TEST Engineering & Management

*January - February 2020*
*ISSN: 0193 - 4120 Page No. 7681 - 7690*

# Prediction of Potholes for PMGSY Roads in India

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***Article Info***
***Volume 82***
***Page Number: 7681 - 7690***
***Publication Issue:***
***January-February 2020***

***Abstract:***
Potholes are indicating the performance of pavements. Potholes directly affect safety, travelling time and Vehicle Operating Cost (VOC). In this study, performance prediction of pothole model for Pradhan Mantri Gram Sadak Yojana (PMGSY) in the state of Tamil Nadu, India. To evaluate the progression of potholes is the universal performance indicator of flexible pavements. Globally more prediction models were developed till today. Not all the models are applicable for all pavements. Many models are implemented only for the standard road with high traffic volume of highways. The standard models are dependent on local condition variable parameters of pavement, which are soil strength, pavement material composition and traffic. In this study, Multiple Linear Regression Analysis (MLRA) technique is proposed to evaluate the performance prediction of PMGSY roads. The model includes variable and distress parameter cracking prediction in India. Based on the results, this prediction model can be recommended as a decision-supporting tool for road maintenance on PMGSY roads

***Article History***
***Article Received***: *18 May 2019*
***Revised***: *14 July 2019*
***Accepted***: *22 December 2019*
***Publication***: *04 February 2020*

***Keywords:*** *Potholes, Cracking, Multiple linear regression techniques, PMGSY road, Ground truth verification*

## I. INTRODUCTION

In India, the road network is nearly 5.4 million km of length of roads [1]. India is in second place of the largest road network in all over the world. Indian highways have the six categories such as (i) Expressway, (ii) National Highways (NH), (iii) State Highways (SH), (iv) Other District Roads (ODR), (v) Village Roads (VR) and (vi) PMGSY Roads. Presently, total length of PMGSY roads in India is around 18, 31,043 km [2]. PMGSY road is an important part of every country. PMGSY roads are indirectly connecting with the agricultural production sector. Rural roads connect with small villages and each other. All rural villages are easy to connect and

Accessible through rural roads. Agricultural products are easy to carry to urban area through rural roads. Good rural roads reduce the lead charge. It indirectly reduces the final product cost. The road is a direct connection of social, cultural, safety and the border of the nation. Rural roads directly help the door to door services for rural peoples for education, employment and medicine. Poverty is one of the Non-curable diseases of rural areas in India [3]; PMGSY roads play a vital role in poverty reduction.

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The Government of India (GOI) is funding a lot for road construction, maintenance and operation of Indian highways.

The problem of managing road maintenance has proved to be a particularly very difficult task for many developing countries. Various agencies and researchers have developed performance prediction models. Several performance prediction models were developed for planning with design, construction and maintenance of roads. In many countries, models are related to flexible pavement performance prediction models, and each model has its limitations. In the AASHTO model, prediction measures the present serviceability index, based on the age, traffic loading on the pavements [4].

Hodges et al. developed a prediction model in Kenya; the model predicts the roughness and cracking. The model also considers the traffic loading and pavement strength [5]. The study conducted and calculated both structural and functional reaction of low-volume village roads which were using the different types of terrain and climatic conditions. The model considers both plain and hilly respectively 13 stretches of plain and five sections of hilly stretches of different districts of Uttar Pradesh and Uttarakhand state in India. This model used regression analysis and ANN's for low volume roads. The model development using the significant independent variables such as California Bearing Ratio (CBR) of the Sub Grade soil, age of the road, traffic, and thickness of the pavements and these were related to riding quality in terms of International Roughness Index. The final output of result found that excellent prediction model exactness with the ANN model than a regression model [6].

The function of traffic model was to predicting the beginning and progression of cracking on the roads. This model had considered that incremental time and traffic, present condition of pavement, its strength, age and environment [7].

The MLR model developed using total roads is ten in three different districts, and the length of each test road was chosen as 0.5 km. Every road stretches was divided into ten section of 50 meter of each segment. The model found that significant variables time in the year, Commercial Vehicle Per Day (CVPD), Annual Rainfall and moisture content of sub-grade. Data collected six times before monsoon and after the monsoon [8].

