainage system of highway structures could be assessed and relevant recommendations could be made.To combat the phenomenon of water erosion,Innovative soil-fixing techniques have been developed within the framework of the Research & Development program deployed by the Marco National Highway Company (ADM).

The aim for the continuation of this project is to set up a monitoring system for a proactive management of the risk of erosion and flooding. In addition, a methodological handbook should be developed and used as a working tool for design engineers.

Management of the risk of flooding and water erosion on motorways in Morocco

Motorways in Morocco cross areas of rugged terrain, generating several slopes exposed to major erosive forces that compromise the safety and durability of the structures. Highway managers is constantly working to combat water erosion and is deploying an important Research & Development program in order to control the phenomenon via the modeling and mapping of erosion with the integration of prediction models: The aim is to determine the main high-risk regions and find appropriate solutions.

In this context, techniques, primarily based on biological engineering and the use of native vegetation, have been developed to combat erosion. Experiments have been carried out on various ecological sites to select suitable and well integrated species, and the choice of techniques and materials to be used to successfully implant plants and stabilize slopes by seeding.

1. ORIGIN AND FORMS OF EROSION

Water erosion is a natural process responsible for the transport and redistribution of soils under the influence of rainfall runoff.

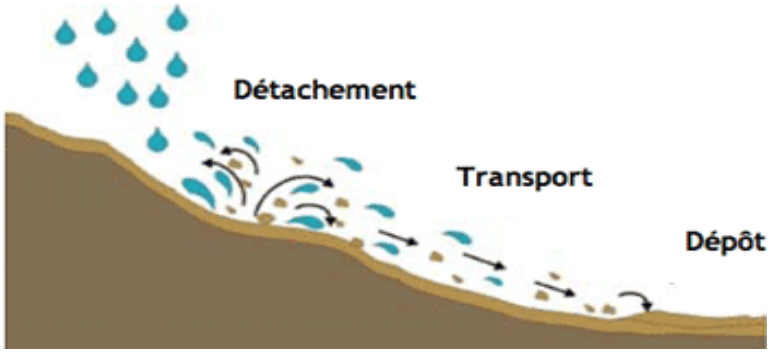

FIGURE 1 Diagram explaining the process of water erosion

This phenomenon is gaining momentum and intensifies with climate change, notably due to periods of heat waves and droughts that are becoming more prolonged and extreme events of heavy precipitation which are more frequent.

Forms of water erosion:

There are four forms of water erosion and four levels of severity:

- Laminar erosion: Displacement of the particles by "splash" effect at short distance and then by surface runoff.
- Linear erosion The formation of interconnected puddles by water streams, the speed of these nets on the steeper slopes gives enough energy to create flow lines (gullying)
- Mass erosion: any displacement of earth volume, such as mass movements, mudslides and landslides.
- Hydrographic erosion: Generated by the dissipation of water energy in the beds of streams and rivers. It is the process of sapping the banks.

FIGURE 2 Illustration of forms of water erosion

2. WATER EROSION ON TRANSPORT INFRASTRUCTURE

Transport infrastructure is severely affected by water erosion due to gullying in the body of earthworks and malfunctions in road sanitation due to solid deposits in the pipelines. The phenomenon is very worrying for the operator, especially because of:

- The frequency of flood repair operations
- The scope of the work to be carried out

In the case of motorways in Morocco, and in order to ensure the durability and security of traffic, motorways managers are constantly deploying measures:

- Corrective: clearing, rehabilitation of earthworks
- Preventative: shallow slopes of the embankments disadvantaging the departure of materials, concrete walls or retention of materials at the feet of the slope etc .

3. EVALUATION AND MODELING OF EROSION

Over the years, motorways managers have launched a major R & D program for the fight against water erosion, among the important projects of this program are:

- Evaluation and modeling of the risk of water erosion on motorways in Morocco under the effect of climate change
- Development of water erosion control techniques based primarily on biological engineering and use of local vegetation

These projects respond to international concerns and are part of the NAGOYA Adaptation to Climate Change and Biodiversity Valuation Program.

