Different Analysis of Rigid Pavement Subjected to Multi Axle Load and Temperature Effect

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Abstract. In this study the axle load studies are carried out to determine actual load of each axles on the road surface. In the present study, Static Weighing method is used for the axle load survey. The Sample size of the axle load survey is determined by conducting Classified Volume Survey as per IRC: 58 – 2015. Axle load Spectrum is generated with the help of axle load study. Based on the Axle load survey and Warping stress, stress – deflection analysis is done with the help of Westergaard Theory, IRC -58 (2015) and ANSYS software. Results which are analysis by Ansys is closed to Westergaard theory and IRC – 58 (2015) In the present study, stretch Kankot to Vavdi, near Punitnagar, Rajkot is selected for the analysis study.

Keywords: Rigid Pavement, 3D FEM, Ansys, Axle load, Westergaard

1. INTRODUCTION

Research concerning the structural behavior of pavement systems receives great recognition, especially after the growing use of heavy trucks in good’s transportation. The Institute for Roads and Railways Technology of Karlsruhe University stated in its 1992 Report "Traffic in graphic’ that traffic performance of goods transportation in 1990 was about 169 billion ton-kilometer. The Institute for Economic Research stated that in the year 1995, the traffic performance of goods' transportation was about 284 million ton-kilometer. With this development of goods' transportation using heavy trucks, and in order to minimize damage to the existing rigid pavement highways, it was necessary to study the behavior of those pavement systems under heavy running loads. Recently, Finite Element Method (FEM) has been increasingly viewed as a fundamental tool to investigate the behavior of numerous structural systems.
2. Objectives
To develop axle load spectrum and determine Vehicle Damage Factor, also design and analysis as per Westergaard theory, IRC – 58 (2015), Ansys 18.0.

3. Data Collection
3.1. Classified Volume Count Survey (CVC): All types of motorized and non-motorized modes of transport that pass through the survey stations in both directions of travel were recorded at site using videography technique. The traffic volumes were extracted in the back office for each category passenger vehicles, commercial vehicles, toll-exempt vehicles, non-motorized transport modes, etc. for 15-minute intervals to finally present in terms of hourly and daily volumes.

3.2 Average Daily Traffic: Average Daily Traffic (ADT) is calculated from the seven days’ average traffic volumes. The ADT in terms of vehicles/day.
3.3. Seasonal Correction Factor: Seasonal variation exists in traffic data collected for short period of time. Therefore, in order to convert the seven days CVC data to Annual Average Daily Traffic (AADT), Seasonal Correction Factors (SCF) were used in this analysis. The factors are determined from petrol and diesel sale data collected from fuel stations in the vicinity of the proposed project corridor.
3.4. Annual Average Daily Traffic: AADT is calculated from ADT and SCF as presented above. SCF of petrol is applied for petrol-driven vehicles such as two-wheelers and cars etc. SCF of diesel is applied for diesel-driven vehicles such as balance portion of cars, all types of buses and heavy/commercial vehicles. For non-motorized vehicles, SCF of 1.0 is considered.
3.5. Day Time and Night Time for Rigid Pavement Design: Candidate commercial traffic volumes are segregated for certain hours during the day to obtain day time and night time traffic volumes as required for rigid pavement design pursuant to provisions of IRC:58-2015. Only vehicular traffic utilizing the rigid pavement for the six (6) hours of the day (10:00 AM to 4:00 PM) and six (6) hours of the night (midnight to 6:00 AM) cause failure in the pavement- Bottom up cracking (BUC) and top down cracking (TDC), respectively, and the same shall be considered as the critical time interval for fatigue analysis in accordance with the said code. Proportion of commercial vehicular traffic for the specified six hours during day time and specific six hours during night time are calculated.
3.6. Axle Load Survey: All types of commercial/heavy vehicles and buses were surveyed on a random sampling basis for both directions of travel for forty-eight (48) hours as per IRC:58-2015. Light Commercial Vehicles (LCV 4 wheels and LCV 6 wheels), buses (standard, government and school buses, excluding mini buses), two-axle trucks, three-axle trucks and various different types of Multi- Axle Vehicles (MAV) were included in the sample. One side of the axle load was weighed using portable axle load weigh pads. Origin, destination, commodity questions were asked to the drivers and axle spacing were recorded as part of the survey. Loaded as well as empty commercial vehicles were captured.
3.7. Axle Load Survey Data Analysis: Traffic loading on any highway is a heterogeneous combination of different types of heavy/commercial vehicles and axles carrying a wide spectrum of axle loads. Axle loads of heavy/commercial vehicles are required for design of rigid pavement of the MCW. Spectrum of axle loads in terms of frequency distribution for different axle types along with various other traffic parameters are derived from Axle Load Surveys. Sample size of ALS is an important criterion. Here which is greater than the minimum specified in Clause 5.2 and Table 4.1 of IRC:58-2015.

