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Enhancing the Philippine Pavement Management System: A Structural Assessment of Roxas Boulevard Using Falling Weight Deflectometer and Backcalculation Method

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Abstract – *The Philippine Department of Public Works and Highways (DPWH) oversees national road construction and maintenance. Under its Pavement Management System (PMS), the agency conducts visual condition surveys and road inventories to support asset preservation and network development planning. Despite regular road monitoring, reports of sudden pavement failures due to unforeseen poor subsurface conditions persist. This research study aims to address the gap in the structural assessment of roads by employing Falling Weight Deflectometer (FWD) and backcalculation method. The FWD measures deflection that is used to backcalculate pavement layer's elastic modulus or strength. As a preliminary analysis for this study, three backcalculation programs—BAKFAA, CalBack, and ELMOD—were compared based on their software characteristics and the consistency of their backcalculation results using deflection data from the Federal Aviation Administration (FAA). ELMOD showed consistent and reasonable results, producing modulus values for each pavement layer material within typical ranges, and was therefore chosen to assess the structural strength of the rigid pavements along Roxas Boulevard, Metro Manila. Sensitivity analysis of the backcalculated modulus values generally showed stable results across different seed values, particularly in trials using seed moduli that align with typical values of pavement layers. The evaluated sections of Roxas Boulevard show a 0.955% to 37.2% deterioration in structural capacity within 2-3 years following reconstruction, contrasting with the Visual Condition Index (VCI) of above 70.1, which indicates good road condition with little to no maintenance required. This discrepancy demonstrates that while the surface may appear satisfactory, the underlying structural integrity is compromised. The research findings underscore the importance of integrating road structural condition evaluation into the Philippine PMS.*

Keywords: *backcalculation, falling weight deflectometer, pavement nondestructive testing, pavement management system*

I. INTRODUCTION

1.1. Pavement Management System in the Philippines

The DPWH has adopted the PMS as the official system to monitor the condition and development of national roads in the Philippines [1]. Visual road condition, road roughness, road inventory, and pavement history surveys are among the important data inputs to the PMS, necessary for roadworks planning and programming processes. Visual road condition survey is conducted annually to assess the surface of the roads following the road condition (ROCOND) manual. The data gathered from the road condition surveys are further analyzed using the formula of VCI, one of the key performance indicators for road infrastructures. To consider the impact of the road distress on pavement conditions, weight factors are assigned to each type of road distress, and these factors are then used to calculate the VCI. Different formulas and weight factors are used depending on the material type of pavement surface as detailed in Department Order No. 120, Series of 2019. Using the VCI range, the road condition rating is determined with the recommended treatment measures as shown in Table 1.

Table 1. VCI-based road condition rating with recommended treatment measures [2]

VCI Range	Condition Rating	Treatment Measures
1 – 20	Bad	Needs to rebuilt pavement (total reconstruction)
20.1 – 40	Poor	Needs extensive full depth repairs, some full slab replacement/rehabilitation
40.1 – 70	Fair	Needs some partial/full depth repairs (preventive maintenance)
70.1 – 100	Good	Little or no maintenance required (routine maintenance)

In addition, VCI is supplemented by the International Roughness Index (IRI), a standard measure to quantify road surface roughness or smoothness. These indices assist in identifying road networks or sections requiring rehabilitation, maintenance, and/or reconstruction which is the replacement of existing pavement layers with new materials [3].

1.2 Structural Pavement Deterioration

As the population increases rapidly, along with the increase of traffic demand, pavement roads experience greater distress, leading to faster road deterioration, not only on the surface but also in subsurface layers. The failure of the underlying pavement layers is far more critical and sudden than surface failures. Complaints regarding the repair and reconstruction of roads without visible surface defects have been a national concern. The DPWH addressed these repair works as the proactive implementation of preemptive measures aimed at preserving pavement structures that appear perfectly fine on the surface but are undergoing internal deterioration [4].

Figure 1 shows examples of pavement failures from structural deterioration in Metro Manila. In June 2019, a section of Roxas Boulevard, Manila collapsed and a 14-wheeler truck carrying 40 tons of sand fell into the hole. The road was built above a double-barrel box culvert that was constructed in the 1970s, which had a capacity of only 20 tons. Reports said that the truck's weight caused the sudden failure [5]. Another example was last April 2024, part of a section in Sales Road in Pasay was closed to traffic because of a hole filled with water. The reports said that it may be caused by leakage of a water pipeline that slowly erodes the soil underneath the road [6].

(a) (b)

Figure 1. Pavement failure in (a) Roxas Boulevard [5] (b) Sales Road, Pasay [6]

These instances highlight the need for monitoring the structural or subsurface condition of roads. Hence, it is important to develop the current PMS in the Philippines to ensure the safety of the local roads and their users.

1.3 FWD and Backcalculation Programs

Countries in North America [7], Europe [8], and Asia [9] conduct functional performance evaluations and structural assessments using nondestructive and/or destructive testing methods. These countries employ cost-effective and well-designed pavement evaluation tools, such as visual inspection through survey vehicles, mobile devices, and other image processing technologies to provide qualitative surface characteristics data. For road structural evaluations, the FWD is widely used to obtain the strength of pavement layers, even though it requires trained personnel to operate the machine. It is often supplemented by Ground Penetrating Radar (GPR) or destructive testing, which involves random coring of the wear surface at the tested section and subjecting it to material testing to obtain Young's modulus [10].

The FWD is a nondestructive equipment that primarily consists of a hammer with a specific mass, a loading plate approximately one foot in diameter with seven or more sensors (geophones or accelerometers) spaced radially around the loading plate as shown in Figure 2 [11]. The procedure involves dropping the hammer directly on top of the loading plate from a certain height, with the geophones or accelerometers then measuring the deflections of the subsurface layers of the pavement roads.

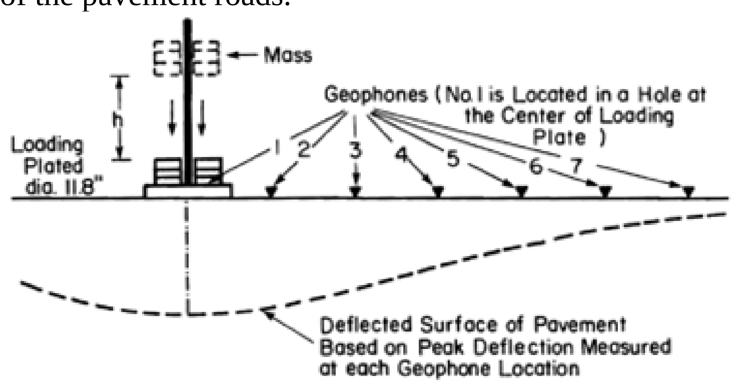


Figure 2. FWD test setup [11]

The deflections measured along the radial distance around the loading plate are called the deflection basin of the tested pavement structure. The measured deflection data from FWD testing are then analyzed using backcalculation software to calculate the elastic modulus of the existing underlayers. The backcalculation process, as shown in Figure 3, involves the random assignment of a seed modulus value for each pavement layer. Ideally, it will be used to calculate the theoretical deflections of these layers. If the calculated deflections deviate beyond tolerable differences from the in-situ deflections, the program will assign another value of modulus (E) to initiate a new iteration. Once it falls within the tolerable differences, it will be reported as the backcalculated modulus (E) of a layer. It is noteworthy that, like the pavement design procedure, there is no unique solution obtained from this method. This is due to the iterative nature of the software which employs various assumptions in determining the moduli (E) of the pavement road [11].

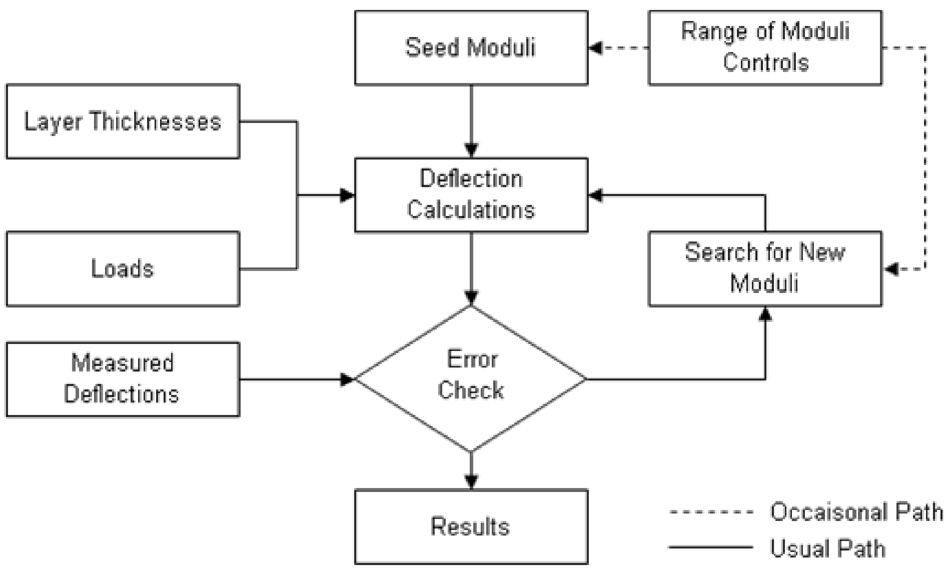


Figure 3. Backcalculation process [12]

Several backcalculation programs have been developed to improve the analysis and optimization of the technique of the program. Early developed programs employed layered elastic theory for the analysis. Structural information including layer thicknesses, and their type of materials are necessary input in the program. It is crucial to acknowledge that the convergence of backcalculated moduli to an acceptable error varies among different backcalculation programs, as they employ diverse methods. Consequently, the outcomes obtained from distinct backcalculation programs may differ.