Roughness model was developed from Pavement Distresses, which is considered pavement distress its severity and five critical explanatory variables of cracking, potholes, patching, rutting, and ravelling for International Roughness Index. The study and model developed were using 90 percentage samples with SPSS Software and the remaining ten percentages for validation purpose. The multiple linear regression model has got good $R^2$ Value as 0.986. The model developed data collected from different categories of NHs, SHs and MDRs. Finally, that study concluded that a major contribution of potholes was quite predominant of the roads [9].

Develop International Roughness Index in Asphalt pavement overlay performance for Canadian roads. Model development data using Long Term Pavement Performance (LTPP) from Canadian country, which was 53 test section with collected data from 13 years were considered, and model development was taken the importance variable such as overlay thickness, years and Environment condition of climatic also considered. The model concluded that result overlay thickness and climate zones have a significant impact on the pavement roughness and sub grade layer also influence the International Roughness Index values. Finally, that study results concluded that good correlation coefficient of roughness progression equations regression analysis found the result $R^2$ Value 0.93.[10].

The study developed two equations namely regression equations of linear and non-linear and

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Neural Network model. This study developed in three regressions equation in various regions of south and north and combined data respectively in India. The multiple linear regression models its model development taken. The south region model developed using total road stretches was 133, and it is model $R^2$ Value was 0.81. The second model developed for the northern region taken the road stretches 377, and it is model $R^2$ value 0.77, and the third combined data model development are road stretches 510 and $R^2$ value 0.80.[11].

A model developed and validation for urban road maintenance in India, which was used seven importance distress parameters such as ravelling, block cracking, longitudinal and transverse cracking, potholes, weathering, depression and patching. Prediction model mainly pavement failures and decision-making purposes for the priority of maintenance and rehabilitation of road networks [12]. Developed performance prediction model using MLR technique. Model using state highways and interstate highways of Pavement Condition Evaluation System (PACES) road distress data of rut depth, ravelling, load cracking, edge distress, bleeding, reflection cracking, corrugation, patches and potholes for the past 15 years in country of Georgia. The pavement distress data collected that road selected sample stretches of 100 feet and distress rating ranges 100 to 0. Finally, that study recommended that a MLR model is to predict pavement performance when the ratings with different Annual Average Daily Traffic (AADT) [13].

MLR analyzed and developed an equation in which parameter of cumulative standard axial load and MSN were used. The main objective of that study for calibration of HDM-4 model for road distress and the second objective was a comparison of pavement performance of flexible pavements and HDM-4 Models of Indian highways which used to calibrate that the importance factors were considered such as MSN, CSA, Premix carpet and bituminous concrete[14]. In this study ranking model was developed using pavement failures. Concluded that systematic procedures to ranking of pavement for pavement management system [15].

In India, many models such as cracking, potholes, ravelling and roughness were developed by CRRI for national and state highways alone [16]. Till now, exact maintenance procedures are evolved based on the performance of PMGSY roads. Even though, several scientific prediction models are presented to test the flexible pavements' performance these models are not implemented to village roads with the low volume of traffic, and the pavement composition's quality is reduced. The models developed, for assessing the prediction performance of flexible pavements are having the basic impediments. Several performance models are evolved particularly in Europe and North America to plan, design, and construction, maintain the pavements. However, these models are not directly transferable for PMGSY roads.

Global models have several explanatory variables, and the models require calibration for the local conditions. In India, developing adjustment rudiments is a questionable decision of PMGSY roads. PMGSY roads have very less little traffic with less than (150 CVPD) and poor pavement composition and the operation of Indian road traffic conditions. From the review of literature, all the research work in the existing models have been concentrated based on specific locations only. In the models developed in India so far, the distress variables are not included and models were developed for the high volume roads. A novel model is developed for PMGSY roads, including distress variables.

