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Analysis of Road Damage Level Using the Pavement Condition Index (PCI) Method on the Surabaya-Gresik Toll Road, East Java

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***Abstract*—The Surabaya–Gresik toll road is a crucial infrastructure connecting Surabaya City with Gresik Regency. In industrial areas such as Gresik Regency, this toll road is indeed needed to expedite the flow of industrial goods distribution to Surabaya City. The toll road experiences frequent damage, such as alligator cracking, as it is traversed daily by heavy traffic. If the road, as a connecting infrastructure, is damaged, it will impede the flow of vehicles passing through it. Therefore, road maintenance is necessary to ensure optimal service for passing vehicles. In this research, an analysis of road damage on the Surabaya – Gresik toll road seeks solutions for addressing these issues utilizing the method of Pavement Condition Index (PCI). The method involves several stages, including a survey of road conditions, determination of severity levels, assessment of damage, and determination of pavement condition. The survey was conducted in 100-meter segments from KM 10 to KM 14, revealing various types of damage on the toll road, including alligator cracking, bleeding, corrugation, shoving, potholes, and more. Thereafter, an analysis of the severity level and damage assessment was carried out, resulting in an average PCI value of 68, categorized as a "Good" condition. Based on these findings, it is recommended to address this issue through routine maintenance, including repairing minor damage, patching potholes, sweeping, repairing pavement edge damage, sidewalk maintenance, side channel and complementary building drainage, road equipment, and roadside maintenance.**

***Keywords*— Infrastructure; pavement condition index; road damage; toll road; traffic.**

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I. Introduction

The Surabaya-Gresik toll road is a crucial infrastructure connecting Surabaya City to the Gresik Regency. The presence of this toll road has a vital function in creating a balanced development in the Surabaya, Gresik, and surrounding areas. Industrial areas like Gresik Regency undoubtedly require a toll road as the primary distribution facility to expedite the movement of industrial goods to Surabaya City. Along with the rapid economic growth in Gresik Regency and Surabaya City, it indeed leads to a significant increase in the volume of vehicles that pass through the Surabaya – Gresik toll road. Of course, it can certainly cause a decrease in road quality and various types of damage, such as alligator cracking, bleeding, corrugation, shoving, potholes, and others, which can undoubtedly cause significant disruptions to the traffic flow [1].

The issue of road infrastructure damage not only concerns the inconvenience of road users but also can impede the traffic flow [2]. Therefore, it is necessary to perform regular and effective road maintenance to ensure that the toll road's function as a primary distribution route remains optimal [3]. This research analyzes the road damage on the Surabaya–Gresik toll road and the solution for addressing this damage using the Pavement Condition Index (PCI) method. The Pavement Condition Index (PCI) method is a system for evaluating pavement condition based on type, extent, and severity of damage, which can be used as a guide in maintenance efforts [4] [5]. PCI aims to provide an objective overview of the level of damage or wear on the road surface based on visual evaluation and specific measurements [6]. The stages of this method include a survey of road damage conditions, determination of severity levels, assessment of damage, and determination of pavement condition [7].

Based on the context description, the research problem formulation is managing the damages along the Surabaya–Gresik toll road using the PCI method. Through a comprehensive understanding of the types and impacts of damages occurring on the Surabaya–Gresik toll road, this research aims to find solutions for handling these damages, formulate maintenance strategies to enhance the toll road's durability, contribute positively to traffic flow, and ensure the continuity of this infrastructure's function in supporting regional economic growth**.**

II. Materials and Method

This research was conducted on the Surabaya – Gresik toll road, specifically from KM 10 to KM 14, as indicated in Fig 1. In the context of assessing the condition of the toll road, the survey yielded significant findings related to various types of damage on the road surface, including alligator cracking, bleeding, corrugation, shoving, potholes, and various other types of damage that can affect the performance and overall condition of the road infrastructure [8]. The study area was chosen because it represents a critical segment of the toll road, frequent traffic with various loads and speeds. This area's survey and condition evaluation results provide a highly relevant basis for formulating specific maintenance and road repair strategies within this segment. Additionally, it aids in more effectively managing the entire toll road network. Therefore, the research area has a crucial function in maintaining and improving the toll road infrastructure, enhancing the comfort and safety of road users.