Various studies have compared different backcalculation programs based on their capabilities and limitations in terms of inputs, backcalculation settings, and outputs. In the backcalculation process, the study of White [13] found that there is a significant influence of the difference in the number of layers of the roads being analyzed to the backcalculated modulus values but not to the pavement strength rating obtained. For that reason, different moduli results can be obtained from different backcalculation software. In addition, Chou and Lytton [14] mentioned that the reason behind the difference in backcalculation results produced by different analysts is the sensitivity of input parameters such as thickness, Poisson's ratio, load configuration, error tolerance, the maximum number of iterations, seed moduli and depth to bedrock, given the same backcalculation program was utilized. Their study shows that layer thickness is one of the crucial inputs that can drastically change the backcalculation result. To check the accuracy of the backcalculation programs, the study of Ahmed [15] compared three software by analyzing the coefficients of variation (CV) of the backcalculated layer moduli. With this, the backcalculation program that gave the least variation in the modulus results was recommended. On the other hand, the study of Priddy [16] compared different procedural analyses of backcalculation programs and gave recommendations for improving the procedures used for backcalculation. They recommended additional research on factors such as seed modulus values, moduli ranges, and Poisson's ratio values as a function of temperature and age. Using their recommendation, different seed modulus values were used in the analysis of the study to determine the variation of backcalculated results of the software being analyzed.

BAKFAA is a software developed by the FAA to backcalculate the moduli of pavement layers through Falling or Heavy Weight Deflectometer Data (FWD/HWD). It is one of the most flexible backcalculation programs as it can analyze different pavement layer types. Although BAKFAA version 2.1.0.1 does not have an option for pavement material per layer, the program provides recommended input values of seed young's modulus of elasticity and Poisson's ratio depending on the type of paving materials, as shown Table 2. [17]

Table 2. Typical modulus and Poisson's ratio values for pavement materials [17]

Material	**Typical Modulus Values, PSI (MPa)**			**Typical Poisson's Ratio Values**	
	Low	Typical	High	Low	High
Asphalt Concrete	70,000 (500)	500,000 (3,500)	$2x10^6$ (14,000)	0.25	0.40
Portland Cement Concrete	$1x10^6$ (7,000)	$5x10^6$ (35,000)	$9x10^6$ (60,000)	0.10	0.20
Lean-concrete Base	$1x10^6$ (7,000)	$2x10^6$ (14,000)	$3x10^6$ (20,000)	0.15	0.25
Asphalt-treated Base	100,000 (700)	500,000 (3,500)	$1.5x10^6$ (10,000)	0.25	0.40
Cement-treated Base	200,000 (1,400)	750,000 (5,000)	$2x10^6$ (14,000)	0.15	0.25
Granular Base	10,000 (70)	30,000 (200)	50,000 (350)	0.20	0.40
Granular Subbase or Soil	5,000 (30)	15,000 (100)	30,000 (200)	0.20	0.40
Stabilized Soil	10,000 (70)	50,000 (350)	200,000 (1,400)	0.15	0.30
Cohesive Soil	3,000 (20)	7,000 (50)	25,000 (170)	0.30	0.45

In obtaining the backcalculation results, the program follows an iterative process using layered elastic analysis. The software calculates the elastic modulus per layer by minimizing the root mean square (RMS) difference between the calculated and measured deflections. The program does not have a representative basin for the analysis, but its iterations are performed using the LEAF (Layered Elastic Analysis, FAA) function. It can also provide joint transfer efficiency, which calculates the distribution of deflections across rigid pavement airfield joints [17].

California Backcalculation (CalBack) is a software developed by California Transportation (CalTrans) to be a Mechanistic-Empirical (ME) Design and Analysis tool used to analyze flexible, rigid, and composite pavements [18]. It was primarily designed for conditions existing in California and uses relevant databases based on the specific location. The software was designed to aid in pavement design of the CalME software, however it may be used as standalone software for backcalculation. The software can handle multiple deflection basins for long stretches of the pavement, and it allows the division of the pavement into statistically similar subsections for design purposes using the cumulative difference method described in AASHTO 1993. Users can choose to manually enter raw data which can also be edited through the user input. For each layer, material properties are from CalME Design Database which assigns values to certain parameters with a maximum of 5 layers to be analyzed. Deflection basins are then fitted to each test point in the batch run to determine their layer elastic moduli. The software implements Westergaard's Equation to determine the elastic modulus of joints and corners of Portland Cement Concrete (PCC) pavements. Bell's Equation is implemented to obtain layer temperatures in the analysis of flexible pavement. For data with several drops used, results may be estimated using linear regression analysis. Lastly, the depth to bedrock of the pavement is determined using the Odemark-Boussinesq Method or LEAP method [19].

Evaluation of Layer Moduli and Overlay Design 6 (ELMOD 6) aims to minimize reliance on the use of empirical software when analyzing pavement. This software can utilize point-related structure information, such as output from GPR testing and analysis obtained onsite. Temperature correction functions and seasonal variations can be graphically displayed in the software, and it can process data in either the US Customary System or the SI Metric System. It has two methods for backcalculating the elastic modulus of the pavement layers. The first method is the radius of curvature method, which is based on the Odemark-Boussinesq Method of Equivalent Thicknesses (MET) using the outer geophone readings to determine the upper pavement layer moduli. The stiffness of the remaining layers is then calculated based on the overall response of the pavement to the applied load. The second method is the deflection basin fit method, which also utilizes the Odemark-Boussinesq method, but it also uses an additional iteration process that has convergence criteria based on the degree of fit between the overall measured and the calculated deflection basins [20].

1.4 *Framework of the Study*

As shown in Figure 4, the outline of the research involved the integration of two important parts of pavement analysis, which include the surface and subsurface evaluation. The surface evaluation assesses the visible condition of pavement and is achieved through the VCI assessment, which uses data from the ROCOND survey. On the other hand, the subsurface evaluation analyzes the deeper condition of the pavement structure with the use of various backcalculation methods on nondestructive test results acquired through FWD equipment. The research presents a comparative study that is derived from the findings of the two levels of analyses, examining the reliability of each method and their complementary relationship in determining pavement performance.

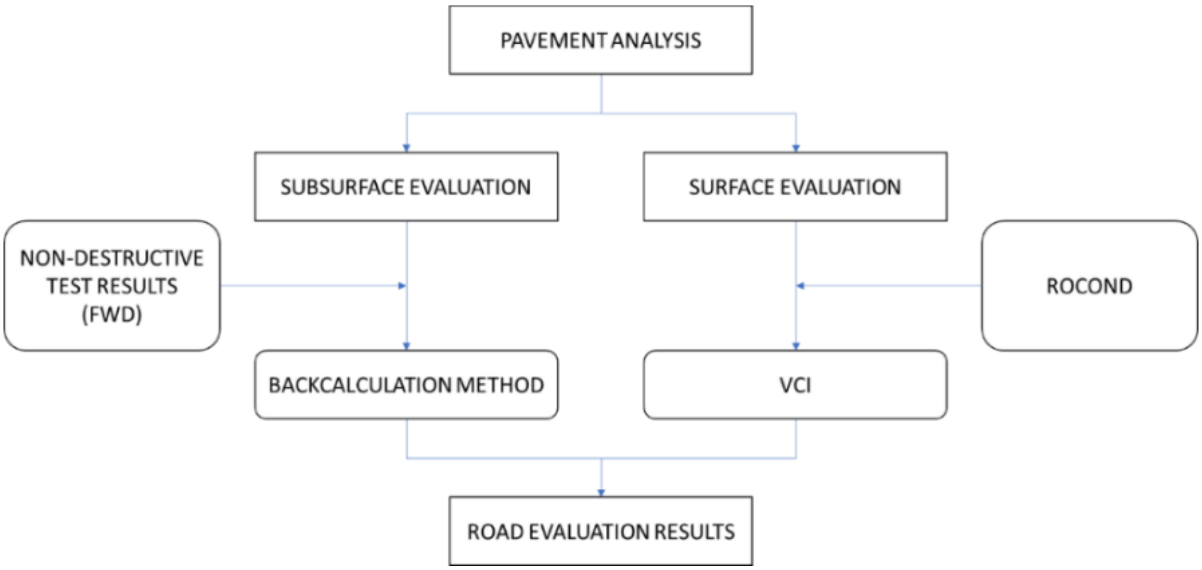


Figure 4. Framework of the study

In addition, this research explores the discrepancies between surface distress and subsurface conditions and the resulting possible indication of hidden defects in construction or material used in pavements. With this, the study aims to integrate the use of nondestructive testing through FWD together with the backcalculation analysis into the Philippines government's official PMS for reliable local assessments of pavements structural integrity. This is targeted towards better decision-making and resource allocation for road maintenance and rehabilitation.

II. METHODOLOGY

2.1 Preliminary Analysis: Comparison of Backcalculation Programs

A comparative analysis focusing on the software's characteristics and features was conducted on three backcalculation programs namely, BAKFAA, CalBack, ELMOD. Table 3 presents a summary and comparison of the characteristics of the programs.