1) Kankot – Vavdi (Rajkot):
A) Average Daily Traffic (ADT):
Surveys were conducted at near Matuki Restaurant, Rajkot. Data is given in Table 1.

Table 1: Average Daily Traffic at Survey Location.

| Vehicle Type | Kankot to Vavdi | Vavdi to Kankot | Total of Both Directions |
|--------------|-----------------|-----------------|--------------------------|
| 2 Wheeler    | 6997            | 6766            | 13763                    |
| 3 Wheeler    | 239             | 309             | 548                      |
| Car          | 1749            | 1810            | 3559                     |
| LCV          | 578             | 659             | 1237                     |
| HCV          | 461             | 443             | 904                      |
| Bus          | 85              | 61              | 146                      |
| Bicycle      | 96              | 65              | 161                      |
| Total Vehicles (Vehicles/Day) | 10205 | 10113 | 20318                  |

B) Annual Average Daily Traffic (AADT):
The AADT values are presented in given table. Where taking values of S.F. are 1.01 (petrol vehicles), 1.1 (diesel vehicles).

Table 2: Annual Average Daily Traffic.

| Vehicle Type | Kankot to Vavdi | Vavdi to Kankot | Total of Both Directions |
|--------------|-----------------|-----------------|--------------------------|
| 2 Wheeler    | 7067            | 6834            | 13901                    |
| 3 Wheeler    | 241             | 312             | 553                      |
| Car          | 1766            | 1828            | 3595                     |
| LCV          | 636             | 725             | 1361                     |
| HCV          | 507             | 487             | 994                      |
| Bus          | 94              | 67              | 161                      |
| Bicycle      | 97              | 66              | 163                      |
| Total Vehicles (Vehicles/Day) | 10408 | 10319 | 20727                  |

C) Day Time and Night Time for Rigid Pavement Design:
Details for Kankot to Vavdi (LHS) and Vavdi to Kankot (RHS) directions are given in Table 3 and Table 4.

Table 3: Proportion of Commercial Vehicles in Critical Time Intervals – Kankot to Vavdi (LHS).

| Category | Commercial Vehicle Volume | % of Commercial Traffic |
|----------|---------------------------|-------------------------|
| Day Time traffic for BUC analysis, % (10 AM to 4 PM) | 526 | 36 |
| Night Time traffic for TDC analysis, % (Midnight to 6 AM) | 256 | 18 |
| Total CVPD | 1,443                  |

Table 4: Proportion of Commercial Vehicles in Critical Time Intervals – Vavdi to Kankot (RHS).

| Category | Commercial Vehicle Volume | % of Commercial Traffic |
|----------|---------------------------|-------------------------|
| Day Time traffic for BUC analysis, % (10 AM to 4 PM) | 578 | 39 |
| Night Time traffic for TDC analysis, % (Midnight to 6 AM) | 285 | 19 |
| Total CVPD | 1,488 |

D) Axle Load Survey Data Analysis:
Surveys were conducted at near Matuki Restaurant, Rajkot in order to capture the current loading of heavy/commercial vehicles. Sample size obtained during the ALS is presented in Table 5. It is seen that the sample size is 24% for candidate traffic.

