EROSION CONTROL FOR URBAN EARTH ROADS: DESIGN AND IMPLEMENTATION IN TOGO

Henry Chloe
Ecole Nationale Supérieure d'Ingénieurs (ENSI) de l'Université de Lomé (UL), Lomé, Togo.

ABSTRACT

The objective of this study is to propose a planning of an anti-erosive work for roads in the Togolese cities that are subject to water erosions as a result of water runoff. From the theory of the compensation slope a model of anti-erosive work in pouring dike is designed to be fixed in a transversal way on roads in order to reduce water erosions. A case study has been carried out on a real model, completed on the road 273 AGP in the district Agbalépédo in the capital town Lomé, Togo. An assessment of the behavior of this work after 15 years of service has shown effectiveness with regard to water erosion that remains quite inexistent.

KEYWORDS: earth road, anti-erosive, work model, compensation slope.

1. INTRODUCTION

Erosion is a natural phenomenon that is very complex and keeps changing the structure of the soils. Four (04) main factors influence erosion: rainfall, landform, soil and human activities. Water erosion represents the major part of responsibility for massive transport of soil.

The pavement of roads is very expensive, and cannot be completed until a feasibility study is performed in order to evaluate the rate of return on their investment. Therefore, in the countries of the sub-Saharan Africa only the big roads and the national roads enjoy a hydrocarbon pavement or pavement with paving stones. The proportion of paved roads is much lower than the non-paved ones on the urban network as well on the whole road network of these counties. In Togo, a sub-Saharan country, the share of non-paved roads and streets accounts for 82.13% of the whole national road system [1].

The urban area being featured by an important constructed surface, and therefore waterproofed, the infiltration of rainfall waters is, consequently much reduced in cities. This reduction in the infiltration of rainfall waters increases their runoff in the roads that are mostly non-paved. Thus, many non-paved roads are transformed into genuine canals by the runoff waters. These waters dig sometimes great gullying erosions on the roads making them for the most part impracticable and causing additional costs of earthwork for urban planning projects (Figure1b). Another consequence of this erosion is the raveling and even sometimes the collapse of houses all along these roads (Figure 1a).

a- Erosion has taken off the soil on a depth of 50 cm at the exterior face of the building.

b- Erosion has transformed the road into a duct of more than 5 m deep leading to the collapse of houses.

Figure 1. Example of the action of water erosion on two roads in Agoé in Lomé, Togo

Because of the extent of the phenomenon, many studies have been conducted on this water erosion and the protection of soils. These studies focus basically on the impact of erosion on farming lands or in rural areas, namely the transport effect of soils leading to losses of fertility of farming lands [2,3]. Relations are determined between losses of soils due to water erosion and slopes of soils [4], lengths of slopes [5], blades of precipitated water [6], state of surface and coverage of the soil [7], and solid debit of liquid [8]. Studies conducted by Amey K. B. [9] on correlation between slope, length and blade water of roads for a reduction in water erosion of these earth roads in Lomé in Togo have helped to elaborate equations and charts allowing the deduction of slopes no matter how large (L) the road and the blade of water (h).

Works have also proposed protection methods, but on farming lands [3] and shore areas. Thus, these techniques and methods are: use of stone barriers and bunds, the containment of expansion of rills with sand bags, the repair of rills with hedgerows and stone barriers, the planning of gabions in the ravines, protection and stabilization of shores with planting and the use of gabion and riprap, etc.

This study is designed to contribute to the reduction in water erosion of roads through the design and experiment of a work that is expected to limit the water erosions of roads for lack of their complete and definitive planning.

2. THEORETICAL CONSIDERATIONS

Theory of slope compensation

A trickle of water in movement in a canal undergoes a transport force *Fe* and a retarding force *Fr*(resistance), caused by the cohesion between the trickle of water and the bed [10]:

$$Fe = \rho_e \, L S \sin\alpha \quad (1)$$

$$Fr = \rho_e LC(c_1 v + c_2 v^2) \quad (2)$$

Where p_e is the density of the liquid, *a* the angle of the bottom of the bed in relation to the horizontal plan, *v* the movement speed of the trickle, $c_1$and $c_2$are parametres defined by PRONY (c_1 =*0.000044 and* c_2 = *0.000309)* and by Eytedwein (c_1 = *0.000024 and* c_2 = *0.000366)* [10].

The equation of the uniform movement is given by the balance between the driving force (attraction) and the retarding force (resistance) (F_e=F_r).