Table 3. Characteristics of backcalculation programs

Program Characteristics	Backcalculation Programs		
	BAKFAA version 2.1.0.1	**CalBACK version 1.02-20200201**	**ELMOD 6**
Developer	FAA	CalTrans	Dynatest
Input			
Files	.csv, .ddx, .dat, .ddx, .F20, .F25, .fwd, .hwd, .txt	.fwd, .hwd, .F10, .F20, .F25, .MDB	Jils FWD Data, Dynatest/ELMOD Database
Pavement Layer Type	Flexible/ Rigid/ Composite	Flexible/ Rigid/ Composite	Flexible/ Rigid/ Composite
Material	X	✓	✓
Poisson's Ratio	✓	X	✓
Thickness	✓	✓	✓
Max # of Layers	10	5	5
Seed Moduli	✓	Material dependent	✓
Error Detection	X	✓	✓
Others	Interference Parameter		
Backcalculation processing			
Temperature Effect	X	✓	✓
Maximum Iteration	5,000	N/A	N/A
Convergence Scheme	RMS	RMS	Various
Representative Basin	X	✓	✓
Output			
Rigid Layer Depth	X	✓	✓
Measured deflection	✓	✓	✓
Calculated deflection	✓	✓	✓
Graph	Measured and Calculated Deflection, Young's Modulus by layer	Deflection, Layer Modulus, Temperature, Deflection Ratio (%)	Deflection, Layer Modulus, Temperature
Others	Joint Transfer Efficiency File conversion	Supplementary to CalME for Pavement Design	

The backcalculation programs vary in their acceptance of file format, but some file types are shared. The programs can analyze multiple pavement types such as rigid, flexible, and composite pavements but input parameters vary. BAKFAA requires seed moduli rather than specific layer materials, and CalBack's Poisson's ratio input is optional. The thickness of each pavement layer is universally required but differences exist in the maximum allowable layers for analysis. For the backcalculation process, variations are evident, particularly in how temperature affects the elastic modulus calculations. Unlike other programs, BAKFAA does not require temperature input. Iteration limits also vary; BAKFAA imposes a maximum iteration, while others have no such constraint. Each program also uses different methods for convergence criteria. For output features, BAKFAA does not calculate rigid layer depth, as other programs do. All programs provide both measured and calculated pavement deflections.

The rationality and consistency of moduli results in analyzing rigid pavements of these backcalculation programs were assessed using the FWD data collected at the National Airport Pavement Test Facility (NAPTF) by the US Army Engineer Research and Development Center (ERDC) Dynatest on 2011 [21]. The pavement structural information and other necessary software inputs are detailed in Figure 5. Note that the program inputs regarding the material type may vary, reflecting the program's limitations. Additionally, the seed moduli inputs were determined based on typical moduli of specific material types, as recommended by the FAA. Moreover, a recorded surface temperature of 55.4°F during data collection was considered as input for Callback and ELMOD, whereas BAKFAA did not consider it in its analysis.

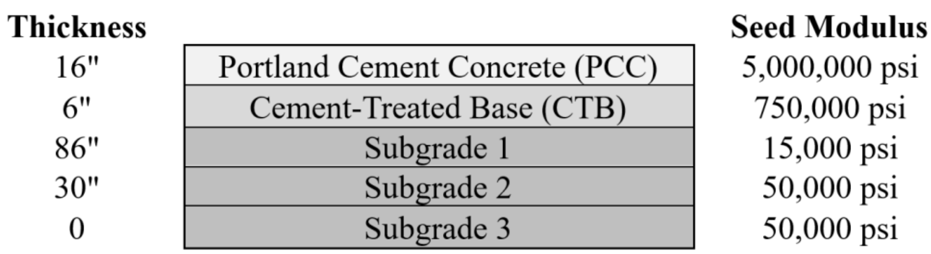


Figure 5. NAPTF rigid pavement structure

2.2 FWD Test in Roxas Boulevard

Roxas Boulevard is an 8-km road section in Metro Manila situated along the shoreline of Manila Bay. The road is known to have a high volume of truckloads with annual average daily traffic (AADT) of 191,120, accommodating 1,858 trucks and trailers in 2017 [22].

In June 2017, the DPWH conducted an FWD test on Roxas Boulevard, Manila, two to three years after the road's reconstruction. The test covered road sections from Luneta Park to a few meters past the intersection of Russell Avenue and Roxas Boulevard. The FWD machine was placed at designated testing locations, which targeted the center points of lanes 1 and 2 (northbound and southbound directions) at 50- or 100-meter intervals along Roxas Boulevard, as illustrated in Figure 6.

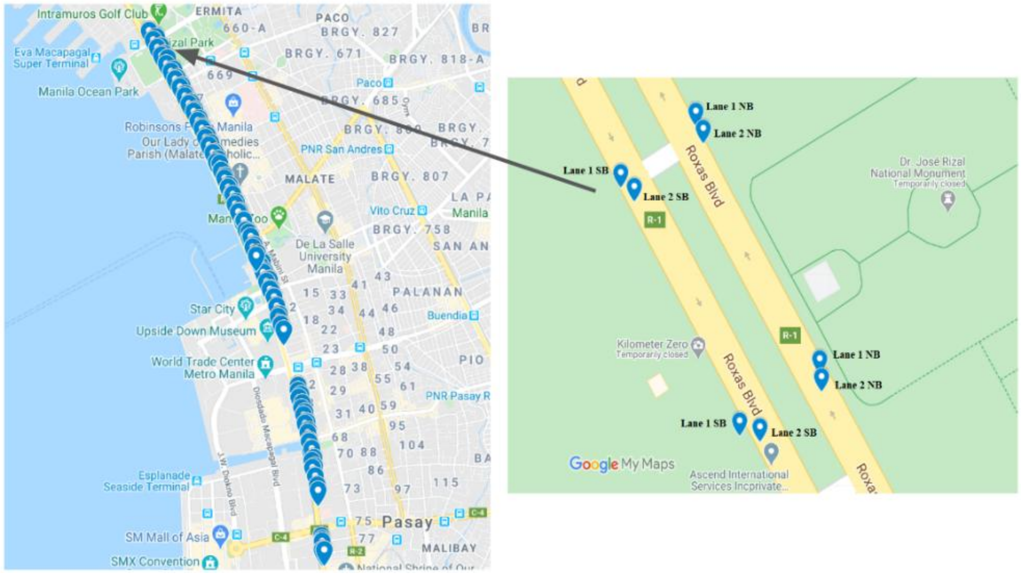


Figure 6. Roxas Boulevard FWD test points

For each test point, the FWD machine applied a load magnitude of 90 kN, repeated three times. The load was released onto a foot plate from a predetermined height, and the 11 sensors (S1 - S11) configured in Figure 7 measured and recorded the deflection data, including the air and surface temperatures. Throughout the survey, the data errors were monitored by observing the deflection pattern, and if any occurred, the testing was repeated.

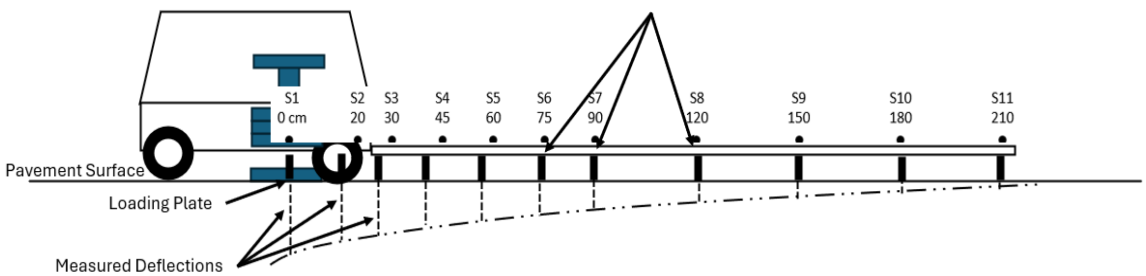


Figure 7. Configuration of FWD sensors (cm)

Ideally, as a load is applied to the pavement surface, the deflection response should decrease as the distance from the load increases. According to FAA Advisory Circular (AC) Guidelines on NDT [23], examining the gradual and smooth transition of the deflection basin prior to backcalculation is necessary. Abrupt changes in value could indicate the presence of anomalies and should not be included in the analysis, as they may lead to unreasonable backcalculated moduli. Data points exhibiting linear negative slope deflection basins such as Figure 8 were included in the analysis, as this graph behavior is indicative of a rigid pavement as stated in the FAA-AC guidelines [23].

