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Application of the Estacade (Cantilever Road) System in Algeria's Kherrata Gorges Despite the Challenging Terrain of a Deep Canyon

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Abstract

This study presents the implementation of the Estacade method, a unique engineering solution applied in the Kherrata Gorges, northeastern Algeria, for road construction in a challenging deep valley where conventional techniques are infeasible, and it details the construction process of this innovative system, initiated in 2014 and completed by the end of 2024. Conventional roads are typically constructed with methods such as excavation, fill, bridges, and viaducts. However, in the Kherrata region, the objective was to widen the RN09 road from a single lane of 3-6 meters to a dual-lane road of 10 meters to alleviate traffic congestion. Given the geomorphological constraints of the deep valley, conventional tunnel or cut-fill methods were unsuitable. Instead, the Estacade System was utilized, involving the placement of 10-meter-long cantilever beams, made of reinforced concrete and steel, perpendicular to the old road. These beams were socketed to the bedrock and overlaid with prefabricated reinforced concrete slabs known as "Predallé," effectively expanding the road width to 10 meters. This method allowed for safe dual-lane traffic without support from the valley floor, presenting significant engineering challenges and highlighting the project's uniqueness.

1. Introduction

Road construction or expansion works are carried out by using the most appropriate method selected through feasibility studies based on parameters such as suitability of land conditions of the region where the road will be constructed, economic conditions, application procedures, static and geotechnical approaches, and traffic components.

When the decision is made to expand or reconstruct an urban or intercity highway, each parameter undergoes evaluation, studies are diversified, and alternative solutions are generated. The selected construction method for a road project may align with the static background, but economic conditions can contradict the method required by this static infrastructure. Alternatively, an economically viable road construction method may be unsuitable from a geotechnical or environmental standpoint. At this point, determining the method that ensures optimal economic and safety conditions is essential.

The following methods are widely used in road construction, expansion, and rehabilitation works around the world:

- Tunnel excavation
- Bridge and viaduct construction
- Cut & fill and retaining wall
- Excavation and blasting, etc.

These methods are selected and applied based on several parameters. However, in regions where land conditions and road routes do not meet standard conditions, conventional methods cannot be applied and alternative road construction, widening, and rehabilitation methods may be needed.

A review of existing literature shows that no similar practice has been documented in previous research. Additionally, this implementation is the first of its kind in both Algeria and the African continent. This pioneering approach marks a significant contribution to the field of highway engineering and infrastructure development in these regions.

However, the cantilever technique is commonly used in bridge construction. A study by Çavdar and Şener [1]

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explains the segmental balanced cantilever method, which involves constructing a bridge superstructure in segments. The research highlights the importance of considering construction stages in bridge design, showing that this method can result in a 14% higher bending moment compared to traditional methods. This study provides valuable insights into the use of innovative construction techniques, which can be adapted for road construction, expansion, and rehabilitation projects, illustrating the application of new methodologies when standard conditions are unsuitable.

The primary objective of this study is to elucidate an innovative approach to highway construction in challenging environmental and geological contexts where conventional methods are impractical. Focusing on the Kherrata District in Algeria, characterized by steep, rocky terrain and historical structures, the research explores how the Estacade System offers a viable alternative. This methodological investigation integrates geotechnical feasibility, economic viability, and safety considerations, aiming to advance construction science by addressing complex infrastructural needs amidst adverse natural conditions.

2. Study Area

2.1. Kherrata District

The road construction project in this study includes areas where conventional methods cannot be applied due to both the geomorphological structure of the terrain and its historical texture. This has led to the development of a new method of road construction. Kherrata is a district located among the rocky mountains, within the Agrioun River basin, along the shores of the Ighil Emda Dam, and connecting the cities of Sétif and Bejaia shown in Figures 1 and 2.

Kherrata, which is strategically located between the highways connecting Sétif and Bejaia, as well as Constantine and Algiers, serves as a transfer zone with high traffic density along the East-West and South highways [2]. The daily average vehicle traffic is 22,000, which can increase to 30,000 during the summer months [3]. Heavy vehicles constitute 45% of the overall traffic. The city of Kherrata is located on the RN09 route that reaches the Mediterranean. There are historical bridges and tunnels from the French colonial period in the region.

