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Parametric Study of a Soil Erosion Control Technique: Concrete Lozenges Channels

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Abstract

A new technique, "the concrete lozenges channels" is described in this paper. It is an erosion control measure to attenuate the water soil loss quantity to a tolerable level. These are open inclined channels that form lozenges on the slope. In fact, they drain rainfall, runoff, and sediments alongside the slope into the ditch. Using the RUSLE erosion model for erosion assessment, the parameters that had the most influence on the percentage decrease of the soil erodibility are discussed. A comparison between techniques already used, that is, the concrete arches and the concrete lozenge channels proposed in this paper, makes it possible to mention the shortcomings and the strengths of each technique. In fact, the percentage decrease in erosion soil loss is about 42% for 2 arches and is about 49% for 2 lozenges. If the number of channels present on the slope increases, the area exposed to erosion decreases. By comparing the study case, the exposed area for one lozenge is less by 39% to 68% than the exposed area for one arch. The total perimeter lengths are comparable. In this article, a parametric study is undertaken to define the optimum dimensions and optimum number of concrete inclined channels. The ditch section and the inclined channel section are determining factors in the lozenge sizing.

Keywords: Water Erosion; RUSLE; Concrete Lozenges Channel Sizing; Parametric Study; Optimal Geometry.

1. Introduction

Landslides are several forms of mass movement that cause a natural modification of terrain. They start when the stability of the slope is touched by a specific stimulus "trigger" such as intense rainfall that moves materials throughout the Earth [1]. Those causes increase the stresses or reduce the strength of slope materials. Then, the slope or a portion of it becomes unstable. In fact, rainfall intensity is the principal driver of the removal of soil: soils erosion and landslides [2]. Adding to that, landslides can be the result of erosion on the slope surface [3]. By definition, water erosion is a process that detach and transport of topsoil particles away from their origin point due to raindrop and runoff impact. Rainfall, soil type, topography, land use, and land management are the principal factors that affect the rates of soil erosion by water [4]. This phenomenon can even affect human activities, inducing large material and human losses [5, 6].

Several water erosion assessment methods are proposed to evaluate soil erosion depending on the purpose of assessment and its suitability, applicability, and compliance with local conditions [7]. Also, Karydas et al. (2014) classified 82 water-erosion models according to their geospatial and temporal characteristics [8]. The Universal Soil Loss Equation (USLE) [9] and its revised version (RUSLE) [10] are the most commonly used soil erosion models. It is an empirical erosion model that estimates long-term average annual soil loss. However, the RUSLE model has some limitations [11]. Kumar (2022) identified the performance of the RUSLE model under varying topographic and climatic conditions [12]. RUSLE is widely used in combination with GIS to map erosion and provide an argument for scenario analysis and the adoption of measures against erosion [13].

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In Morocco, a new anti-erosive technique has been adopted on the slopes of the Kilometric Points 21, 28, 34, 40, and 47 of the Tangier-Rabat highway (Figure 1). Concreted arches are channels of concrete, reinforced concrete, or masonry, extended by columns. The arches' width varies from 10 to 40 cm, and their height varies from 40 to 70 cm. This variation depends on their diameter [14]. In the first experimentation, diameters of 50 m were arbitrarily used [14]. Observations made a few years after their installation show the technical gaps, such as the arches' instability and a diameter that is not suitable for all projects [15].

Figure 1. The concrete arches realized in the KP 47 of the Tangier-Rabat highway [16]

The Moroccan linear railway infrastructure located in the Fez-Meknes region of Morocco is subject to recurring disorders. In fact, they cross areas dominated by marl formations. Indeed, the many observations made on a large number of slopes have highlighted the essential role of water and the slope inclination in triggering instabilities that can be gradually accelerated as human activities develop [17].

All those disorders call for an urgent soil erosion measure to slow down water runoff and reducing the transport of solid particles. The objective is preventing the development of soil erosion damage and reducing intensity of soil erosion to a tolerable level. However, soil erosion control techniques generally used are simple and easy in theory but in the practice, they are difficult, expensive and taking a lot of time [18]. In this perspective, a new technique with a new design is proposed by this study to protect the slopes and reduce the quantity of eroded soils. At the same time, ensure a good Quality-Price-Ratio: the Concrete lozenges channels. They are a soil erosion control technique that maintains stability on shallow soil and slopes. These are inclined concrete drainage channels that form a diamond-shaped network [6]. They limit the formation of deep drainage channels that collect and transport water downhill.

The objective of this study is to identify the sensitivity of slope to water erosion. It is a question of evaluating in a first time the erodibility of the soils and in a second time, the effect of the new solution proposed to attenuate soil erosion. In the second part, the results of the parametric study will be discussed. The parametric study allowed the concrete lozenges channels sizing: Optimum number and dimensions.

2. Soil Erosion Model: Revised Universal Soil Loss Equation (RUSLE)

In this study, the soil erosion model (Revised Universal Soil Loss Equation) is used. It is a model that predicts the long-term average annual soil loss (A) due to runoff from specific field slopes and pastures in specific farming systems. Also suitable for non-agricultural conditions such as construction sites [19]. The long-term average annual soil loss (A) can be calculated using the Revised Universal Soil Loss Equation such as:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A is the Predicted soil loss (ton.ha-1.year-1), R is the Rainfall and runoff factor (MJ.mm/ha.h.year), K is the Soil erodibility factor (t.h/MJ.mm), LS is the Slope length and steepness factor (a dimensionless factor), C is the Crop management factor (a dimensionless factor) and P is Support practices factor (a dimensionless factor).