Since in India, due to insufficiency of funds. many PMGSY roads were not exposed to maintenance of PMGSY roads. Hence, an effort is made in this research to develop a performance prediction model for PMGSY roads with less traffic volume and least maintenance.

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## II. OBJECTIVES

. Based on the above-reviewed literature and present condition of ground requirements, the objectives of this study are presented are as follows:-

(i) To develop a prediction of potholes model for PMGSY roads in India.
(ii) To statistical validation of potholes model.
(iii) To carry out the ground truth verification of pothole model.

## III. SELECTION OF STUDY AREA

The study area of 1, 30,058 $Km^2$ with a population of 7,21,47,030. The state has 32 districts; It is consists of 385 blocks and 12618 village Panchayats. In discussion with PMGSY road and Panchayat Raj Department Officials, 173 test sections would be divided into smaller segments of 500 meters; each road failures data have been calculated manually. The distresses were calculated cracking and potholes in low volume roads. This study attempts to develop the model for performance prediction of potholes.

## IV. METHODOLOGY

The whole work has been separated into the six stages which are as follows. Stage I: The road test stretches on flexible pavements were chosen with different age groups. Pavement distresses such as cracking, and potholes were calculated. Stage II: The strength of the test stretches has arrived in terms of modified structural number (MSN), which is a function of sub grade California Bearing Ratio (CBR) and pavement composition. The pavement details were obtained from the PMGSY road department, the road was making and put the trial pits to colleting soil samples for CBR tests. Stage III: The potholes prediction model was developed by MLR analysis using SPSS 19 software. Stage IV: Statistical validation analysis was carried out for the pothole model. Stage V: The ground truth verifications were carried out. Stage VI: To compare the predicted pothole model and the field value.

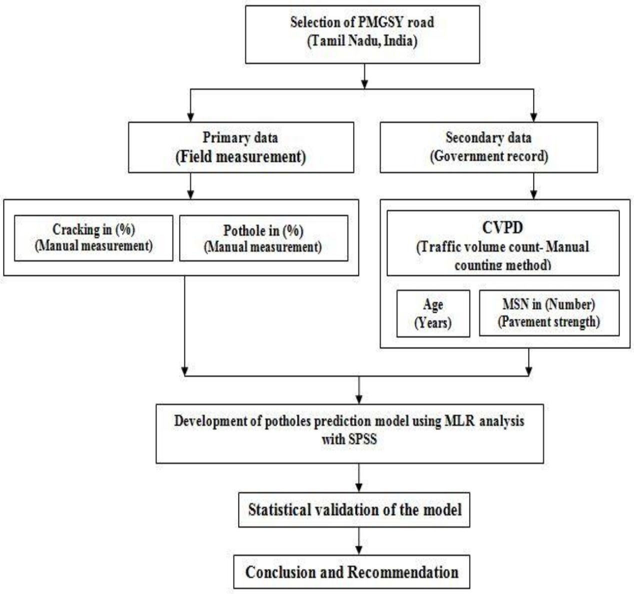


Figure 2. Methodology flow chart to the prediction of potholes for PMGSY roads

### A. Selection of test Sections

A total of 173 test stretches and a length of 500m each were identified. The given criteria were adopted for the test sections. (i) All test sections are low traffic volume of PMGSY roads; (ii) Road sections on straight stretches with plain terrains, (iii) Selection of test stretches without crossroads, curved portion, cross drainage works and habitations.

### B. Data Collection

The road data collection of Age, Modified Structural Number, Traffic in terms of CVPD, distress such as potholes area and cracking area were measured and calculated in all the 173 test stretches of PMGSY roads.

### C. Measurement of Cracking Areas

The affected area was marked with shape of square, rectangular and triangular. In every segment, the total area of cracking was calculated and entered as a percentage of segment area [16].

### D. Measurement of Potholes Areas

The affected potholes areas were identified and measured. The length and width of the potholes areas were measured by using a steel tape. The potholes was calculated and entered as a percentage of segment area [16].

E. Volume count survey on PMGSY Roads

The traffic surveys were carried on PMGSY roads for one week consecutive days round the clock, by engaging a competent number of enumerators. From the traffic census data, the No. of CVPD calculated for every test stretches and the same has been used for model development [17].

