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Contribution to the Study of Pathologies and the Management of Civil Engineering Structures of the Bafoussam Makenene Section of the National Road Rn4 in Cameroon

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ABSTRACT

In industry, and particularly in the field of Civil Engineering, it has become essential nowadays to assess the condition of Civil Engineering Structures (CES). To effectively estimate and evaluate their state, it is fundamental to analyze the causes of disorders that manifest as pathologies. The objective of this research is to evaluate the condition of civil engineering structures throughout their service life, in order to establish a necessary diagnosis for decision-making and for defining maintenance strategies. First, a condition assessment and an inventory were carried out on the Bafoussam-Makenene section of the RN4 national road, aimed at gathering basic information on the structures. Following this inventory campaign, an inspection was also conducted on all the civil engineering structures. Apart from the observed degradations on various deck elements and the lack of monitoring, the surveyed structures were found to be in an “acceptable” state from a structural point of view. Then, using Pareto’s law, statistical analyses were conducted to distinguish the strategic structures for which an enhanced monitoring process must be established. Decision-support tools were also developed, along with a flowchart highlighting the different steps to follow for assessing the condition of a bridge. Finally, the overall operations clearly demonstrated the evaluation of the condition of civil engineering structures along the itinerary, particularly the Ndé Bridge and the Mlem Bridge, on the Bafoussam–Makenene section of the RN4 national road.

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Introduction

In the face of increasing economic constraints and the pursuit of sustainable infrastructure management, project owners seek to keep their networks operational over increasingly extended periods. During road construction, several obstacles may arise, including rivers, streams, mountains, railways, and others. Crossing such obstacles requires the construction of artificial structures known as civil engineering structures (bridges, culverts, box culverts, tunnels, as well as large embankments and drains). Several causes underlie the disasters observed on our road networks. For example, on the Douala–Yaoundé axis, the collapse of a culvert led to the derailment of the train at Eseka, which resulted in numerous fatalities. Other examples include the scouring of the large embankment on the communal road (Second Bishop’s Crossroad-Cami Toyota), and the settlement of the large embankment on the CAMN000407 section (Banganté-Bandjoun) of the RN4, which has caused traffic congestion in Bafoussam and traffic jams in the Banganté area, directly impacting transport costs. In addition, in the collapse of the Amakpapé bridge on the RN1 – the main corridor linking Lomé port with hinterland countries such as Burkina Faso, Niger, and Mali had major economic implications at both national and sub-regional levels [1]. Similarly, in Algeria, the collapse of the bridge on RN77 at PK 101+350 in Setif Province in Canada (Québec), the collapse of the combined railway and road bridge over the Saint Lawrence River near Lévis (Saint-Nicolas district), which fell first in 1907 and again on September 11, 1916; and in Italy, the collapse of the Genoa Bridge (Northeast) in August 2018 (Ouest France, published 03/08/2020). Following these disasters, we focused our attention on bridge-type civil engineering structures [2].

Many studies on the pathologies and management of civil engineering structures have been carried out in developed countries, but very few in Africa, particularly in Cameroon. This chapter primarily aims at a deeper understanding of the triggering phenomena of disorders leading to pathologies, which provides guidance for preserving our civil engineering structures while considering all eventualities [3-6].

Literature Review

Focused on pathologies and the rehabilitation of bridges. Over time, bridges lose the original quality of their materials and part of their structural resistance. This occurs even when such structures were initially well designed and executed during study and construction stages. This loss of initial performance can be attributed to aging and changing operating conditions, such as increased traffic and loads beyond the design specifications. The research conducted by focused mainly on diagnosing a pathological bridge, detecting the nature and probable sources of various disorders, understanding the different non-destructive testing methods to be used, and ultimately evaluating the structure in order to propose a repair or reinforcement project. From this work emerged both the availability of knowledge required for diagnosing a pathological bridge and the proposal of a repair or reinforcement project [7-10].

Worked on the management and life cycle of civil engineering structures based on a cross-sectional approach, ranging from modeling to decision-making. The aging of infrastructures, maintenance, and management of structures form one of the greatest challenges of the 21st century. Identified during the previous century, this issue compels us to rethink our methods, methodologies, and ability to integrate new technologies. According to Orcesi, decision-making complexity arises from multiple aspects: multi-scale (system/network, asset, structure), multi-criteria, multi-stakeholder, multi-temporal, uncertainty (risks, incomplete information, lack of knowledge), reliance on heterogeneous data (qualitative, quantitative), and sometimes subjectivity (political dimensions) [11-13]. Orcesi's research contributed to developing optimized management methodologies for infrastructure assets, expanding knowledge of life cycle cost analysis methods, and integrating structural health monitoring strategies into civil engineering management. His work highlighted the need for generic integrated management models to guide design and construction decisions, control economic and environmental impacts, and enhance structural robustness against accidental events[14-15].

Focused on the issue of infrastructure maintenance through "management tools." Bridge management has thus become a crucial issue for national economies. According to Godart, it requires the design of a Bridge Management System (BMS)[16]. His work aimed at ensuring user safety, especially for masonry bridges that retain high safety margins, capable of withstanding significant disorders without compromising safety, where visual inspections alone can provide a management basis. Godart's work sought to improve management procedures and encourage preventive maintenance of bridges. He introduced a simplified yet realistic calculation approach to approximate actual structural behavior. Fixed and variable loads were evaluated through partial structure calculations (beams, slabs, hammer piles), ensuring that the simplified model closely matched real behavior with an error margin under 10% [17-19].