Figure 1. Location map of the study area [10]

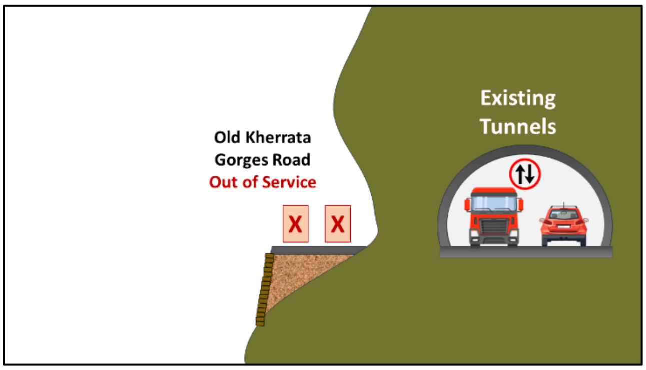
Figure 2. Drone view of the road route

Travel, transportation, tourism, and other road services between these major cities are provided by the RN09 road. Due to its role as a transit point between different locations, Kherrata experiences significant traffic congestion.

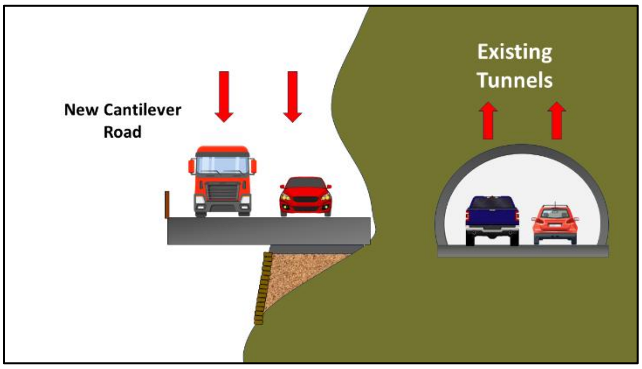
2.2. Traffic and Infrastructure Development

Until 1984, vehicle passage in this region was facilitated through narrow and hazardous single-lane roads in the Kherrata Gorge. To reduce traffic congestion in the Kherrata Gorge and create a dual carriageway (2x1) alongside the existing road, highway tunnels were constructed in 1984. It was initially planned that these tunnels would completely solve the traffic issue. However, in recent years, substantial traffic growth, especially from heavy-load vehicles, has made the traffic flow nearly impassable and dangerous. As an urgent measure, uphill movement of trucks within the tunnels has been prohibited and these vehicles were required to travel on the old RN09 road in the Bejaia-Sétif direction [2]. Subsequently, large viaducts were built to create a bypass road for the Kherrata district. However, over time, these viaducts proved insufficient to handle the traffic volume, highlighting the need for a divided road with two lanes for each direction. In response to this need, the Estacade project was introduced to revitalize the use of the Kherrata Gorges as explained in Figure 3.

The RN09 Kherrata Gorge Rearrangement Works, which includes the Estacade project, is a highway work of 7.2 km in total. There are 4 new tunnels (1535 m in total), 5 viaducts (500 m in total), 280 meters of retaining wall, 13 half bridges (540 m), 23 culverts, and 2331 meters of Estacade road along the road.



(a)



(b)

Figure 3. Traffic flow in Kherrata region (a) before starting of the project and (b) after the project

2.3. Geological and Geomorphological Structure of the Kherrata Region

The Kherrata Region is located in the canyon between Bordj Mira and Kherrata, within the Babor Mountains in the mountainous geography called Atlas Tellien, which was formed during the convergence of the European and African plates during the Late Jurassic period (about 160 million years ago) [4].

The region, which includes the canyon formed by the deep erosion of the river within the limestone rocks, took its final form as a result of thrust faults and nappes of compressional tectonism [5].

3. Materials and Methods

Some natural and artificial conditions along the planned road route in Kherrata Gorge are not conducive to standard highway construction methods. The land conditions requiring the Estacade System, which is the subject of this study, are given below in general terms 8 [6]:

- Steep and nearly vertical slopes
- Deep river valley (too deep for embankment) (Depth > 50 m)
- Mountains that have reached the limit of expansion through excavation and blasting and have taken the shape of a cliff
- Protecting historical structures built between 1863 and 1925

The land where this historical road in the Kherrata Gorge is located in a very special region in terms of orography and geology. The historic Kherrata Gorge road passes through the very steep slopes of the Agrion Valley, and both slopes consist of rocky cliffs. This condition of the terrain makes it impossible to design a simple and comfortable highway and apply minimum road design parameters in many regions along the route [6].

3.1. Terrain and Challenges

The Oued Agrion River flows through the valley beneath the road route, reaching the Chabet El Akra Dam in the nearby area. Constructing a retaining wall on the steep slopes where the river flows from below, with a depth exceeding 50 meters, or expanding the road by filling the slope, is not feasible. In certain areas, the slope inclination reaches 90 degrees.