Fig. 1 Research area

A. Data Collection

In the research process, careful analysis is required, and the more complex the issues faced, the more complicated the analysis needed. Practical analysis necessitates accurate data and information supported by relevant theories [9]. In this research, two types of data are used as follows:

1) Primary Data: Primary data is data collected by researchers or collected directly in the field from relevant people [10]. The primary data in this research are as follows.

- Data in the form of images for each type of road damage
- Data on the dimensions and extent of each type of damage

2) Secondary Data: Secondary data is data that the researcher obtains not directly from the subject but through other sources, both oral and written [11]. Secondary data in this research is as follows.

- Road Network Maps
- Road Geometrics
- Data on road length and width

B. Analysis Method

In analyzing road damage condition, the Pavement Condition Index (PCI) method is used with the following stages:

1) Density: Density is the area percentage of the total length of the damage type or the total length of the measured road segment [12]. Therefore, the density formula can be seen in the following equation [13].

$$Density = \frac{Ad}{As} \times 100\% \qquad (1)$$

Description:
Ad: The overall types of damage for each level of damage
As: The number of segments for each sample unit

2) Deduct Value: The deductible value or mitigation value is calculated for each type of damage thanks to the relationship curve between density and deductible value [14]. These reduction values is differentiated based on the level of damage for each type of damage [15].

3) Total Deduct Value (TDV): The total amortization value is the result of adding up the individual abatement values for each type and extent of damage found in a sampling unit [16].

4) Corrected Deduct Value (CDV): Before determining the CDV, it is necessary to establish the maximum CDV obtained through the most minor deduct value approach, which is set to become 2. Subsequently, the value of q will decrease until it reaches q = 1 [17]. After that, the total deduct value (TDV) is calculated and correlated with the value of q [18]. The graph of the relationship between CDV and TDV can be seen in Fig 2 [19].

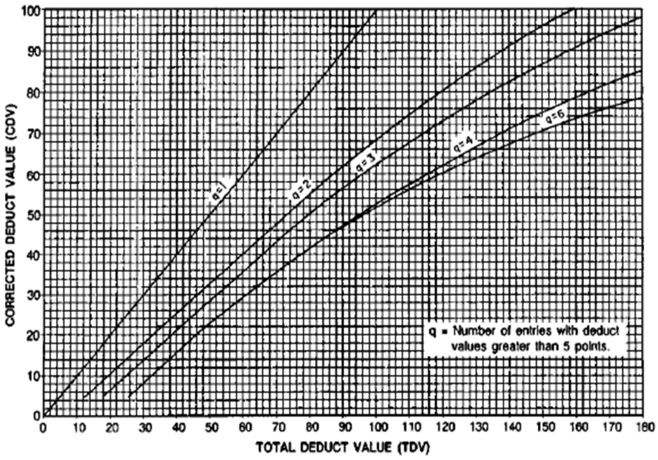

Fig. 2 The Relationship between Flexible Pavement CDV and TDV

5) Pavement Condition Index Value (PCI)

$$PCI = \frac{(\Sigma PCI\ (s))}{N}\ \% \qquad (2)$$

Description:
PCI : Total PCI Pavement Value
PCI (s): PCI value for each unit
N : Quantity of Units

The quality of the pavement layer in a section can be observed in the PCI values of each research sample, which are based on specific conditions, including excellent, very good, good, fair, poor, very poor, and failed [20]. The road condition values based on the PCI method can be seen in Table 1 [21].

TABLE I
THE ROAD CONDITION VALUE BASED ON THE PCI METHOD

PCI	Condition	Color
85-100	Excellent	Dark green
70-85	Very good	Light green
55-70	Good	Yellow
40-55	Fair	Light red
25-40	Poor	Medium red
10-25	Very poor	Dark red
00-10	Failed	Dark grey

C. Research Flowchart

The research methodology for analyzing road damage levels using the Pavement Condition Index (PCI) method on the Surabaya – Gresik toll road is illustrated in the research flowchart in Fig 3. The stages of this research include collecting data, analyzing density values, determining deduct values, TDV and CDV analysis, PCI value analysis, and analyzing road conditions and road damage.