He proposed quantitative indicators comparing resisting forces to acting loads: the higher the indicator, the more resistant the structure. In prestressed structures, resistance depends greatly on prestress integrity. Indicators focused on beam flexure (SLS, ULS), beam shear (SLS, ULS), slab flexure (SLS, ULS), and hammer pile flexure (SLS, ULS) [20-23].

Table 1: Classification of Bridge Condition According to Prestress Percentage (ULS)- Bruno Godart (2018)

Bridge condition	level	Index range	Required prestress % / initial prestress
Robust	1	I > 1.25	P < 90%
Likely compliant with modern design	2	1.15 < I < 1.25	90% < P < 100%
Likely undersized but capable of bearing loads	3	1.00 < I < 1.15	100% < P < 115%
Undersized, likely unable to bear code loads 130%	4	0.85 < I < 1.00	115% < P < 130%
Undersized, incapable of bearing code loads	5	1 < I < 0.85	P > 130%

Table 2: Classification of Bridge Condition According to Prestress Percentage (SLS) [24]

Bridge condition	level	Index range	Required prestress % / initial prestress
Compliant with modern bridge, good durability	1	I > 1.00	P < 100%
Likely undersized, may show disorders reducing service life	2	0.85 < I < 1.00	100% < P < 115%
Behavior leading to shortened service life	3	1 < 0.85	P > 115%

defined the global indicator QR for the strength of beams with respect to bending, shear, and for the slab by taking the maximum of the different coefficients. A structure is then classified among the five categories given in table 3[25-27].

Table 3: Global Quantitative Risk Indicator for a Structure – Bruno Godart (2018)

QR index	Assessment
1	Good
2	Fairly good
3	Average
4	Poor
5	Bad

The works of made it possible to obtain, from severity scores, the identified factors with a weighting system. Following tests carried out on about ten structures, a choice of weighting scores by theme was proposed and retained, which led to the classification of structures into five risk classes (Table 4) [28-30].

Table 4: Classification of Bridges According to Risk (APR) – Bruno Godart (2018)

Bridge classification	Scores
No risk	0 – 20
Moderate risk	20 - 40
Rather high risk	40 - 60
High risk	60 - 80
Very high risk	80 - 100

According to, it is therefore appropriate to cross-reference these indicators in order to evaluate the mechanical health condition, taking into account the probable state of prestressing. A decision-making matrix was thus proposed and is illustrated in Table 5[31-33].

Table 5: Percentage of Structures Belonging to Each (APR, QR) Pair – Bruno Godart (2018)

Classe APR	Classe QR				
	1	2	3	4	5
0-20	0 %	3 %	4 %	0 %	0 %
20-40	5 %	8 %	34 %	7 %	9 %
40-60	3 %	3 %	14 %	3 %	5 %
60-80	0 %	0 %	1 %	0 %	2 %
> 80	0 %	0 %	0 %	0 %	1 %

Worked on the decision-support tool applied to civil engineering structures. He found that structures may be affected by disorders of very varied severity, whose causes are multiple. The purpose of his work was to develop a Geographic Information System (GIS) as a decision-support tool for civil engineering structure managers. In this research, used a method based on visual inspection of damage. This inspection referred to the pathology of structures, which made it possible to classify four structures according to the principle of the IQOA (Image Qualité Ouvrage d'Art) method. From this work emerged the classification of four structures according to the IQOA method: The frame bridge at PK44+300 (class 2ES), The mixed bridge at PK44+700 (class 3), The railway bridge at PK46+600 (class 2E), The central underpass at PK46+850 (class 2) [34-35].

Bridge Condition Classification

The condition of bridges is characterized by the choice of one class of condition among five, possibly supplemented by the mention "S" for user safety (see Table 6) [36].

Table 6: Classification of Structures According to the IQOA Method

Class 1	Structure in good condition, requiring only routine maintenance
Class 2	• Structure with minor defects requiring specialized maintenance, but not urgent. • Structure in apparent good condition, but protective equipment or elements have defects that require specialized maintenance, without urgency.
Class 2E	• Structure with minor defects requiring specialized maintenance. • Structure in good condition, but protective equipment or elements have defects that require specialized maintenance, without urgency. Unlike class 2, the urgent nature in this case must be noted to prevent rapid deterioration of the structure and its future classification into class 3. The index 3 in class 2E was chosen to indicate the possible evolving nature of the load-bearing structure's condition over a short period.
Class 3	Structure with a compromised load-bearing system requiring repair work, without urgency.
Class 3U	Structure with severely compromised load-bearing capacity, requiring urgent repair work due to insufficient structural capacity or rapid deterioration.

According tothe approach to assessing the class in which a bridge should be placed is carried out according to the process summarized in the flowchart of Figure 1. The decision elements refer to a set of notions and terms concerning the different parts of bridges to be considered and the types of intervention, the definitions of which are provided afterwards [37-38].