Apart from the river's depth, the steep slopes on the mountainside of the road do not allow for any excavation or blasting to widen the road. In the previous road construction process in the region, the existing road passing along the mountain slope was already expanded to its maximum capacity. As rocks were shaved from below, the road width increased, but this caused the rocks above to become unstable. Further shaving would lead to rock collapse. Consequently, as it is seen in Figures 4a and 4b it is impossible to excavate beyond the existing limit along the route's mountainside.

(a)

(b)

Figure 4. A view of (a) deep valley unsuitable for filling (b) cliff-shaped rocky mountains that have reached the expansion limit.

The region remained under French sovereignty for many years. Between 1863 and 1925, the French constructed historical structures such as bridges, protective tunnels, culverts, and retaining walls along this route for logistical purposes. This project requires carrying out a transition while preserving these historical structures, some pictures are given in Figure 5.

Figure 5. Historical buildings on the road route [7]

All these conditions in the terrain have rendered the application of conventional road-widening methods impossible. Figure 6a shows the existing road with a width varying between 3 to 6 meters. The project aims to transform this single-lane road, which is 3 to 6 meters wide, into a dual-carriageway road with a width of 10 meters as seen in Figure 6b. To achieve the 10-meter dual-carriageway width, pre-stressed reinforced concrete, or concrete beams combined with post-tensioned steel beams, each 10 meters long, have been placed perpendicular to the road direction at specific intervals along the existing road.

As explained in the Results and Discussion section, the traffic loads are categorized under various systems.

System A pertains to the traffic load distributed over a specified length. Specifically, when the distance between each estacade is assumed to be 4 meters, the following formula (1) is applied, resulting in a load of 24.8 kN per square meter.

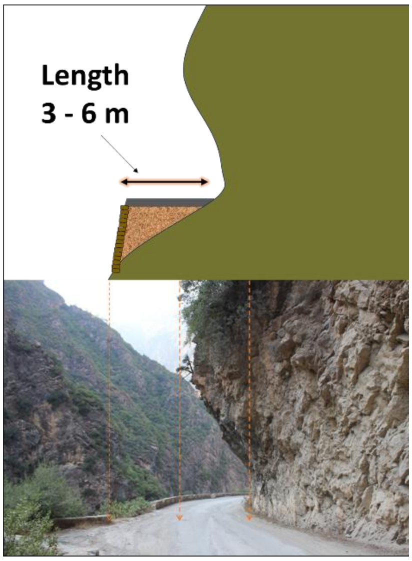
$$A\,(l) = 2.3 + \frac{360}{l+12} = \frac{360}{4+12} = 24.8\,kN \qquad (1)$$

System B is dedicated to vehicle-type classifications. For trucks, this system specifies a total load of 300 kN, with the load distribution allocated as 60 kN to the front wheels and 120 kN + 120 kN = 240 kN each to the rear wheels, reflecting the greater load carried by the rear.

System M addresses tracked vehicles such as tanks, with loads ranging from 720 kN to 1100 kN. In this system, the load per track is categorized as 360 kN and 550 kN.

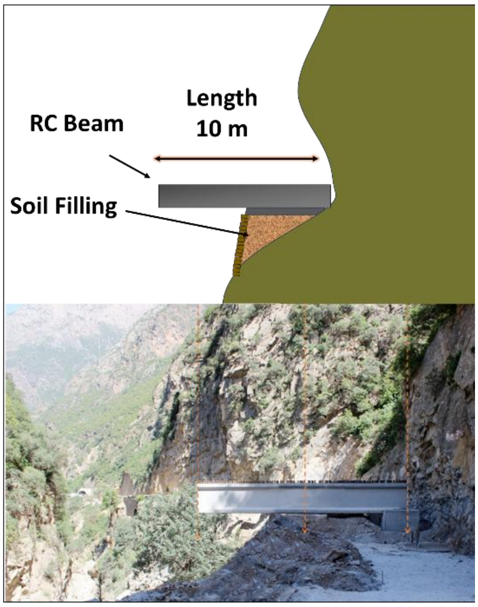
System Exceptional, or the convoy system, evaluates scenarios involving an 18-meter general vehicle convoy. It includes calculations for loads of 2400 kN and 3600 kN, with the load distribution assessed per meter. [10]

Since the portion of each beam placed along the route remains exposed on the valley and riverside, they function as cantilevers [6].



