Improvement of earthen dikes with binders: a civil engineering advancement for agricultural irrigation and drought mitigation in Algeria

Driz Hafida
Doctor in Civil Engineering
Institution: Material and Hydrology Laboratory, University of Djillali Liabes
Address: Sidi Bel-Abbes, Algeria
E-mail: drizhafida@gmail.com

Rezagui Djihad
Doctor in Hydraulics
Institution: Ecosystem Protection in Arid and Semi Arid Zones Laboratory at Univ of Ouargla, University Centre of Maghnia
Address: Maghnia, Algeria
E-mail: rezagui_djihed19@yahoo.fr

ABSTRACT
In recent decades, Algeria has faced significant challenges due to climate change, resulting in cracks in agricultural soils and degradation of the vegetation layer, especially during unusual summer rains. Dikes play a crucial role in preserving this vegetation layer, allowing farmers to restore soil integrity and utilize dikes as earth barriers for crop irrigation and animal watering. Within civil engineering, dikes are often classified as either hydraulic or geotechnical structures, typically constructed using compacted earth, especially in non-draining soils like clays or soft soils. It has been observed that accumulation of mud or water can compromise their structural integrity partially or completely. To address these issues, this study focuses on presenting reinforcement systems for earth-built dikes using commonly used binders in the Algerian market such as Portland cement, lime, gypsum, etc. Specific calculations are conducted to assess the strength, mechanical behavior, and resilience of each dike type based on soil type, reinforcement method, and concentration. This approach aims to enhance the mechanical properties of dikes
and optimize soil characteristics, offering solutions to strengthen the irrigation and agricultural sector, potentially yielding significant economic benefits for the country.


**RESEMO**

Nas últimas décadas, a Argélia tem enfrentado desafios significativos devido às mudanças climáticas, resultando em fissuras nos solos agrícolas e degradação da camada vegetal, especialmente durante chuvas de verão incommuns. Os diques desempenham um papel crucial na preservação desta camada vegetal, permitindo aos agricultores restaurar a integridade do solo e utilizar os diques como barreiras naturais para a irrigação de cultivos e o fornecimento de água para animais. Dentro do campo da engenharia civil, os diques frequentemente são classificados como estruturas hidráulicas ou geotécnicas, geralmente construídos com terra compactada, especialmente em solos pouco drenantes como argilas ou solos moles. Observa-se que a acumulação de lama ou água pode comprometer parcial ou totalmente sua integridade estrutural. Para abordar esses problemas, este estudo concentra-se em apresentar sistemas de reforço para diques de terra utilizando aglutinantes comumente utilizados no mercado argelino, como cimento Portland, cal, gesso, entre outros. São realizados cálculos específicos para avaliar a resistência, o comportamento mecânico e a resistência de cada tipo de dique de acordo com o tipo de solo, método de reforço e concentração. Este enfoque visa melhorar as propriedades mecânicas dos diques e otimizar as características do solo, oferecendo soluções para fortalecer o setor de irrigação e agricultura, o que poderia gerar benefícios econômicos significativos para o país.


**RESUMEN**

En las últimas décadas, Argelia ha enfrentado desafíos significativos debido al cambio climático, lo que ha provocado grietas en los suelos agrícolas y la degradación de la capa vegetal, especialmente durante lluvias de verano inusuales. Los diques desempeñan un papel crucial en la preservación de esta capa vegetal, permitiendo a los agricultores restaurar la integridad del suelo y utilizar los diques como barreras naturales para la irrigación de cultivos y el abastecimiento de agua para animales. Dentro del campo de la ingeniería civil, los diques a menudo se clasifican como estructuras hidráulicas o geotécnicas, generalmente construidas con tierra compactada, especialmente en suelos poco drenantes como arcillas o suelos blandos. Se ha observado que la acumulación de barro o agua puede comprometer parcial o totalmente su integridad estructural. Para abordar estos problemas, este estudio se centra en presentar sistemas de refuerzo para diques de tierra utilizando aglutinantes comúnmente utilizados en el mercado argelino, como cemento Portland, cal, yeso, etc. Se realizan cálculos específicos para evaluar la resistencia, el comportamiento mecánico y la resistencia de cada tipo de dique según el tipo de suelo, el método de refuerzo y la concentración. Este enfoque tiene como objetivo mejorar las propiedades mecánicas de los diques y optimizar las características del suelo,
ofreciendo soluciones para fortalecer el sector de la irrigación y la agricultura, lo que podría generar beneficios económicos significativos para el país.