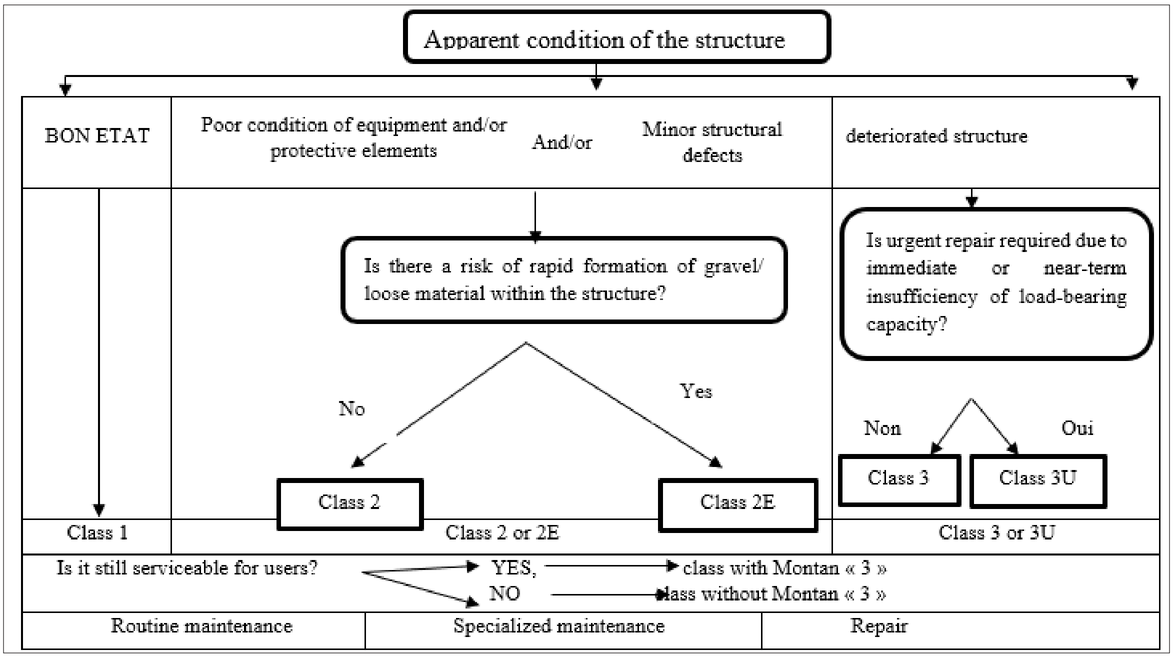

Figure 1: Flowchart of the Methodology for Bridge Classification

Equipment

Defines equipment as devices added to the load-bearing structure and intended to allow the use of the structure by users under satisfactory conditions of comfort and safety. They also facilitate monitoring of the structure, its maintenance, and improve its aesthetics [39-40].

The most frequently encountered equipment is summarized in Table 7.

Table 7: Summary of Bridge Equipment [41]

Equipment	Functions			Equipment	Functions		
	C	A	S		C	A	S
Wearing course	X			Water evaluation	X		
Sidewalks, curbs, medians	X			Pavement Joints	X		
Parapets, guardrails	X	X		Transition slabs	X		
Safety barriers, crash barriers	X			Streetlights and traffic signs	X		
Central void covering	X			Inspection and maintenance equipment			X
Cornices		X		Retention devices	X	X	

With C: comfort and safety of the user, A: aesthetics, S: monitoring.
The author presents an example of the classification of four bridges on the RN12 in Table 8.

Table 8: Example of Classification of 4 Bridges on the RN12

Pont cadre pk44+300									
Element Type		Disorder	Classification Criteria	Class					Mention «s »
				1	2	2E	3	3U	
Equipment	pavement	Erosion of bituminous concrete pavement due to improper slope for rainwater drainage or poor compaction of the asphalt layer (figure D1-P1). Cause: vehicle misalignment during passage.	Pavement exposed to rapid general degradation due to water infiltration		x				x
	Curb	No defect under bridge (figure D2-P1)	In good condition	x					
	Retention device	Nonexistent	Pedestrian insecurity			x			x
	Cornices	nonexistent (figure D3-P1)	Lack of aesthetics affecting safety		x				
	Water drainage device	Nonexistent	Causes pavement degradation			x			
	Embankment	Apparent good condition except vegetation problem (figure D7-P1)	Degradation and cracking due to vegetation		x				
	Access	Stairs damaged (figure D8-P1)	Stairs may cause material and human damage in case of flooding			x			x
	Sidewalk pavement joints	Nonexistent	No effect since it is a frame bridge	x					
Protective elements	Waterproof layer	Poor waterproofing as infiltration observed above the slab (figure D4-P1)	Degradation reinforced concrete slab, risk of rebar corrosion and asphalt layer deformation		x				
	Protective coating of metallic surfaces	No metallic surfaces		x					
	Over-height vehicle deterrent portals	Nonexistent	Risk of collision of over-height vehicles with the slab causing damage		x				

Structure	Superstructure and substructure	Medium condition, localized holes caused by water infiltration at slab joints, exposed slab due to water rising on reinforced concrete walls (figure D5-P1) (figure D6-P1)	Could cause slab and wall saturation over time and total rebar corrosion			x			

The structures are classified according to the most unfavorable class of each element type, summarized in Table 9[42-44].

Table 9: Summary of Final Classifications of Structures

Final Bridge Class	Class for			Final Bridge Class
	Equipment	Protection elements	Structures	
PK44+100 Bridge	2ES	2E	2	2ES
PK44+700 Bridge	2ES	3	2ES	3
PK46+600 Bridge	2E	2	2S	2E
PK46+850 Bridge	1	2	1	2

Materials and Methods

Study site location: The study covers the West Region. The project area is bounded by the following geographic coordinates:

- Latitude: 5° 30' 0 North
- Longitude: 10° 40' 0 East

The project consists of three sections, as shown in Table 10.