(a)

Figure 6. View from road section; (a) before beam placement (b) after beam placement

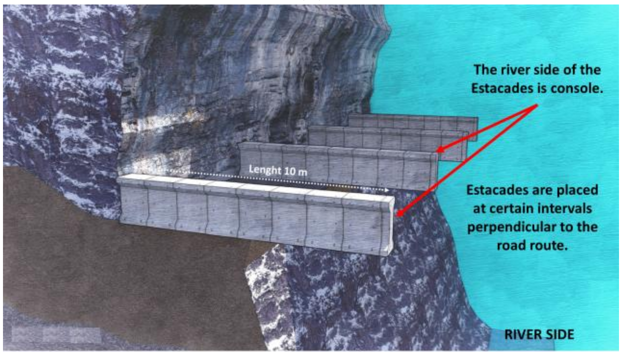


(b)

Figure 6. (Cont.) View from road section; (a) before beam placement (b) after beam placement

The sequential arrangement of these cantilever beams along the road direction is given below. The route was planned so that each beam was placed consecutively 4 meters apart. Since these reinforced concrete beams are called Estacade in the specific project, the term Estacade will be used when talking about the beams in this study.

(a)



(b)

Figure 7. Sequential placement of Estacades on the old road; (a) photo from site (b) schematic view

3.2. Structural Design

Estacades placed consecutively along the road are exposed to both dead and live loads caused by traffic. The traffic on the cantilevered portion of the beam results in the formation of moments. A critical step for Estacade beams is ensuring their strength against the effect of overturning moments. When a heavy vehicle moves or stops on the road, a moment will be generated on the mountain side of the beam, and if this moment is not countered by an opposing force, it can lead to the overturning of the Estacades. To mitigate the rotational effect and prevent the beams from toppling toward the abyss, all beams should be securely anchored to solid ground/bedrock on the mountain side, dampening the resulting moment. In Figure 7a, a photo and in Figure 7b, a schematic view is given. On the valley and river side, due to the significant axial load, reinforcing the ground in that area is necessary to protect it from the pressure exerted by the load.

Based on static analyses conducted throughout the system and specific to each beam, as well as design checks based on soil parameters, it has been determined that beams should be anchored to bedrock using a tension-compression element capable of withstanding the shear and moment forces generated by the loads on the road. For this purpose, composite elements known as "micro piles," consisting of steel and concrete, are employed.

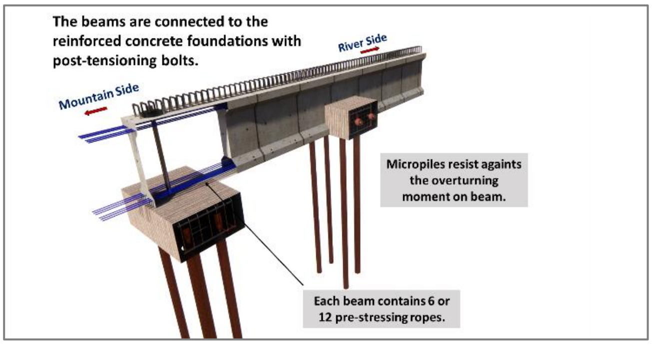
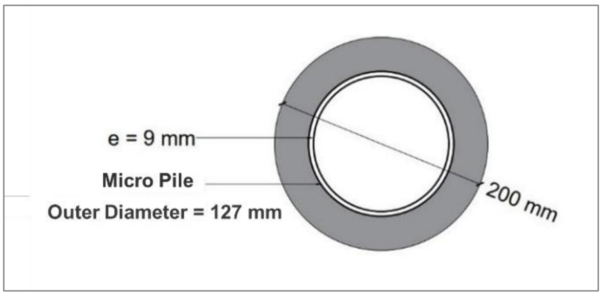


Figure 8. Type section Estacade model and interior details [7]

Micro piles are driven into the ground at each location where an Estacade beam will be placed, until they socket into the bedrock. These socketed micro piles are then connected to the Estacade beams using bolts. This approach ensures a road substructure that can withstand torsional moments and maximum axial forces. The cross-section and detailed view of the system are provided in Figure 8.

(a)



(b)

Figure 9. Micropiles (a) socketed view along the route (b) cross-section [9].