According to Darcy and Bazin, for the water courses transporting pebbles, the equation of the uniform movement may be given by:

$$\frac{R_m \sin\alpha}{v^2} = 0{,}00040\left(1 + \frac{1{,}75}{R_m}\right) \quad (3)$$

With R_m the mean radius of the canal.

Thus, the speed *v* given by:

$$v = \sqrt{\frac{R_m \sin\alpha}{0{,}00040\left(1+\frac{1{,}75}{R_m}\right)}} \quad (4)$$

For a particle with dimensions x, y and z put on the bottom of the bed in slope, if the direction of the movement of the particle is x, the impetus F_i provided by the shock of the fluid vein on the particle and the friction force F_f of the particle on the bed are given by:

$$F_i = (K + K')\rho_e yz \frac{v^2}{2g} \quad (5)$$

$$F_f = (\rho_c - \rho_e) xyzf \cos\alpha \quad (6)$$

With:
F, the coefficient of friction; its value for the case of friction between stones is *f* = 0.76;
ρ_e, the density of the carried particle;
K and *K'*, the coefficients of cubic particles given by: *K* = *1.19*and *K'*= *0.27* [10].

There will be movement of the particle if F_i>F_f. The speed limit of the particle movement will therefore be given by the expression:

$$v \geq \sqrt{\frac{0.76(\rho_c - \rho_e)x \cos\alpha}{0.0744\rho_e}} \quad (7)$$

The compensation slope will be given by the balance of the two speeds given by the equations (4) and (7).

$$p = 100tg\alpha = \frac{304x(\rho_c - \rho_e)\left(1+\frac{1.75}{R}\right)}{744\rho_e R} \quad (8)$$

Compensation slope of the roads in Lomé

The works of Amey K. B. [9] have indicated that the slopes of compensations that enable to reduce water erosion of earth roads of Lomé in Togo with characteristics given by table 1, may be determined by the equations (9a) and (9b) and the graphs of figure 2.

- For L≤20 m

$$\begin{aligned} p(h,L) &= 5004.7\, h^{(-1.623)}\, L^{-(0.0004\,h+0.0104)} \\ &= 5004.7\, e^{-1.623\ln(h)} e^{-0.0004\,h\ln(L)} e^{-0.0104\,ln(L)} \\ &= 5004.7\, e^{A1} \end{aligned} \quad (9a)$$

- For L≥20 m

$$\begin{aligned} p(h,L) &= 10696\, h^{(-1.809)} L^{-(0.0001h+0.0015)} \\ &= 10696\, e^{-1.809\ln(h)} e^{-0.0001\,h\ln(L)} e^{-0.0015\,ln(L)} \\ &= 10696\, e^{A2} \end{aligned} \quad (9b)$$

With:

$$A1 = -(1.623\ln(h) + 0.0004\,h\ln(L) + 0.0104\ln(L)) \quad (10a)$$
$$A2 = -(1.809\ln(h) + 0.0001h\ln(L) + 0.0015\ln(L)) \quad (10b)$$

h, the water sheet on the road;
L, the length of roads
P, the slope of compensation.

Table 1. Characteristics of sediments of non-paved roads of the lagoon northern zone of Lomé in TOGO [9]

Number of samples	Class granular d/D (mm)	Density absolute d_{ab}	Density apparent d_{ap}	Module of fineness Mf	Equivalent sand ES (%)
330	0/1	2.61±0.02	1.49±0.03	1.92±0.19	87.94±4.03