Table 10: Different Sections of the Study Itinerary

Region	Road Code	Road Type	Itinerary	Section	Length (Km)
WEST	CAMN000406	N4	Makenene - Bafoussam	Pont sur le Ndé - Bangangté	37,50
	CAMN000407			Bangangté - Bandjoun	33,35
	CAMN000408			Bandjoun - Bafoussam	14,05
TOTAL					84.90

Figure 2: Delimitation of the Study Area (Forêtcommunale-Cameroun.org)

Choice of the Itinerary

Over forty (40) years old, the crossing structures located on National Road RN4 were built in the 1980s. This road was undergoing development works intended to bring it up to the standard norms of a major road. Since then, apart from a few routine maintenance operations, these structures have not undergone any further rehabilitation. Bridge-type civil engineering structures are designed for a service life of about one hundred years. During this period, in order to fulfill their functions, they must be maintained at a permanently acceptable service level through various maintenance operations. However, subject to the combined action of climate variations, traffic (growth and aggression of overloaded axles), and of course time, these structures show signs of fatigue, cracks, and deformations which worsen due to the absence of specific interventions. This leads to disorders that can result in their destruction. To prevent this failure, which would otherwise prove catastrophic, we undertook a study of the civil engineering structures of the Bafoussam- Makenene (RN4) section in Cameroon [45-46].

Methods

The adopted methodology consists of a literature review resulting in works highlighting apparent or hidden defects. We also include bridge assessment tools and maintenance and monitoring regulations, leading to a statistical analysis and the establishment of a Geographic Information System (GIS) for evaluation. It also consists of data collection following an inventory and inspection mission, concluded by works based both on the set objectives and the expected results [47-50].

Results

With regard to bridges, each structure, in general, was carefully examined. The degradations by category of structural elements were established based on visual observations. In addition, Table 11 presents the main degradations classified according to their degree of recurrence, as well as the different Pareto diagrams [51-54].

Table 11: Classification of Degradations According to their Degree of Recurrence

Disorders	Classes	Structures										
		O A1	O A2	O A3	O A4	O A5	O A6	O A7	O A8	O A9	O A10	O A11
Worn bearings and absence of jacking bossage	D1		X					x		X		
Deformations and anomalies on structural elements	D2			x		x			x			
Slope erosion	D3	x			x		x				X	
Deterioration of expansion joints	D4			x	x			x	x	X		
Blocked and grassed water downpipes	D5		X				x		x		X	x
Clogged and non-functional scuppers	D6	x			x	x	x			X	X	
Collapse of guardrails and deformation of safety barriers	D7		X	x	x	x	x			X	X	
Silting of riverbed and clogging by vegetation	D8	x	X	x	x		x	x	x		x	x

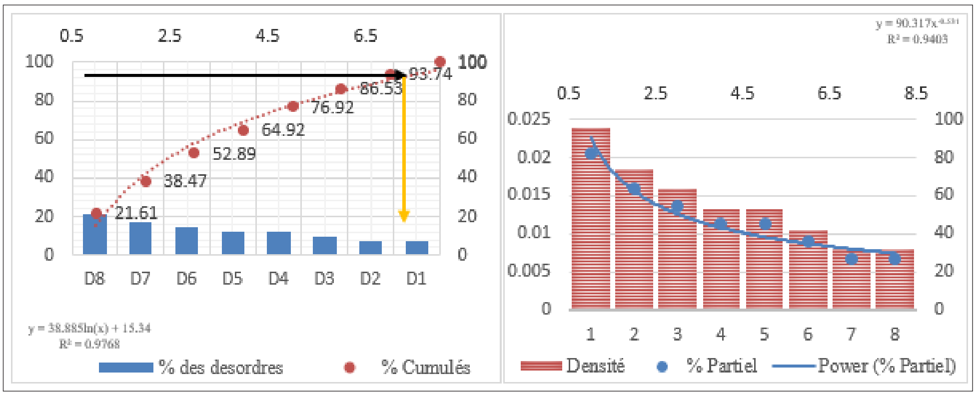

Figure 3: Histogram of the Pareto Diagram of Bridge Degradations

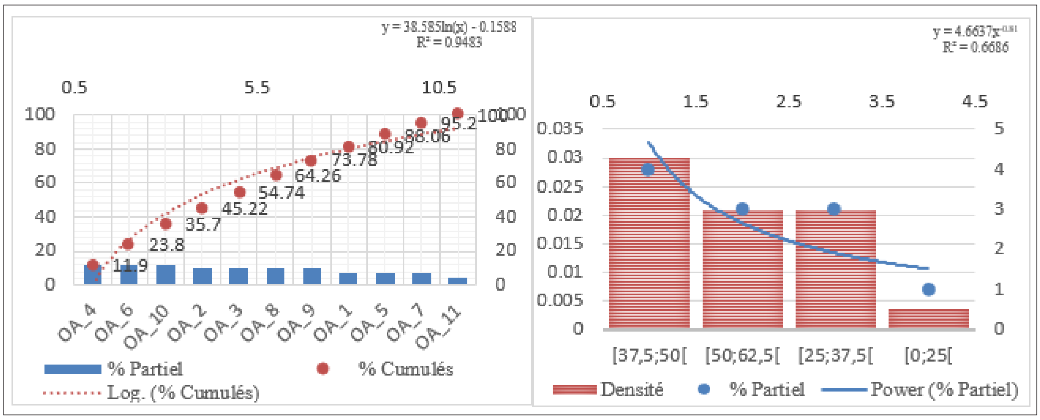

Figure 4: Histogram of the Pareto Diagram of Bridges in the Study Area

For each of these degradations, adequate solutions were identified and are presented in Table 12.

Table 12: Adequate solutions adopted sizing of bearings; supply and installation; choice of bearing type according to structure type

Disorder class	Adequate solutions
D1	Sizing of bearings; supply and installation; choice of bearing type according to structure type
D2	Resizing of the structure; choice of applicable standard
D3	Masonry slope protection; planting of grass or trees
D4	Repair of expansion joints; milling and resurfacing of wearing course
D5	Rehabilitation of downpipes and scuppers
D6	Cleaning of scuppers and extension of PVC columns
D7	Demolition, replacement, or reconstruction of guardrail supports or safety devices
D8	Opening and recalibration of the riverbed; weeding, clearing, and tree felling

For culverts, each structure, in general, was also carefully examined. The degradations by category of elements were established based on visual observations. In addition, Table 13 and the Pareto diagrams present the main degradations according to their recurrence [55-57].