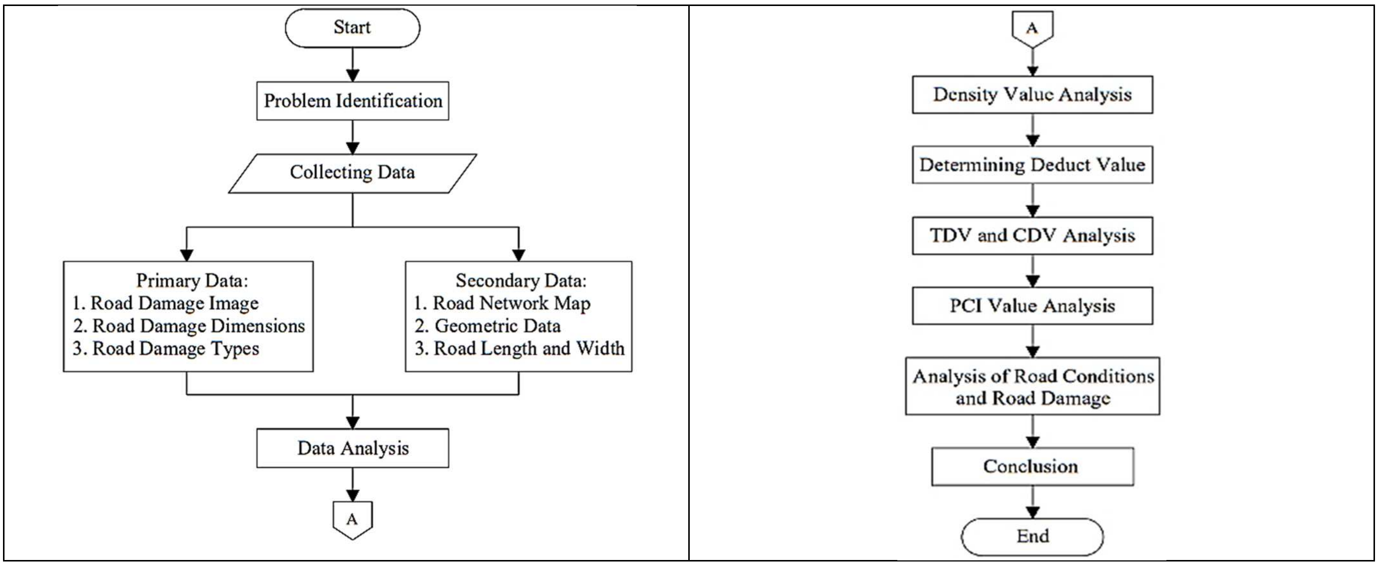

Fig. 3 Research flowchart

III. RESULTS AND DISCUSSION

A. Road Damage Condition Survey

The survey was conducted to collect primary data, such as images of damage, dimensions of damage, and types of road damage, and secondary data, such as road network maps, geometric data, and road length and width. The road length to be surveyed is 4 km, from KM 10 to KM 14. The survey area is carried out every 100 meters to get more accurate results [22]. Therefore, the total number of segments obtained is as follows.

$$N_{segment} = \frac{L_{total}}{L_{survey}} \quad (3)$$

$$N_{segment} = \frac{4000\ m}{100\ m}$$

$$N_{segment} = 40\ segment$$

The road damage condition survey for flexible pavement sampled damage patterns segment by segment, assessing the level of damage on the road and recording the dimensions of the damage.

ASPHALT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT				SKETCH:
LOCATION	SURABAYA - GRESIK TOLL ROAD	SECTION	-	SAMPLE UNIT
SURVEYED BY		DATE		SAMPLE AREA

1. Alligator Cracking
2. Bleeding
3. Block Cracking
4. Corrugation
5. Depression
6. Jet Blast
7. Jt. Reflection (PCC)
8. Long. & Trans. Cracking
9. Oil Spillage
10. Patching
11. Polished Aggregate
12. Raveling/Weathering
13. Rutting
14. Shoving from PCC
15. Slipppage Cracking
16. Swell
17. Pothole

DISTRESS SEVERITY	QUANTITY										TOTAL	DENSITY %	DEDUCT VALUE

Fig. 4 Road damage survey form

The results of the road condition were recorded and later analyzed using the PCI method. The survey form of road damage conditions can be documented, as shown in Fig 4, for data processing convenience.The following is the documentation of survey results, including images of damage, dimensions of damage, types of road damage, geometric data, as well as road length and width, as indicated in Fig 5.