2.1. Rainfall and Runoff Factor (R)

The R factor represents the erosivity index of rainwater and runoff in RUSLE. It corresponds to the annual average of the sum of the EI value; which is the product of the total kinetic energy of a storm multiplied by the maximum intensity of the rains for 30 minutes (I30). This method is suitable when precipitation intensity data for a period of 22 years or more are available [20]. The availability of the data on the amounts of annual and monthly precipitation encourages the use of the empirical equation of Rango and Arnoldus (1987) for the calculation of the factor *R* [21]. Therefore, the R-factor can be expressed as:

$$\text{Log R} = 1{,}744 * \text{Log}\,\Sigma\left(\frac{\text{Pi}^2}{\text{P}}\right) + 1{,}299 \tag{2}$$

Where, P_i is the monthly precipitation in inch and P is the annual precipitation in inch.

2.2. Soil Erodibility Factor (K)

The soil erodibility factor (K) is the rate of soil loss per unit area caused by the effect of precipitation and runoff. It is measured initially on a plot 22.1 m long, 1.83 m wide minimum with a slope of 9%. K can be calculated using the algebraic approximation (3) which takes into account three main factors of the soil: its proportions of silts, clays and very fine sands, its organic matter content (OM), classes for structure (s) and its permeability (p), such us [17, 18]:

$$\text{K} = \frac{[2.1\times10^{-4}(12-\text{OM})\text{M}^{1.14}+3.25(\text{s}-2)+2.5(\text{p}-3)]}{100} \tag{3}$$

where, $\text{M} = \text{a} \times (\text{b} + \text{c})$, (4) is the product of the primary particles size (in %); a= (0.002 - 0.1) mm size fraction (in %); b= fraction of silt (in %); c= fraction of sand (in %). To defining the s factor, a nomographic classification of the soil structure based on the particles size [19], it is given in Table 1:

Table 1. Value of the s factor

Type of soil structure	Size (mm)	Class
Very fine granular or without structure	-	1
Fine granular	<2	2
Medium granular	2-5	3
Coarsegranular	5-10	
Polyhedral, lamellar, massive, prismatic	>10	4

According the soil structure and the soil permeability [14] are defined six permeability class. They are presented in the following Table 2.

Table 2. Value of the p factor

Structural class	Permeability class	Permeability [cm/s]	Permeability code
Gravel, coarsesand	Fast	$>4.4\times10^{-3}$	1
Loam sand and loams sandy	Moderate to Fast	$(1.4 – 4.4) \times10^{-3}$	2
Fine sandloams, loams	in moderation	$(0.4 – 1.4) \times10^{-3}$	3
Loams, clay loams	Slow to moderate	$(0.14 – 0.4) \times10^{-3}$	4
Clay loams, clays	slow	$(4 – 14) \times10^{-5}$	5
Tight, compacted	Very slow	$<4\times10^{-5}$	6

2.3. Slope Length and Steepness Factor (LS)

LS represents the effect of topography on the soil erosion. It is a dimensionless factor which combines both the slope length factor (L) and the slope steepness factor (S). The steeper and longer the slope, the higher the risk of erosion.

2.3.1. Slope Length Factor (L)

The following formula containing the horizontal projection (l), the RUSLE unit plot length (22.13 m) and a dimensionless variable slope length exponent (m) calculates the slope length factor. Then L factor is as following [20]:

$$\text{L} = (l/22.13)^{\text{m}} \tag{4}$$

The slope length exponent (m) characterizes the favoured mode of erosion: rill or interrill erosion. The value of β is multiplied by two, when the rill erosion becomes very important and divided by two, when the rill erosion becomes less important. The slope length exponent (m) is calculated by the following equation:

$$\text{m} = \beta/(1+\beta) \tag{5}$$

$$\beta = \frac{\sin\theta}{0.0896[3\times(\sin\theta)^{0.8}+0.56]} \tag{6}$$

2.3.2. Slope Steepness Factor (S)

The slope steepness factor S is defined by the following formulas [21]:

$$S = 10.8 \sin \theta + 0.03 \qquad s < 9\% \tag{7}$$

$$S = 16.8 \sin \theta - 0.5 \qquad s \geq 9\% \tag{8}$$

2.4. Crop Management Factor (C)

C is a dimensionless factor that represents the effect of cultivation and management practices on the erosion rate of natural or engineered slope soils. The density of the vegetation cover of the soil surface is a determining parameter of the C factor. The value of C can vary from a value close to 0 for a well-protected soil to 1.5 for a soil surface very exposed to precipitation which generates very significant erosions in gullies [21-23]. Therefore, this factor is also used to compare different preservation solutions. It is calculated by combining the effect of four sub-factors such as:

$$C = PLU \times CC \times SC \times SR \tag{9}$$

where, PLU is the Prior Land Use, CC is the Crop Canopy, SC is the Surface Cover and SR is the Surface Roughness

2.5. Support Practices Factor (P)

In RUSLE, P is a dimensionless factor expressing the effect of a specific support practice on soil erosion from a slope. The main effects of these support practices on the amount of soil eroded generally lie in altering the type of runoff, altering the content or direction of runoff, and reducing the amount and rate of runoff [22]. This factor supports the culture factor (C). The value of the factor P can be those developed by Smith (1948) [23] who gave a value of 1 for a zero slope (0%) because no direction of flow is defined and for a slope which exceeds 25% because such a ridge would not store water.

3. Methods

3.1. Research Methodology

The objective of this study is to research the design and sizing of this new control measures method, by investigating parameters that influence the performance of the proposed solution. The flowchart of the research methodology is shown in Figure 2.