Table 13: Classification of Degradations According to Their Degree of Recurrence (Culverts)

Disorders	Classes	Structures								
		O H1	O H2	O H3	O H4	O H5	O H6	O H7	O H8	O H9
Outlets blocked by vegetation	D8	x	x		x	x	x	x	x	
Clogging by soil deposits	D7	x		x				x	x	X
Obstruction of inlets by garbage	D4	x			x	x	x			
Scour	D3	x	x		x	x				
Absence of culvert heads	D2	x		x				x	x	
Absence of signage	D9	x	x	x	x	x	x	x	x	X
Corrosion / Oxidation	D6	x		x				x	x	X
Slope erosion	D5	x		x			x		x	X
Ovalization	D1						x			

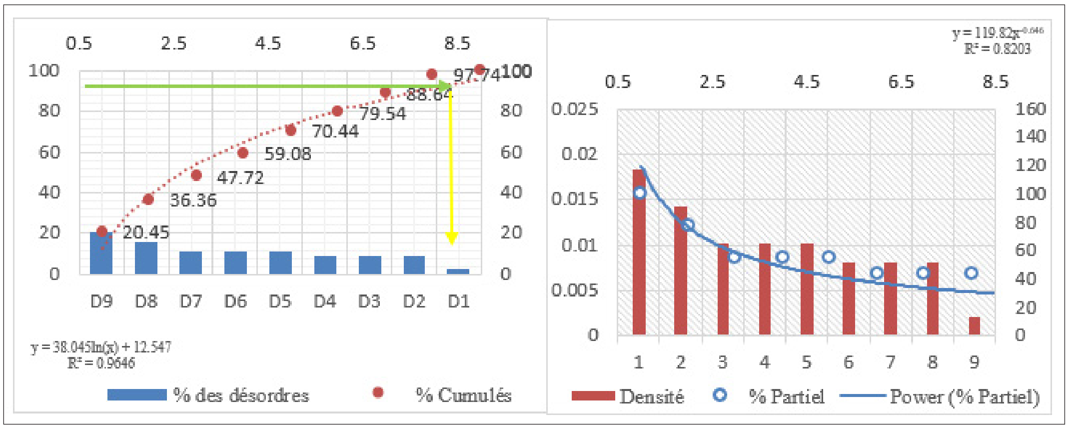

Figure 5: Histogram of the Pareto Diagram of Culvert Degradations

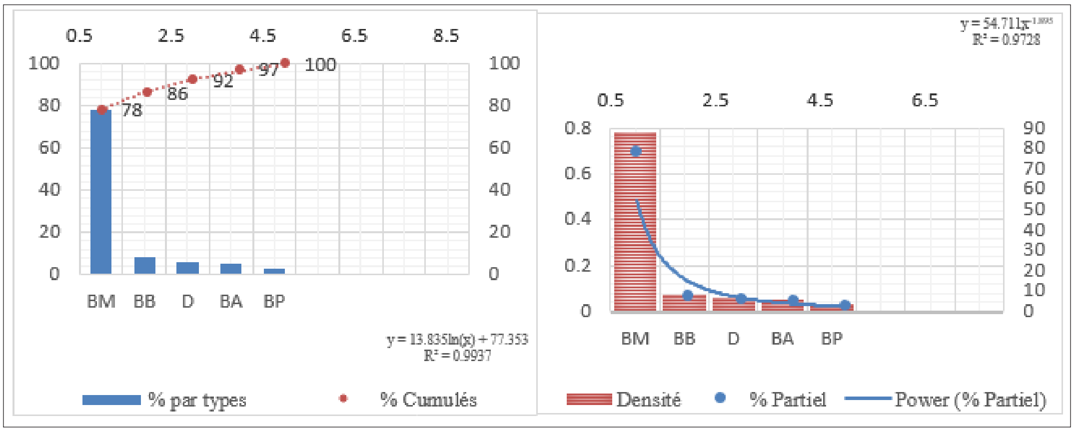

Figure 6: Histogram of the Pareto Diagram of Different Types of Structures

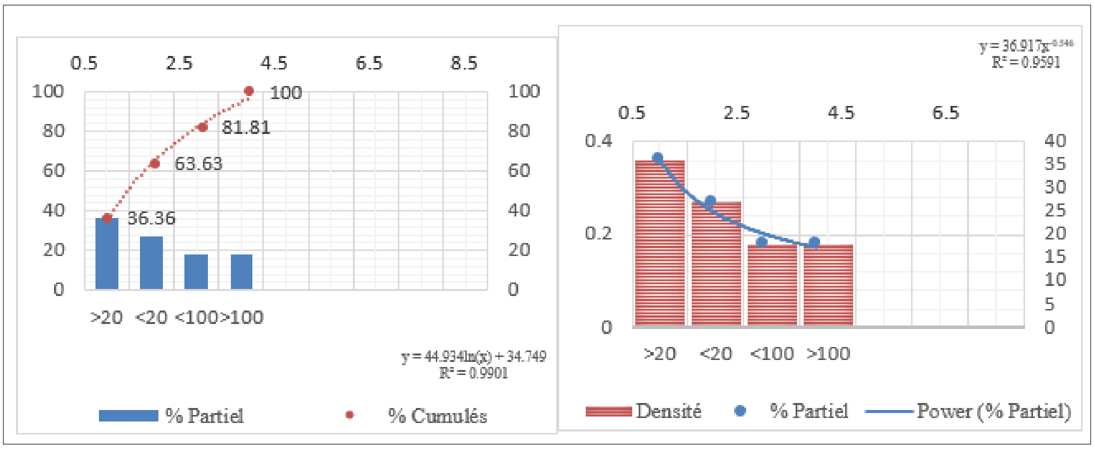

Figure 7: Histogram of the Pareto Diagram of Bridge Openings

For a sound analysis, we defined the population, the statistical unit, the studied variable, and the nature of the variable. In our case, the variable is discrete quantitative. This enabled us to produce the tables showing position and dispersion characteristics [59-60].