(a) (b) (c)

Fig. 5 (a) Research area survey, (b) Road damage length, (c) Road damage

After surveying the field, the data written is the type of damage, level of damage, length, width, depth, and area of severity [23]. There are 3 levels of damage, namely low (L), Medium (M), and high (H) [24]. Table 2 provides an example of data recap results obtained from survey results at STA 10+000 to 10+500.

TABLE II
DATA OF MEASUREMENT RESULTS STA 10+000 - STA 10+500

STA	Road Damage		Length	Width	Area	Types of Road Damage
	Type	Level	(m)	(m)	(m^2)	
10+000 - 10+100	8	L	3.7	0.07	0.259	Longitudinal and Transverse Cracking
	8	L	50	0.01	0.500	Longitudinal and Transverse Cracking
10+100 - 10+200	17	L	0.08	0.03	0.002	Pothole
	5	L	0.3	0.24	0.072	Depression
	8	L	3.7	0.02	0.074	Longitudinal and Transverse Cracking
	8	L	1.9	0.01	0.019	Longitudinal and Transverse Cracking
	8	L	2.85	0.01	0.029	Longitudinal and Transverse Cracking
	10	L	0.24	0.24	0.058	Patching
	10	L	0.4	0.3	0.120	Patching
	17	L	0.1	0.09	0.009	Pothole
	10	L	0.4	0.33	0.132	Patching
	10	L	0.4	0.32	0.128	Patching
	17	L	0.08	0.04	0.003	Pothole
	17	M	0.2	0.16	0.032	Pothole
10+200 - 10+300	8	L	0.73	0.01	0.007	Longitudinal and Transverse Cracking
	8	L	1.3	0.01	0.013	Longitudinal and Transverse Cracking
	8	L	11	0.01	0.110	Longitudinal and Transverse Cracking
	12	L	0.08	0.04	0.003	Raveling and Weathering
	12	L	0.1	0.06	0.006	Raveling and Weathering
	8	L	2.13	0.01	0.021	Longitudinal and Transverse Cracking
10+300 - 10+400	17	M	0.13	0.09	0.012	Pothole
	8	L	3.9	0.01	0.039	Longitudinal and Transverse Cracking
	8	L	1	0.01	0.010	Longitudinal and Transverse Cracking
	8	L	3.7	0.01	0.037	Longitudinal and Transverse Cracking
	8	L	26	0.01	0.260	Longitudinal and Transverse Cracking
10+400 - 10+500	12	L	0.1	0.05	0.005	Raveling and Weathering
	17	M	0.2	0.15	0.030	Pothole
	10	L	0.3	0.23	0.069	Patching
	8	L	3.7	0.01	0.037	Longitudinal and Transverse Cracking
	17	L	0.18	0.1	0.018	Pothole
	11		3.7	1	3.700	Polished Aggregate
	8	L	50	0.01	0.500	Longitudinal and Transverse Cracking

TABLE III
DAMAGE AND PERCENTAGE OF ROAD DAMAGE

List of Road Damage	Percentage of Road Damage
Alligator Cracking	72.27 %
Bleeding	0.33 %
Block Cracking	1.93 %
Corrugation	13.52 %
Depression	2.00 %
Longitudinal and Transverse Cracking	0.53 %
Patching	4.83 %
Polished Aggregate	1.32 %
Raveling and Weathering	0.77 %
Shoving	2.47 %
Pothole	0.04 %
Total	**100.00 %**

B. Damage and Percentage of Road Damage

Based on research results, 11 types of road damage occur on the Surabaya–Gresik toll road, including alligator cracking, bleeding, block cracking, corrugation, depression, longitudinal and transversal cracking, patching, polished aggregate, raveling and weathering, shoving, and potholes. [25]The most frequent damage is alligator cracking, with a percentage of 72.27%, and the least frequent damage is potholes, with a rate of 0,04%. Table 3 lists the road damage and the percentage of road damage on the Surabaya—Gresik toll road.