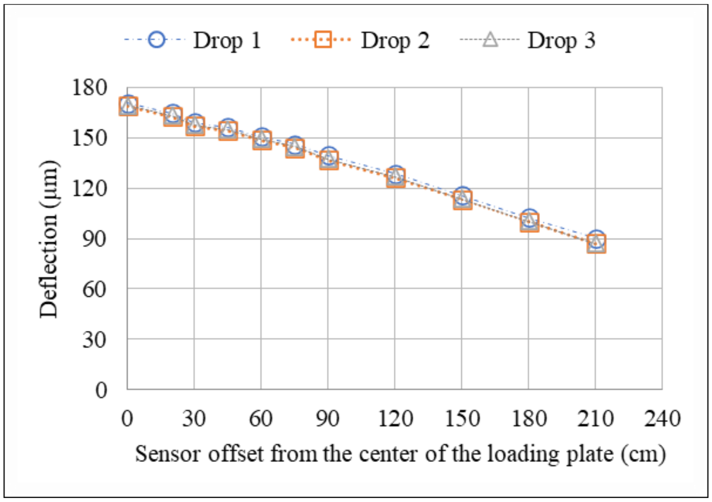


Figure 8. Deflection basin of rigid pavement at chainage 0+098 of section A, lane 1

The measured deflection data from the FWD test were filtered for rigid pavement behavior. A total of thirty (30) out of one hundred (100) data points, as detailed in Table 4 and illustrated in Figure 9, met the deflection basin criteria for rigid pavement and were used to backcalculate the modulus of the rigid pavement structure of Roxas Boulevard. The pavement material type and slab thickness of the selected sections were verified in the 2018 road inventory summary of NCR [24]. All test points have a concrete slab thickness of 340 mm, except for chainage 6+000, which has a 300 mm slab thickness.

Table 4. FWD test points of the rigid pavement of Roxas Boulevard

Direction	Road Section	Section ID	Chainage (m)	
			Lane 1	Lane 2
Northbound (NB)	A	S02883LZ	0 + 098	0 + 100
			0 + 200	0 + 200
			0 + 295	0 + 300
			0 + 362	0 + 347
	B	S04543LZ	5 + 887	5 + 700
				5 + 800
				5 + 900
	C	S03494LZ	6 + 000	6 +000
Southbound (SB)	D	S02725LZ	0 + 000	0 + 000
			0 + 105	0 + 100
			0 + 203	0 + 200
			0 + 300	0 + 306
	E	S04542LZ	5 + 846	5 + 616
			5 + 906	5 + 700
			5 + 995	5 + 900
				5 + 987
	F	S03353LZ		6 + 000

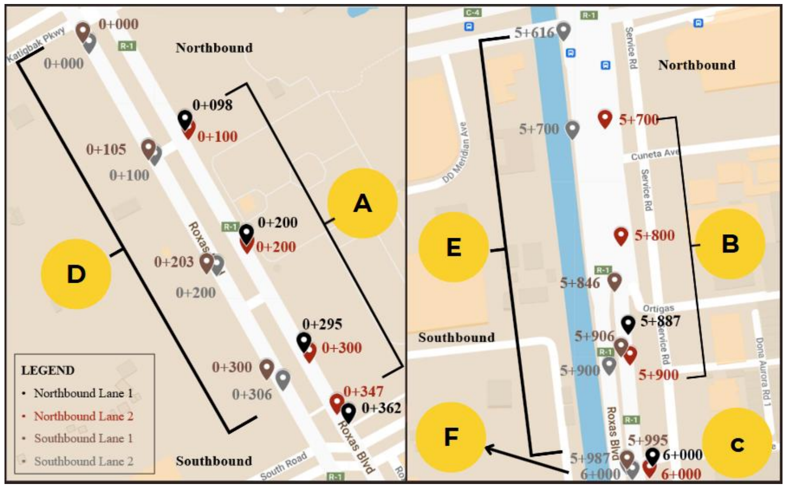


Figure 9. Location of FWD test points on rigid pavement

A comprehensive understanding of the data's behavior was further achieved through statistical analysis. To assess the variability in deflection measurements across different test points within a road section, test points with identical section IDs were systematically grouped. The analysis involved calculating the CV in FWD deflection data to determine the uniformity of pavement properties. In general, a CV less than 10% shows that structural properties are quite consistent over the tested area. In a 10 to 20% CV range, small variances in pavement properties are expected but can still be considered acceptable. CV values above 20% indicate significant variations in pavement structure, which call for further investigation as structural weaknesses may exist.

2.3 Backcalculation of Roxas Boulevard FWD Data

The recommended backcalculation software from the preliminary analysis was then used for the backcalculation analysis of Roxas Boulevard's rigid pavements. Figure 10 shows the road section's structural information including the layer materials, thicknesses, and design modulus from the DPWH database, design manual, and BAKFAA. Note that the subgrade is assumed to have the design modulus of a stabilized soil, as the DPWH Dynamic Cone Penetration Data Report indicates a California Bearing Ratio (CBR) of 60-100% at depths of 557 mm and beyond [25].

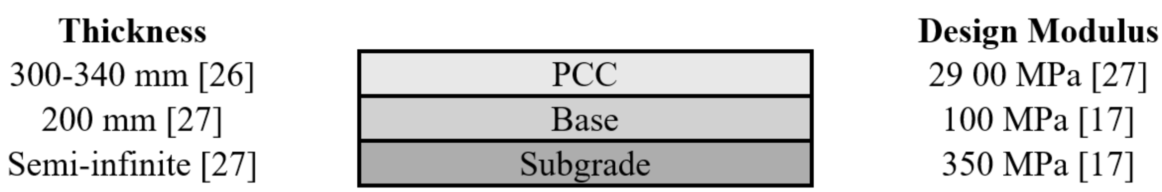


Figure 10. Roxas Boulevard rigid pavement structure

Deflection data from thirty (30) specified points along Roxas Boulevard were used for backcalculating moduli using the deflection basin fit method. This method was selected due to reliance on the principles of Odemark-Boussinesq and its incorporation of an additional iteration process to take advantage of convergence criteria, which are determined by assessing the degree of fit between the overall measured and calculated deflection basins [20]. In addition, a sensitivity analysis was conducted to evaluate the reliability of the backcalculated modulus results in relation to the input seed modulus as shown in Table 5.

Table 5. Trial seed moduli for backcalculation analysis of Roxas Boulevard FWD data

Layer No.	Material Type	Seed Modulus, MPa				
		Trial 1: All Typical	Trial 2: Design (1), Typical (2), Typical (3)	Trial 3: Middle (1), Typical (2), Typical (3)	Trial 4: All Middle	Trial 5: Design (1), Middle (2), Middle (3)
(1)	PCC	35,000	29,000	21,000	21,000	29,000
(2)	Base	100	100	100	65	65
(3)	Subgrade	350	350	350	210	210

2.4 Analysis of Backcalculated Moduli Results

2.4.1 Consistency of the Backcalculated Moduli

The consistency of backcalculated modulus results from the five trials with different seed modulus results were assessed using statistical analysis. The analysis was performed at each point, comparing the p-value results of One-Way ANOVA. In this test of statistical significance, the independent variable is the different trials while the dependent variable is the modulus results obtained from the trials. In cases where the data violated the assumption of homogeneity of variances (Levene's Test), having a p-value less than 0.05, an alternative mean comparison called Welch's ANOVA was applied [28]. Additionally, a Games-Howell Post Hoc Test was executed to compare variability between two trials. This post hoc test was chosen due its independence from equal variances and sample sizes [29].

2.4.2 Road Deterioration and Visual Condition Index

To assess the relationship between the results from FWD and ROCOND survey, the deterioration and VCI of the road sections were compared. Road deterioration indicates the deviation over the years of the backcalculated modulus results from the design modulus. The percent change (%) for each road section was determined using the formula below.

$$Road\ Deteriotation\ (\%) = \frac{Average\ Modulus - Design\ Modulus}{Design\ Moduus} \times 100 \qquad (1)$$

The average backcalculated results for each lane per road section were calculated using a 5% trimmed mean, removing the outliers through interquartile range and boxplot analysis. Meanwhile, the VCI and condition rating of the road sections analyzed in the study were obtained from the DPWH database. Table 6 shows the factors considered in calculating the VCI for concrete pavement. After determining the weight value for each distress, the sum of weight distress (SDWf) is computed using Equation 2 and then applied in Equation 3 to calculate the VCI. The VCI and condition rating of the road data were then used to compare the evaluated pavement surface conditions and the backcalculated modulus results, providing an assessment of the correlation between the conditions of surface and subsurface layers.

Table 6. Distress weight factors for Concrete VCI [2]

Distress	Weight Factor (Wf)
Cracking – Multiple – Narrow	3.6
Cracking – Transverse - Wide	5.5
Cracking – Transverse - Narrow	3.5
Spalling (spalling severity)	3
Faulting (faulting average)	4.2
Shattered Slabs (number)	1.36
Scaling – Severe	1.2
Scaling - Minor	0.55
Joint Sealant Deterioration	0.13