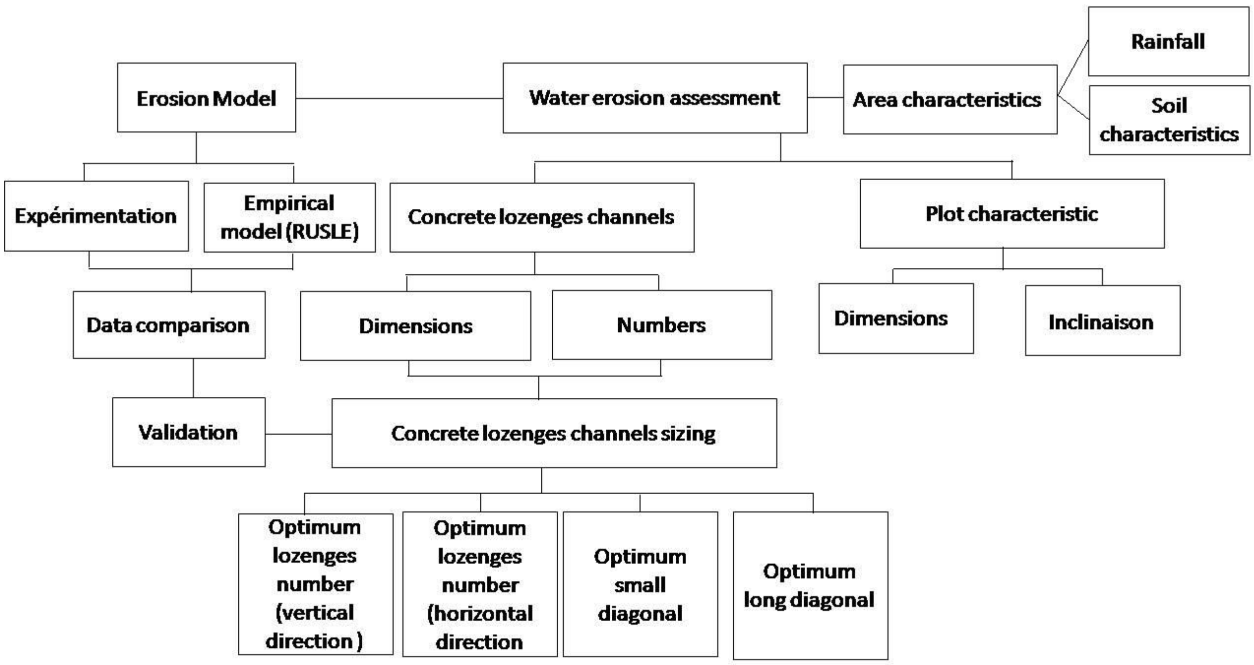

Figure 2. The flowchart of the research methodology

3.2. Site Context

The project is located in the Fes-Meknes Moroccan region. It is situated From KP 57+000 to KP57+300 of the Fez-Taza railway axis (Figure 3). Several factors are combined which cause water erosion of the slopes soils such as slope inclination, the impermeability of the soils and the heavy rainfall.

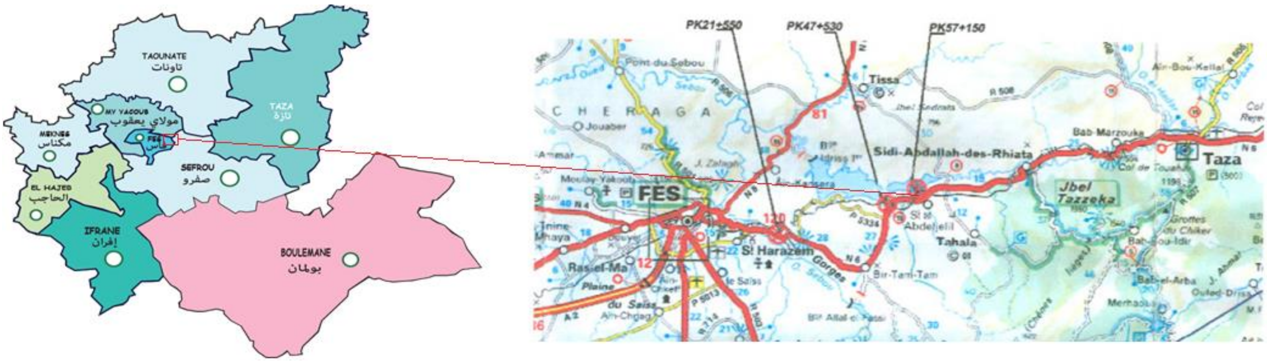

Figure 3. Geographical location of the project

In the geological context the project is situated in the external Rif [24]. Structurally, this unit is linked to the Miocene stage [25]. Soils are marls with a greenish gray and sometimes yellowish color. Indeed, Marls are plastic soils [26]. They are sensitive to water [27]. This sensitivity is mainly reflected by a significant volumetric instability [28], a strong reduction of friction and effective cohesion [29], and a low permeability [30], preventing water absorption and promoting very strong runoff. These characteristics give this type of soil a propensity to shrinkage-swelling [28], a significant progressive creep [31] along the slopes and a risk of erosion around runoff areas [32]. The Table 3 below presents a summary of the type, composition and physical properties of the soils.

Table 3. Types, compositions and physical properties of soils

Soil composition				Atterberg limits		LCPC Classification
Sand (%)	Limon (%)	Clay (%)	MO (%)	Wl (%)	Ip (%)	
17	36	45.9	1.1	35	21	Sandy clay

The climate on the Fez / Oujda section is continental and relatively temperate. Rainfall varies between 500mm/year towards the west and 700 mm/year towards the east. The mountainous areas bordering the corridor are much more watered: up to 1500 mm/year. In this case, the rainfall can constitute penalizing factors for slops stability. The rains are characterized by seasonal variability. Figure 4 below shows an average of total monthly precipitation (1979- 1980/-2014-2015) of Fez.