C. Density and Deduct Value

Density is the rate of a sort of harm to the area of a unit section measured in square meters or long meters [26]. For density analysis, calculations are carried out for each type of road damage by plotting it on the graph provided. The following is an example of calculating distress density for STA 10+100 - 10+200.

$$Density = \frac{Ad}{As} \times 100\% \quad (4)$$

$$Density = \frac{129,19}{4,5 \times 100} \times 100\%$$

$$Density = 28,71\%$$

Deduct value is the diminishment esteem for each sort of harm gotten from the relationship bend between density and deduct value [27]. For example, on STA 10+100 – STA 10+200 which one of the analyzes can be seen in Fig 6. In this figure there is a graph with a distress density of 3.70% with a low level of damage. After that, it is plotted on the graph and produces a deduct value of 22. A recapitulation of this overall calculation results can be seen in Table 4.

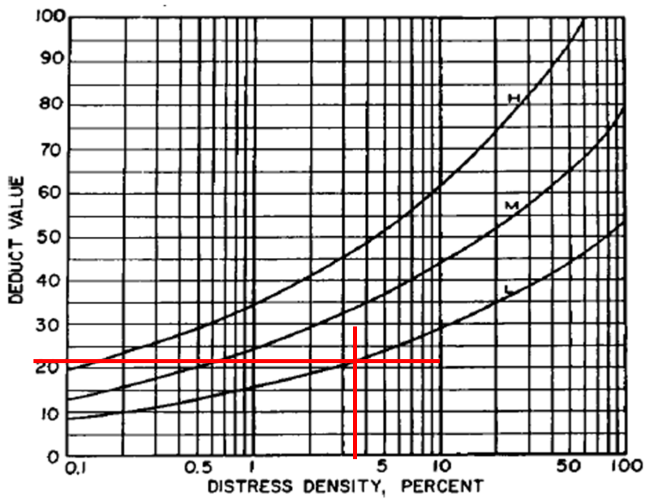

Fig. 6 Correlation between distress density and deduct value

TABLE IV
RECAPITULATION OF DENSITY AND TOTAL DEDUCT VALUE (TDV)

Samp.	STA	Distress Severity	Total	Density (%)	q	Total Deduct Value (TDV)
1	10+000 - 10+100	8 L	2.86	0.64%	5	102,5
2	10+100 - 10+200	17 M	129.19	28.71%	3	96
3	10+200 - 10+300	8 L	3.83	0.85%	2	27
4	10+300 - 10+400	17 M	10.17	2.26%	4	54,5
5	10+400 - 10+500	17 M	10.92	2.43%	5	95
6	10+500 - 10+600	17 M	37.10	8.24%	2	52
7	10+600 - 10+700	5 L	9.00	2.00%	2	51
8	10+700 - 10+800	12 M	122.55	27.23%	3	53
9	10+800 - 10+900	17 L	82.49	18.33%	3	46
10	10+900 - 11+000	4 H	1.35	0.30%	1	15
11	11+000 - 11+100	8 H	4.80	1.07%	3	35
12	11+100 - 11+200	8 L	0.20	0.04%	2	40
13	11+200 - 11+300	8 L	5.90	1.31%	4	47
14	11+300 - 11+400	17 M	180.42	40.09%	3	51
15	11+400 - 11+500	8 L	180.00	40.00%	1	32
16	11+500 - 11+600	17 M	5.40	1.20%	2	50
17	11+600 - 11+700	10 L	5.40	1.20%	2	34
18	11+700 - 11+800	8 L	20.08	4.46%	4	59
19	11+800 - 11+900	14 L	5.19	1.15%	2	50
20	11+900 - 12+000	17 M	28.85	6.41%	3	39
21	12+000 - 12+100	12 L	4.30	0.96%	2	47
22	12+100 - 12+200	12 L	4.42	0.98%	1	25
23	12+200 - 12+300	17 M	180.00	40.00%	1	30
24	12+300 - 12+400	12 M	180.00	40.00%	1	28
25	12+400 - 12+500	1 M	29.24	6.50%	2	54
26	12+500 - 12+600	1 L	1.62	0.36%	5	58
27	12+600 - 12+700	1 L	10.44	2.32%	2	30
28	12+700 - 12+800	10 M	81.36	18.08%	4	65
29	12+800 - 12+900	1 H	20.10	4.47%	2	55
30	12+900 - 13+000	5 H	32.23	7.16%	3	32
31	13+000 - 13+100	10 H	26.24	5.83%	3	25
32	13+100 - 13+200	12 H	28.93	6.43%	1	54
33	13+200 - 13+300	14 M	18.54	4.12%	2	51
34	13+300 - 13+400	12 H	14.54	3.23%	4	30
35	13+400 - 13+500	1 L	26.45	5.88%	2	35
36	13+500 - 13+600	1 L	8.44	1.88%	2	41
37	13+600 - 13+700	1 L	4.60	1.02%	2	27
38	13+700 - 13+800	1 M	2.70	0.60%	1	20
39	13+800 - 13+900	1 H	30.50	6.78%	5	47
40	13+900 - 14+000	8 L	0.12	0.03%	2	30