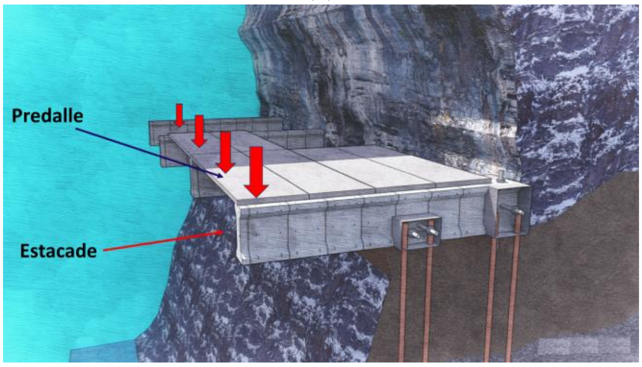
The rotation effect on the console part is balanced by the micro piles on the mountain side, and the pressure effect on the river side is balanced by the micro piles on the valley side. The length of micro piles being socketed into the rock is stated in the static calculation report as follows: "Micro piles driven from the ground surface will continue to be anchored into the ground until they are socketed into the bedrock two and a half meters from the point where they reach the bedrock." Since the depth of the bedrock is not precisely known, micro pile lengths are initially uncertain and are determined by on-site applications as the socketing process continues. The cross-section specified in the project and the site application view of the micro piles placed along the road route in accordance with their elevations and coordinates are given in Figures 9a and 9b.

Figure 10. Estacade beam and bolted connection placed to be connected to micro piles

3.3. Construction Process

The gaps between the Estacades placed on the road at 4-meter intervals are closed with precast reinforced concrete slabs called "Predalle". Precast slabs called Predalle, shown in Figure 11a and shown in rectangular shape in different color tones in Figure 11b, are placed one by one between the beams, and the reinforced concrete slab that will cover them again serves as a formwork for the road. Considering the difficulty of installing floor formworks, 7 cm thick reinforced concrete prefabricated floor slabs were preferred as formwork instead of installing wooden or steel formwork in such a land. These precast floors (Predalle) work as intermediate elements that provide the connection between the upper part of the road, which is in direct contact with traffic, and the Estacade beams at the bottom. 18 cm of concrete will be poured on the pre-floors (Predalle) placed as designed to obtain a load-bearing floor layer. [10]

(a)



(b)

Figure 11. Views from Predalle and Estacade (a) from construction site (b) and schematic view [8]

Ultimately, a holistic structure is formed along the route, connected to each other with slabs (Predalle) from the upper parts and solidly connected to the bedrock with steel-concrete composite piles from the lower parts. The material classes of the building elements used in the project are given in Table 1.

Table 1. Material classes used in Estacades and Predalles

Titles	CC*	CS*	Material	YS*
Micro Pile Concrete	C30/37	30	-	-
Road Paving Concrete	C30/37	30	-	-
Beam Concrete	C40/50	40		
Steel for Passive Reinforcement	-	-	B500C	500
Steel for Active Reinforcement	-	-	Y1860 S7	1860
Steel For Bars	-	-	Y1030	1030
Steel For Micro Pile	-	-	TM 80	355

***CC :** Concrete Class*
***CS :** Compressive Strength (MPa)*
***YS :** Yield Strength (MPa)*

3.4. Numerical Calculation Model

Calculation and design of Estacades were carried out using SAP2000 software. Three-dimensional models were created containing rod elements and shell elements representing various structural elements. In particular, models for micro piles and prestressed beams were created with rod elements with mechanical properties corresponding to the relevant sections. At the same time, the slabs resting on prestressed beams were modeled with 0.25 m thick shell elements [6].

Below in Figure 12, the geometry of one of the generated models is shown. This model represents a road section created by placing 7 pre-stressed beams (Estacade), corresponding to a length of 4x6=24 meters. This length is a distance considered sufficient and reference to properly apply all traffic loads and perform static analysis.

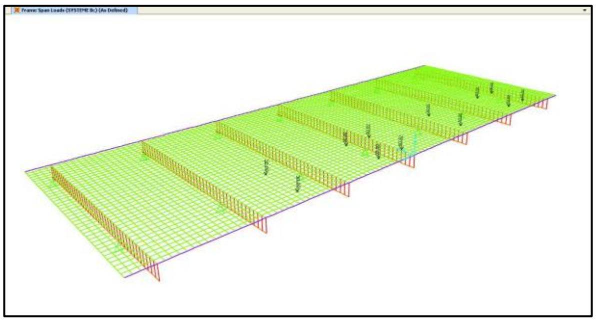


Figure 12. Sample design calculation model

Upon completion of the design processes, Estacade types were determined according to regions and production has been carried out accordingly. Estacade Types 1 and 2 are designed as pre-stressed, while Type 3 is designed as post-tensioned.

4. Results and Discussion

4.1. Findings and Interpretation of Significant Data

The design of highways in Algeria is determined according to the criteria specified in the document "B40 Technical Standards for Road Development" published by the Algerian Ministry of Public Works. Route RN09 is classified as Category 1 according to B40 Standards, in a typical E3 environment. The B40 standard recommends a maximum slope of 6% for Category 1 and 2 roads in terrain with difficult vertical clearance. However, the Standard allows increasing the maximum value by 2% for significant and regional elevations. Similarly, ARP (B40 - Normes techniques d'aménagement des routes - Technical standards for road development) allows a maximum slope of up to 8% for difficult off-road roads. The RN09 route has an average slope of 4%, but at some points this value increases up to around 7.50% [11].