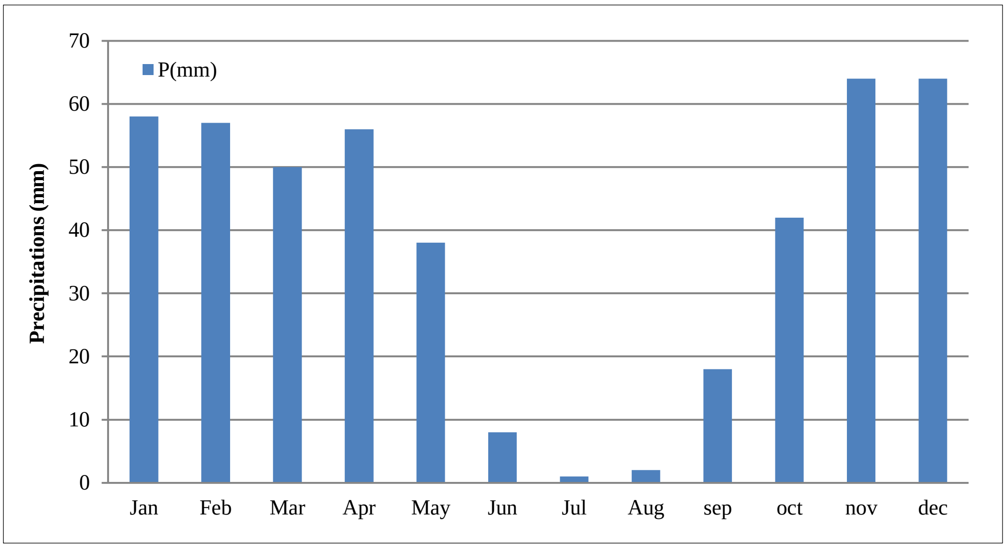

Figure 4. The average of total monthly precipitation (1979- 1980/-2014-2015) of Fez [33]

4. Results & Discussion

4.1. Results

To compare The Concrete Arches and lozenges concrete channels techniques and show the shortcomings of the Concrete Arches technique and the strengths of Lozenges Concrete channels technique, the application of this two techniques is studied on a reference plot of (100×100) m^2 in the Fez region which is presented in the chapter above by application of the Revised Universal Soil Loss Equation (RUSLE).

Table 4 gives the data needed for the soil erosion model used to assess the predicted soil loss. The plot is devoid of vegetation cover and supporting practice so vegetation cover factor and support practice factor are taken equal to 1.In this study, L factor is the one variable of the RUSLE erosion model. Also the optimal arrangement of lozenges concrete channels (Figure 5) is defined by studying the influence of the model parameters on the results.

Table 4. RUSLE factor's values

		Value	Unit
Rainfall and runoff factor	R	69.00	MJ.mm/ha.h.year
Soil erodibility factor	K	0.191	mm.t.h/MJ
Vegetation cover factor	C	1.00	-
Support practice factor	P	1.00	-
steepness factor	S	4.81	-

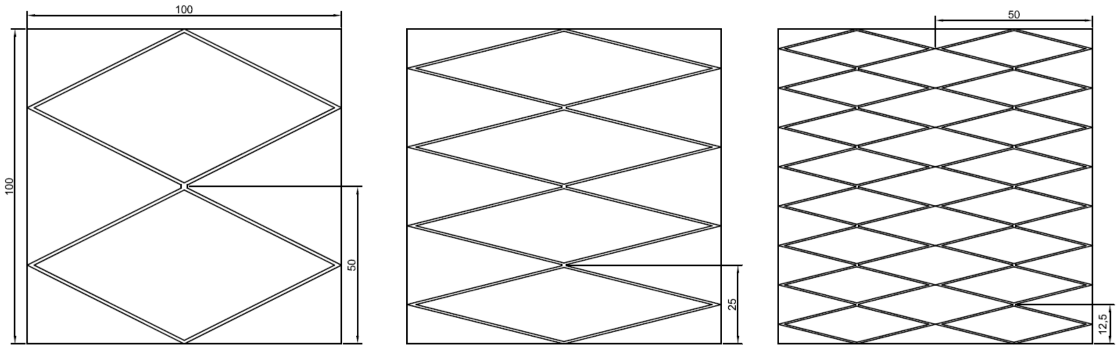

Figure 5. The arrangement of concrete lozenges for each studied case

The concrete lozenges open channels are studied for 2, 4 and 16 lozenges (Figure 5). A diameter of 100, 50 and 25 m of Concrete Arches are studied (figure 6) that respective numbers are 2, 8 and 32.

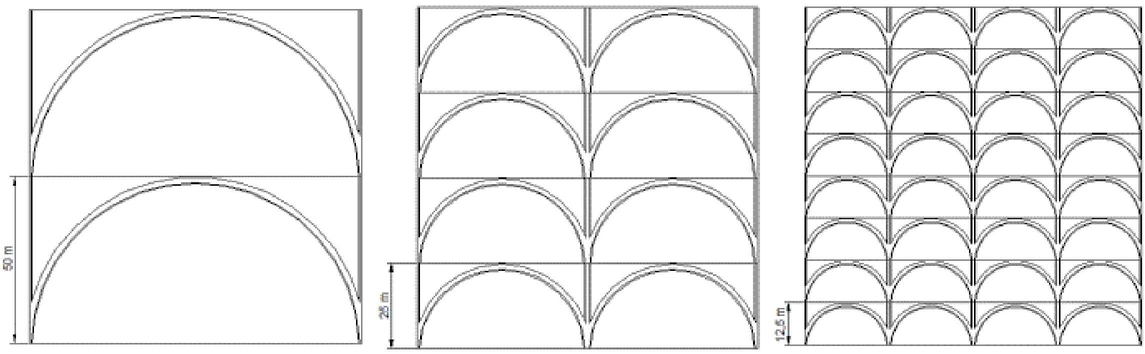

Figure 6. The arrangement of Concrete Arches

Table 5 shows the calculation results.

Table 5. Calculation results

	Reference plot	Concreted Arches technique			Concreted lozenges technique		
Technique number	0	2	4	32	2	4	16
L Factor	2.64	1.66	1.05	0.66	1.43	0.90	0.57
The area for one element (m^2)	10000	7854	1963	491	2500	1250	312.5
Predicted soil loss (t/year)	167.59	97.60	57.74	32.27	85.42	49.19	28.08
Perimeter length (m)	-	414	853	1606	447.21	824.62	1649.24

4.2. Discussions

In discussing results of table 5, a sensitivity analysis is realized to search the influence of different parameters of the model on the predicted soil loss and the necessary characteristic of each technique.