1 INTRODUCTION

Algeria, facing the threat of drought, experienced peak agricultural production in the north from 1950 to 1975 due to high rainfall. Since 1976, declining precipitation has led the country to adopt various solutions, such as building dams and improving irrigation systems. Recently, the creation of treatment plants has allowed treated water to be used for irrigation, and desalination now provides drinking water. The Ministries of Forests and Agriculture have warned of the dangers of drought and the resulting decrease in agricultural production.

(Reuters Algeria, 2024), Algeria plans to produce 3.7 million cubic meters of desalinated water daily by 2024 and 5.6 million by 2030, investing $4.5 billion to address drought. Last winter’s high temperatures and reduced rainfall worsened the drought, despite having over 80 dams and 15 desalination plants. The country aims to meet 42% of the water needs for its 47 million population. (Meteoblue, 2024), From January to late June, the Mediterranean coast has seen decreased precipitation and intense, short-duration rainfall, causing irrigation failures for farms. Figure 1 illustrates these issues, while Figure 2 shows a significant annual temperature increase in Algeria, highlighting a notable climatic shift since 1940-1980.
Figure 1: A chart illustrating precipitation levels during the first half of 2023/2024.

Source: https://www.meteoblue.com/

Figure 2: A chart illustrating the decrease in precipitation and the increase in temperature from 2019 to 2024.

Source: https://www.meteoblue.com/

(Emad Sahib Al- Mutar; Ali Jabbar Creedy Al-Qadi, 2023), Climate change, driven by natural phenomena and human activities using non-renewable energy, is a critical global threat. Catherine Hayhoe, a leading climate scientist, stresses the urgent need for action to mitigate its severe impacts. The international community must establish robust frameworks and regulations to limit global temperature rise to 1.5 to 2 degrees Celsius by 2050, aiming to restore pre-industrial levels. (Toprak et al., 2012), Global climate change is a critical issue in various scientific fields, impacting the atmosphere, Earth, and oceans. This has led to international debates among experts and policymakers. Reliable and visually presented data are essential for understanding local effects and developing effective strategies. Standardized scenarios, national data, and consistent
meteorological observations are needed to address climate change patterns for adaptation and mitigation efforts.

Based on the findings from the first five references, it can be inferred that Algeria is grappling with a severe heatwave and acute water depletion, potentially leading to desertification. This poses a significant challenge affecting natural, environmental, and ecological aspects of life in Algeria. Next, we will explore how water depletion and irregular rainfall are impacting agriculture, particularly in terms of environmental appearance and agricultural imbalances.

(Bakhtache Radia; Hadjene Omar, 2023), Algerian agriculture struggles with inadequate natural resources like precipitation and fertile land, hindering crop growth. Climate change exacerbates water scarcity in a country facing severe shortages (<500m3/inhabitant/year), impacting vital crops and threatening food security. Effective solutions must address these interconnected challenges through strategic public interventions. (Bouri Chaouki; Mohamed Brahim Rachid, 2010), Climate change poses a significant global threat, acknowledged through international agreements like the Kyoto Protocol and Copenhagen Agreement. However, countries in the Maghreb region have not prioritized combating global warming. This article examines potential impacts on agriculture, water resources, migration, and national security in the Maghreb, proposing adaptation strategies. (Mustapha Bouakel; Ibrahim Berkane, 2017), This study evaluates climate change's agro-economic impact through climate indices and variability factors. It underscores Algeria's vulnerability to food insecurity, linked to a 9% reduction in agricultural land (2007-2014) and the sector's modest economic contribution. (Kaabache Rachida; Badaoui Brahim, 2022), The current climate crisis, described as the most rapid in millennia, presents global threats like food insecurity and rising costs. In Algeria, reduced precipitation directly threatens agriculture and food security. Addressing these challenges demands a new agricultural policy focused on sustainable resource management and revitalization, crucial for building resilience against climate impacts on food security and public health. (Bouzelha Samia, 2020), The rapid climate crisis poses global threats including food insecurity and cost escalation. In Algeria, reduced precipitation directly endangers agriculture and food security. Addressing these challenges requires a new agricultural policy emphasizing sustainable resource management
and resilience-building against climate impacts on food security and public health. (Sahnoune Sara; Benhassine Nassira, 2019), The article emphasizes the critical importance of climate change and sustainable development in research and policy, given their profound environmental impacts. It explores urban sustainable development in response to environmental degradation, focusing on climate change effects like the urban heat island phenomenon. Urban areas facing higher temperatures than rural areas must integrate adaptation and mitigation strategies for sustainable bioclimatic solutions, crucial for maintaining environmental balance. (Abderrahmani et al., 2010) The study emphasizes rainfall's critical role in climate characterization, especially when combined with temperature. Daily rainfall analysis is pivotal for understanding climate variations, affecting the onset of rainy seasons and dry spells, crucial for local agriculture. Using a Markov model on daily rainfall in Alger Dar El Beida, the study aims to inform adaptive strategies for climate change, essential for enhancing agricultural resilience in the region. (Khodja Sofiane et al., 2022). The Mediterranean region faces profound transformations due to human activities like coastal urbanization, tourism, and industrial development, concentrating vulnerabilities along coastlines. These changes pose economic challenges and threaten livelihoods and ecosystems. Algeria and other Mediterranean countries have committed to international agreements to mitigate pollution and protect their environments through legislation and initiatives. (Gaaloul Noureddine et al., 2021), The Maghreb region faces worsening water scarcity exacerbated by inefficient water use and resource overexploitation, compounded by climate change-induced erratic rainfall, droughts, and floods. Agricultural challenges include soil salinization and decreased productivity. This paper provides a detailed country profile on water resources and usage to guide policy-making and inform stakeholders, researchers, and the public.