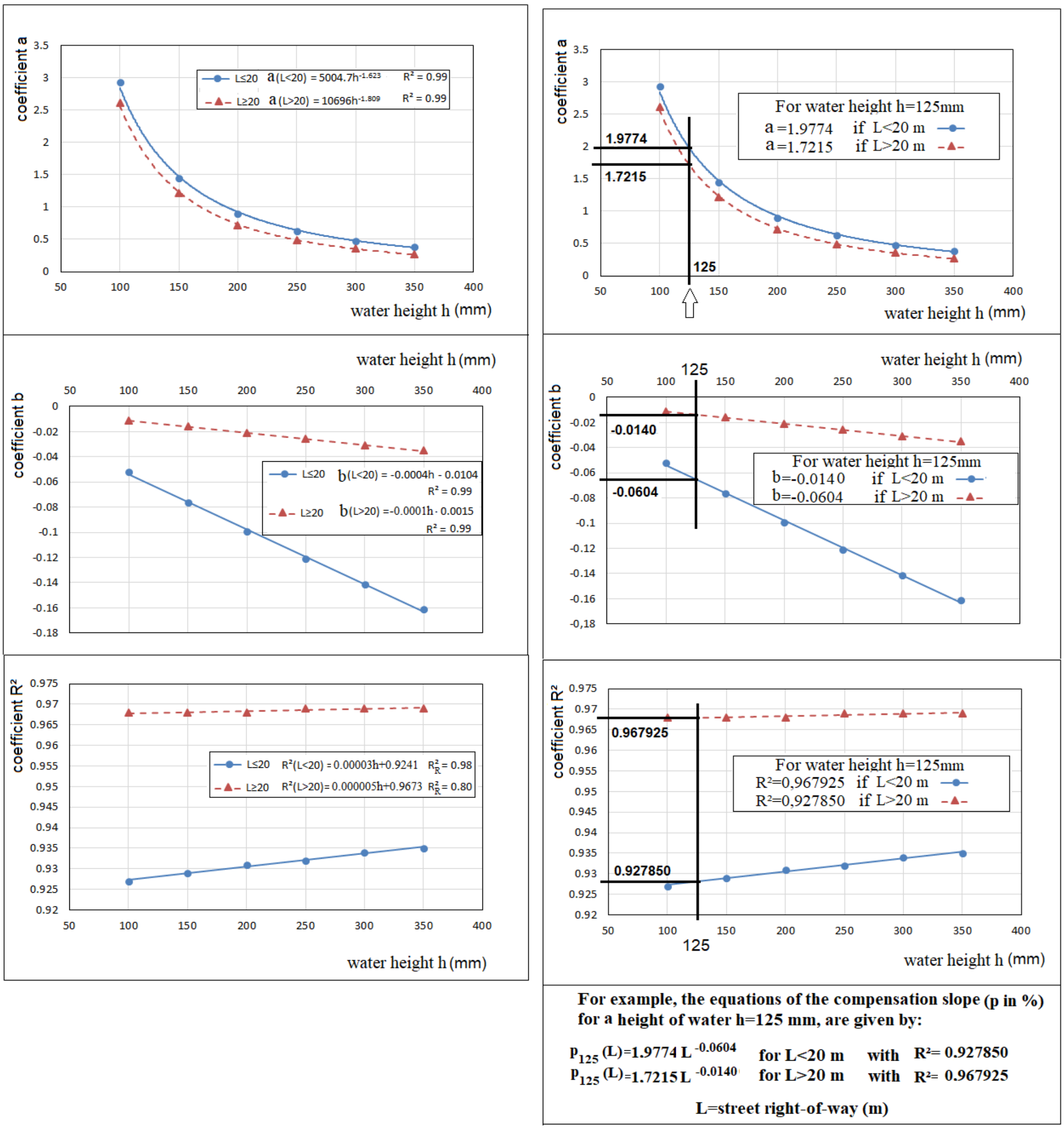


Figure 2. Coefficient c, d and R^2 according to the height of water [9]

3. MATERIAL, MATERIALS AND METHOD

In order to develop a work model to stop water erosion of roads in Togo, the following procedure is applied:

- Identification of sand sediments of the road 273 AGP: taking of three (03) samples of sediments in three (3) points that are subjected to laboratory tests according to norms NF EN 933-1 [11], NF EN 933-2 [12], NF ISO 9276-1 [13], NF EN 933-8 [14], NF EN 12620 [15] for determining properties in the form of

  granulometric analysis (on a game of sieve of series 0.063-0.08-0.125-0.25-0.5-1-2-4 and 5 mm) for the determination of the granular class (d/D), the module of fineness (Mf), physical tests (absolute density (d_{ab}), apparent density (d_{ap}) and the equivalent of the sand (ES);
- Topographical records on the road that constitutes the canal before the project for the design and 15 years after the putting on service of the work carried out (transversal records);
- The design of the work based on the characteristics of works in the control of floodings [16], fundamental parametres of the design of roads [17], equations and graphs developed for roads in Togo [9];
- Experiments of the work on the road 273 AGP in the district Agbalépédo in Lomé, Togo (Figure 3).