Table 5: Sample Size for Axle Load Survey.

| Number of samples of candidate ALS | Candidate ADT | Sample Size (%) |
|-----------------------------------|---------------|-----------------|
| 575                               | 2405          | 24              |

i) Axle Load Spectrum:
Axle load spectrum at near Matuki Restaurant is analyzed to obtain the spectrum applicable for candidate traffic that will use the proposed project corridor. Axle load spectrum for candidate traffic in Kankot to Vavdi (LHS) and Vavdi to Kankot (RHS) directions are presented in Table 6 and Table 7, respectively.

Table 6: Axle Load Spectrum for Kankot to Vavdi Direction (LHS).

| Single Axle Load (Standard Axle) | Tandem Axle Load | Tridem Axle Load |
|----------------------------------|------------------|------------------|
| Axle Load, kN | No of Axles | Freq (% of No. of Axles) | Axle Load, kN | No of Axles | Freq (% of No. of Axles) | Axle Load, kN | No of Axles | Freq (% of No. of Axles) |
| >215 | 0 | 0.00 | >440 | 0 | 0.00 | >620 | 0 | 0.00 |
| 205-215 | 0 | 0.00 | 420-440 | 0 | 0.00 | 590-620 | 0 | 0.00 |
| 195-205 | 0 | 0.00 | 400-420 | 0 | 0.00 | 560-590 | 0 | 0.00 |
| 185-195 | 0 | 0.00 | 380-400 | 0 | 0.00 | 530-560 | 0 | 0.00 |
| 175-185 | 0 | 0.00 | 360-380 | 0 | 0.00 | 500-530 | 0 | 0.00 |
| 165-175 | 0 | 0.00 | 340-360 | 0 | 0.00 | 470-500 | 0 | 0.00 |
| 155-165 | 0 | 0.00 | 320-340 | 0 | 0.00 | 440-470 | 0 | 0.00 |
| 145-155 | 0 | 0.00 | 300-320 | 0 | 0.00 | 410-440 | 0 | 0.00 |
| 135-145 | 0 | 0.00 | 280-300 | 1 | 1.16 | 380-410 | 0 | 0.00 |
| 125-135 | 3 | 1.63 | 260-280 | 1 | 1.16 | 350-380 | 0 | 0.00 |
| 115-125 | 0 | 0.00 | 240-260 | 3 | 3.49 | 320-350 | 0 | 0.00 |
| 105-115 | 1 | 0.54 | 220-240 | 9 | 10.47 | 290-320 | 0 | 0.00 |
| 95-105 | 0 | 0.00 | 200-220 | 25 | 29.07 | 260-290 | 0 | 0.00 |
| 85-95 | 3 | 1.63 | 180-200 | 12 | 13.95 | 230-260 | 1 | 3.45 |
| <85 | 177 | 96.20 | <180 | 35 | 40.70 | <230 | 28 | 96.55 |
| Total Axles | 184 | 100.00 | 86 | 100.00 | 29 | 100.00 |
Table-7 Axle Load Spectrum for Vavdi to Kankot Direction (RHS).