3.1. Development of an overview map of the risk of water erosion in Morocco

With the research project concerning the assessment and modeling of the risk of water erosion on highways in Morocco under the effect of climate change, an overall map of the risk of erosion in Morocco was developed. With this high-resolution modeling, the quantities of displaced materials (erosion / deposition) under the effect of precipitation specific to each region can be evaluated.

The simulations were carried out using the EROSION-3D model, which shows through physical laws the process of runoff formation and erosion for each given precipitation event. In order to carry out this modeling, four types of data are indispensable:

Digital Elevation Model:

The elevation model is indispensable for the simulations, all the topographic parameters are drawn from this model. The ASTER GDEM, which is offered online by NASA, was used. It is a high-resolution photographic sensor that is housed on board the earth-observing TERRA satellite. The data was transferred to a GIS, processed to suppress parasitic noises and transformed into Lambert coordinates.

Soil parameters: texture, structure and erodibility:

For calculation of flows (infiltration) and sediments (dissolution of particles, transport capacity and sedimentation), data on the soil texture, i.e. the granular composition and the mineral

substance of the soil, are required, distinguishing between clay, silt and sand. The soil map provided by the Moroccan Direction du cadastre et de la cartographie was geo-referenced and digitized for the project's need.

Land use parameters:

The model is divided into a number of well-defined categories such as: abundance of trees, meadows, roads, built-up areas, etc. We used data provided by the Royal Center for Spatial Remote Sensingm which was complemented and adjusted by the global map of global achetypes of land use and by data of Globcover map of the Envisat stellite.

Precipitation parameters:

Rainfall data are key data. The intensity of precipitation and the high spatial and temporal resolution are decisive in order to better model erosion. The data provided by the rainfall stations of the National Metrology Department and the Watershed Agencies have been used.

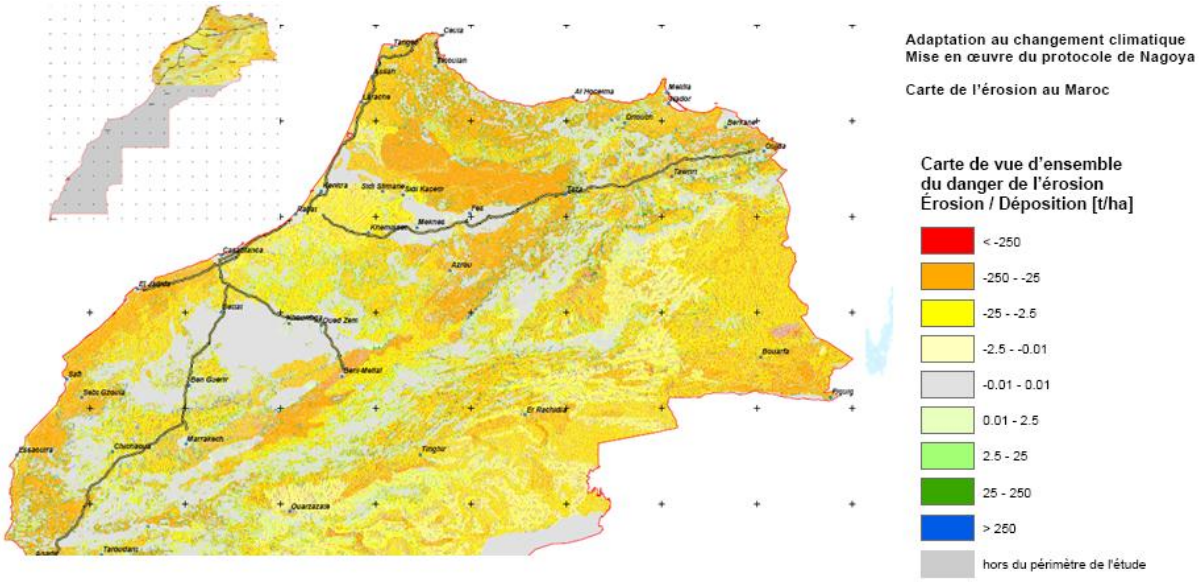

FIGURE 3 Part of the overview map of the risk of erosion in morocco

3.2. In-situ tests for model calibration:

In-situ measurements were carried out to adjust the model parameters, in particular rainfall simulation tests allowing the following characteristics to be measured in real-life:

- runoff
- infiltration
- flow coefficient
- concentration of sediments
- rate of soil loss

The advantages of rainfall simulators should be noted:

- Mobile Devices

- Ability to produce rainfall of intensity and energy similar to natural rainfall
- Ability to simulate rare rain showers
- Reduction of field observation times

3.3. Soil / erodability catalog

The research program consists in establishing a soil / erodibility catalog in order to enrich the soil classification with information on the erosive character of the soils, based on additional tests:

- Structural stability test: The physical behavior of a soil subjected to rain
- Tests for determination of physico-chemical characteristics, such as:
    - limestone content
    - electrical conductivity
    - organic matter content

4. SOIL FIXATION TECHNIQUES

Innovative soil-fixing techniques have been developed within the framework of the Research & Development program deployed by the Marco National Highway Company (ADM), in particular:

- Biological engineering Techniques
- Slope protection by arcades

4.1. Soil fixation using biological engineering techniques:

The seeding technique adopted combines the fixation of soils and their vegetation, and uses materials that are harmless to nature and ensure a dual role:

- The fixation of soils by mulching with cane reeds or straws: which is ephemeral and supposed to disappear over time at the same rate of biodegradation of the elements that compose it. But by then, this fixation retains the earth and offers the conditions necessary for the thrust of the seeds.
- Vegetalisation: seeding of slopes by means of a finely selected and tested seed composition among indigenous species.

The following four steps are identified:

- Step 1: Preparation of the soil
- Step 2: Mulching with reed screenings
- Step 3: Seeding
- Step 4: Fixation of the mulching

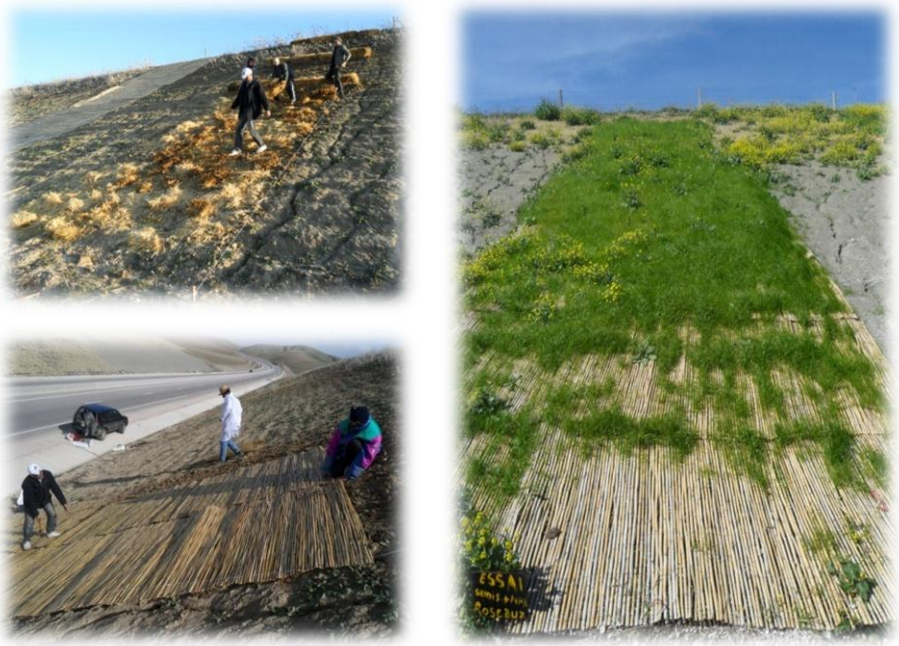

FIGURE 4 Photos of work and results of soil fixation by biological engineering techniques on Moroccan highways