F. Pavement Structural strength of PMGSY roads

Pavement structural strength of PMGSY roads in this study is calculated in terms of Modified Structural Number (MSN). The concept of Structural Number (SN), a pavement strength indicator, was artistically incurred during the AASHTO Road Test [4]. The relationship used to obtain the structural number of pavement equation is given below.

$$SN = a_1 xt_1 + a_2 xt_2 + a_3 xt_3 + \cdots\cdots + a_n xt_n = \sum_{i=1}^{n} a_n xt_n \cdots\cdots > 1$$

Where,

$a_1$, $a_2$, $a_3$ ….$a_n$, are the strength coefficients of road construction materials. The $t_1$, $t_2$,$t_3$…$t_n$ are the corresponding thickness of pavement in inches.

The above mentioned strength coefficients recommended by CRRI. The structural number (SN) thus obtained is modified to account for the sub-grade strength using the given MSN Equation [16].

$$MSN = SN + 3.51(\log_{10} CBR) - 0.85(\log_{10} CBR)^2 - 1.43 \ldots\ldots\ldots\ldots\ldots > 2$$

Where, MSN- Modified Structural Number, CBR-California Bearing Ratio of sub-grade soil and SN- Structural Number.

G. Data Analysis

Table 1 Descriptive statistics summary and results

| Data Information | Crack in (%) | Pothole in (%) | AGE in (Years) | MSN in (Nos.) | CVPD in (Nos.) |
|---|---|---|---|---|---|
| Mean value | 5.715 | 8.123 | 4.905 | 1.907 | 4.77 |
| Std. Error of Mean | 0.373 | 0.493 | 0.283 | 0.023 | 0.126 |
| Median | 4.00 | 6.00 | 3.00 | 1.840 | 5.00 |
| Mode | 0.00 | 0.00 | 2.0 | 1.84 | 4.0 |
| Std. Deviation | 4.910 | 6.484 | 3.733 | .3135 | 1.661 |
| Variance | 24.112 | 42.048 | 13.937 | .098 | 2.760 |
| Range | 17.0 | 27.0 | 10.5 | 1.87 | 7.0 |
| Minimum | 0.0 | 0.0 | 0.0 | 0.91 | 2.0 |
| Maximum | 17.0 | 27.0 | 10.5 | 2.78 | 9.0 |
| Sum | 988.7 | 1405.3 | 848.5 | 329.91 | 825 |

Source: Primary data

## V. DEVELOPMENT OF POTHOLES PREDICTION MODEL

MLR analysis has been considered for developing the correlation between potholes and explanatory variables. The functional relationship, thus developed, is presented in equation (3).

$$\mathbf{Pothole} = a_0 + a_1 * \mathbf{Age} + a_2 * \mathbf{MSN} + a_3 * \mathbf{CVPD} + a_4 * \mathbf{CR}$$

----------(3)

Where, $a_0$= model constant, and $a_1$, $a_2$, $a_3$, and $a_4$ = coefficients of Age, MSN, CVPD and Cracking for potholes model.

The distresses calculated were made on all the 173 test sections and to obtain the input parameters for the development of pothole model.

TABLE 2: Residuals Statistics of prediction of potholes model

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| Predicted Value | -1.517 | 19.551 | 8.757 | 6.453 |
| Residual | -6.970 | 7.687 | 0.00 | 2.245 |

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| | | | | |
|---|---|---|---|---|
| | | | 0 | |
| Std. Predicted Value | -1.592 | 1.673 | 0.000 | 1.000 |
| Std. Residual | -3.052 | 3.365 | 0.000 | 0.983 |

