TECHNICAL NOTE NO: 18

Sub: **Design of Flexible Pavements- Importance of VDF values pertains to Multi Axles and Overloaded Vehicles in the design of Pavements – Reg.**

Ref: Inspection of APRRP works by the Project Advisor.

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1. Introduction:

VDF, which stands for Vehicle Damage Factor, is an important parameter in the design of flexible pavements. Flexible pavements are those that have multiple layers of materials, with the top layer being the asphalt or bituminous concrete. The VDF is a measure of the damage caused to the pavement by the passage of a standard axle load.

The Vehicle Damage Factor (VDF) of overloaded vehicles has a significant impact on the design of pavements. VDF is a measure of the relative damage caused by a specific axle load compared to a standard or reference axle load. Understanding and accounting for the effects of VDF in pavement design is crucial for ensuring that the pavement can withstand the traffic loads over its intended service life. Here are the key effects of VDF on pavement design:

a) Pavement Thickness Design:

VDF is used in pavement design methods to calculate the structural requirements of the pavement layers. Higher VDF values indicate a higher potential for damage, and this is considered when determining the thickness of each pavement layer. Pavements exposed to higher VDF loads may require thicker asphalt or additional base layers to resist the additional stress and strain.

b) Load Distribution:

VDF values are used to distribute the applied loads from vehicles to the various pavement layers. The distribution of loads is a critical factor in preventing premature pavement distress such as rutting, fatigue cracking, and permanent deformation. VDF helps in determining how much damage each axle load is likely to cause to the pavement structure.

c) Pavement Performance Prediction:

VDF is incorporated into pavement performance prediction models. Pavement engineers use these models to estimate the long-term performance of the pavement under various traffic conditions, including the effects of overloaded vehicles. This aids in identifying potential distress mechanisms and designing pavements that can resist the anticipated damage.

d) Durability Considerations:

Pavement durability is influenced by the cumulative damage caused by repeated loads over time. Higher VDF values indicate a higher potential for damage, which can impact the overall durability of the pavement. Engineers consider VDF in selecting materials and designing pavements that can provide the necessary durability under the expected traffic conditions.

e) Maintenance Planning:

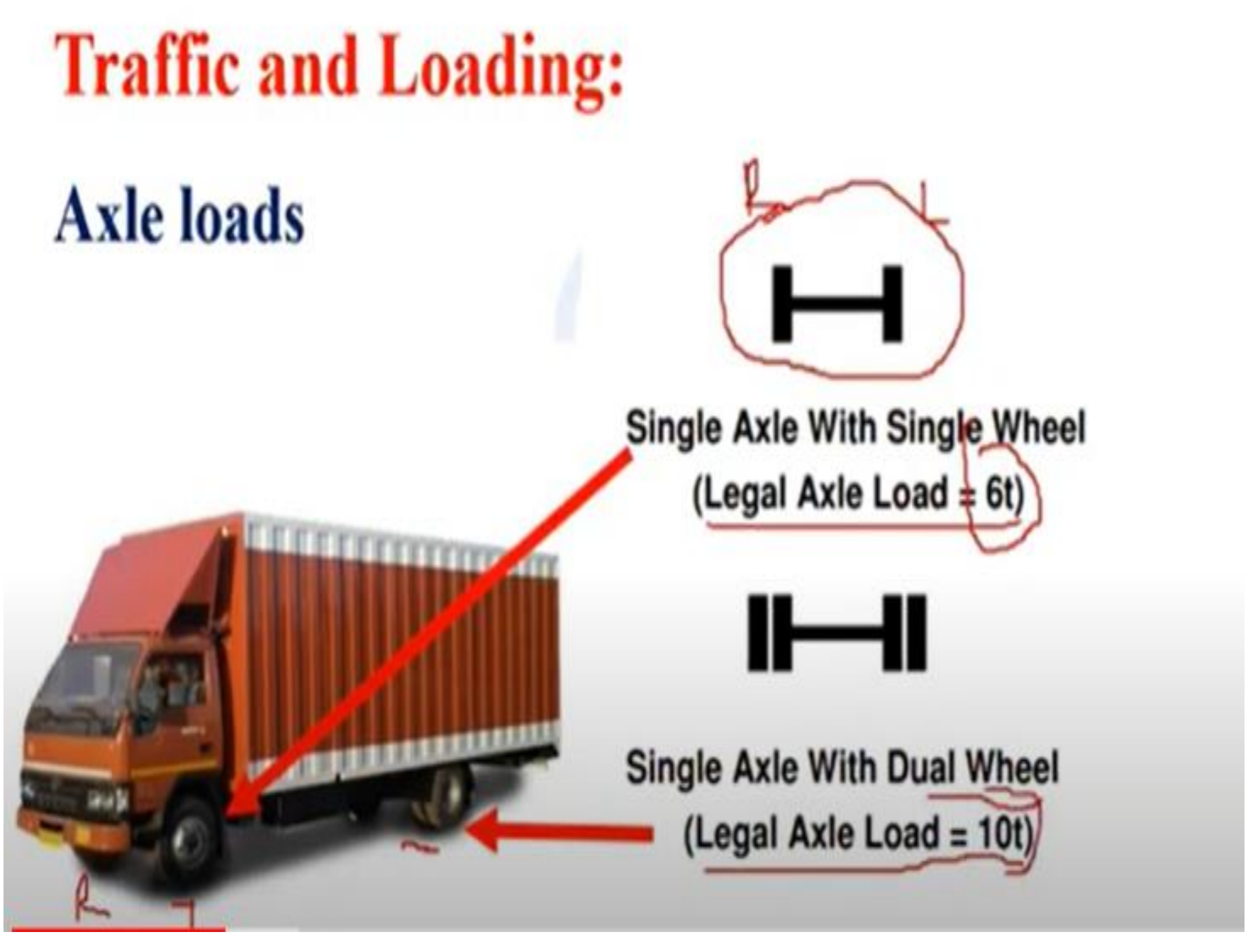
Understanding the effects of VDF allows for better planning of maintenance activities. Pavements subjected to high VDF loads may experience accelerated deterioration, and maintenance schedules can be adjusted accordingly. Regular maintenance, rehabilitation, or strengthening may be required to address the impact of overloaded vehicles.

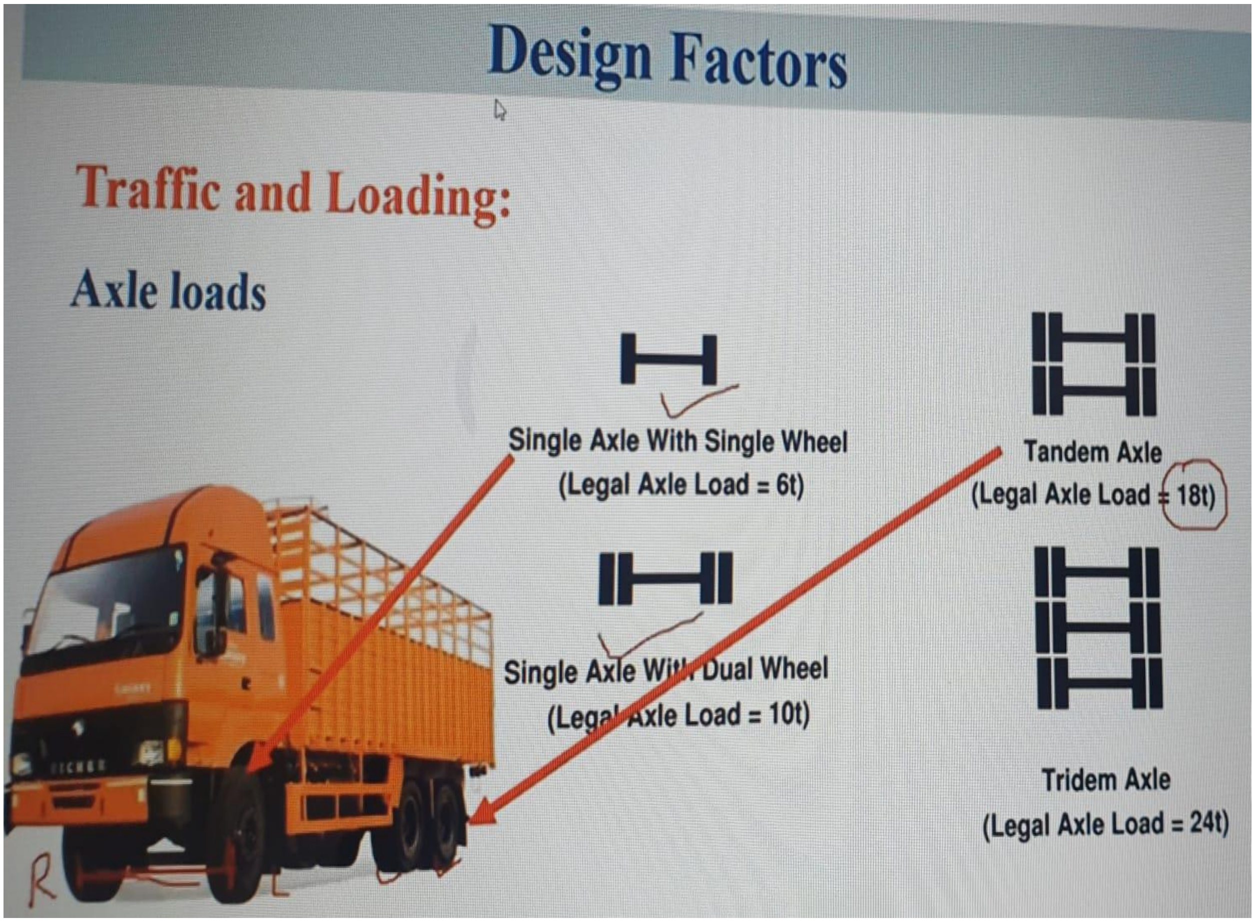
f) Life-Cycle Cost Analysis:

VDF values play a role in life-cycle cost analysis. Pavements with higher VDF loads may require more frequent maintenance and rehabilitation, leading to higher life-cycle costs. Evaluating these costs helps in making informed decisions about pavement design and management strategies.

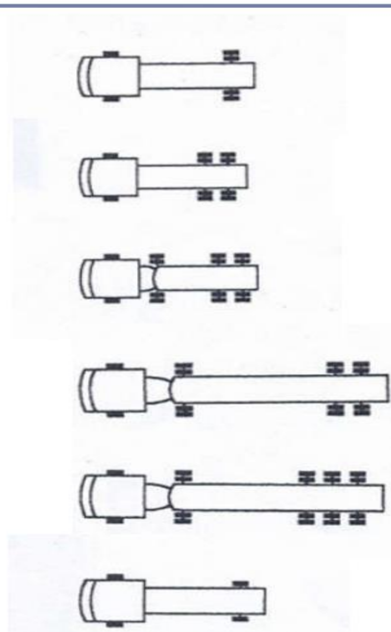
In summary, the VDF of overloaded vehicles is a critical factor in the design and management of pavements. It informs the selection of materials, pavement thicknesses, and maintenance strategies to ensure that the pavement can withstand the traffic loads and provide the desired performance over its design life. Incorporating accurate and representative VDF values is essential for designing cost-effective and durable pavements.