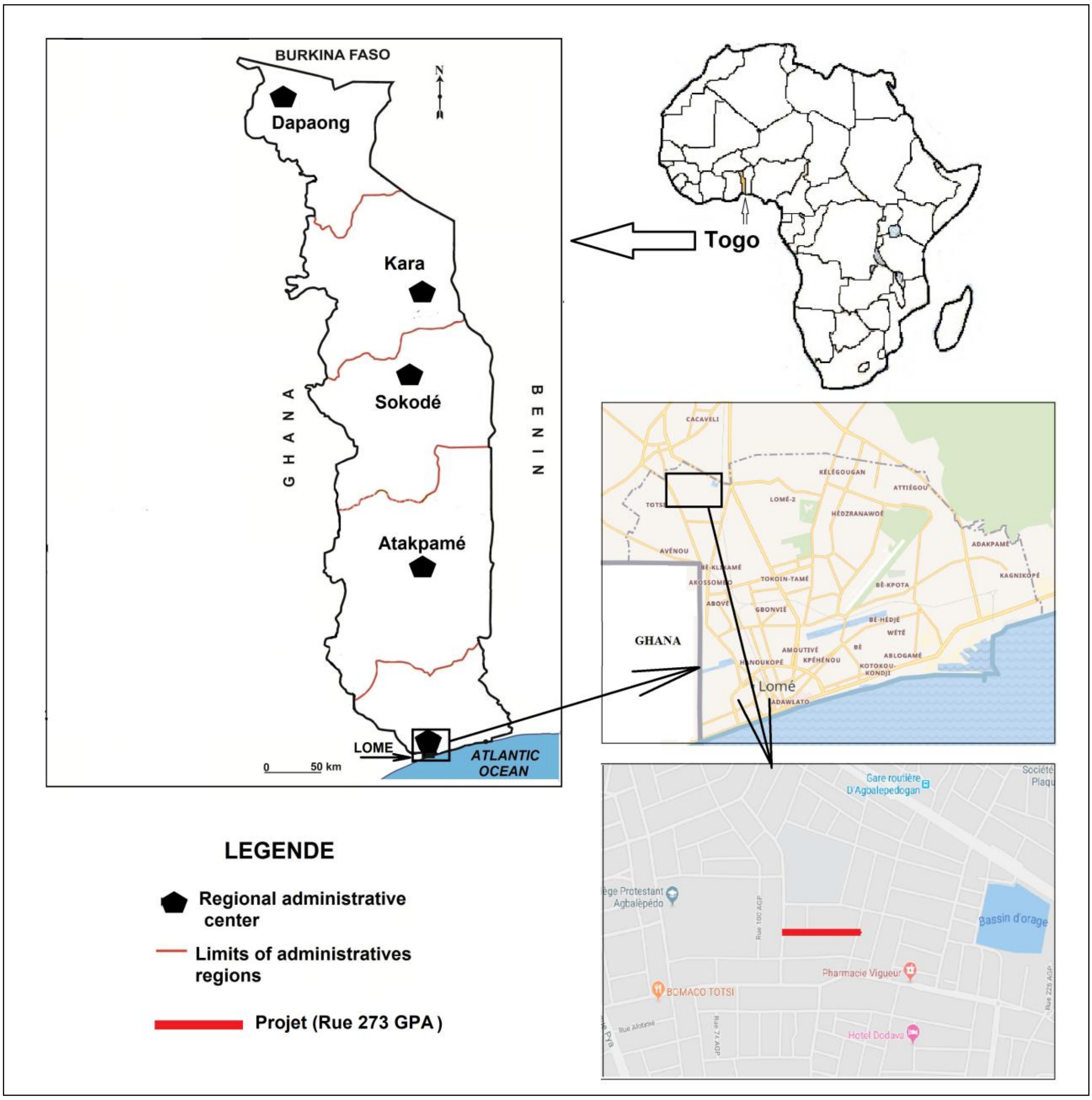


Figure 3. Localisation of study area (the road 272 AGP)

4. RESULTS AND DISCUSSION

Design of the model of the anti-erosive work

In order to stop erosion, the construction of overflowing dike which is intended to stop the soil erosion by let going the runoff water is projected. Figure 4 and figure 5 give the operation principle of the work.