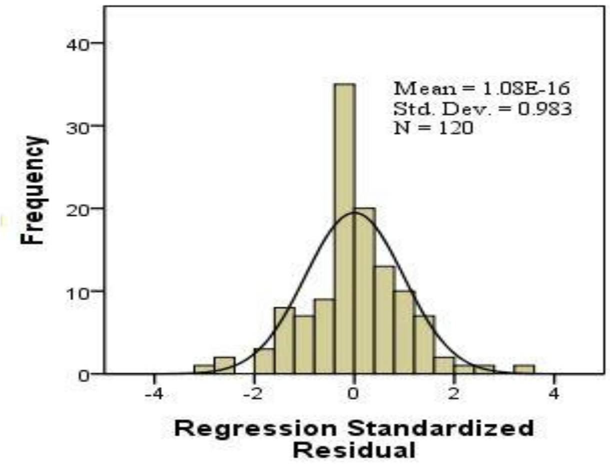


Fig 3: Histogram explanatory variable potholes

Figure 3 is histogram explanatory variables of potholes, The regression residual values are within the limit.

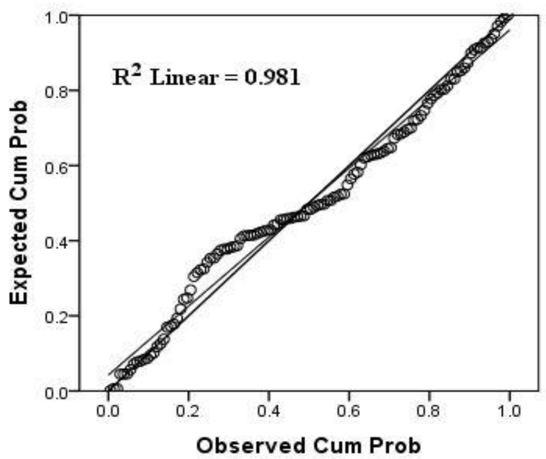


Fig 4: Normal P-P Plot of Regression Standardized Residual

From the figure 4, shows the Normal P-P Plot of Regression Standardized Residual observed that the normal distribution with $R^2$ Value 0.981. In prediction potholes, measured potholes value was taken as the explanatory variables, and the measured pavement parameters like AGE of pavements, MSN, CVPD and CRACK, were consider as explanatory variables.

The best model obtained using MLRA is below.

PH =2.816 + 0.780 AGE - 1.886 MSN + 0.456 CVPD + 0.523 CR ------------------------------------->4

($R^2$=0.892, N=120)

Figure 5, shows that comparison between the potholes model predicted values and field observed pothole value. From the figure 5, it is observed that x - axis observed pothole values and Y axis direction indicates that model predicted potholes values. The alignment of plotted points between observed and predicted potholes line of equality with $R^2$ value is 0.869.

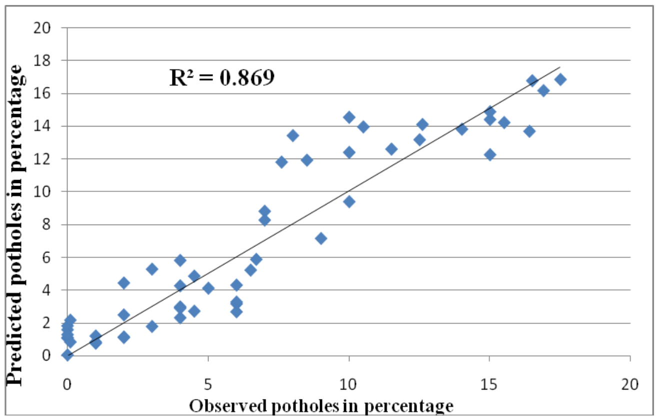


Figure 5: Comparison between predicted and observed potholes

## VI. STATISTICAL VALIDITY OF PREDICTION POTHOLES MODEL

To verify the statistical strength of prediction model and to confirm the significance of the explanatory variables, a well-known 'student-t' and 'p-values' for each of the explanatory variables Age, MSN, CVPD and Cracking were considered in the prediction of pothole model is estimated and presented in Table 3.