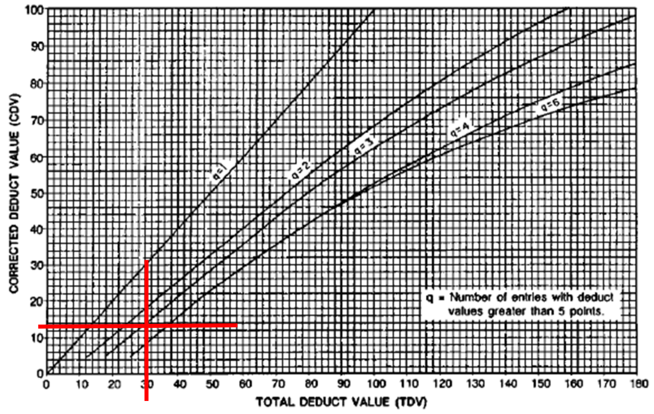

Fig. 7 Calculation of Corrected Deduct Value (CDV)

From the deduct values obtained from each type of road damage in each segment, after that these numbers will be added up to produce the total deduct value [28]. The Total Deduct Value (TDV) is obtained by adding the individual deduct values. From the TDV value, the CDV value can be obtained [29]. CDV (Corrected Deduct Value) is determined from q and the total deduction value (TDV), using the correction value in a curve or graph as in the example in Fig 7.

D. Pavement Condition Index Values (PCI Values)

The recapitulation graph of PCI values in 100-meter segments from KM 10 to KM 14 can be seen in Fig 8. The results obtained were that most of road conditions are marked in yellow, indicating that the road is in "Good" condition. There are only two points that are in 'Poor' condition, including on Sta. 10+900 – 11+000 and Sta. 12+800 – 12+900.

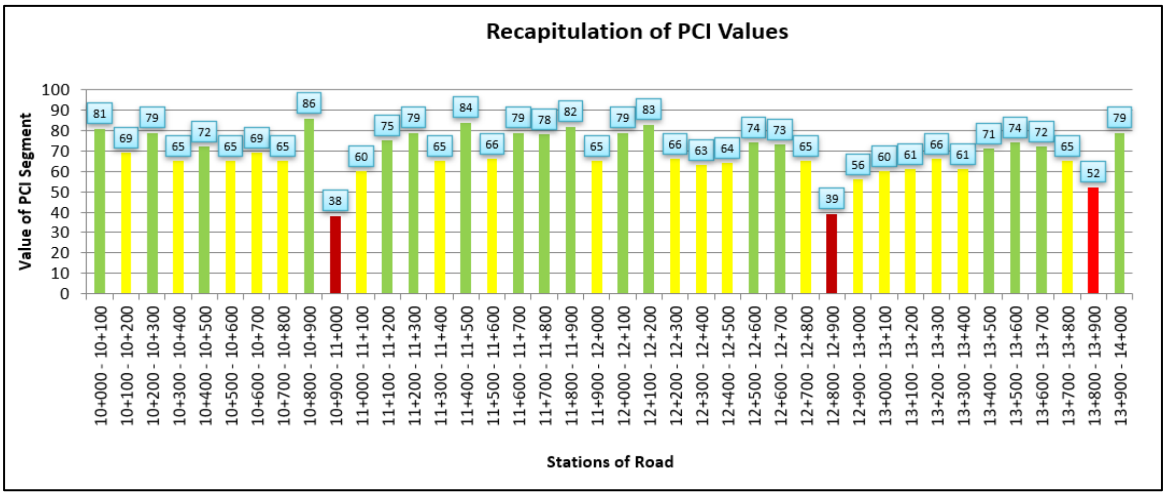

Fig. 8 Recapitulation graph of PCI values

Detailed recapitulation regarding the severity of damage, maximum CDV, PCI values, and road conditions in 100-meter segments from KM 10 to KM 14 can be seen in Table 5.