On this new RN09 highway in the Kherrata Gorge, the total length of linear roads is 6636 meters. Considering the mountainous terrain where the average cumulative height difference is greater than 4% and taking into account the size of the sinuosity (s > 0.3) in the terrain, the road reference speed (Vref) is considered to be 40 km/h, and in some parts of the terrain the reference speed is 60 km/h. It is increased up to 1 hour. According to these criteria, the minimum permitted curve radii for the region where the RN09 road is built are determined as giveb in Table 2.

Table 2. Minimum radius relative to reference speed

Reference Speed	60 km/h	40 km/h
Absolute Minimum Radius	125 m	50 m
Normal Minimum Radius	250 m	125 m

4.2. Load Parameters and Technical Conditions

During the ground surveys and preliminary project preparation, the scenarios involving maximum traffic capacity and vehicle weights, both live and dead loads, were analyzed. Based on this analysis, the dimensions and static systems of the Estacade beams were determined.

4.3. Different Estacade Types Depending on Console Length

The Estacade facilitates the main route passage, whether through cut-fill, viaducts, or tunnels. Due to the variable width of the existing road along the route, the lengths of the consoles for the Estacades on the planned 10-meter wide road vary according to the current road width (3-6 meters). This variation indicates that a single type of Estacade beam is impractical. Consequently, design parameters differ based on the console size. As a result of these evaluations, three different types of Estacades, named Type-1, Type-2, and Type-3, were designed as shown in Table 3.

Table 3. Classification of Estacades [6].

Estacade Type	Distance between Consecutive Estacades (s)	Cantilever length (L)
Type-1	4 m or less	L ≤ 3 m
Type-2	4 m or less	3 m ≤ L ≤ 5 m
Type-3	4 m or more	5 m ≤ L

In instances where the existing road width measures 7 meters or more, the console segments of 10-meter-long beams positioned on the roadway will exhibit a span of 3 meters or less. To accommodate such scenarios, rectangular-section prestressed reinforced concrete beams, denoted as Type-1, have been specifically engineered. These Type-1 beams are designed to withstand a maximum shear stress of 931.65 kN.

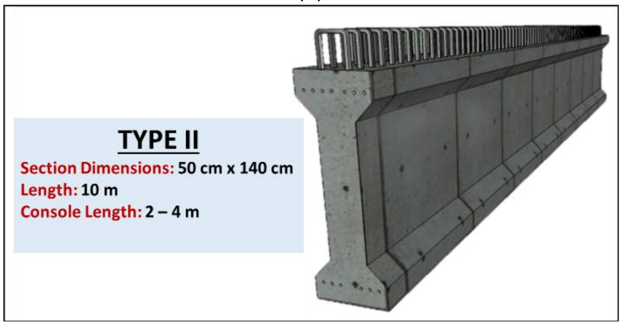
As the road width diminishes, increasing the cantilever span, the Type-1 beam becomes subject to heightened shear stress and moment of inertia, surpassing the 931 kN threshold. Consequently, Type-2 prestressed reinforced concrete beams, engineered to endure elevated stress levels and increased moment of inertia, are manufactured. The maximum shear stress tolerance for Type-2 beams is 1657.59 kN. Each of the tendons, numbering 6 in Type-1 Estacades and 12 in Type-2 Estacades, is subjected to pre-tensioning pressure of 265 bar.

When the existing road width contracts to less than 5 meters, the length of the beam's console will extend beyond 5 meters, resulting in a shear force exceeding 1650 kN. This surpasses the maximum capacity of the Type-2 beam to withstand such shear forces. Merely augmenting the cross-section of the Type-2 beam proves inadequate to address the escalating shear force. Details and shapes of the beams are shown at Figures 14a, 14b and 14c.

In response, Type-3 beams were developed, featuring a reinforced concrete portion supported by the road and a console portion constructed from steel. These Type-3 beams are engineered to withstand a maximum shear stress of 2167.40 kN and prestressing application is shown in Figure 13.