4.2. Slope protection by arcades

The technique consists of reworking the surface of the embankments by subdividing it into a set of small surfaces in the form of arcs with routings for rainwater. The arcades allow to:

- break the water flow speeds on the slope
- reduce exposed surfaces and their lengths
- Collect the flowing water and convey it to the foot of the excavation slope

Treatment begins at the foot of the slope in the following order:

- Preparation of the support soil (filling of gullies, modeling, etc.);
- Implantation of the arcades on the excavation slope;
- Excavation works for the construction of arcades
- Casting of the clean concrete of the arcades
- Implementation of reinforced concrete arches cast (B20 metered at 300Kg) or laying of arcades in prefabricated elements;
- When the arched elements are prefabricated, the interlocking is realised with a joint made of anti-shrinkage mortar to ensure perfect continuity between the elements of the arch;
- Placement of the masonry stone between arches and vault.
- Realization of the arcs / cuttings connection along the treated area.

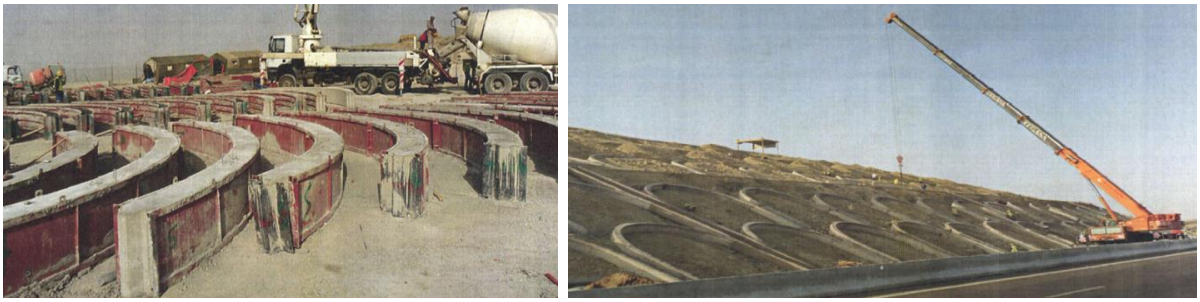

FIGURE 5 Illustration of the works on the highways in Morocco

As a synthesis of ADM's experience in erosion control, it should be noted that water erosion is a major threat and that the phenomenon is gaining momentum with climate change. Moreover, the extent of the phenomenon imposes cross-cutting projects and solutions at the scale of the big watersheds.

But it is also advisable to favor an anticipatory approach to the phenomenon, and to opt for innovative techniques that ensure a good compromise between efficiency and cost. And in this sense the biology engineering techniques have shown their effectiveness, the relatively low cost advantage and the ability to reconcile with the environment.

5. PERSPECTIVES IN MANAGING THE RISK OF FLOODING AND WATER EROSION ON MOTORWAYS IN MOROCCO

The aim for the continuation of this project is to set up a monitoring system for a proactive management of the risk of erosion and flooding. In addition, a methodological handbook should be developed and used as a working tool for design engineers. This practical guide is aimed at contributing to a better management of the risk of flooding and water erosion in transport infrastructure projects and may be extended to other land-use developments that are more vulnerable to this risk.

By strengthening the adaptation of infrastructures to future climatic conditions, this project responds directly to the overall objectives defined by the INDCs for Morocco: minimize the risk of the impacts of climate change and invest in adaptation to climate change. That is why this R & D project is set to continue. For a reproducible evaluation of the risk of erosion, an interdisciplinary approach is needed, with the implementation of integrated water management and the fight against soil degradation and desertification in the catchments along highways. This approach also aims to develop:

a) new contributions for strategic environmental planning to predict the potential benefits from the adoption of Sustainable Land Management (SLM) practices that will minimize social and environmental risks to both road infrastructure and affected populations in rural areas

b) the economic evaluation of the feasibility of adaptation measures to climate change (technical construction costs and economic aspects of the impact on affected land in the catchment areas of road sectors)