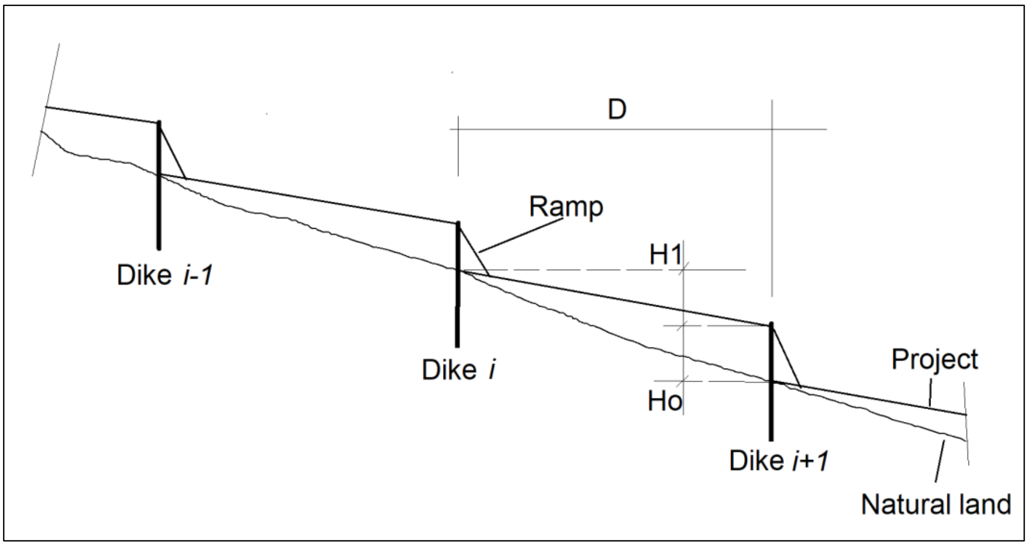


Figure 4. Operation principle of a succession of anti-erosive works

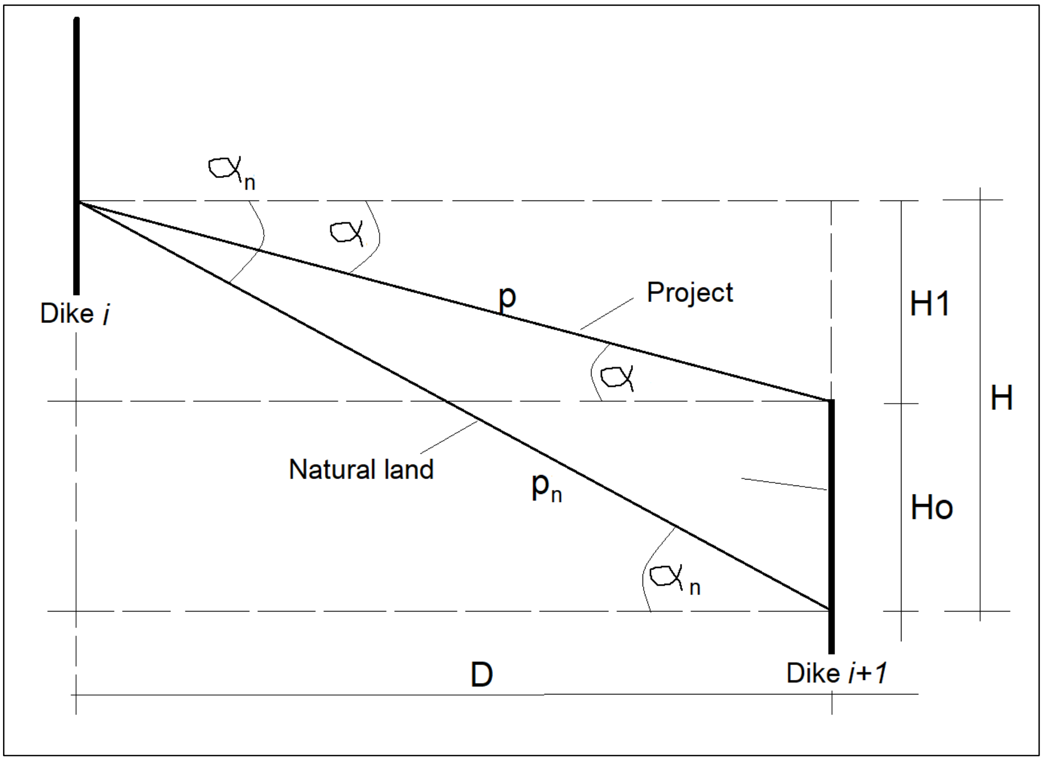


Figure 5. Definition of geometric characteristics of the work

The compensation slopes p (project) and natural p_n are provided by (Figure 5):

$$p = 100tg\alpha = \frac{H_0+H_1}{D} \times 100 \qquad (11a)$$

$$p_n = 100tg\alpha_n = \frac{H_1}{D} \times 100 \qquad (11b)$$

With:
H_1, drop of natural land at the position of the dike i at the dike crest $i+1$; its expression is :

$$H_1 = H - H_0 \qquad (11c)$$

H_0, the height of the dike;
H, drop of natural land at positions of two successive dikes;
D, the distance between the two successive dikes;
a_n, angle of the slope of natural land;
a, angle of the slope of the project;

From these three equations ((11a), (11b), (11c)), the values of D and H_0 are provided by:

$$\begin{cases} H_0 = H\left(1 - \frac{p}{p_n}\right) \\ D = \frac{H}{p_n} \times 100 \end{cases} \quad (12)$$

The relation may also be deducted between D and H_0 provided by:

$$D = \frac{100H_0}{p_n - p} \quad (13a)$$

$$H_0 = \frac{D(p_n - p)}{100} \quad (13b)$$

The parametres of these equations are defined as previously.