Figure 13. Pre-tensioning application

(a)



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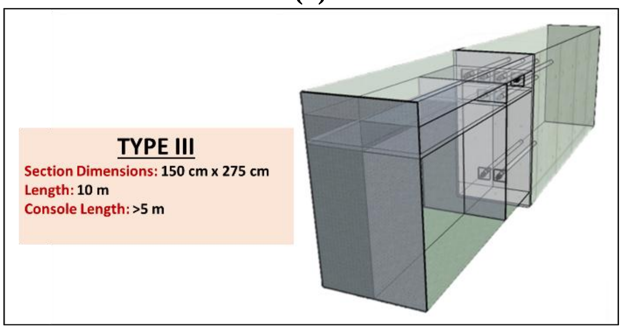

(c)

Figure 14. Estacade section details of (a) Type I, (b) Type II (c) Type III

The primary load-bearing system employs steel consoles made of S355J2N grade steel, possessing a unit weight of 78 kN/m³, with total weights ranging from 3 to 10 tons. These steel components are integrated with reinforced concrete parts using post-tensioning bolts. To enable post-tensioning, the compressive strength of the Type-3 beam concrete must meet a specified minimum value of 4 MPa. Post-tensioning is carried out at 365 bar to counteract the maximum shear force anticipated in the connection area.

The impact of the shear force at the connection area, identified as the weakest point between the distinct reinforced concrete and steel components, is transmitted to the reinforced concrete section and subsequently to the ground through bolts, as given in Figure 15, thus mitigating its effect.

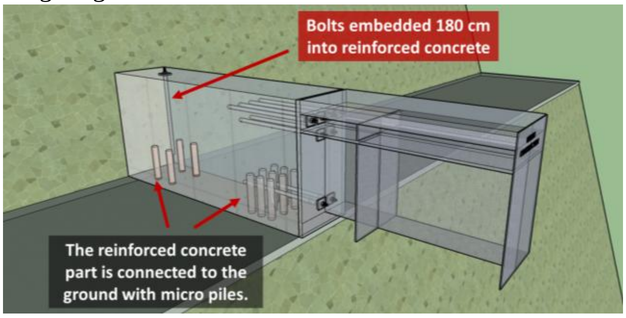

Figure 15. Interior detail view of Type-3 Estacade layout, micro piles and post-tensioning bolts

For spans shorter than 5 meters, reinforced concrete sections typically suffice. However, for spans exceeding 5 meters, the required reinforced concrete section to bear the load would become excessively large. Consequently, there's a concern that such a sizable reinforced concrete section may struggle to support its weight, as depicted in Figure 14.

The image at the bottom left of the photo presents the actual appearance of the beam in field application, while the modeling in Figure 16 is based on the hypothetical scenario of "If it were entirely reinforced concrete." Implementing such a production, characterized by significant cross-sectional dimensions and beam weight, is unfeasible due to challenges in both statics and site production.

Figure 16. Assuming that the Type-3 beam is entirely reinforced concrete

Therefore, the challenge of accommodating large openings was addressed through the adoption of a composite system comprising reinforced concrete and steel, offering a more secure solution. This approach involves mounting steel, which is easier to install and lighter than reinforced concrete, onto the console part. The static calculations and project planning for the Estacade system were conducted by the TEC 4 company using SAP2000 software. Numerous load parameters and environmental factors were considered in the design of the cantilever road. Reduction coefficients (Coefficient de minoration), as specified in the RPOA 2008 Standard for both normal and earthquake situations, were determined for concrete and steel (Table 4).

Table 4. Reduction coefficient [6] used in structural design analysis for safety and stability

Coefficients/Materials	Concrete (General)	B500C Steel
Reduction Coefficient (Normal)	1,5	1,15
Reduction Coefficient (Earthquake)	1,3	1

The artistic structures in the project were designed following the guidelines outlined in the RCPR (2010), RPOA (2008), EN (1991), EN (1992), EN (1997), and EN (1998) regulations and standards. During the calculations, the design parameters were categorized as continuous effects and variable effects. Table 5 provides a concise overview of the continuous effects impacting the design, along with their respective units and values.

Table 5. Values of continuous effects on design parameters[6].

Continuous Effects	Unit	Value
Self Weight of Concrete	kN/m³	25,0
Self Weight of Steel	kN/m³	78,5
Weight of Road Covering	kN/m³	24,0

The account report provides a detailed overview of variable effects. Among these, the first examined are the effects associated with traffic. These effects establish the loads necessary for the calculation and testing of bridges, viaducts, and similar engineering structures, adhering to the rules outlined in RCPR 2010. Analyses are conducted based on traffic loads categorized as systems A and B, as defined within these systems. System A's traffic loads are scrutinized based on vehicle traffic and computed following RCPR 2010 regulations. Load values are determined based on the length and class of the loaded vehicle and then multiplied by coefficients α1. System B's traffic loads encompass the Bc, Br, and Bt subsystems, each representing distinct load cases whose effects are computed separately. Within these subsystems, various load types are considered, and their individual effects are calculated. These analyses play a pivotal role in ensuring the reliability and longevity of the design, as referred in Table 6.