| Axle Load (Standard Axle) | Tandem Axle Load | Tridem Axle Load |
|---------------------------|------------------|------------------|
| Axle Load, kN             | No of Axles      | Freq. (% of No. of Axles) | Axle Load, kN | No of Axles | Freq. (% of No. of Axles) | Axle Load, kN | No of Axles | Freq. (% of No. of Axles) |
| >215                      | 0                | 0.00              | >440          | 0           | 0.00              | >620          | 0           | 0.00              |
| 205-215                   | 0                | 0.00              | 420-440       | 0           | 0.00              | 590-620       | 0           | 0.00              |
| 195-205                   | 0                | 0.00              | 400-420       | 0           | 0.00              | 560-590       | 0           | 0.00              |
| 185-195                   | 0                | 0.00              | 380-400       | 0           | 0.00              | 530-560       | 0           | 0.00              |
| 175-185                   | 1                | 0.50              | 360-380       | 0           | 0.00              | 500-530       | 0           | 0.00              |
| 165-175                   | 2                | 1.00              | 340-360       | 0           | 0.00              | 470-500       | 2           | 50.00              |
| 155-165                   | 0                | 0.00              | 320-340       | 1           | 1.32              | 440-470       | 1           | 25.00              |
| 145-155                   | 2                | 1.00              | 300-320       | 2           | 2.63              | 410-440       | 1           | 25.00              |
| 135-145                   | 0                | 0.00              | 280-300       | 7           | 9.21              | 380-410       | 0           | 0.00              |
| 125-135                   | 3                | 1.50              | 260-280       | 1           | 1.32              | 350-380       | 0           | 0.00              |
| 115-125                   | 2                | 1.00              | 240-260       | 4           | 5.26              | 320-350       | 0           | 0.00              |
| 105-115                   | 0                | 0.00              | 220-240       | 2           | 2.63              | 290-320       | 0           | 0.00              |
| 95-105                    | 8                | 4.00              | 200-220       | 3           | 3.95              | 260-290       | 0           | 0.00              |
| 85-95                     | 8                | 4.00              | 180-200       | 5           | 6.58              | 230-260       | 0           | 0.00              |
| <85                       | 174              | 87.00             | <180          | 51          | 67.11             | <230          | 0           | 0.00              |
| Total Axles               | 200              | 100.00            | 76            | 100.00      | 4                | 100.00        |

ii) Other Traffic Parameters:
Proportion of different axle categories are calculated for the candidate traffic from the survey data and the same is presented in table 8.

Table-8 Proportion of Different Axle Types.

| Axle Type                      | Kankot to Vavdi (LHS) | Vavdi to Kankot (RHS) |
|-------------------------------|-----------------------|-----------------------|
|                               | No. of Axle | %    | No. of Axle | %    |
| Front Single (Steering Axle)  | 295         | 49.7 | 280         | 50.0 |
| Single Axle and Standard Axle | 184         | 31.0 | 200         | 35.7 |
| Tandem Axle                   | 86          | 14.5 | 76          | 13.6 |
| Tridem Axle                   | 29          | 4.9  | 4           | 0.7  |
| Total No. of Axles            | 3882        |      | 3530        |      |
| Total Number of Commercial Vehicles | 1700        |      | 1525        |      |
| Average Number of Axles per Commercial Vehicle | 2.28 |      | 2.31 |      |

Proportion of vehicles with spacing between the front and rear axle less than the proposed spacing of the transverse joints in the concrete slab (4.5 m) is required for the estimation of the design traffic for computing top down fatigue cracking damage. This wheel base characteristics is presented in Table 9.

Table-9 Wheel Base Characteristics.

| Sl. No. | Direction                      | % of Vehicles with Spacing between the Front (steering) Axle and First Rear Axle < 4.5 m |
|---------|--------------------------------|--------------------------------------------------------------------------------------|
| 1       | Kankot to Vavdi (LHS)          | 79                                                                                    |
| 2       | Vavdi to Kankot (RHS)          | 87                                                                                    |

From the axle load survey, the Vehicle Damage Factor (VDF) for each type of vehicle has been determined and tabulated in table 10.

Table 10 Vehicle Damage Factors (VDF).
4. DATA ANALYSIS

4.1. Analysis by Westergaard Theory:

By using Westergaard’s stress, deflection equations and required all conditions, data analyzed and get critical stress, which shows in Table – 11.

| Vehicle Type | Kankot to Vavdi (LHS) | Vavdi to Kankot (RHS) |
|--------------|-----------------------|-----------------------|
| Bus          | 0.06                  | 0.07                  |
| 2 Axle       | 0.35                  | 2.25                  |
| 3 Axle       | 4.28                  | 4.40                  |
| MAV          | 1.25                  | 19.15                 |

Table-11 Data Inputs for Westergaard.