Amid challenges like climate variability, sustainable agricultural irrigation solutions include concrete dams, water reservoirs, and earthen dams. Earthen dams, made from compacted soil or clay, combat erosion and floods to preserve agricultural land, retaining crucial water for irrigation and livestock. Despite challenges, they play a pivotal role in water retention and agricultural sustainability.
"Dikes" are vital structures designed to prevent floods and submersions, particularly in urbanized areas. They form a comprehensive protection system requiring technical analyses such as risk assessment and hazard studies to safeguard flood-prone areas. This review focuses on the risks impacting geotechnical and hydraulic structures (dikes), illustrated in accompanying figures.

Figure 3: The different types of degradation of dikes due to erosion.


Figure 4: The different types of landslides and the phenomenon of settlement of a dam.


Several works address geotechnical issues and dikes. (Costet; Sanglerat, T 1 and T2, 1975) This book is divided into two parts. The first part is dedicated to
the calculation of various geotechnical parameters such as the physical and chemical properties of soil mechanics. The second volume focuses on the calculation of geotechnical structures. (Bouafia, 2018) In a new edition, Professor Bouafia is releasing a book intended for engineers, which is set to become a fundamental reference for calculating foundations, soil slippage, slopes, and retaining structures. (Kari Terzaghi, 1943) In "Theoretical Soil Mechanics" by Terzaghi, various formulas for calculating soil stresses and verifying formulations for different soil types are detailed. The book includes essential guidance for engineers designing hydraulic structures like dams and dikes. In geotechnical engineering, homogenization calculations for composites typically rely on multiple references and methods to achieve accurate results. (Royet et al., 2011) The group of authors establishes a set of Recommendations for the justification of the stability of embankment dams and dikes. (Yasmina Boussafir et al., 2024) Climate change affects weather patterns, water levels, and flood intensity, with indirect impacts on hydraulic structures now being addressed. The soil-climate interaction observatory on the La Riche dike will collect soil and meteorological data using sensors installed in March 2023. This data aims to enhance understanding and develop guidelines for adapting flood protection structures to climate change. (Reasl, 1903), A foundational book that explores the study of pressure and stability and their influence on dams. Additionally, it provides precise formulas for calculating the support of various types of retaining structures. (Univ Hallab, 2012) A course manual from the University of Hallab in Syria provides thorough explanations of methodologies for calculating embankments and earth dams from both hydraulic and civil engineering perspectives.

In this work, we focus on reinforcing a clay dam with lime to improve soil quality. We introduce a process of homogenizing the clay with lime, followed by detailed calculations of the dam's geotechnical behaviors and integration into hydraulic engineering systems.
2 THE MATHEMATICAL MODEL WITH RESULTS AND DISCUSSIONS

2.1 THE EFFECTIVE MECHANICAL PROPERTIES OF SOILS IMPROVED BY DIFFERENT VOLUMETRIC FRACTIONS OF LIME

Firstly, let us recall that: (Bouassida, 2006), This article develops a conceptual framework for the dimensioning of foundations on reinforced soils, and it clearly specifies the properties of granular soils. (Pigeot, 2023) In another study on the proposal of a model for homogenizing the mechanical properties of a silt soil treated with lime, we rely on this article to take the initial characteristics of the silt or clay soils and the reinforcement, which is a hydraulic binder (lime). The results obtained are excellent.