Table 6. Continuous effects affecting the design B systems [6]

Design System Name	Definition	Properties
Bc	The second class consists of trucks of the type used for bridges.	Contains truck types suitable for a particular load class.
Br	It consists of a single isolated wheel.	The independent characteristics of the wheels and their load carrying capacity are taken into account.
Bt	It consists of two axle groups, the name of this group is known as double axle.	The group formed between two axles is examined in terms of load carrying capacities and carrying dynamics.

Another variable impact is special loads, where non-standard loads are taken into account. Special convoys and heavily loaded vehicles are typically analyzed individually, with loads calculated based on specific situations and transportation conditions. These analyses play a crucial role in ensuring the safety and durability of the design.

Another variable effect that significantly impacts the road is the earthquake effect. The dynamic response of structures under earthquake-induced loads is evaluated following the Algerian Earthquake Regulations (RPOA, 2008). According to the earthquake zone map provided in RPOA 2008 for Algeria, the structures in this region fall under earthquake zone IIa. The seismic acceleration value used to determine the earthquake risk levels of structures in these zones is ac = 0.20g (as per RPOA 2008 - Table 3.1). Initially, static approaches were employed in the region, classifying the ground as S2 due to limited definitive data. Considering the structure's composition of prestressed beams, a damping factor of ξ=2 was applied [6].

Figure 17. Bottom view of the road built with the Estacade system

Figure 18. General view of the road built with the Estacade system

5. Conclusions

In this study, a detailed evaluation of a road construction work carried out in the Kherrata region in Algeria is presented. Kherrata has a strategic location between the cities of Sétif and Bejaia and is a region that requires an urgent solution because the capacity of the existing road infrastructure is not sufficient for the traffic density. In the study, the difficult terrain conditions of the Kherrata region were discussed. It was shown that conventional road construction methods could not be applied, and an alternative road construction method was described. Although the road construction method described is a structurally risky and economically costly option, it was preferred due to the geological and geomorphological condition of the land on which the road will be built.

In the study, the technical characteristics of the project and the construction methods used were examined. The methods used in the road construction process have been meticulously evaluated for compliance with engineering standards. These technical analyzes and plans play an important role in determining the solutions and potential improvement areas for special situations during the construction phase of the project. It was envisaged that the road project, which was designed with millimetric precision while preserving occupational safety next to a steep cliff, should be implemented in the field with millimetric precision and the application methodology was determined accordingly. As a result of these studies, a new 10-meter wide highway was created with a sequential arrangement of Type-1, Type-2 and Type-3 Estecades, fixed to the rock with micro piles, resistant to rotational effects, with a cantilever span extending up to 6 meters above the cliff. This structure is designed to pass all heavy vehicles, including tracked military vehicles, and is the product of an interdisciplinary study of geology, geotechnical, reinforced concrete, statics and steel.

One of the most important advantages of the system is the use of pre-tensioned and post-tensioned C40/50 reinforced concrete elements on the road base instead of standard materials defined as sub-base and foundation. Since there is no granular or fine material on the road base, water leaking into the road base due to time or sudden effects will not cause expansion or contraction. Many risks were foreseen during the design. It is planned that in cases where the foreseen standard risks occur, there will be no collapse, settlement, breakage or any situation that would require repair in the road structure.

Maintenance cost can become a significant issue when roads are deformed or locally collapsed due to unforeseen circumstances. Such situations often necessitate localized concrete cutting, which can be costly.

Another risk involves the topographical sensitivity during the construction phase. Specifically, when placing Estacade beams on curves, even millimetric deviations on the mountainside can lead to centimeter-scale deviations over a 10-meter span on the riverside. This sensitivity to topographical variations can significantly impact the accuracy of the construction.

As a result, the road was turned into an integrated structure by socketing the separate cantilever beams lined up one after the other into the rock with piles and connecting them with floors from above. One side is fixed with stakes anchored to the rock, and the other side has a balcony-like shape suspended in the sky.

Thus, a new road construction system was developed in one of the most difficult terrains. Road construction works in the Kherrata region have had a positive impact on the transportation infrastructure of the region. Increasing connections with other cities in and around the region lead to the development of economic and trade activities. In addition, it contributes to the region in terms of tourism. In the Kherrata region of Algeria, the insights gained from road expansion projects and the development of ‘special solutions’ serve as valuable guidance for planning and executing similar initiatives.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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