Table 3: Statistics of the performance prediction of pothole model

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| e | Explanatory Variable | Coefficients | Student-t | p-value | e Inflation Factor |
|---|---|---|---|---|---|
| Pothole | Age (Years) | 0.780 | 4.448 | 0.000 | 10.467 |
| | MSN (No.) | -1.886 | -2.406 | 0.018 | 1.312 |
| | CVPD in (Nos.) | 0.456 | 2.899 | 0.004 | 1.521 |
| | Cracking (%) | 0.523 | 3.859 | 0.000 | 11.860 |

The above model is acceptable for all the parameters the 'p-values' are less than 0.05. Hence, all the explanatory variables like Age, MSN, CVPD and Cracking area are included in the potholes model. Hence, Potholes prediction model is acceptable and found to be significant.

The 'student-t' value for 95 % determined level is 1.645. The 3 indicate that the 'student-t' values estimated for all the distress parameters are greater than 1.645, which involve the all explanatory variables falls a normal distribution with a constant variance across observations.

Table 4: Regression statistics of prediction of potholes model

| Statistics Value | Pothole model |
|---|---|
| Multiple R value | 0.944 |
| $R^2$ value | 0.892 |
| Adjusted $R^2$ Value | 0.888 |
| Standard Error (SE) | 2.283 |
| No.of Samples | 120 |

Table 4 represents that the MLR statistics and R square value is 0.88 for potholes model. Standard Expected Error (SEE) between the observed field value and predicted pothole value was 2.283%.

From Table 5, represents that 'Significance F' is less than 0.05 for the model signifying the pothole model. Hence, prediction of pothole model is significant.

Table 5: ANOVA Result for prediction of potholes model

| | Degree of freedom | Sum of Squares (SS) | Mean Sum of squares | Statistics F | Significance F |
|---|---|---|---|---|---|
| Regressio | 4 | 4956.013 | 1239.003 | 273.523 | 0.000 |
| Residua | 115 | 599.880 | 5.216 | --- | --- |
| Total | 119 | 5555.893 | --- | --- | --- |

From Table 5, represents that 'Significance F' is less than 0.05 for the model signifying the pothole model. Hence, prediction of pothole model is significant.

## VII. STATISTICAL VALIDATION OF POTHOLE PREDICTION MODEL

The MLR model is evaluated for the PMGSY roads data. The following performance measures are used in the validation process.

(i) Mean Absolute Error (MAE)

$$\boldsymbol{MAE} = \frac{\sum_{i=1}^{n} |\boldsymbol{yi} - \boldsymbol{y}\boldsymbol{i}|}{\boldsymbol{n}} \tag{5}$$

Where, Yi = observed Rutting; and

Y^i = estimated rutting value from the MLR model.

(ii) Root Mean Squared Error (RMSE)

$$\boldsymbol{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |\boldsymbol{yi} - \bar{\boldsymbol{y}}\boldsymbol{i}|} \tag{6}$$

(iii ) Mean Absolute Relative Error (MARE)

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$$MARE = \frac{1}{n}\frac{\sum_{i=1}^{n}|yi-\bar{y}i|}{yi} \qquad (7)$$

The relative measures of the pothole model are estimated and summarised in Table 5.

From Table 5, it can be observed that the MAE of the model is 0.514 %, Mean Absolute Percentage Error (MAPE) was 0.031%, and RMSE was 0.262 %. Considering these, it is concluded that the MLR model better forecast of road pothole for PMGSY roads in India.

Table 5 Statistical Evaluation of pothole model

| Relative measures | Values (%) |
|---|---|
| RMSE | 0.262 |
| MAPE | 0.031 |
| MAE | 0.514 |

## VII. GROUND TRUTH VERIFICATION

As ground truth verification, twenty roads were randomly selected. Conducted the field survey with measured the percentage of potholes. Comparison of result based on Potholes prediction model value and actual value field measured. The value shows that very closer result. The analysis has been performed to confirm the effectiveness of the potholes model, and from this, it can be observed that the percentage variation between field and model is within 1 %.