In this study, we use the general homogenization law known as the law of mixture (Berthelot, 2012).

\[
\begin{align*}
E_{Eff} &= E_{Lime} \times V_{Lime} + E_{Soil} \times V_{Soil} \\
\gamma_{Eff} &= \gamma_{Lime} \times V_{Lime} + \gamma_{Soil} \times V_{Soil} \\
v_{Eff} &= v_{Lime} \times V_{Lime} + v_{Soil} \times V_{Soil}
\end{align*}
\]

where:

\[
\begin{align*}
E_{Eff} & : \text{Effective modulus of elasticity.} \\
E_{Lime} & : \text{The modulus of elasticity of lime.} \\
V_{Lime} & : \text{The volumetric fraction of lime.} \\
E_{Soil} & : \text{The modulus of elasticity of soil.} \\
V_{Soil} & : \text{The volumetric fraction of soil.} \\
\gamma_{Eff} & : \text{Effective soil density.} \\
\gamma_{Lime} & : \text{Lime Bulk density.} \\
\gamma_{Soil} & : \text{Soil Bulk density.} \\
v_{Eff} & : \text{Effective Poisson's ratio.} \\
v_{Lime} & : \text{Poisson's ratio of lime.} \\
v_{Soil} & : \text{Poisson's ratio of soil.}
\end{align*}
\]
Table 1: The characteristics of the three types of granular soils (Fill-Clay-Sand) and Lime.

<table>
<thead>
<tr>
<th>Type</th>
<th>H[m]</th>
<th>f [°]</th>
<th>C [KPas]</th>
<th>E [KPas]</th>
<th>g [KN/m^3]</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fil</td>
<td>01.00</td>
<td>30.00</td>
<td>00.00</td>
<td>6750</td>
<td>18.00</td>
<td>00.33</td>
</tr>
<tr>
<td>Clay</td>
<td>01.50</td>
<td>15.00</td>
<td>50.00</td>
<td>1880</td>
<td>18.00</td>
<td>00.35</td>
</tr>
<tr>
<td>Sand</td>
<td>01.00</td>
<td>35.00</td>
<td>00.00</td>
<td>450000</td>
<td>21.00</td>
<td>00.30</td>
</tr>
<tr>
<td>Lime</td>
<td>00.20</td>
<td>35.00</td>
<td>120.00</td>
<td>2823000</td>
<td>38.00</td>
<td>0.25</td>
</tr>
</tbody>
</table>


Table 2: The characteristics of the three types of granular soils + V(%) Lime.

<table>
<thead>
<tr>
<th>Type</th>
<th>V_{Lime} [%]</th>
<th>E [MPas]</th>
<th>g [KN/m^3]</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fil</td>
<td>00%</td>
<td>6.75</td>
<td>18</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>05%</td>
<td>147.56</td>
<td>19</td>
<td>0.326</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>288.38</td>
<td>20</td>
<td>0.322</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>429.19</td>
<td>21</td>
<td>0.318</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>570.00</td>
<td>22</td>
<td>0.314</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>710.81</td>
<td>23</td>
<td>0.31</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>851.63</td>
<td>24</td>
<td>0.306</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>992.44</td>
<td>25</td>
<td>0.302</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>1133.25</td>
<td>26</td>
<td>0.298</td>
</tr>
<tr>
<td>Clay</td>
<td>00%</td>
<td>1.88</td>
<td>18</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>05%</td>
<td>142.936</td>
<td>19</td>
<td>0.345</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>283.992</td>
<td>20</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>425.048</td>
<td>21</td>
<td>0.335</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>566.104</td>
<td>22</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>707.16</td>
<td>23</td>
<td>0.325</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>848.216</td>
<td>24</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>989.272</td>
<td>25</td>
<td>0.315</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>1130.328</td>
<td>26</td>
<td>0.31</td>
</tr>
<tr>
<td>Sand</td>
<td>00%</td>
<td>45</td>
<td>21</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>05%</td>
<td>183.9</td>
<td>21.85</td>
<td>0.2975</td>
</tr>
<tr>
<td></td>
<td>10%</td>
<td>322.8</td>
<td>22.7</td>
<td>0.295</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>461.7</td>
<td>23.55</td>
<td>0.2925</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>600.6</td>
<td>24.4</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>739.5</td>
<td>25.25</td>
<td>0.2875</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>878.4</td>
<td>26.1</td>
<td>0.285</td>
</tr>
<tr>
<td></td>
<td>35%</td>
<td>1017.3</td>
<td>26.95</td>
<td>0.2825</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>1156.2</td>
<td>27.8</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Source: (Authors).

Figure 5: The diagram of the evolution of mechanical properties of soil improved with lime (a: Effective elasticity modulus; b: Poisson's ratio).

Source: (Authors).
The diagram (a) shows the evolution of the effective elasticity modulus (E) of different types of soils (Fil, Clay, and Sand) improved with lime as a function of the lime volumetric fraction (V).