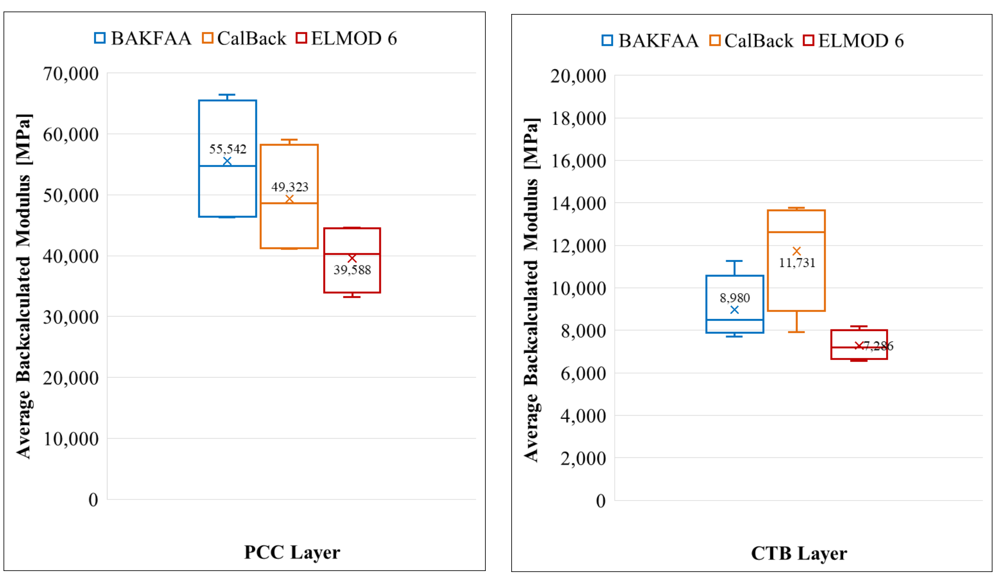
$$SDWf = (\text{Cracking} \times \text{Wf}) + (\text{Spalling} \times 3) + (\text{Faulting} \times 4.2) + (\text{Shattered Slabs} \times 1.36) + (\text{Joint Sealant} \times 0.13) + (\text{Scaling} \times \text{Wf}) \quad (2)$$

$$\text{VCI} = 100 \times \left(1 - \frac{\sqrt{1-\left(100-\frac{SDW_f}{3}\right)}}{100}\right)^2 \text{ where } SDWf \geq 300 \quad (3)$$

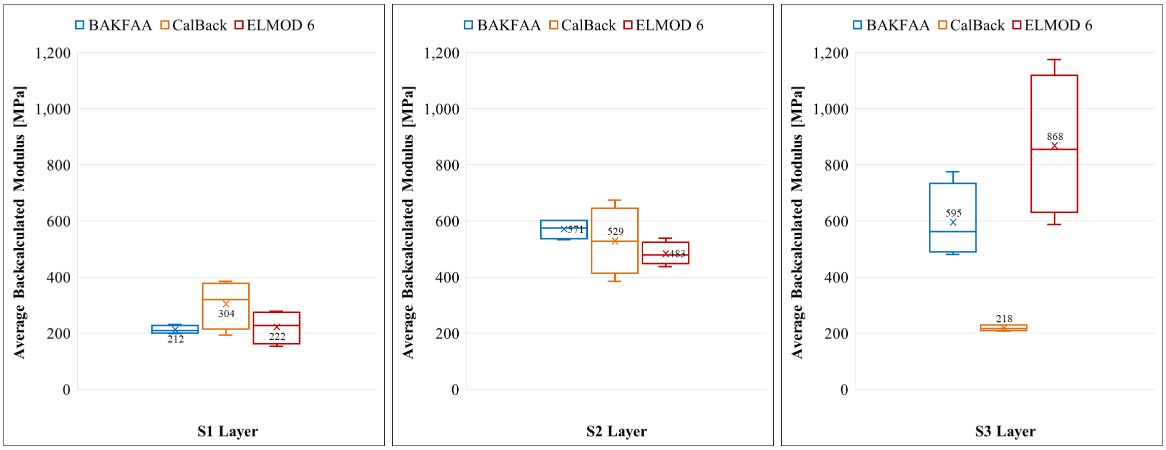
III. RESULTS AND DISCUSSIONS

3.1 Comparison of Backcalculation Programs: NAPTF Backcalculation Results

Figure 11 presents a comparison of the average backcalculated modulus of the rigid pavement layers of NAPTF, as determined by BAKFAA, CalBack, and ELMOD 6.



(a) (b)



(c)

Figure 11. Average backcalculated modulus of the NAPTF rigid pavement structure for (a) (a) PCC (b) CTB layers (c) subgrade layers – S1, S2, S3

BAKFAA has the highest average backcalculated modulus for the PCC layer. In contrast, ELMOD consistently presents the lowest moduli values, closely aligning with the typical material modulus of 35,000 MPa, as presented in Table 2. For the CTB layer, CalBack provides the highest average backcalculated modulus, while ELMOD gives the lowest value, aligning closely with the typical modulus value which is 5,000 MPa. For the subgrade layers, backcalculated values of CalBack exceed the expected range (30 – 200 MPa) for the upper subgrade layer but remain within acceptable limits (70 – 1400 MPa) for the lower layers. The average moduli values of BAKFAA and ELMOD for subgrade layers slightly exceed the upper limit (200 MPa) for the upper subgrade layer but remain within the range (70 – 1400 MPa) for the lower two layers.

Table 7 shows the relative difference between the average modulus and the typical modulus value of each layer. BAKFAA consistently produces higher backcalculated modulus values compared to the typical modulus values across all layers. Meanwhile, CalBack records the highest deviations, particularly in S1 (193.78%), which surpasses the upper limit for the layer modulus, indicating a significant overestimation. Moreover, CalBack has a negative deviation (-36.77%) in S3 layer, indicating that the backcalculated modulus is much lower than the typical value, suggesting potential sensitivity to the lowest layer. ELMOD demonstrates moderate deviations (15 and 41%) in the upper layers (PCC and CTB), making it the most conservative among the three. However, it records the highest deviation in the lowest layer (S3), suggesting a possible challenge in the estimation of the modulus of the deepest layer.

Table 7. Percent difference between average modulus and typical layer modulus

Software	Deviation of average modulus from typical layer modulus (%)				
	PCC	CTB	S1	S2	S3
BAKFAA	61.11	73.67	104.96	65.53	72.62
CalBack	43.07	126.87	193.78	53.37	-36.77
ELMOD	14.83	40.91	114.58	40.25	151.93

ELMOD's backcalculation results were consistently within an acceptable range for each layer material, aligning closely with typical modulus values. Hence, it was chosen as the software for analyzing Roxas Boulevard. Selection was further amplified by its user-friendly interface, easy access to all the required data, and convenient manual editing for input parameters.

3.2 Coefficient of Variation in Roxas Boulevard Deflection Data

The summary of the CV of deflections measured by each sensor for each road section is presented in Table 8. In road section A, consistent low CV with values below 10% for all sensors are observed. Meanwhile, road section B shows a moderate to high CV, particularly for sensors 1 to 7, with values well above 20%. Moderate CV ranging from 10.66% to 18.47% are observed for road section C. In road section D, low CV in deflections, all below 11% are observed across sensors. Road section E has relatively high CV, exceeding 20% for sensors 1 to 8, with the first sensor reaching over 50%. Lastly, the road section F shows a low CV in deflections and likely resulting from the small sample size.

Table 8. CV of measured deflections by sensors across road sections

Sensor	Coefficient of Variation (%)					
	A	B	C	D	E	F
1	8.36	26.35	10.66	9.70	51.65	0.69
2	7.97	24.45	11.80	10.20	25.86	0.80
3	8.20	25.25	12.51	10.92	26.41	0.89
4	8.04	24.28	13.22	9.68	25.62	1.00
5	8.23	23.56	14.11	8.84	25.17	1.00
6	8.45	22.35	14.60	8.22	24.30	1.07
7	8.16	21.42	15.27	7.45	23.47	1.18
8	7.62	18.53	16.15	6.67	21.55	1.39
9	7.81	16.80	17.08	6.19	19.48	1.71
10	8.48	15.36	17.96	5.89	18.01	2.03
11	9.19	12.94	18.47	6.19	16.24	2.39

Significant differences in the CV deflection data between the test sections suggest substantial variations in the elastic modulus for each test point within the road section. The material heterogeneity with differences in properties of aggregates or variability in compaction and construction, including uneven densities or layer thicknesses across the different sections, could account for such variability. Temperature and moisture may also influence modulus values since environmental factors affect material stiffness whereas load-induced changes cause differential material fatigue across heavily and lightly trafficked areas. The large CV differences in deflection across the road section, especially with some sensors in road sections B and E having a CV greater than 20%, indicate that the layers' material properties are not uniform within the tested area, suggesting possible pavement strength anomalies. Thus, a deeper analysis of pavement layer strength within these test sections is essential.

3.3 Pavement Elastic Moduli of Roxas Boulevard

Statistical analyses are conducted to evaluate the consistency of the backcalculated modulus results with respect to seed modulus values. Table 9 shows the results of Levene's test and ANOVA on the backcalculated results of each pavement layer of Roxas Boulevard.