2. Different Types of Traffic and their Legal Axle Loading:





Axle Configurations



2 Axle Truck – 16t

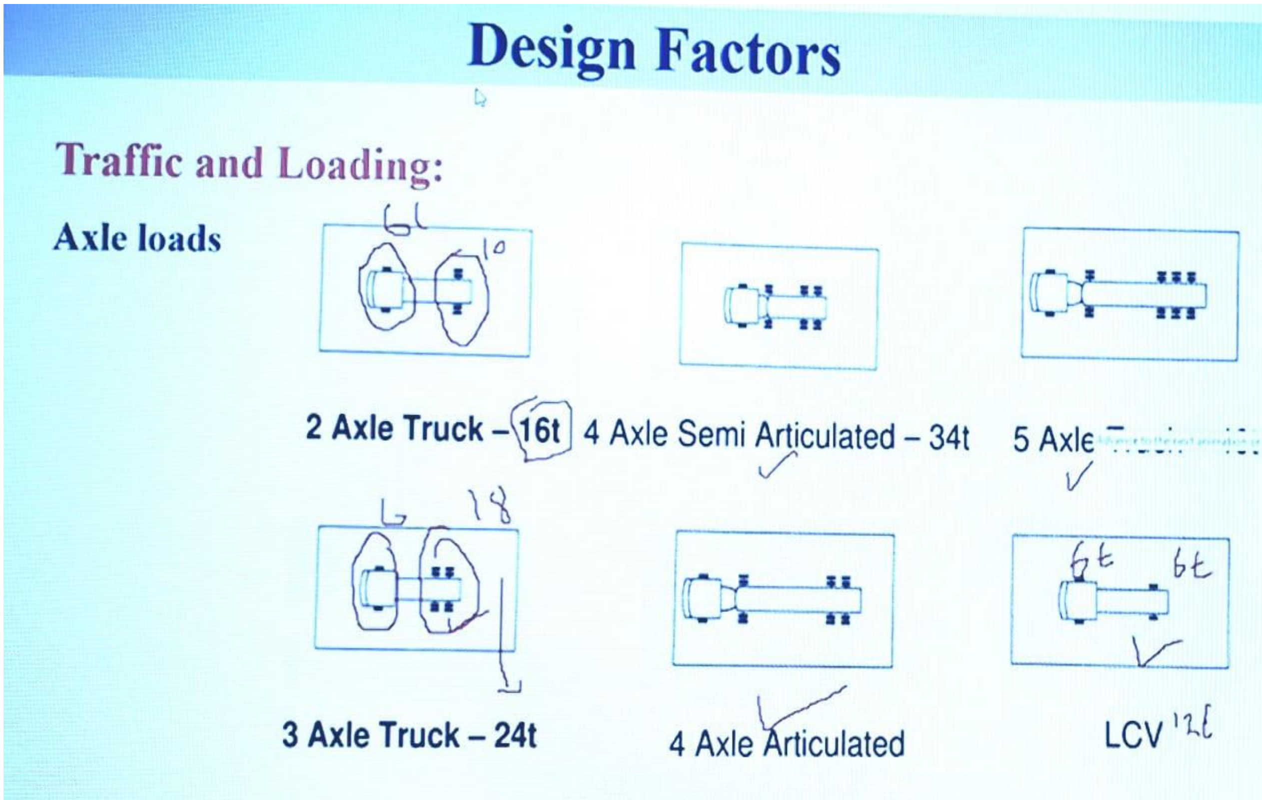
3 Axle Truck – 24t

4 Axle Semi Articulated – 34t

4 Axle Articulated – 34t

5 Axle Truck – 40t

LCV



3. Maximum Permissible Weights:

3.1 Single Axle Weight

The total gross weight imposed on the highway by a **single axle fitted with dual wheels** shall **not exceed 10.2 tonnes**. In the case of **axles with single wheels**, the axle weight shall **not exceed 6 tonnes**.

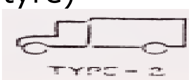
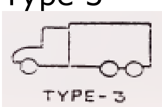
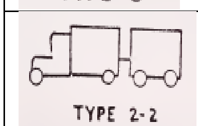
3.2 Tandem Axle Weight

The total gross weight imposed on the highway by **two axles in tandem** articulated from a common attachment to the vehicle or individually attached to the vehicles and spaced not less than 1.20 m but not more than 2.5 m apart, shall **not exceed 18 tonnes** fitted with dual wheels shall not exceed 10.2 tonnes.

4. Maximum Permissible Gross Weight:

The maximum permissible gross weight for a given vehicle or vehicle combination would be equal to the sum of the individual single axle and tandem axle weights indicated above. For typical vehicles, maximum permissible gross weights are given in the Table.

Table: Maximum Permissible Gross Weights and Maximum Axle Weights of Transport Vehicles.