- The effective elasticity modulus (E) increases linearly with the increase in the lime volumetric fraction (V) for all soil types;
- For V ranging from 0% to 40%, E increases from almost 0 to 1200 Mpa.

For comparison between all type of the soil, we see that:

- Fil, clay, and sand soils show similar trends with comparable increases in the effective elasticity modulus;
- The linear increase suggests that the addition of lime has a beneficial effect on all tested soil types, proportionally improving their elasticity modulus.

The eventual practical implications, it’s that:

- Adding lime is an effective method to enhance the rigidity and load-bearing capacity of soils;
- This linear improvement in the elasticity modulus with the increase in the lime volumetric fraction is useful for designing and engineering infrastructures that require solid foundations.

In conclusion, this diagram demonstrates that incorporating lime into different soil types leads to a significant and linear increase in the effective elasticity modulus, which is beneficial for geotechnical and construction applications.

The diagram (b) shows the evolution of Poisson's ratio (ν) for different types of soils (Fil, Clay, Sand) as a function of the lime volume fraction (V %). Here is a detailed discussion of the graph:

- The Poisson's ratio of Fil soil steadily decreases with the increase in lime volume fraction. Initially, at 0% lime, ν is around 0.32, and it decreases to about 0.30 when the lime volume fraction reaches 40%;
- Clay soil follows a similar trend to Fil soil but starts with a higher Poisson's ratio of about 0.35 at 0% lime and gradually decreases to around 0.32 at 40% lime;
- Sand soil has the lowest Poisson's ratio among the three types of soil. At 0% lime, ν is around 0.30, and it decreases to about 0.28 when the lime volume fraction reaches 40%.
The addition of lime seems to reduce Poisson's ratio for all types of soils studied. This may indicate that lime improves the soil's stiffness, thus reducing its tendency to deform laterally under axial compression.

Clay soil, being more clayey, shows a more pronounced decrease in $\nu$ compared to the other soil types, which may be due to the strong reaction of lime with clay particles, leading to greater improvement in mechanical properties.

For conclusion, graph b clearly illustrates that the improvement of soil with lime systematically decreases Poisson's ratio, which could be beneficial for applications requiring greater soil stability and stiffness.

2.2 THE HYDRAULIC CALCULATION OF THE DAM

Figure 6: A diagram representing the hydraulic and geometric parameters of the earth dam.

![Diagram of hydraulic and geometric parameters of the earth dam.]

Given a dam with a base of (B), we propose a height of (H) for a simple dam. The notations are indicated in Figure 6. The small base (b), the total height (h), the height of the wave or debris (FB), the height of the water (hw), and the height of the wave only (hw) are determined by the following formulas: we take 2% of the wave drop, and the height of the dam is less than 30 meters, considering a watershed width noted as (f). It is preferable in earthen dams to protect the walls with ballast stones nailed.

$H = h + FB$

$b = \frac{5}{3} \times \sqrt{H}$
\[ B = 5 \times b \]

\[ FB = 1.5 \times h_w + 2\% \times H \]

\[ F \leq 30 \text{ km} \]

\[ h_w = 0.032 \times \sqrt{v \times F} + 0.763 - 0.271 \times \sqrt{F} \]  \hspace{1cm} (2)

The task now is to vary the wave length noted as (F) to obtain the different wave heights noted as (hw), then deduce the total height (H) to see if it meets the conditions or not. It is noted that (H=15 m, hw=14m, b=7m, B=50m). and also depends on the variation of the wind speed noted as (v) and lenght of wave (F).

Table 3: The variation in wave length, denoted as (F) with a constant wind speed (v = 20 km/h) on the hydraulic parameters of the dike.

<table>
<thead>
<tr>
<th>F(km)</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>hw(m)</td>
<td>0.64</td>
<td>0.66</td>
<td>0.70</td>
<td>0.72</td>
<td>0.74</td>
<td>0.76</td>
<td>0.78</td>
<td>0.80</td>
<td>0.82</td>
<td>0.84</td>
</tr>
<tr>
<td>FB(m)</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>B(m)</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
</tr>
<tr>
<td>B(m)</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
</tr>
</tbody>
</table>

Source: (Authors).

It is noted from Table 3 that the preliminary design is correct because there are no further changes in the dimensions if the wave length (F) varies, except it affects the wave height (hw). In what follows, we take (F=20 Km), which indicates a very large watershed, and the variation is made only in the wind speed (v).

Table 4: The variation in wave length, denoted as (F) with a constant wind speed (v = 20 km/h) on the hydraulic parameters of the dike.