Table 9. Statistical test results for each pavement layer of Roxas Boulevard

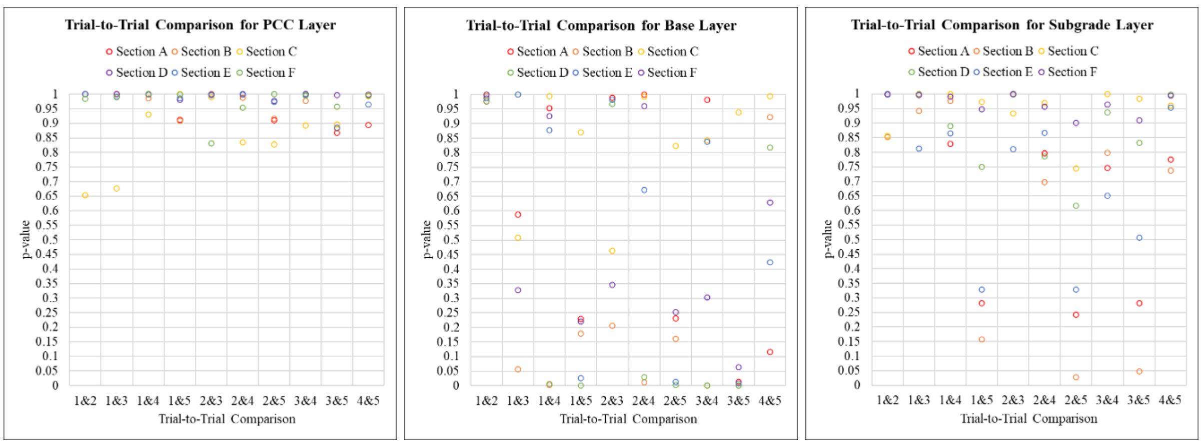
Direction	Road Section	PCC		Base		Subgrade	
		Levene's	**ANOVA**	**Levene's**	**ANOVA**	**Levene's**	**ANOVA**
Northbound (NB)	A	0.719	0.855	0.118	0.035	0.054	0.186
	B	0.979	0.852	0.005	9.80×10^{7}	9.80×10^{4}	0.034
	C	0.624	0.537	0.403	0.466	0.716	0.754
Southbound (SB)	D	0.993	0.977	0.681	2.50×10^{7}	0.823	0.572
	E	0.998	0.919	0.107	0.009	0.161	0.159
	F	0.839	0.911	0.355	0.014	0.641	0.828

Levene's test results reveal that the variances for the five trials of backcalculated elastic modulus are homogeneous across all layers for each road section, with the exception of the base and subgrade layers in road section B, which showed p-values below 0.05. This means that standard ANOVA applies to most layers and sections, whereas Welch's ANOVA is applied to base and subgrade layers in section B to account for unequal variances.

For the PCC layer across all road sections, the ANOVA analysis reveals no statistically significant differences in the backcalculated modulus values, suggesting consistency in this layer's modulus results regardless of the seed moduli values used. In the base layer, only road section C demonstrates no significant differences in modulus, whereas the other sections display significant variations. For the subgrade layer, only road section B shows a statistically significant difference in modulus results, while the other sections indicate no significant differences. The significant differences in results are influenced by variability in material properties and layer strengths within the tested area, as well as the impact of seed moduli values on the base layer's backcalculated modulus results. Further investigation into specific trials is needed to identify which seed moduli values are driving these differences, especially in sections other than section C, where variability is pronounced.

The results of the Games-Howell test on the five trials with different seed moduli values for the pavement layers of each test section are shown in Figure 12. In the PCC layer, the p-values in all trials are greater than 0.05, indicating that there are no significant differences between the means of each trial-to-trial comparison and that the PCC backcalculated modulus is not affected by the seed moduli values applied. For the base layer, road sections C and F show no significant difference for all trials. Meanwhile, road section A recorded a significant difference only in trials 3 and 5. In road section B, trials 3 and 5, as well as trial 4 compared to all other trials, are significantly different, showing that trial 4 seed moduli values largely affect the resulting backcalculated modulus. In road section D, the major differences are found between the comparison of trial 4 and all others (except trial 5), and between trial 5 and all others (except trial 4), suggesting that trials 4 and 5 contribute to variability within this section.

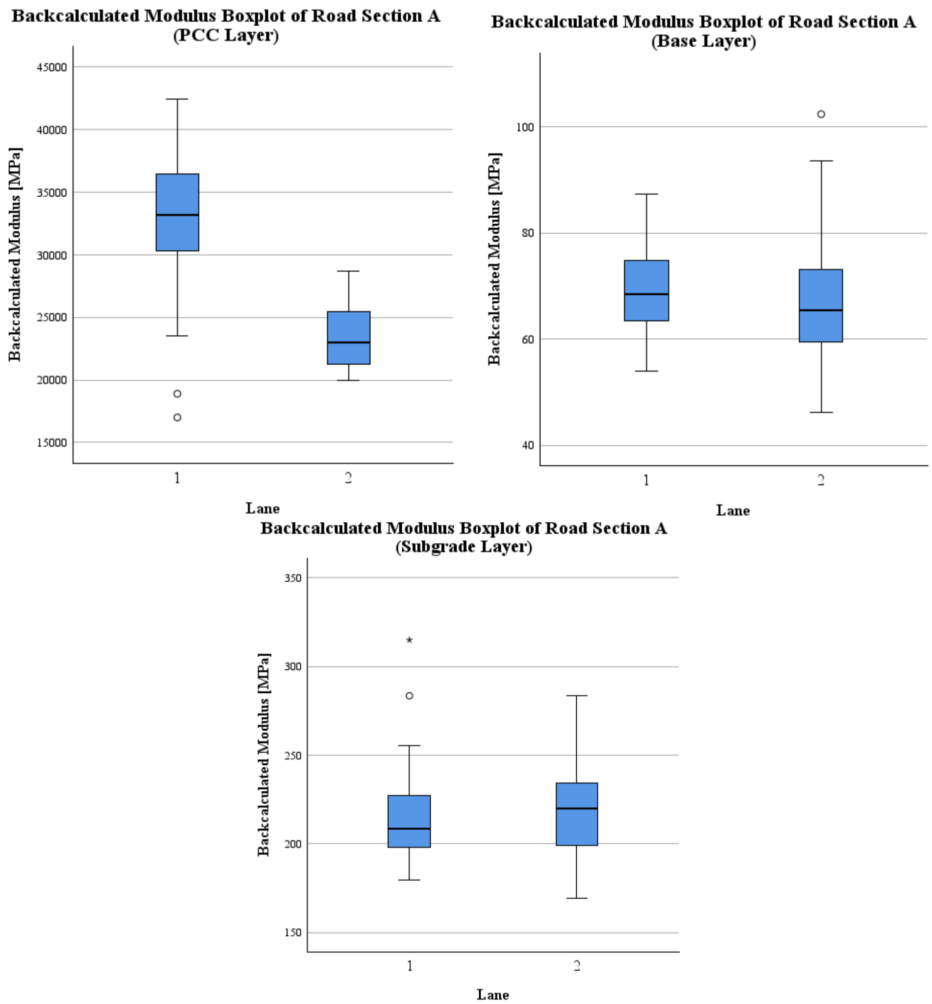
In road section E, trial 5 is significantly different from trials 1, 2, and 3, meaning that trial 5 also provides unique backcalculated modulus results in this road section. For the subgrade layer, the p-values for the mean comparison from trials 2 and 5, and trials 3 and 5 fall below 0.05 for road section B only. This means that in this road section, the seed modulus of Trial 5 is not recommended for the backcalculation analysis. Overall, the Games-Howell test results show that although there is a variety in some sections of roads in particular trials, modulus results are homogeneous for most of the layers, especially in PCC and subgrade layers. This suggests that, for most sections, the seed moduli values used do not substantially impact the backcalculated modulus results, especially in trials using seed moduli values that align with typical moduli values of pavement layers. However, the significant differences in sections B and E, especially with trial 5 in the subgrade layer of section B, indicate that this trial's seed modulus may not be suitable for reliable analysis.



a) (b) (c)

Figure 12. Trial-to-trial comparison of backcalculated modulus results for Roxas Boulevard's (a) PCC (b) base (c) subgrade layers

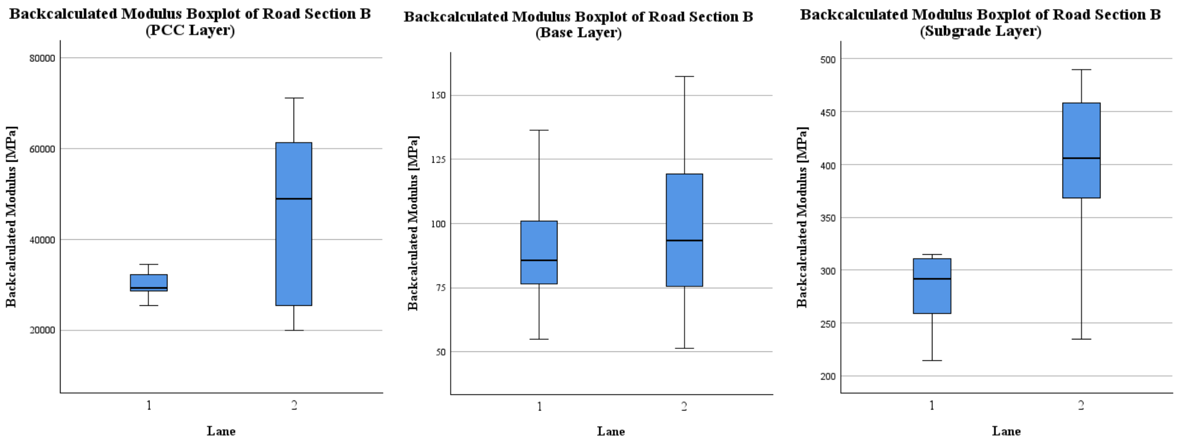
The boxplots for the average backcalculated modulus of each lane in the test sections are presented in Figures 13-18. Road section A's PCC layer shows variability, with lane 1 having two mild outliers (represented by circles), and a higher average modulus than lane 2. The base layer is uniform with nearly equal modulus values between lanes except for lane 2 that has one mild outlier. In subgrade layer, lane 1 has one mild and one extreme outlier (represented by an asterisk), while lane 2 shows no outliers, with both lanes having similar modulus values.