4.2.1. Number of Lozenges and Arches

The first parameter analyzed is the number of Concrete Lozenges and Concrete Arches for each study case. In fact, the variation of Concrete Arches number from 2 to 32 and Concrete Lozenges number from 2 to 16 conducts to the following notices: if the number increases, the value of the percentage decrease of the predicted soil loss will increase. The percentage decrease of the predicted soil loss is about 42% for 2 arches and is about 49% for 2 lozenges (Figure5)

Figure 7 shows that lozenges technique has a great influence on the soil loss quantity than the concrete arches technique. It is clear that as the number increases the predicted soil losses decrease. The number of lozenges present on the slope has a positive impact on the soil loss quantity than Concrete Arches by more than 7%. The objective is to find the optimal dimensions and number to have the best price-quality ratio.

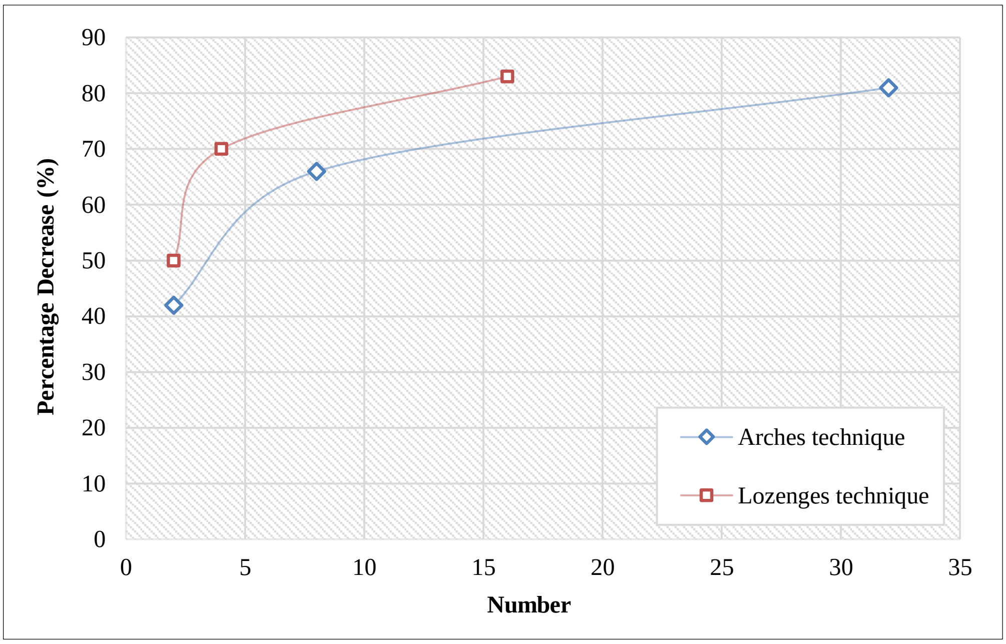

Figure 7. Variation of the percentage decrease in soil losses according to the number of Lozenges/ Arches

4.2.2. Perimeter Length

The second parameter analyzed from table 5 is the perimeter length. The perimeter length increase when the solution number increases. In fact, the values presented in Table 4 show that for the same study case, the perimeter length of Concrete Arches is less by an average of 2% than Concrete Lozenges. The perimeter length has a direct impact on the Project Cost and the stability of the proposed solution.

4.2.3. Exposed Area

Values presented in Table 5 show that if the number of channels presents on the slope increases the area exposed to erosion decreases. By comparing the study case (Figure 5 and 6), the exposed area for one lozenge is less by 39% to 68% than the exposed area for one arch.

4.3. Concrete Lozenges Design

Tolerable soil loss quantity is defined as the amount of soil loss allowing the ditch alongside the slope as well as the inclined channels on the slope to drain water. The number of lozenges in the vertical direction is conditioned by the quantity of soil tolerable to be evacuated by the ditch alongside the slope, while the number of lozenges in the horizontal direction is conditioned by the tolerable soil loss rate to be evacuated through the inclined channels on the slope. In this parametric study, the same plot (100×100) m^2 is investigated. The annual quantity of soil loss is A=167.59t, the plot drains towards a ditch of cross sections S. the soil loss characterized by a unit weight of 18 kN/m^3.

4.3.1. Design of the Optimum Length of the Small Diagonal of Lozenge Concrete Channels

Assuming that the sediments can occupy up to 50% of the section of the ditch. A rate that allows the drainage of water and avoids the sediments deposition. The graph in Figure 6 shows the variation of Lozenges channels number in the vertical direction of the slope with the ditch section for 3 angles inclination of the slope.

Ditch Section

Figure 8 shows that for the same angle inclination, if the ditch section increases the necessary lozenges number decreases. However, the commonly feasible sections do not exceed $1m^2$. It is preferable to provide an adaptable ditch section to the quantity of eroded soil to optimize the project cost. Ditch section is a determining factor.