<table>
<thead>
<tr>
<th>v(km/h)</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>120</th>
<th>140</th>
<th>160</th>
<th>180</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>hw(m)</td>
<td>0.84</td>
<td>1.2</td>
<td>1.4</td>
<td>1.54</td>
<td>1.62</td>
<td>1.76</td>
<td>1.88</td>
<td>2.00</td>
<td>2.12</td>
<td>2.22</td>
</tr>
<tr>
<td>FB(m)</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
</tr>
<tr>
<td>B(m)</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
<td>6.32</td>
</tr>
<tr>
<td>B(m)</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
<td>44.16</td>
</tr>
</tbody>
</table>

Source: (Authors).

It is observed from the results in Table 4 that the increase occurs in the wave height (hw); this height decreases as the wind speed increases. Finally, it is well noted that the dimensions of the dike are very accurate.
Figure 7: Variation in wave height ($h_w$): a) Variation in wave length ($F$ in Km), b) Variation in wind speed ($v$ in Km/h).

The graph (7.a) shows the variation in wave height ($h_w$) as a function of the variation in wave length ($F$).

- the graph shows a positive linear relation ship between the wave length and wave height. As the wave length ($F$) increases, the wave height ($h_w$) also increases;
- for shorter wave lengths (around 2 km), the wave height is approximately 0.65 m;
- as the wavelength increases, the wave height increases steadily;
- at a wavelength of 20 km, the wave height reaches approximately 0.85 m;
- the relationship appears to be linear, meaning that for each unit increase in wave length ($F$), there is a proportional increase in wave height ($h_w$);
- this relationship can be used to predict wave height based on wave length;
- this can be relevant for maritime applications, environmental studies, and coastal risk management.

In graph (7b), the variation of wave height ($h_w$) as a function of wind speed ($v$), can be described as:

- the wave height ($h_w$) increases almost linearly with the increase in wind speed ($v$);
- this means that the higher the wind speed, the higher the waves;
- for wind speeds between 20 km/h and 180 km/h, a steady increase in wave height is observed;
• at lower wind speeds (20 km/h to 60 km/h), the increase in wave height is relatively modest;
• when the wind blows at a higher speed, it transfers more energy to the water surface, resulting in an increase in wave height;
• the quasi-linear relationship suggests that within the range of wind speeds presented, other factors such as wind duration and the surface over which it blows (fetch) might have constant or proportional effects;
• the graph does not show signs of saturation or plateau within the studied range of speeds, indicating that the waves would likely continue to increase if the wind speed increased further;
• it would be interesting to consider how other variables (such as wind duration and water depth) might influence this relationship in a broader context.

In summary, the graph indicates a direct and positive relationship between wind speed and wave height, which aligns with theoretical expectations regarding the effect of wind on ocean waves.

Figure 8: The hydraulic slope (water jet).

Mathematical formulas:

\[ K = \frac{v}{1 - v} \]

\[ Q = K \times (h_1^2 - h_2^2) \times \left(2 \times L\right)^{-1} a = \frac{L}{\cos \alpha} - \sqrt{\left(\frac{L^2}{\cos^2 \alpha} \frac{1}{\sin^2 \alpha} \right) - \frac{h^2}{\sin^2 \alpha}} \]

\[ Q = K \times a \times \cos \alpha \times \tan \alpha \]
\( h_1 \): initial jet height; \( h_2 \): end jet height
\( K \): Coefficient of earth pressure at rest.
\( \alpha \): The jet angle with the 00 level. (30°)
\( Q \): The jet flow rate.
\( L \): Length of water traversing the dike.
\( a \): Length in the direction of the water jet.

The detailed calculation:

\[
K = \frac{v}{1 - v} = \frac{0.33}{1 - 0.33} = 0.5;
\]

\( h_1 \): initial jet height (14m); \( h_2 \): end jet height (16m)
\( L \): Length of water traversing the dike. \((L = 3 \times b = 3 \times 7 = 21 m)\)

\[
Q = K \times (h_1^2 - h_2^2) \times (2 \times L)^{-1}
\]

\[
Q = 0.5 \times (14^2 - 6^2) \times (2 \times 21)^{-1}
\]

\( Q = 1.9 m^3 s^{-1} \)

\( Q \): The jet flow rate. (1.9 \( m^3 s^{-1} \))

\( \alpha \): The jet angle with the 00 level. (30°)

\( a \): Length in the direction of the water jet.

\[
a = \frac{L}{\cos \alpha} - \sqrt{\left(\frac{L^2}{\cos^2 \alpha} - \frac{h^2}{\sin^2 \alpha}\right)}
\]

\[
a = \frac{21}{0.87} - \sqrt{\frac{21^2}{0.76} - \frac{6^2}{0.25}}
\]

\( a = 3.25 m \)

\[
Q = K \times a \times \cos \alpha \times \tan \alpha
\]

\[
Q = 0.5 \times 3.25 \times 0.87 \times 0.58
\]

\( Q = 0.82 m^3 s^{-1} \)

\( Q \): The jet flow rate (0.82 \( m^3 s^{-1} \)).