| P - Load | 9500 Kg |
|----------|---------|
| h - Thickness | 30 cm |
| Radius of wheel load a | 15 cm |
| Subgrade Reaction k | 5.2 kg/cm³ |
| Modulus of Elasticity E | 300000 kg/cm² |
| μ | 0.15 |
| Thermal coefficient, e | 10⁻⁵ |
| Density | 24 KN/m³ |
| Day time temperature | 16.8 C |
| Night time temperature | 13.4 C |

Table-12 Critical Stresses and Deflection.

| Different Locations | Critical Stresses in MPa | Deflection in mm (Interior, Edge, Corner) |
|---------------------|--------------------------|------------------------------------------|
| Kankot to Vavdi     | 3.18                      | 0.14, 0.42, 1.02                         |
| Vavdi to Kankot     | 3.91                      | 0.19, 0.57, 1.39                         |

4.2. Design as per IRC – 58 (2015)

Put the collected above data in this IRC -58 (2015) excel sheet Figure-3, it gives the finalized thickness of PQC slab for both direction.

Figure 3. IRC-58 (2015) Excel Sheet.
The PQC layer thickness in the tables below is inclusive of the extra 10mm thickness in addition to the design requirement as per IRC: 58 -2015

| Layer                                     | Direction          | Kankot to Vavdi (LHS) | Vavdi to Kankot (RHS) |
|-------------------------------------------|--------------------|-----------------------|------------------------|
| Pavement Quality Concrete (PQC), mm       |                    | 230                   | 250                    |
| Dry Lean Concrete (DLC), mm               |                    | 150                   | 150                    |
| Granular Subbase (GSB), mm                |                    | 150                   | 150                    |
| Subgrade, mm                              |                    | 500                   | 500                    |

A minimum PQC thickness of 300 mm is specified. Therefore, the thickness of PQC has been proposed as 300 mm as shown in Table 14.

| Layer                                     | Direction          | Kankot to Vavdi (LHS) | Vavdi to Kankot (RHS) |
|-------------------------------------------|--------------------|-----------------------|------------------------|
| Pavement Quality Concrete (PQC), mm       |                    | 300                   | 300                    |
| Dry Lean Concrete (DLC), mm               |                    | 150                   | 150                    |
| Granular Subbase (GSB), mm                |                    | 150                   | 150                    |
| Subgrade, mm                              |                    | 500                   | 500                    |

4.3) Analysis by Ansys Software:

After providing all necessary data and boundary conditions, Ansys analyzed the panel in 3D modeling. Following models shows that analysis of respective higher single axle load applied on pavement for both direction of them. Meanwhile same procedure can analyze other all axle load which affect on pavement.

i) Kankot to Vavdi Modeling

Figure 4 and Figure 5 shows the stress and deflection result of analysis at edge of pavement for single axle single wheel load for direction Kankot to Vavdi .

Figure 4. Stress Analysis (Kankot to Vavdi).
**Figure 5.** Deflection Analysis (Kankot to Vavdi).

ii) Vavdi to Kankot Modeling

Figure 6 and Figure 7 shows the stress and deflection result of analysis at edge of pavement for single axle single wheel load for direction Vavdi to Kankot.

**Figure 6.** Stress Analysis (Vavdi to Kankot).
Figure 7. Deflection Analysis (Vavdi to Kankot).

From the above analysis we get following result which shown in Table 15.

Table-15 Stress And Deflection Analysis By Ansys.

| Direction       | Stress (Mpa) | Deflection (mm) |
|-----------------|--------------|-----------------|
| Kankot to Vavdi | 2.56         | 0.4             |
| Vavdi to Kankot | 2.14         | 0.6             |

5. Conclusion

1. Classified Volume Count survey shows various types of commercial vehicles like Bus, LCV, Single Axle Truck, Tandem Axle Truck and Multi Axle Truck are moving on the selected road stretch.
2. From Axle load survey, the average Vehicle Damage Factor found out 1.49 and 6.47 for respective direction.
3. Results which are analysis by Ansys is closed to Westergaard theory and IRC – 58 (2015). Therefore Ansys is useful in FEM analysis in rigid pavement.

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