Table 14: Statistics of Bridge Degradations (OA) According to Number

Number of disorders (x_i)	1	2	3	4	5	6	7	8	Total
Numbers (n_i)	3	3	4	5	5	6	7	9	42
Frequencies (f_i)	7,21	7,21	9,17	12	12	14	16,80	21,61	100

Cumulative frequencies (F_i)	7.21	14,42	23,59	35,59	47,59	61,59	78,39	100	
$n_i x_i$	3	6	12	20	25	36	49	72	223
$n_i x_i^2$	3	12	36	80	125	216	343	576	1391
Mean (x)	5, 31								
Standard deviation (σ)	2, 22								
Confidence interval	[3; 8]								
Mode	8								

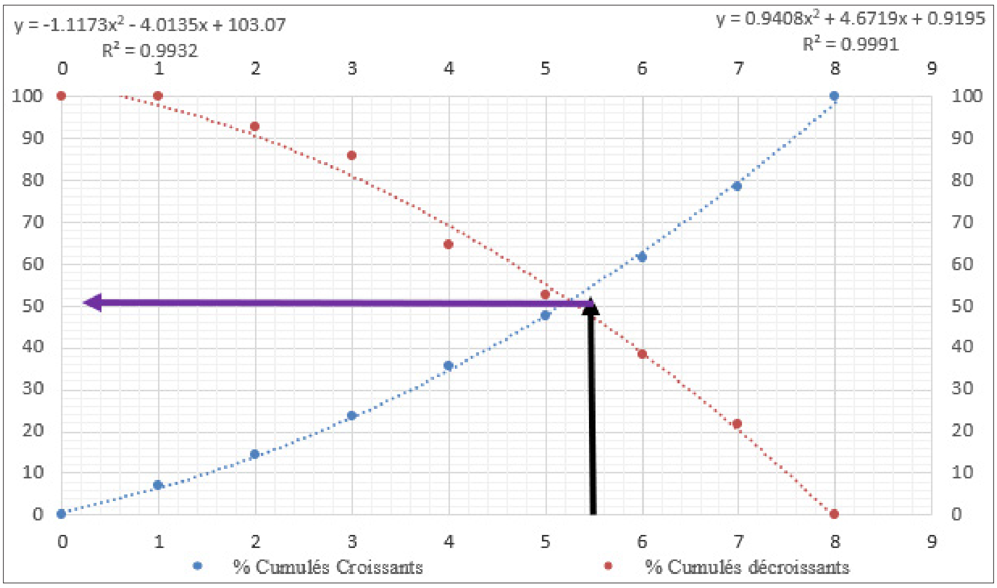

Figure 8: Histogram of the Cumulative Frequencies of Bridges

Table 15: Statistics of Culvert Degradations (OH) According to Number

Number of disorders (x_i)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**Total**
Number (n_i)	1	4	4	4	5	5	5	7	9	44
Frequencies (f_i)	2,27	9,10	9,10	9,10	11,36	11,36	11,36	15,90	20,45	100
Cumulative frequencies (F_i)	2,27	11,37	20,47	29,57	40,93	52,29	63,65	79,55	100	
$n_i x_i$	1	8	12	16	25	30	35	56	81	264
$n_i x_i^2$	1	16	36	64	125	180	245	448	729	1844
mean (x)	6									
Standard deviation (σ)	2,43									
Confidence interval	[4; 9]									
Mode	9									

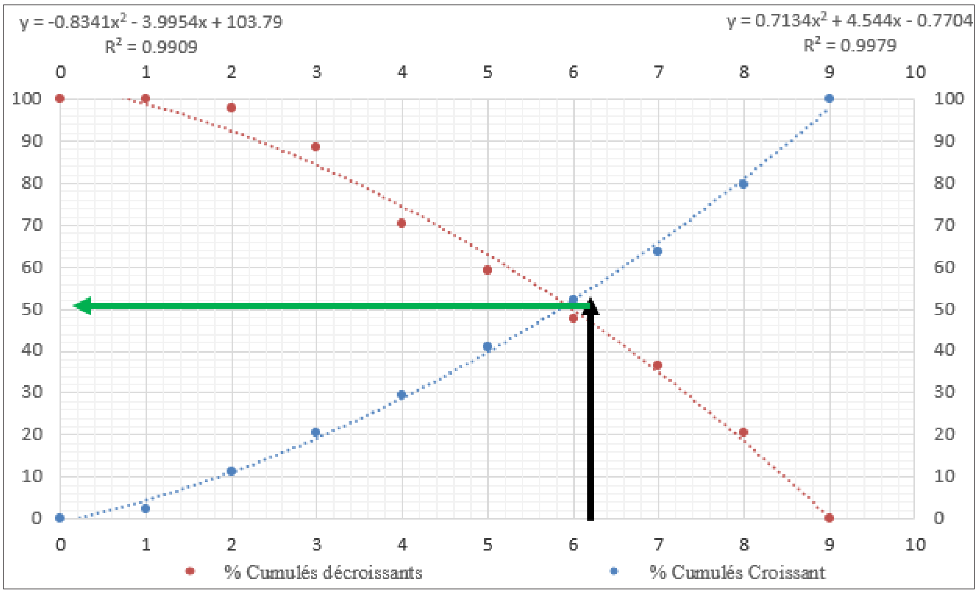

Figure 9: Histogram of the Cumulative Frequencies of Bridges

Table 16: Statistics of the Types of Structures Studied and According to Their Span