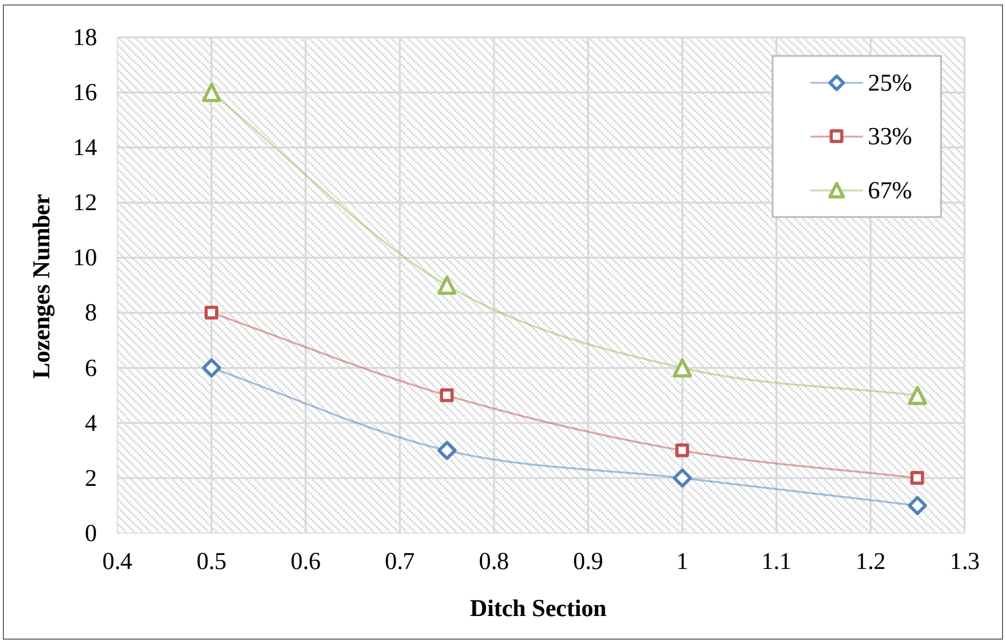

Figure 8. The variation of Lozenges channels number in the vertical direction of the slope with the ditch section for 3 angles inclination of slope (25, 33, and 67%)

Slope Inclination

Figure 8 shows that the necessary lozenges number decreases when the slope inclination decreases. If the slope is very steep (67%), the number of lozenges will be greater. in this case, either adjust the slope or provide berms.

Ditch Fill Rate: τ

The filling rate of the ditch depends on the periodicity and the maintenance budget chosen by the project manager. That is why, it is considered constant. Experimentation has shown that a rate that exceeds 50% allows water drainage and avoids sediment stagnation. The other parameters of the formula are considered constant because they depend on the site conditions according to the RUSLE erosion model ($R, K, C, P,$ and S). The application of the formula on several slopes made it possible to extract the formula for sizing the small diagonal of lozenges. Such as:

$$d \leq \left({}^{At}/_{Cst}\right)^{m^{-1}} \tag{10}$$

$$At = \tau \times \gamma \times S_d \times L_d \tag{11}$$

$$Cst = R \times K \times C \times P \times S \times \left(\frac{\cos\theta}{22.13}\right)^{m} \tag{12}$$

where, d is the length of the small diagonal of lozenge, At is the tolerable soil loss quantity, τ is the ditch filling rate, γ is the density of eroded soil, S_d is the ditch section, L_d is the ditch length, R is the Rainfall and runoff factor, K is the Soil erodibility factor, C is the crop management factor, P is the support practices factor, S is the steepness factor, m is the slope length and θ is the slope angle.

4.3.2. The Optimum Length of the Long Diagonal of Lozenge Concrete Channels

Assuming that the sediments can occupy up to 1/3 of the section of the inclined channel. The graph in Figure 9 shows the variation of Lozenges channels number in the horizontal direction of the slope with the inclined channels section for 3 angles inclination of the slope.

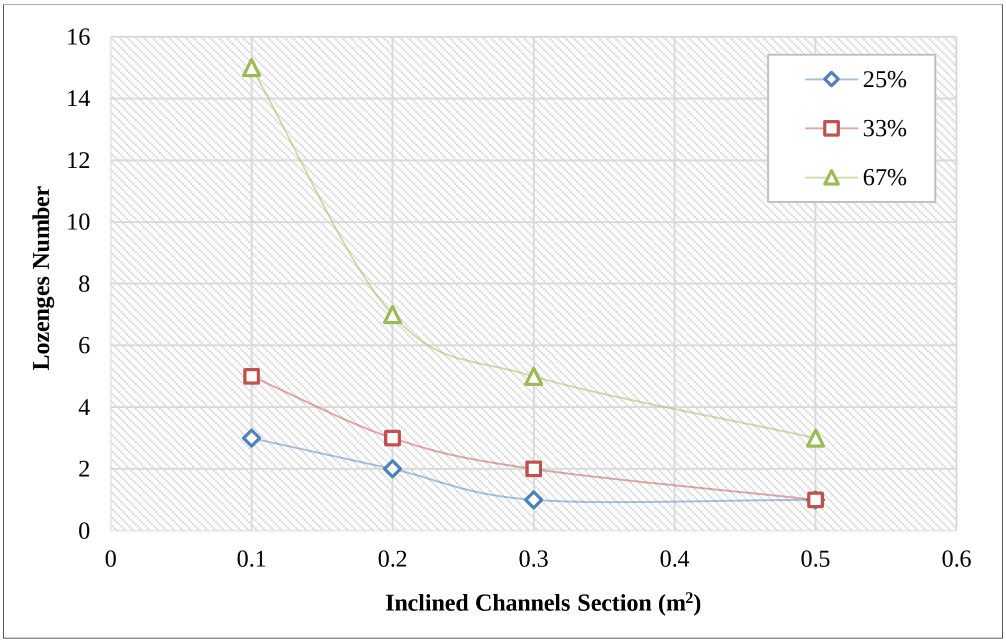

Figure 9. The variation of Lozenges channels number in the horizontal direction of the slope with the ditch section for 3 angles inclination of slope (25%, 33% and 67%)

4.3.2.1. Ditch Section

Figure 9 shows that for the same angle inclination, if the inclined channels section increases the necessary lozenges number decreases. However, as the section of the channel increases, the cost of the project increases, it is necessary to choose an optimal section. The section of the inclined channel is a determining factor in the lozenges sizing.

4.3.2.2. Slope Inclination

Figure 9 shows that the necessary lozenges number decreases when the slope inclination decreases. If the slope is very steep (67%), the number of lozenges in the horizontal direction of the slope will be greater. in this case, either adjust the slope or provide berms.