The work will be made up of (Figure 6):

- The overflowing dike that is designed to stop the soil and let go water through a sheet of water; it may be an reinforced concrete or not reinforced, block, gabion and riprap; the joints will be in mortar or dry, in this case, they will be squeezed (the blocks will be stucked one to another) in order to avoid the movement of materials at the downstream of the work;
- An upstream bank in reinforced concrete or cyclopean concrete that will serve as the transition slab for access to the work by vehicles avoiding therefore shocks against the dike and compressions localized at the downstream foot of the work;
- A downstream slope, made of earth embankments in selected materials (laterite, silty sands, gravels, etc.) and covered by paved coatings or other materials; there will be slope (maximal declivity) determined by the fundamental parametres of geometrical dimensioning of roads (see chart 2);
- Cut-offs will be performed at the foot of downstream and upstream slopes.

Figure 2. Declivities between intersections [17]

Type of local road	Local industrial	Local secondary and tertiary residential	Local main residential	Collective	Road
maximal declivity (%)	8	8	8	8	7

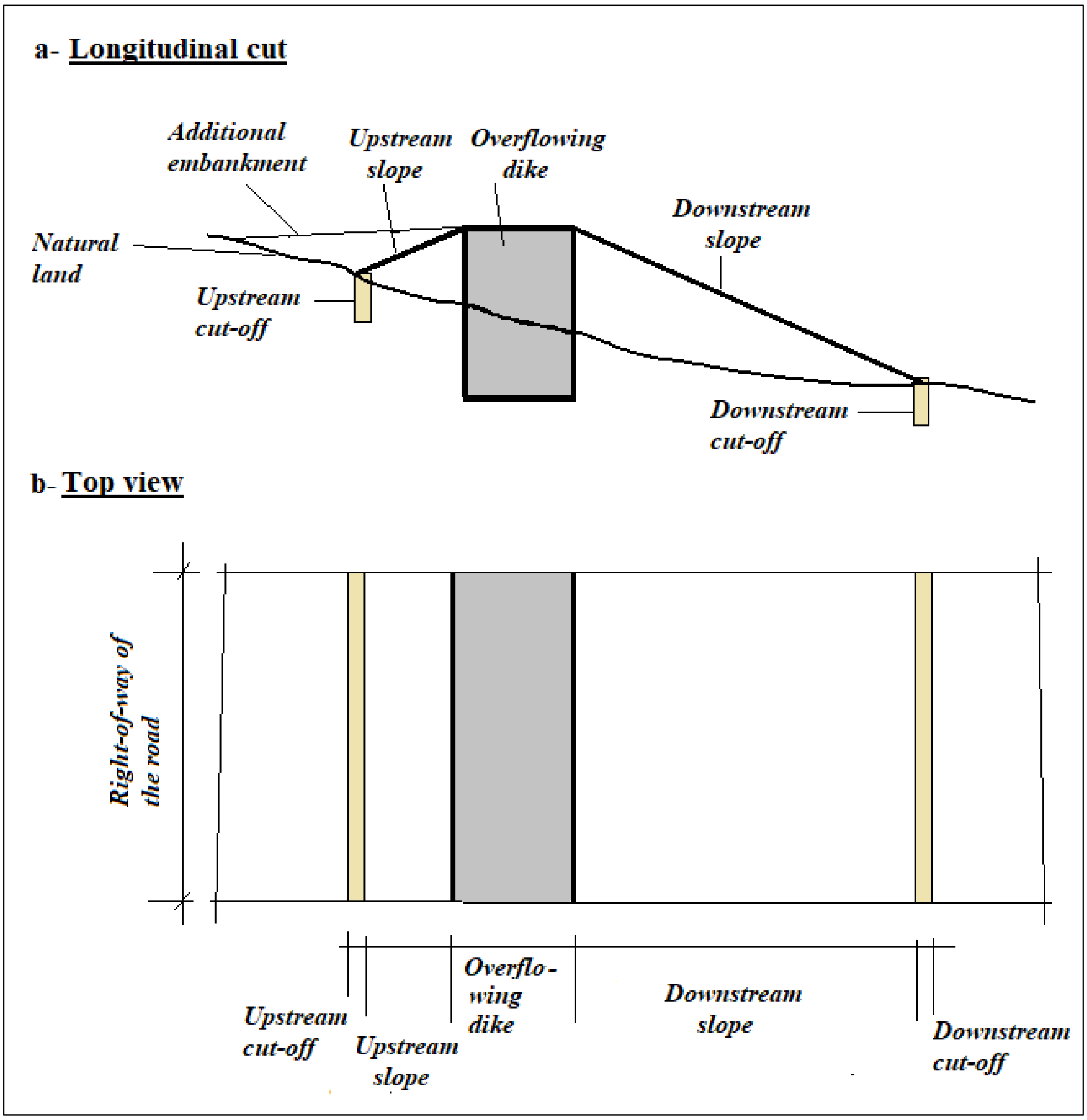


Figure 6. Model of anti-erosive work

Experimentation of the model on a street of Lomé
For an experiment of the model, the road 273 AGP located in the district Agbalépédo in Lomé, Togo is selected.

- Characteristics of the road:
  - Width: $L= 14\ m$
  - Length: *290.75 m*
  - Mean slope of the natural land $P_n= 3.5\%$
  - Water sheet of the road: $h = 200\ mm$
- Slope of compensation of the road: the length of the road (L=14) being lower than *20 m*, Slope of compensation *P(%)* will be provided by the equation (9a);Thus, *P*(100.14) = 2.49%.
- Maximal declivity of the downstream slope: the street being a road« residential secondary and tertiary locale», the maximal declivity is 8% (table 2).
- Height of the dike: in positioning the dike in the middle of the road, distance D becomes 145.375 m (corresponding to 290.75/2), the maximal height of the dike will be H_0 = 1.47 m (equation (13b)).

The application of the model (Figure 6) in relation to data of the road 273 AGP provides the diagram of figure 7.