Type of structures (x_i)	1	2	3	4	5	Total	Spans (x_i)	1	2	3	4	Total
numbers (n_i)	105	10	8	7	4	134	Numbers (n_i)	3	4	2	2	11
Frequencies (f_i)	78	8	6	5	3	100	Frequencies (f_i)	27,28	36,36	18,18	18,18	100
Cumulative frequencies (F_i)	78	86	92	97	100		Cumulative frequencies (F_i)	27,28	63,64	81,82	100	
$n_i x_i$	105	20	24	28	20	197	$n_i x_i$	3	8	6	8	25
$n_i x_i^2$	105	40	72	112	100	429	$n_i x_i^2$	3	16	18	32	69
Mea n (x	1,48	Mean (x	2,27									
Standard deviation (σ)	1,006	Standard deviation (σ)	1,052									
Confidence interval	[1; 3]	Confidence interval	[1; 3]									
Mode	1	Mode	2									

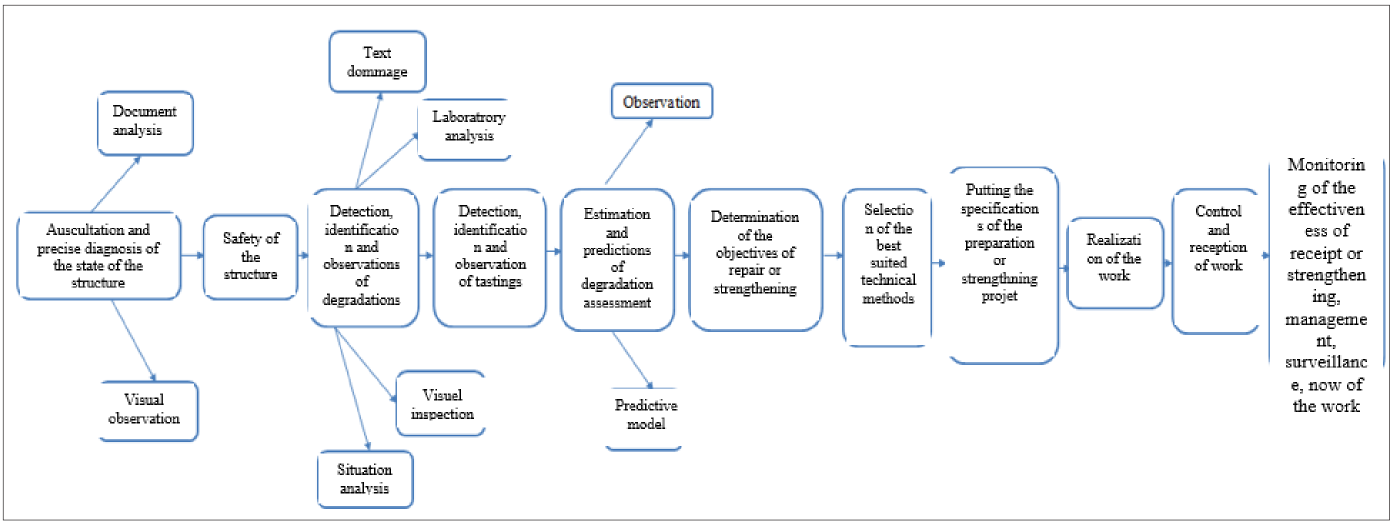

Figure 10: Organization Chart of the various Stages to follow for the Assessment of the Condition of a Bridge

Discussion

After performing the different laboratory tests, the following results emerge:

According to the ABC diagrams, we classify the disorders and the structures into three classes as follows:

Class A: The disorders that account for 80% of the bridge pathologies in the histogram of Figure 39 are 5 out of 8 and range from D8 to D4. These correspond to environmental pathologies and construction-related pathologies.

The structures that account for 80% of management problems in our study area in the histogram of Figure 40 are 9 out of 11.

Class B: The disorders that represent 15% of the bridge pathologies in the histogram of Figure 39 are 2 out of 8 and range from D3 to D2. These also correspond to environmental and construction-related pathologies.

The structures that represent 15% of the management problems in our study area in the histogram of Figure 40 are 2 out of 11.

Class C: The disorder that represents 5% of the bridge pathologies in the histogram of Figure 39 is 1 out of 8, which is D1. This corresponds to design pathologies [61-63].

The structure that represents 5% of the management problems in our study area in the histogram of Figure 40 is 1 out of 11.

We can therefore observe that the Pareto 20/80 principle is verified. Thus, according to Pareto, the bridge pathologies and management problems to be treated as a priority are environmental and construction-related. For each of these degradations, adequate solutions were identified and presented in Table 12 [64].

According to the ABC Diagrams, We Classify the Disorders and Structures into Three Classes as Follows:

Class A: The disorders that account for 80% of culvert pathologies in the histogram of Figure 41 are 6 out of 9, ranging from D9 to D4. These correspond to environmental and construction-related pathologies.

Class B: The disorders that represent 15% of culvert pathologies in the histogram of Figure 41 are 2 out of 9, ranging from D3 to D2. These also correspond to environmental and construction-related pathologies.