4.3.2.3. Ditch Fill Rate: τ

The filling rate of the inclined channels depends on the periodicity and the maintenance budget chosen by the project manager. That is why it is considered constant. Experimentation has shown that a rate that exceeds 33% allows water drainage and avoids sediment stagnation. The parametric study carried out during our research has made it possible to define the formula, allowing the calculation of the length of the longest diagonal of the lozenges. This is given by the following formula:

$$D \leq \frac{2 \times Cst2}{A \times \sin\theta} \tag{13}$$

$$Cst2 = \tau \times \gamma \times Sc \tag{14}$$

where, τ is the ditch filling rate, γ is the density of eroded soil and Sc is the inclined channel section, A is the predicted soil loss and θ is the slope angle.

5. Conclusion

In this paper, the erodibility of KP 57+000 of the Fez-Taza railway line in the Fez-Meknes area in Morocco has been investigated. Two erosion control measures are studied: a previous technique (concrete arches) and a new technique (concrete lozenge techniques). Using the RUSLE erosion model (Revised Universal Loss Equation), a comparison of the two techniques was undertaken to evaluate the performance of the two techniques and extract the most significant factors that affect soil loss rate. In fact, the lozenge technique channels had an influence on the percentage decrease of soil loss compared to the old method, which varied from 49% for two lozenges to 83% for 16 lozenges. A parametric study allowed the design and sizing of the lozenge technique and evaluating the necessary number to reduce the amount of eroded soil to the tolerable amount: (1) the parameter that has a great influence on the small diagonal length is the tolerable soil that can be evacuated by the ditch (ditch section); (2) the parameter that has a great influence on the long diagonal length is the tolerable soil that can be evacuated by inclined channels (inclined channels section).

This work contributes to enhancing the knowledge about erosion control techniques by presenting an existing technique and proposing a new solution to mitigate the soil loss rate on slopes. However, the validation of the performance of the new solution was only subjected to the empirical evaluation of the percentage decrease in soil loss. However, the objective at this stage is to convince decision makers of the effectiveness of the method to move on to experimentation. In further development of this research, it is expected to analyze the experimentation results to correct the difference between the direct soil erosion assessment and the estimated erosion and to validate the proposed equations of sizing of the new solution. It is clear the significant environmental impact of this new erosion control technique. In future research, an environmental impact study of the proposed solution will be carried out.

6. Declarations

6.1. Author Contributions

Conceptualization, L.E.B.; methodology, L.E.B., K.B., G.A., F.Z.L., and A.B.; validation, G.A., K.B., G.A. and F.Z.L.; formal analysis, L.E.B.; resources, K.B. and L.E.B.; data curation, L.E.B.; Investigation, L.E.B., K.B., G.A. and F.Z.L.; writing—original draft preparation, L.E.B.; writing—review and editing, L.E.B., K.B., G.A. and F.Z.L.; visualization, K.B.; supervision, K.B. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

7. References

[1] McColl, S. T. (2022). Landslide causes and triggers. Landslide Hazards, Risks, and Disasters, 13–41. doi:10.1016/b978-0-12-818464-6.00011-1.

[2] Piacentini, T., Galli, A., Marsala, V., & Miccadei, E. (2018). Analysis of soil erosion induced by heavy rainfall: A case study from the NE Abruzzo Hills Area in Central Italy. Water (Switzerland), 10(10), 1314. doi:10.3390/w10101314.

[3] Karapa, E., Harianto, T., Muhiddin, A. B., & Irmawaty, R. (2022). Slope Reinforcement Model Scale Test with X-Block. Civil Engineering Journal (Iran), 8(3), 612–621. doi:10.28991/CEJ-2022-08-03-014.

[4] Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., & Alewell, C. (2015). The new assessment of soil loss by water erosion in Europe. Environmental Science and Policy, 54, 438–447. doi:10.1016/j.envsci.2015.08.012.

[5] Salvati, P., Petrucci, O., Rossi, M., Bianchi, C., Pasqua, A. A., & Guzzetti, F. (2018). Gender, age and circumstances analysis of flood and landslide fatalities in Italy. Science of the Total Environment, 610–611, 867–879. doi:10.1016/j.scitotenv.2017.08.064.

[6] Elbouanani, L., Baba, K., Ouadif, L., Lahmili, A., & Bahi, L. (2018). Concrete lozenges impact on the slope erodibility. MATEC Web of Conferences, 149, 02073. doi:10.1051/matecconf/201814902073.

[7] Ketema, A., & Dwarakish, G. S. (2021). Water erosion assessment methods: a review. ISH Journal of Hydraulic Engineering, 27(4), 434–441. doi:10.1080/09715010.2019.1567398.

[8] Karydas, C. G., Panagos, P., & Gitas, I. Z. (2012). A classification of water erosion models according to their geospatial characteristics. International Journal of Digital Earth, 7(3), 229–250. doi:10.1080/17538947.2012.671380.

[9] Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses: a guide to conservation planning (No. 537). Department of Agriculture, Science and Education Administration, the University of Virginia, Charlottesville, United States.

[10] Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1996). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 537, U. S. Department of Agriculture (USDA), Washington, United States.

[11] Alewell, C., Borrelli, P., Meusburger, K., & Panagos, P. (2019). Using the USLE: Chances, challenges and limitations of soil erosion modelling. International Soil and Water Conservation Research, 7(3), 203–225. doi:10.1016/j.iswcr.2019.05.004.

[12] Kumar, M., Sahu, A. P., Sahoo, N., Dash, S. S., Raul, S. K., & Panigrahi, B. (2022). Global-scale application of the RUSLE model: a comprehensive review. Hydrological Sciences Journal, 67(5), 806–830. doi:10.1080/02626667.2021.2020277.