\( Q \): The jet flow rate is the max \((Q = 1.9 m^3 s^{-1})\) (4)
2.3 GEOTECHNICAL CALCULATION OF THE EARTH DAM

(Dhouib et al., 2004), this research group provides us with empirical formulas to deduce the value of settlement, as well as the value of the oedometer modulus and the overall stress, as shown in the following formulas:

\[ E_{oed} = \frac{E_{eff} \times (1 - \nu_{eff})}{(1 - 2 \times \nu_{eff}) \times (1 + \nu_{eff})} \]

\[ \sigma_t = \gamma_{eff} \times H \]

\[ w_s = \frac{H \times \sigma_t}{l \times E_{soil} + (1 - l)E_{oed}} \]

\[ \sigma_c = \frac{E_{soil} \times \sigma_t}{l \times E_{soil} + (1 - l)E_{oed}} \]  

(5)

Noting that:

- \( E_{oed} \): The oedometer modulus.
- \( E_{eff} \): The effective elasticity modulus.
- \( \nu_{eff} \): The effective Poisson's ratio.
- \( \sigma_t \): The applied stress (of the dam).
- \( \gamma_{eff} \): The effective unit weight.
- \( H \): The height of the dam.
- \( l \): The length of the dam.
- \( E_{soil} \): The soil elasticity modulus.
- \( w_s \): The settlement value.
- \( \sigma_c \): The final soil stress.

Table 5: the calculation of stress and settlement with a dam height of 15 meters and a maximum length of 250 meters.

<table>
<thead>
<tr>
<th>( V_{\text{Lime}} ) [%]</th>
<th>( E_{eff} ) [MPas]</th>
<th>( \gamma_{eff} ) [KN/m³]</th>
<th>( n_{eff} )</th>
<th>( S_l ) [MPas]</th>
<th>( E_{oed} ) [MPas]</th>
<th>( w_s ) [mm]</th>
<th>( \sigma_c ) [MPas]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>00%</td>
<td>6.75</td>
<td>18</td>
<td>0.33</td>
<td>570</td>
<td>2.71</td>
<td>0.23</td>
<td>1052.36</td>
</tr>
<tr>
<td>05%</td>
<td>147.56</td>
<td>19</td>
<td>0.326</td>
<td>570</td>
<td>59.41</td>
<td>0.18</td>
<td>83.31</td>
</tr>
<tr>
<td>10%</td>
<td>288.38</td>
<td>20</td>
<td>0.322</td>
<td>570</td>
<td>116.52</td>
<td>0.10</td>
<td>43.22</td>
</tr>
<tr>
<td>15%</td>
<td>429.19</td>
<td>21</td>
<td>0.318</td>
<td>570</td>
<td>174.02</td>
<td>0.06</td>
<td>29.12</td>
</tr>
<tr>
<td>20%</td>
<td>570.00</td>
<td>22</td>
<td>0.314</td>
<td>570</td>
<td>231.92</td>
<td>0.05</td>
<td>21.91</td>
</tr>
<tr>
<td>25%</td>
<td>710.81</td>
<td>23</td>
<td>0.31</td>
<td>570</td>
<td>290.21</td>
<td>0.04</td>
<td>17.55</td>
</tr>
<tr>
<td>30%</td>
<td>851.63</td>
<td>24</td>
<td>0.306</td>
<td>570</td>
<td>348.90</td>
<td>0.03</td>
<td>14.61</td>
</tr>
<tr>
<td>35%</td>
<td>992.44</td>
<td>25</td>
<td>0.302</td>
<td>570</td>
<td>407.96</td>
<td>0.03</td>
<td>12.51</td>
</tr>
<tr>
<td>40%</td>
<td>1133.25</td>
<td>26</td>
<td>0.298</td>
<td>570</td>
<td>467.42</td>
<td>0.02</td>
<td>10.92</td>
</tr>
</tbody>
</table>

Clay
In Figure 9, the graph shows the variation of the oedometer modulus (Eoed) as a function of the lime volumetric fraction (VLime %) for three different soil types: FIL, CLAY, and SAND.

- for all three soil types (FIL, CLAY, and SAND), the oedometer modulus (Eoed) increases linearly with the increase in the lime volumetric fraction;
- this means that adding lime improves the stiffness or compressive resistance of the studied soils;
- l’ajout de chaux au sol provoque une réaction chimique qui augmente la cohésion et la résistance des particules de sol, ce qui se traduit par une augmentation du module œdémétrique;
• cette augmentation linéaire suggère que l'effet de la chaux est proportionnel à sa fraction volumique, et il n'y a pas de saturation observée dans la plage de valeurs étudiées.