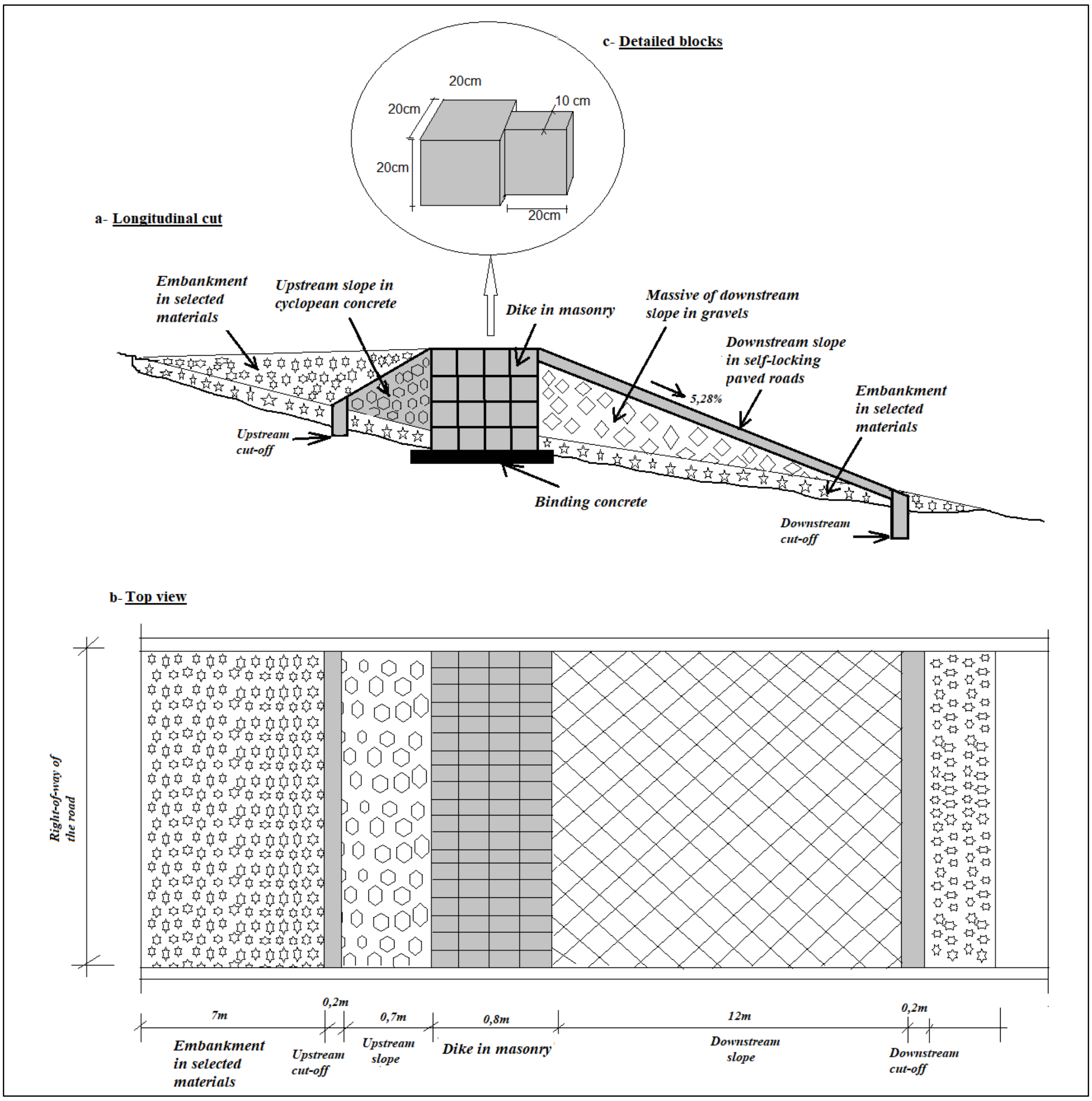


Figure 7. Diagram of the model adapted to the road 273 AGP

Figure 8 provides the operation for implementing the model on the selected road.

Figure 8. Work in implementation (laying pavers on the downstream slope) (2003)

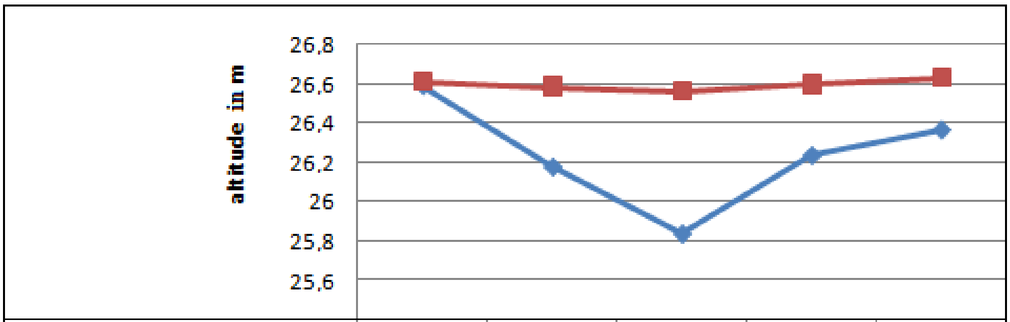
Figure 9. Work after 15 years of exploitation (2018)

The completed work on 20.9 m long and 14 m large has costed on the whole Fcfa 800, 000.

Which corresponds to an amount of Fcfa 2, 752/m^2 of the planning of the work model for the protection of a 290.75 m-long road. The cost of the protected road, therefore, accounts for Fcfa 197/m^2. But there must be an amount of around Fcfa 12,000/m^2 (or 6,092% against the existing model) in order to complete a road construction of hydrocarbon coating and Fcfa 20,000/m^2 (or 10,153%) of the paved coating.

For the validation of the model, a work follow-up has been carried out. Figure 10 provides the cross profiles of the road under consideration (273AGP) and a parallel, witness road (274AGP) located at 74 m. The Figure 10 indicates that the cross profile of the road 273AGP remained practically undamaged after 15 years of exploitation whereas the witness road (road 274AGP) presents serious longitudinal gullying erosion with a depth of 75 cm, making it impracticable even though it enjoy periodic reprofilings.

These results show the validity of the model of the anti-erosion work developed with regard to cost and stabilization of earth roads.



Profile number	1	2	3	4	5
Cumulated distance (m)	0	3,5	7	11,5	14
Road dimension (273AGP)	26,608	26,5855	26,563	26,5955	26,628
Road dimension (274AGP)	26,591	26,177	25,838	26,236	26,366

Figure 10. Cross profiles of the roads 273AGP 274AGP in June 2018

5. CONCLUSION

In order to limit the disorders of earth roads caused by water erosion, the compensation slopes of these roads, allowing them to avoid degradations, are determined and a model of an anti-erosion work has been developed for roads whose natural slope is expected to be deeper than that of compensation. An experiment of this model on the road 273AGP in the district Agbalépédo of Lomé in Togo, has helped to show its effectiveness after 15 years of exploitation. This work model is a tool that the designers of earth roads and the implementation players of cities' urbanization have at their disposal for protecting roads from degradations such as gullying erosion as a result of water erosion.

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