(a) (b) (c)

Figure 13. Boxplot of backcalculated modulus for road section A:
(a) PCC (b) base and (c) subgrade layers

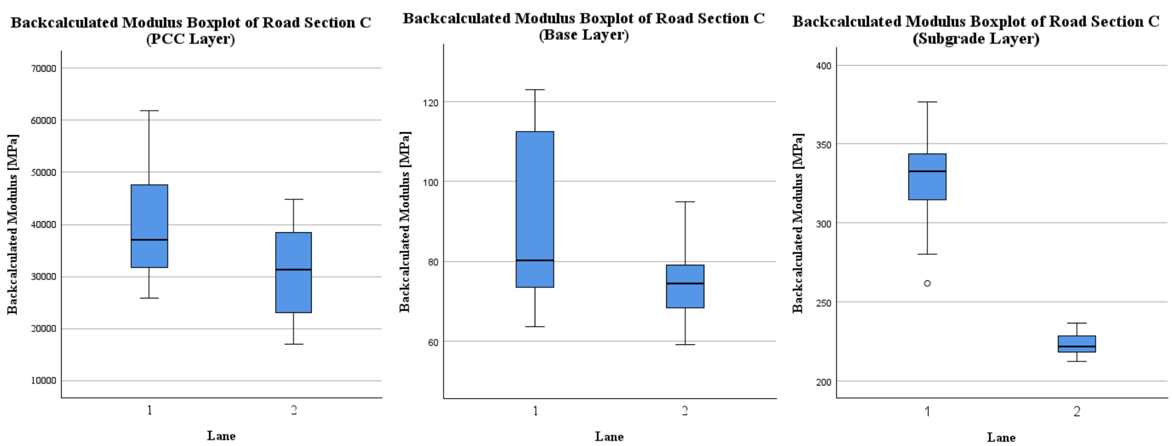
The boxplot analysis in road section B shows no outliers for each layer, signifying that the data are consistent and within expected ranges. The values in lane 1 are more uniform than those in lane 2 in the PCC layer, which has higher average modulus but greater variability in modulus, thus indicating some variability in the material properties or conditions. For the base layer, lanes 1 and 2 are similar in average modulus but lane 2 has a higher range of modulus results. For the subgrade layer, lane 2 has a greater average modulus than lane 1.



(a) (b) (c)

Figure 14. Boxplot of backcalculated modulus for road section B: (a) PCC (b) base and (c) subgrade layers

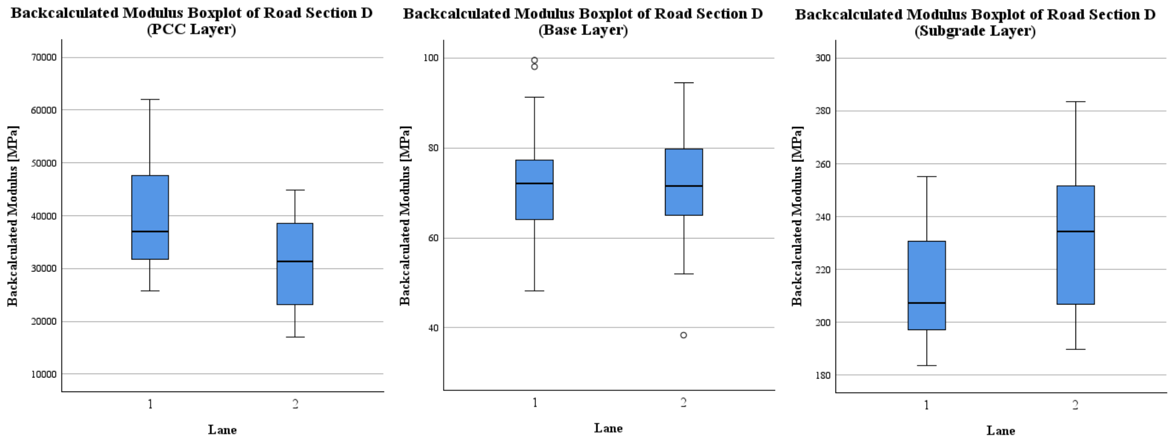
The boxplot results for road section C in Figure 15 show no outliers in the modulus results, except for lane 1 of the subgrade layer. Lane 1 consistently has a higher backcalculated modulus than lane 2 across all layers. While the base layer in lane 1 shows greater variability, lane 2 exhibits more uniform modulus values, particularly in the subgrade layer.



(a) (b) (c)

Figure 15. Boxplot of backcalculated modulus for road section C: (a) PCC (b) base and (c) subgrade layers

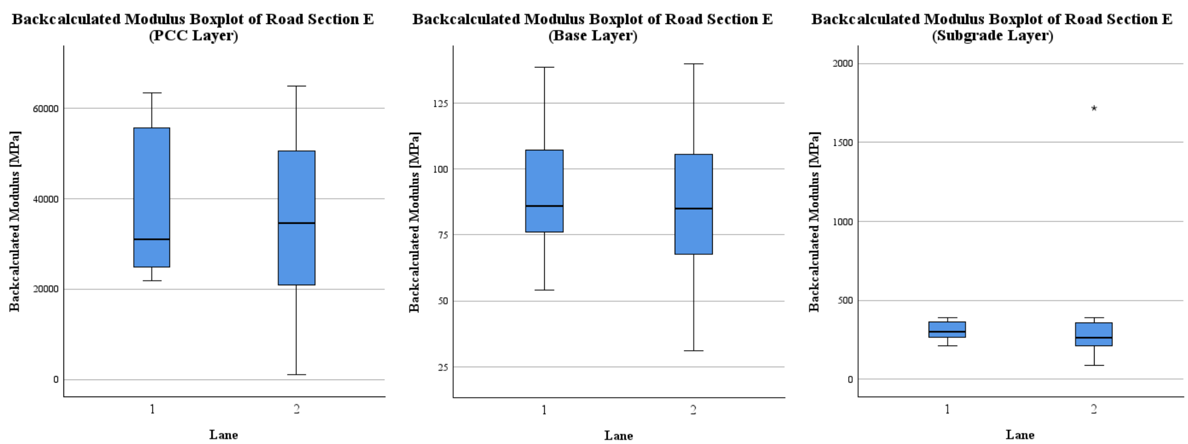
Figure 16 shows no outliers in section D's PCC layer. However, lane 2 has a lower backcalculated modulus compared with lane 1, suggesting differences in stiffness. For the base layer, the average modulus values of lanes 1 and 2 are almost similar although both have mild outliers. In the subgrade, lane 2 has a higher average modulus than lane 1, with no outliers in either lane, indicating more robust support in lane 2's subgrade compared to lane 1.



(a) (b) (c)

Figure 16. Boxplot of backcalculated modulus for road section D:
(a) PCC (b) base and (c) subgrade layers

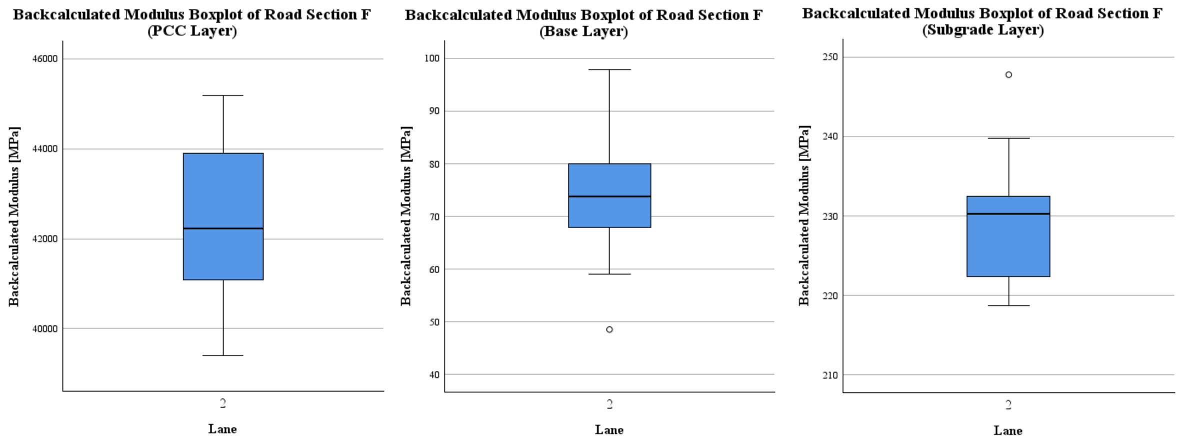
There are no outliers present in sections E's backcalculated PCC layer results as shown in Figure 17, though lane 2 shows higher values than lane 1, indicating some variability in the top layer strength. The base layer results are nearly equal between lanes, suggesting uniformity. In the subgrade layer, while modulus values are generally consistent, lane 2 has an extreme outlier and a slightly lower average modulus than lane 1.



(a) (b) (c)

Figure 17. Boxplot of backcalculated modulus for road section E:
(a) PCC (b) base and (c) subgrade layers

In Section F, only lane 2 was tested, revealing consistent results with minimal variability across layers as shown in Figure 18. The PCC layer shows no outliers, indicating uniformity in its modulus values. However, both the base and subgrade layers each have a mild outlier, suggesting slight deviations in these layers’ material properties or conditions.