TABLE V
RECAPITULATION VALUES AND ROAD CONDITION

Samp.	STA	Distress Severity	Max. CDV	PCI Value	Road Cond.
1	10+000 - 10+100	8 L	19	81	Very Good
2	10+100 - 10+200	17 M	31	69	Good
3	10+200 - 10+300	8 L	21	79	Very Good
4	10+300 - 10+400	17 M	35	65	Good
5	10+400 - 10+500	17 M	28	72	Very Good
6	10+500 - 10+600	17 M	35	65	Good
7	10+600 - 10+700	5 L	31	69	Good
8	10+700 - 10+800	12 M	35	65	Good
9	10+800 - 10+900	17 L	14	86	Excellent
10	10+900 - 11+000	4 H	62	38	Poor
11	11+000 - 11+100	8 H	40	60	Good
12	11+100 - 11+200	8 L	25	75	Very Good
13	11+200 - 11+300	8 L	21	79	Very Good
14	11+300 - 11+400	17 M	35	65	Good
15	11+400 - 11+500	8 L	16	84	Very Good
16	11+500 - 11+600	17 M	34	66	Good
17	11+600 - 11+700	10 L	21	79	Very Good
18	11+700 - 11+800	8 L	22	78	Very Good
19	11+800 - 11+900	14 L	18	82	Very Good
20	11+900 - 12+000	17 M	35	65	Good
21	12+000 - 12+100	12 L	21	79	Very Good
22	12+100 - 12+200	12 L	17	83	Very Good

Samp.	STA	Distress Severity	Max. CDV	PCI Value	Road Cond.
23	12+200 - 12+300	17 M	34	66	Good
24	12+300 - 12+400	12 M	37	63	Good
25	12+400 - 12+500	1 M	36	64	Good
26	12+500 - 12+600	1 L	26	74	Very Good
27	12+600 - 12+700	1 L	27	73	Very Good
28	12+700 - 12+800	10 M	35	65	Good
29	12+800 - 12+900	1 H	61	39	Poor
30	12+900 - 13+000	5 H	65	35	Poor
31	13+000 - 13+100	10 H	65	35	Poor
32	13+100 - 13+200	12 H	62	38	Poor
33	13+200 - 13+300	14 M	34	66	Good
34	13+300 - 13+400	12 H	61	39	Poor
35	13+400 - 13+500	1 L	29	71	Very Good
36	13+500 - 13+600	1 L	26	74	Very Good
37	13+600 - 13+700	1 L	28	72	Very Good
38	13+700 - 13+800	1 M	35	65	Good
39	13+800 - 13+900	1 H	61	39	Poor
40	13+900 - 14+000	8 L	21	79	Very Good
		PCI Average		**68**	**Good**

The research results indicate that the average PCI value is 68, categorized as "Good" condition. For road pavement conditions classified as "Good" condition, the required maintenance type is routine maintenance [30]. Routine maintenance is conducted throughout the year and serves as protection against damage. Routine maintenance activities that can be carried out such as repairing minor damage, patching potholes, sweeping, repairing pavement edge damage, sidewalk maintenance, side channel and complementary building drainage, road equipment and roadside maintenance.

IV. Conclusion

Based on the research results and calculations conducted in the analysis of road damage using the Pavement Condition Index (PCI) method on the Surabaya – Gresik toll road, the following conclusions is various types of damage were identified on the Surabaya – Gresik toll road, including such as alligator cracking, bleeding, block cracking, corrugation, depression, longitudinal and transverse cracking, patching, polished aggregate, raveling and weathering, shoving, and potholes. The most frequent damage is alligator cracking with a percentage of 72,27% and the least frequent damage is pothole with a percentage of 0.04%.

The assessment of damage obtained an average PCI value of 68, categorized as "Good" condition. The recommendations for treatment that can be carried out are routine maintenance with the activities that can be carried out such as repairing minor damage, patching potholes, sweeping, repairing pavement edge damage, sidewalk maintenance, side channel and complementary building drainage, road equipment and roadside maintenance.

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