Class C: The disorder that represents 5% of culvert pathologies in the histogram of Figure 41 is 1 out of 9, which is D1. This corresponds to environmental and construction-related pathologies.

Again, the Pareto 20/80 principle is verified. Thus, according to Pareto, the culvert pathologies and management problems to be treated as a priority are environmental and construction-related. From our study, our itinerary includes five types of civil engineering structures: Metal Culverts (MC), Concrete Culverts (CC), Box Culverts (BC), Reinforced Concrete Bridges (RCB), and Prestressed Concrete Bridges (PCB). Concerning bridges, their choice and design depend on several factors, such as functional data, highlighting here the span. Hence, the Pareto diagrams were developed for their analysis [65].

According to the ABC Diagrams, We Classify the Disorders and Structures into Three Classes as Follows:

Class A: The structures that account for 80% of the types of structures in the histogram of Figure 42 are metal culverts, with a ratio of 105/134 in our study area.

The structures that account for 80% according to their span in the histogram of Figure 43 are structures with spans > 20 and also < 20, totaling 4/11 and 3/11, respectively.

Class B: The structures that represent 15% of the types of structures in the histogram of Figure 42 are concrete culverts and box culverts, with a ratio of 10/134 for CC and 8/134 for BC. The structures that represent 15% according to their span in the histogram of Figure 43 are those with spans > 100 and ≤ 100, each totaling 2/11.

Class C: The structures that represent 5% of the types of structures in the histogram of Figure 42 are bridges, with a ratio of 7/134 for RCB and 4/134 for PCB [66].

We can therefore conclude that the Pareto 20/80 principle is verified. Thus, according to Pareto, the types of structures to be treated as a priority are culverts, although bridges are not excluded, as they represent the Pareto tail, hence the use of Deming's Wheel (PDCA cycle). From Table 14, we observe that the most frequent pathology for bridges corresponds to the mode (8). Our study shows that the number of disorders averages 5 for the pathologies recorded during the investigation campaigns. The confidence interval is 85.71%, which leads to pathologies with a number of disorders around an average of 5.31 for a standard deviation of 2.22 disorders. About 50% of the pathologies in our study involve at least 5 disorders out of 8.

From Table 15, we observe that the most frequent pathology for culverts corresponds to the mode (9). Our study shows that the number of disorders averages 6 for the pathologies recorded during the investigation campaigns. In our study, the confidence interval is 79.54%, leading to pathologies with a number of disorders around an average of 6, with a standard deviation of 2.43 disorders. About 50% of the pathologies involve at least 6 disorders out of 9[67].

We note that the value of the median is close to the mean, indicating that the distribution of values is symmetric.

From Table 16, our study shows that metal culverts are the most numerous structures, with a mode of 1. Regarding spans, the mode is 2. Thus, culverts are the most degraded types of structures, with an average of 1. Concerning spans, the average span is 2. Consequently, 97.01% represents the confidence interval percentage for structure types, with an average around 1.48 per structure type and a standard deviation of 1.006. Similarly, 82% represents the confidence interval percentage for spans, with an average around 2.27 depending on the span and a standard deviation of 1.052 [68].

Recommendations

In the end, it is clear that the overall work carried out for the management of civil engineering structures is multidisciplinary: it involves both the manager (project owner), who aims to ensure the durability of the assets, and the inspector (design office or contractor), responsible for identifying and quantifying the defects. All these approaches therefore converge toward the same goal: not only to detect disorders and their causes as early as possible in order to promote minor maintenance over major repairs, but also, and above all, to minimize risks to the structure and its users. Although it has been demonstrated that most of the disorders recorded on structures occur during the operation phase, it is nonetheless important to emphasize that strictness during the design and construction phases would prevent many complications during maintenance and also in the repair of defects (see the issue caused by the absence of bearing bosses). At the end of our study, we recommend stricter control during the execution of structures with particular emphasis on: The construction of waterproofing systems (deck slab coating, scuppers, and downpipes), The selection and installation of bearing devices (always providing systems for their maintenance), Concrete mix design (water content and quality, reinforcement cover, aggregate size), Its implementation (vibration, compaction, etc.) [69-70]. Hence, the necessity and importance of a quality assurance plan (QAP) for civil engineering structures [70-71].

Conclusion and Perspective

Conclusion

This research work focused on the pathologies and management of civil engineering structures for the assessment of their condition and the enhancement of their durability. Based on the above, the following conclusions emerge:

- The stock of civil engineering structures is relatively recent, as approximately 30% of bridges managed by the Directorate of Road Operations and Maintenance are less than 50 years old,
- An overall view of the stock of civil engineering structures in our country, based on the inventory and inspection carried out in 2015, even though it was only based on visual observations,
- Thus, at the end of this work, we can affirm that given the complexity of road network management, the use of Geographic Information Systems (GIS) constitutes a considerable time-saving advantage: "The ability to quickly visualize, in map form, the position of an infrastructure and access its characteristics from the office provides a daily time-saving benefit for users." Moreover, one of the main strengths of GIS is the ability to provide unified management of all data related to the network. After thematic analysis of equipment such as safety devices, it was observed that 9.09% of safety devices along the Bafoussam–Makenene section are in good condition, 9.09% in poor condition, and 81.8% in average condition. This makes it possible, through a single tool, to integrate all parameters essential to achieving a satisfactory level of safety [72-75].

Perspectives

At the end of this work, it becomes clear that there remain numerous aspects worth further investigation or exploration, such as:

A deeper study of the issue of the durability of civil engineering structures in Cameroon, so that the elaboration of the influencing factors of this durability is considered across different regions,

The establishment of a Quality Assurance Plan (QAP).

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