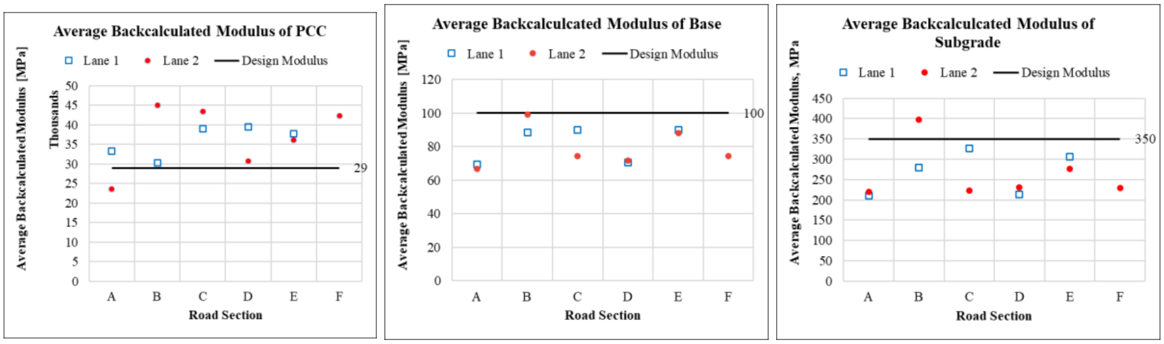


(a) (b) (c)

Figure 18. Boxplot of backcalculated modulus for road section F: (a) PCC (b) base and (c) subgrade layers

The results of the boxplot analysis show stable and consistent modulus values across the road sections, with only 1 to 2 mild or extreme outliers in specific layers and lanes. This pattern suggests generally reliable results from backcalculation analysis.

Figure 19 shows the comparison between the average backcalculated moduli of the pavement layers from their design modulus. In the PCC layer, the average backcalculated results for most sections are greater than the assumed design modulus of 29 GPa, except for road section A, lane 2. In contrast, the base layer indicates a consistent pattern of being lower than the 100 MPa elastic modulus values in all sections. The subgrade layer has backcalculated modulus values that are below the 350 MPa design modulus except in the case of section B, lane 2. For the base and subgrade layers, the average backcalculated moduli of road sections A, C, D, and F are significantly less than the design modulus. This trend suggests possible internal deterioration or loss of stiffness in the pavement structure relative to the surrounding areas [30]. However, there are also other factors that contribute to these results. A well-constructed PCC layer with good load transfer mechanisms like dowels or aggregate interlock at joints, provides greater resistance to deformation. Under loading, the localized stress felt by the pavement is reduced resulting in minimized deformation that in turn would increase the observed modulus. Moreover, low modulus results in base layers often occur when a thin base course is beneath a thick PCC layer. This happens because the thin base provides minimal structural contribution compared to the much stiffer and thicker surface layer. In addition, similar behaviors are observed for granular base/subbase materials having increased modulus with confinement, leading to variations. Recorded deflections may also be affected by random variations in pavement layer thicknesses and subgrade parameters, presence of high water table level, and temperature differences in the slab that can cause slab curling or warping [31].



(a) (b) (c)

Figure 19. Average backcalculated moduli of (a) PCC, (b) base, and (c) subgrade layers in Roxas Boulevard

3.4 Comparison of Road Deterioration and Road Condition Rating

Figure 20 presents the deterioration percentage, calculated by comparing the average backcalculated modulus with the assumed design modulus, along with the VCI sourced from the DPWH database, for each lane within the analyzed test sections.

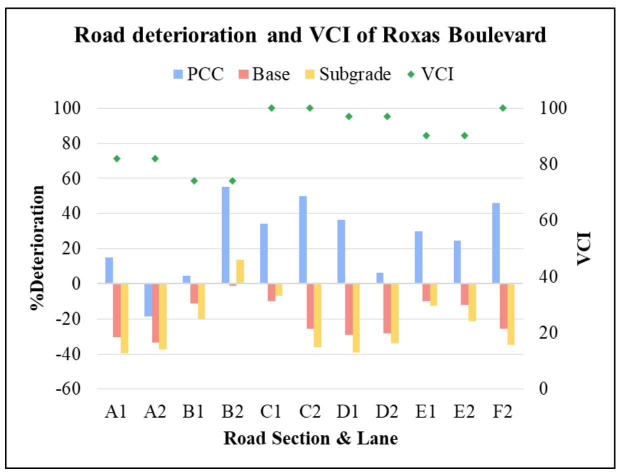


Figure 20. Road deterioration and VCI of Roxas Boulevard

All the road sections have a VCI value greater than 70.1 and obtained a "Good" condition rating, suggesting that little to no maintenance is recommended as a *treatment* measure for the road section. The high strength results of PCC layers for all road sections except lane 2 of section A obtained through the backcalculation method produce a positive percent deterioration, suggesting that the constructed PCC layer may have a higher original modulus than the assumed design modulus. Even then, the results remain consistent with the good road condition rating derived from the VCI. Meanwhile, the deterioration results of base and subgrade layers reveal a decrease in strength over time, indicated by negative deterioration percentages ranging from -6.67% to -39.03%. The low moduli of base and subgrade layers in relation to their design moduli values suggests inadequate stiffness felt by these layers that affect the overall stability of the structure [30]. Internal deterioration occurred in sections A, C, D, and F, which had negatively deteriorated by 20-30% in the base and subgrade layers is likely due to increased traffic loading, particularly from stopping vehicle loads near commercial areas and intersections, especially in Road Sections A and D which are on the side of Luneta Park, having above 28% deterioration. However, since some of the design parameters are based on assumed values, it is still recommended to compare the backcalculated results with the laboratory modulus values or data for acceptance tests, such as coring, for in-depth results verification and correlation determination.

While the visual condition index and condition rating suggest that the road sections are still in good condition and do not require major maintenance, the road deterioration results indicate a need for checking the road's base and subgrade layers for rehabilitation. This contrast underscores the importance of assessing not only the surface conditions of the road through the Visual Condition Index but also the strength and condition of the subsurface layers through nondestructive testing.

IV. CONCLUSION AND RECOMMENDATIONS

The study explored the FWD data analysis and backcalculation method to assess the pavement structural condition of Roxas Boulevard. Among the three backcalculation programs—BAKFAA, CalBack, and ELMOD, the recommended software for analysis of FWD rigid pavement data is ELMOD because of its consistent performance in giving backcalculated modulus results that align closely with the typical modulus values of the pavement material.

Careful engineering judgment is advised in the interpretation of the results as the software has sensitivity to input parameters. The general results of the sensitivity analysis indicate that the pavement's backcalculated elastic moduli show consistency even with different seed moduli values are used, except for a couple of specific trials and some layers. From the ANOVA analysis, the values of modulus in the PCC layer are stable across trials with p-values greater than 0.537, while the layers of base and subgrade show some variability in some sections, especially in section B having p-values for the base and subgrade layers equal to 9.80×107 and 0.034, respectively. The Games-Howell test further investigates the effect of the seed moduli values using trial-to-trial comparison. The results confirm that the backcaclulated moduli in PCC layers are consistent with a minimum p-value of 0.653. However, the base and subgrade layers' results are reactive to the seed moduli values of trials 4 (21 GPa for PCC, 65 MPa for base, and 210 MPa for subgrade) and 5 (29 GPa for PCC, 65 MPa for base, and 210 MPa for subgrade). The base layers of road sections B, D, and E have trials 4 and 5 producing p-values lower than 0.05 and subgrade layer's section B produces a p-value less than 0.05 in trial 5. Input parameters, particularly seed moduli values, must be carefully selected to ensure accurate strength results. For improved accuracy and reliability, backcalculated modulus output results are suggested to be evaluated by accounting for effects due to temperature fluctuations, traffic loads, and construction/rehabilitation histories of the structures. Standardized procedures for conducting FWD testing and adherence to a set of established guidelines are of great importance to ensure minimal errors and yield appropriate results.

In the pavement evaluation of Roxas Boulevard, even though the surface layers of road sections A-F showed little to no defects with VCI greater than 70.1, the road deterioration results through backcalculation analysis show a 0.955% to 39.6% road deterioration. Sections

A, C, D, and F exhibit more significant deterioration in the base and subgrade layers, amounting to 18.67 to 39.64% road deterioration. These results indicate a need for checking the road's base and subgrade layers for rehabilitation.

Overall, the assessment shows that there is a need to monitor and evaluate the condition of the roads beyond visual inspections, especially in areas where underlying structural issues may not be apparent. Theoretically, the FWD testing may be used to assess the national road network in the Philippines since it primarily depends on well-skilled operators and proper equipment. Additionally, it can be applied to road sections of any pavement type and is especially recommended for pavements showing surface defects. However, a considerable degree of judgment is needed to assess adjustment factors for specific sites. Although the DPWH is capable of using FWD tests in their investigative reports, these reports do not fully utilize the potential of FWD data. Specifically, the gathered deflection data in local roads are not evaluated using backcalculation analysis to determine the properties and structural condition of the pavements. Including backcalculation analysis would increase the value of FWD testing since it would extract more pavement condition information. The study further supports the integration of FWD testing and backcalculation analysis into the existing Philippine PMS framework since the technique presents a promising tool for the enhancement of road infrastructure management. Official road condition survey data must include FWD test data to provide more comprehensive information about pavement health. Combining methods like FWD testing and backcalculation analysis with the existing practices in road condition assessments will allow policymakers and road authorities to take more informed decisions to maximize maintenance efforts and resource allocation in improving quality and safety of roads.

V. ACKNOWLEDGEMENT

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