[13] Lu, H., Prosser, I. P., Moran, C. J., Gallant, J. C., Priestley, G., & Stevenson, J. G. (2003). Predicting sheetwash and rill erosion over the Australian continent. Australian Journal of Soil Research, 41(6), 1037–1062. doi:10.1071/SR02157.

[14] Chehlafi, A., Kchikach, A., & Derradji, A. (2014). Protection of motorway embankments by concrete or masonry arches. Journées nationales de géotechnique et de géologie de l'ingénieur. (In French).

[15] Mouisat, A., Harrouni, C., Chaouki, A. L., Douaik, A., Derradji, A., & Tlemcani, N. E. B. (2020). Effectiveness of biological engineering methods to fight against water erosion of the marly slopes of the Fez-Taza highway. Revue Marocaine des Sciences Agronomiques et Vétérinaires, 8(1), 1-12. (In French).

[16] Boukhir, M., Mohamed, J., Lahsaini, M., & Mounadel, A. (2017). Geological studies and technical recommendations for an eventual new track map of the portion of road that connects Fez to my Yaacoub (North Morocco). American Journal of Innovative Research and Applied Sciences, 5(6), 424-433. (In French).

[17] Roose, E., & De Noni, G. (2004). Les effets d'actions incitatives de lutte contre l'érosion en Afrique du nord et en Amérique Latine/The effects of incentive schemes in the fight against erosion in North Africa and Latin America. Revue de géographie alpine, 92(1), 49-60. doi:10.3406/rga.2004.2277. (In French).

[18] Bala Subramanian, A. (2017). Methods of controlling soil erosion. Centre for Advanced Studies in Earth Science, University of Mysore. Mysore, India.

[19] Rango, A., & Arnoldus, H. M. J. (1987). Development of watersheds. Cahiers techniques de la FAO, 36. (In French).

[20] Breckling, J. (1989). The Analysis of Directional Time Series: Applications to Wind Speed and Direction. Lecture Notes in Statistics, Springer, New York, United States. doi:10.1007/978-1-4612-3688-7.

[21] Renard, K., Foster, G., Weesies, G., Mcool, D., & Yoder, D. (1995). The Revised Universal Soil Loss Equation. Department of Defense. In Interagency Workshop on Technologies to Address Soil Erosion on Department of Defense Lands, San Antonio, United States.

[22] Xiao, L., Li, G., Zhao, R., & Zhang, L. (2021). Effects of soil conservation measures on wind erosion control in China: A synthesis. Science of the Total Environment, 778, 146308. doi:10.1016/j.scitotenv.2021.146308.

[23] Smith, D. D. (1948). Evaluating soil losses from field areas. Journal of Agricultural Engineering Research, 29, 394-398.

[24] Gimeno-Vives, O., de Lamotte, D. F., Leprêtre, R., Haissen, F., Atouabat, A., & Mohn, G. (2020). The structure of the Central-Eastern External Rif (Morocco); Poly-phased deformation and role of the under-thrusting of the North-West African paleo-margin. Earth-Science Reviews, 205. doi:10.1016/j.earscirev.2020.103198.

[25] D'Assisi Tramparulo, F., Ciarcia, S., El Ouaragli, B., Vitale, S., & Najib Zaghloul, M. (2016, April). The Eocene-Miocene tectonic evolution of the Rif chain (Morocco): new data from the Jebha area. EGU General Assembly Conference, 17-22 April, 2016, Vienna, Austria.

[26] Mustafa, Y. M., Al-Amoudi, O. S. B., Ahmad, S., & Maslehuddin, M. (2018). Geotechnical Properties of Plastic Marl Contaminated with Diesel. Arabian Journal for Science and Engineering, 43(10), 5573–5583. doi:10.1007/s13369-018-3224-0.

[27] Arifuzzaman, Md., Najjar, M., Mahmud, M. N., Saiful Islam, A. B. M., Khan, M., & Ali, M. M. (2017). Enhancing the Properties of Marl Soils for Effective Construction in Saudi Arabian Region. Engineering Journal, 21(4), 111–126. doi:10.4186/ej.2017.21.4.111.

[28] Mebarki, M., Kareche, T., Benyahia, S., Derfouf, F. E. M., Abou-Bekr, N., & Taibi, S. (2020). Volumetric behavior of natural swelling soil on drying-wetting paths. Application to the Boumagueur marl -Algeria-. Studia Geotechnica et Mechanica, 42(3), 248–262. doi:10.2478/sgem-2019-0042.

[29] Alonso, E. E., Pineda, J. A., & Cardoso, R. (2010). Degradation of marls; two case studies from the Iberian Peninsula. Geological Society Engineering Geology Special Publication, 23(1), 47–75. doi:10.1144/EGSP23.5.

[30] Krisnayanti, D. S., Bunganaen, W., Frans, J. H., Seran, Y. A., & Legono, D. (2021). Curve number estimation for ungauged watershed in semiarid region. Civil Engineering Journal (Iran), 7(6), 1070–1083. doi:10.28991/cej-2021-03091711.

[31] Jalali-Milani, S., Asghari-Kaljahi, E., Barzegari, G., & Hajialilue-Bonab, M. (2017). Consolidation deformation of Baghmisheh marls of Tabriz, Iran. Geomechanics and Engineering, 12(4), 561–577. doi:10.12989/gae.2017.12.4.561.

[32] Zobiri, M., Mazour, M., & Morsli, B. (2018). Water erosion on marl slopes and prevention of its effects using conservation of water and soil systems in the Wadi Isser watershed - Algeria. Journal of Water and Land Development, 37(1), 161–169. doi:10.2478/jwld-2018-0035.

[33] Qadem, Q. Z. (2019). Climate variability and their impact on the spatio-temporal organization of precipitation. Case of the Wadi Mikkes and Fez watersheds. Morocco. Environmental and Water Sciences, public Health and Territorial Intelligence Journal, 3(4), 253-260. doi:10.48421/IMIST.PRSM/ewash-ti-v3i4.16153.