Figure 10: The settlement value as a function of the lime volumetric fraction

The graph in Figure 10, shows the variation of the settlement value (Ws) as a function of the lime volumetric fraction (V Lime %) for three different soil types:

• for all three soil types (FIL, CLAY, and SAND), the settlement value (Ws) decreases as the lime volumetric fraction increases;
• this means that adding lime reduces the settlement of the studied soils;
• at 0% lime, the settlement is highest, with values around 0.4 mm for FIL and CLAY, and slightly lower for SAND;
• a sharp decrease in settlement is observed with the initial increases in the lime volumetric fraction, especially between 0% and 10%;
• beyond 10% lime, the decrease in settlement becomes more moderate and tends to plateau;
• adding lime improves the mechanical properties of the soils by increasing their cohesion and reducing their compressibility, resulting in a decrease in settlement;
• The rapid reduction in settlement at low lime volumetric fractions suggests that even small amounts of lime can have a significant effect on soil stabilization.
Figure 11: The final stress at the base of the dam as a function of the lime volumetric fraction

![Graph showing stress variation with lime addition](image)

Source: (Authors).

The graph in Figure 11 shows the variation of the final stress (Sigma T) at the base of the dam as a function of the lime volumetric fraction (VLime %) for three different soil types:

- for all three soil types (FIL, CLAY, and SAND), the final stress (Sigma T) decreases significantly as the lime volumetric fraction increases;
- this means that adding lime greatly reduces the stress at the base of the dam;
- at 0% lime, the stress is highest, reaching about 1000 MPa for SAND, and about 200 MPa for FIL and CLAY;
- a sharp decrease in stress is observed with the initial addition of lime, particularly between 0% and 10%;
- beyond 10% lime, the decrease in stress becomes more moderate and tends toward a plateau near zero;
- adding lime improves the mechanical properties of the soils by increasing their cohesion and strength, which reduces the stress applied at the base of the dam;
- The rapid reduction in stress at low lime volumetric fractions suggests that even small amounts of lime can have a significant effect on soil stabilization.

3 CONCLUSION

Incorporating lime into different soil types has shown significant benefits for geotechnical and construction applications. Key improvements include:
• effective Elasticity Modulus: Lime addition substantially and linearly increases soil elasticity, enhancing structural integrity and load-bearing capacity;
• poisson's ratio: lime systematically reduces Poisson's ratio, improving soil stability and stiffness;
• stiffness (oedometer modulus): lime treatment consistently increases soil stiffness across various soil types;
• soil settlement: lime significantly reduces soil settlement, especially at low volumetric fractions, stabilizing at higher levels;
• final stress at dam base: lime addition substantially reduces stress at the base of dams, stabilizing at higher lime fractions.

These advancements align with green economy principles, offering solutions such as:
• sustainability: enhances durability and longevity of structures, reducing maintenance needs;
• earthen dams: provides a novel approach for safer, more effective dam construction;
• drought mitigation: improves soil stability, aiding in resilient water retention structures;
• irrigation innovations: supports efficient irrigation systems, enhancing water management and conservation.

Overall, lime as a soil stabilizing agent significantly enhances soil properties, supporting sustainable construction, infrastructure resilience, and efficient agricultural practices.

FUTURE RESEARCH DIRECTIONS
• Utilize earthen dams to combat extreme weather conditions and forest fires;
• Improve fragile soils with lime to create durable soils and enable the use of less expensive foundations;
• Develop cost-effective dams for irrigation and even for potable water supply.
REFERENCES


BOUSSAFIR, Y. et al. Instrumentation of the La Riche Dike: First Step Towards an Observatory of Soil-Climate Interactions. French Journal of Geotechnics, March 2024. DOI: 10.1051/geotech/2024008


GAALOUL NOUREDDINE, SAEID ESLAMIAN, RIM KATLANE. Status of water resources and Climate change in Maghreb regions (Mauritania, Morocco, Algeria, Tunisia and Libya), International Journal Water Sciences and Environment


MOHAMMED BOUTABA. General Manager of the Algerian Energy Company. Statement to the Algerian Reuters agency 15th MAY 2024. "Algeria aims to produce 3.7 million cubic meters of desalinated water daily to cover 42% of the population's needs." The Algerian Reuters agency. Al-Arabiya article (Algerian Economy). doi: https://www.alarabiya.net/aswaq/economy/2024/05/15/.