Table 6. Ground truth verification of road details

| Name of PMGSY road | Age | MSN | CVPD | Crack in (%) | Pothole value at field (%) | Predicted Potholes (%) |
|---|---|---|---|---|---|---|
| M.P. Road to Jambilabath | 1.0 | 2.0 | 3 | 0.3 | 1.5 | 1.3 |
| Neithavoyal | 1.5 | 2.8 | 5 | 1.0 | 1.5 | 1.5 |
| TPP RoadAthiramangalam | 3.0 | 2.0 | 4 | 2.5 | 4.2 | 4.5 |
| Perumalpet to Koilkuppam Rd | 4.0 | 2.2 | 5 | 2.1 | 5 | 5.2 |
| Vellur - Nagacheri road | 5.6 | 1.0 | 6 | 6 | 11.5 | 11.2 |
| MP Road - Kadapakkam Road | 6.0 | 2.0 | 3 | 8.3 | 10.3 | 9.4 |
| Koladi Road - Anjugam Nagar | 7.5 | 0.5 | 4 | 7 | 13 | 13.2 |
| Erankuppam - Sarathkandigai | 8.0 | 0.9 | 5 | 10 | 15 | 14.9 |
| Konetampet to Konetampet | 9.0 | 1.5 | 9 | 8.5 | 16 | 15.6 |
| Melapudi H/C Rd | 10.0 | 1.8 | 10 | 9 | 17 | 16.5 |
| Pallipet - Podaturpet | 2 | 1.0 | 5 | 1 | 5 | 5.3 |
| Melnedugal Village Rd | 2.5 | 1.6 | 4 | 1.5 | 4.5 | 4.4 |
| Mahankaligapuram - Pudupet | 3.5 | 2 | 7 | 2.2 | 6.0 | 6.1 |
| Periaramapuram-Gopalapuram | 4.5 | 2.8 | 8 | 3 | 6.0 | 6.1 |
| CT – Adhivaragapuram road | 6.6 | 1.8 | 7 | 4 | 10 | 9.9 |
| CT - | 7 | 2.3 | 6 | 4.5 | 9.0 | 9.0 |

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| | | | | | | |
|---|---|---|---|---|---|---|
| Chandravilasapuram | | | | | | |
| Podatturpet to Ellampalli Rd | 8.4 | 1.95 | 8 | 7 | 13.2 | 13.0 |
| Uthandamaharajapuram | 9.2 | 2.9 | 9 | 6.6 | 11.5 | 12.1 |
| KTP Road Bandikavanam | 10.5 | 0.5 | 6 | 9 | 18 | 17.5 |
| Adayalampattu - Millinium | 8.5 | 1.4 | 7 | 7.3 | 13.7 | 13.8 |

Fig 9 Newly constructed road with zero potholes of PMGSY road.

Fig 10 After three years as the same road predicted potholes value is 4.5 %.

Figure 9 shows the photograph of the TTP Athiramangalam road taken immediately after road construction. Figure 10 shows the photograph of the same road after three years.

Fig 11 Newly constructed of PMGSY road without potholes.

Fig 12 After 4.5 years as the same road predicted potholes value is 6.2 %.

Moreover, also, Figure 11 shows the pictures of the Periaramapuram – Gopalapuram road taken immediately after the construction of road. Figure 12 shows the pictures of the same road after 4.5 years. From the road figure 10 & 12 concluded that the prediction values were closely related to field measured value and referred in table no.6.

## VIII. CONCLUSION

In this study, the prediction of potholes model was developed using MLR analysis. The ANOVA outcome of MLR indicate that cracking, Age, MSN and CVPD are as highly associated with potholes. The t-statistic values of these parameters are also more significant than the critical value of 1.95. Highly correlated parameters were significant in estimating the potholes. The MLRA model is better $R^2$ and MARE values. Cracking area, MSN, Age and

CVPD are found to be significant contribution to Potholes. Pothole model was functional for efficient pavement management systems for PMGSY roads. The pothole model was statistically evaluated and also carried out the ground truth verification of pothole model. Compared to the model predicted values and field values; Model values are much closed to filed values. The study concluded that the percentage error between field and estimate is within 2%. Pothole model can be used as an efficient tool in the Pavement Maintenance Management System (PMMS) for PMGSY roads in India.

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