**Year of CfP: 2007**

**Project No: 07054 Completed**

**Project title:** Digital analysis of the stability of a forest slope with integration of the space-time dynamics of the stand

**Unit managing the project:** AMAP (botany and computational plant architecture) (CIRAD, CNRS, INRA, IRD, UMII)

**Project leader:** Thierry Fourcaud (thierry.fourcaud(a)cirad.fr)

**Country involved in the project:** Togo

**Research units from the Foundation's scientific network involved:** Eco&Sols, System

**Subthematic axes:** STDI-1 (Socio-Technical Dynamics of Innovation 1: *Agri-environmental innovations, agri-ecosystems, resources management*)

**Objectives:**

In many parts of the world, increased precipitation resulting from climate changes intensifies landslide risks considerably. In southern countries, these risks are aggravated by the strong pressure exerted on land by local farming and development policies. The emergence of questions about the best way of achieving sustainable management of sites exposed to such risks is the subject of a research theme called 'eco-engineering for slope stability'.

Togo is faced with serious landslide problems in the southern part of the Atakora mountain range. Large areas of forest have been cleared since the 1970s for growing coffee, cacao, cotton and food crops. The harvesting of construction timber and firewood and the intensive gathering of plants used in the traditional pharmacopeia have led to the degradation of vegetation, loss of soil fertility, erosion, landslides and the silting of watercourses by the sedimentation of particles resulting from erosion. Togo now faces a major challenge—the restoration and rehabilitation of highland soils. New reforestation, development and sloping land restoration programmes have been initiated for this, supported by the public authorities, NGOs and village associations. The programmes are financed by the International Tropical Timber Organisation. Developing master plans for works requires data on the intensity of soil degradation and the capacity of the different local species to strengthen and conserve slopes. Such data are currently lacking.

The installation of suitable vegetation is an environment-friendly alternative to the structures traditionally used by geotechnicians (netting, geotextiles, etc.). Indeed, the roots improve soil cohesion by their tensile strength and adhesion and friction at the root-soil interface. Furthermore, the vegetation changes the water regime of the slope through various soil/plant interactions. Increased study is being devoted to the contribution of roots to slope stability. However, older models consider vegetation that is spatially homogeneous in planes parallel to the surface of the ground. Such models are not suited to a forest situation in which root distribution is heterogeneous as regards the individual and the slope.

We developed a finite element slope stability model in the laboratory. This analytical tool takes the 3-D structure of a forest stand into account and makes it possible to quantify the contribution of forest tree root systems to the stability of sloping soils, taking the forest structure (density, spatial distribution of species and of their root system) into account. This project is aimed at integrating the space-time aspects of the growth of trees and their roots (by integrating hydrological processes) to appraise the impact of forest management on the strengthening of slopes in the long term.

**Action carried-out and results obtained:**

This project has set up a battery of digital tools and 2D and 3D models (based on the finite element method, FEM) to analyze in a generic way the influence of vegetation on slope stability. These tools and models take into account the mechanical effects (soil reinforcement by roots) and water (influence of roots on soil hydraulic conductivity and water status of the slope). They have been used in studies conducted in Togo (unpublished results) and on the Loess Plateau in China (results under publication). The actions undertaken concern the following:

Action 1 - Development of a library of tools (under the form of Python scripts) in the computer code Abaqus FEA to model a forest slope and determine its degree of stability. This library consists mainly of: 1 - a generic builder of slope geometry that can set a rectilinear slope (profile, angle, height, ...) and associate its physico-mechanical properties, 2 - a generator which allows to set the geometry and properties of root compartments depending on the species (represented by half-sphere, cylinder or cone; dimensions; associated additional cohesions) and distribute the trees on the slope according to regular (rows of trees) or random patterns; 3 – a manager of analyses, which can run successive simulations to determine the safety factor (cohesion reduction method) and to perform sensitivity studies to different geometrical and mechanical parameters, 4 - a data extractor to determine the safety factor of the slope, the depth of the slip surface and the volume of soil mobilized from simulation results;

Action 2 - Development of a module to read root data (field data, extraction of simulation results the plant architecture simulator AMAPsim, ...) from a domain discretized in space voxels. This tool allows defining continuous maps of additional cohesions (via root densities) that will overlay the original properties of the bare soil at scales of the individual or the slope. This work is still in progress and future results will be published.

Action 3 - Numerical analyses of the impact of various reforestation scenarios on slope stability, taking into account the morphology and size of the root systems, as well as the structure and density of the stand. The model and the results of numerical analyses have been the subject of an article accepted in Ecological Engineering. The results were used to quantify the relative roles of root characteristics and planting patterns on the soil reinforcement.

Action 4 - Consideration of hydrologic factors in the numerical model. Equations of water flow and soil mechanics have been coupled for the analysis of slope stability. The ultimate goal is to take into account the effect of vegetation on the water regime of the slope and its relative impact on the safety factor. This work is being finalized as part of the thesis of Miss Jinnan Ji (co-tutelle Université Montpellier 2, Beijing Forestry University), 2008-2011).

Action 5 – Application to case studies in Togo and China. Field studies were conducted in Togo and on the Loess Plateau in China (Ji Jinnan thesis). They aimed to quantify and spatialize rooting properties (biomass, root number, root area ratio "RAR) in the context of monoculture forests. These data were supplemented by tensile tests conducted in the laboratory and used to calculate the additional cohesion. This information was then integrated into the simulator of slope stability to quantify their contribution to increasing the safety factor. The measurement campaign conducted in China has also identified correlations between root density and soil hydraulic conductivity. These results will help calibrating the hydrological model developed as part of the Jinnan Ji's thesis (see action 5).

**Publications:**

Adzo Dzifa Kokutse, Alexia Stokes, Nomessi Kuma Kokutse, Kouami Kokou (2010) Which factors most influence heartwood distribution and radial growth in plantation teak? Ann. For. Sci. 67 (2010) 407

Ji, J.N., Kokutse, N., Zhang, Z.Q., Fourcaud, T., 2010. Towards a numerical simulation model of short-term impact of forested hillslope stability under rainfall condition. In: Chen, S.-C. (Ed.), INTERPRAEVENT 2010. International Research Society INTERPRAEVENT, pp. 446-453.

**Prospects for the future:**

Action 6 - Establishment of new collaboration projects (Master, PhD thesis, Interuniversity Scientific Cooperation Project AUF) and reinforcing partnerships: Support to this RTRA project and framework for continued works with the University of Lomé (Faculty of Science, Agronomy Faculty,

National School of Engineers), the Beijing Forestry University and the University of Abomey Calavi (Bénin).

**Total Agropolis Fondation funding:** € 120,000 (salary for a post-doctoral fellow, travel expenses)

**Funding categorie(s):** Agropolis Fondation post-doctoral fellowship

**Project duration:** March 1 2008 – July 1 2010

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