Vehicle Type	Maximum Gross Weight (tonnes)	Maximum axle weight (tonnes)			
		Truck/Tractor		Trailer	
		FAW	RAW	FAW	RAW
Type 2 (Both axles single tyre) 	12	6	6		
Type 2 (FA: Single tyre, RA : Dual tyre)	16.2	6	10.2		
Type 3 	24	6	18 (TA)		
	36.6	6	10.2	10.2	10.2

FA: Front Axle, **RA**: Rear Axle, **FAW**: Weight on Front Axle, **RAW**: Weight on Rear Axle, **TA**: Tandem Axle fitted with 8 tyres.

5. Determination of ESAL applications:

Commercial Vehicles with a gross laden weight of 3 tonnes or more along with their axle loading are considered- Trucks (Heavy, Medium), Buses and Tractors- Trailers.

Pavement design is always done for Standard axle load of 80 kN (8160 Kg)

Axle Load Factor: $[W/Ws]^4$

Where W: Axle load (in kN) of the rural vehicle in question

Ws: Standard Axle Load of 80 kN or 148 kN in case of tandem axles.

5.1 Calculation of VDF values: Cl 3.4.4 of IRC:SP:72-2015.

i) Laden Heavy Commercial Vehicles (HCV)

Rear Axle load: 10.2 tonnes

Front Axle load: 5 tonnes

VDF works out to: $[10.2/8.16]^4 + [5/8.16]^4 = 2.44+0.14 = 2.58$

ii) Unladen/Partially loaded Heavy commercial Vehicles

Rear Axle load: 6 tonnes

Front Axle load: 3 tonnes

VDF works out to: $[6/8.16]^4 + [3/8.16]^4 = 0.29 + 0.02 = 0.31$.

iii) Over loaded HCV: If 20% overloading is there (instead 10.2 t and 5 t, it is 12.24 t and 6 t)

Then VDF = $(10.2 \times 1.2/8.16)^4 + (5 \times 1.2/8.16)^4$

$= 5.06+0.29 = 5.35$.

If only 10% of the laden HCV are 20% overloaded,

Then VDF: $0.9 \times 2.58 + 0.1 \times 5.35 = 2.86$.

iv) Laden Medium Commercial Vehicle (MCV)

Rear Axle Load: 6 t

Front axle load: 3 t

VDF = $0.29 + 0.02 = 0.31$.

6. Overloaded Vehicles and Infrastructure Damage:

6.1 Pavement Damage:

Overloaded vehicles exert higher loads on the pavement, accelerating wear and tear. This can lead to increased rutting, cracking, and overall pavement deterioration.

6.2 Maintenance Costs:

Overloaded vehicles contribute to higher maintenance costs for road infrastructure. Increased wear and damage necessitate more frequent repairs and maintenance, placing a financial burden on transportation agencies.

6.3 Safety Considerations:

Overloaded vehicles not only damage infrastructure but also pose safety risks. Structural failures due to excessive loads can lead to accidents and endanger road users. Incorporating this factor into road design enhances safety considerations.

7. Importance of traffic count in respect of Number of Overloaded and Percentage of Over loading of vehicles:

Normally, the designers will follow 20% overloading and 10% of vehicles in their ESAL application calculations and arrive at the VDF values without accounting actual situation on the ground and sometimes no overloaded vehicles are considered in the design.

If the road is constructed/ Upgraded the traffic flows will improve duly crossing the above percentage of overloaded vehicles. This will reflect adversely in calculation of ESAL applications and in turn we can get lesser volume of traffic in terms of ESAL applications and lesser thickness of crust instead of actuals. Flexible pavements are designed for 10 years of life, due to improper estimation of VDF values the roads are getting damaged within defect liability period also.

Certain roads leading to Pilgrim centers, Quarry areas and industrial zones, there is every possibility of increase in number of overloaded vehicles (HCVs) and overload over Standard legal Axle load beyond our assumptions.

The following road was designed for normal traffic of T4 category without considering the overloaded vehicles in the design. Now the road caters the need of so many overloaded vehicles carrying raw granite to polishing industries in Chittoor Dist. as show below. **(Pkg : 77- Chittoor Dist - R/F MBT road to Gadadeshi and Gurukalapalli).** Same may be the case in most of the estimates in all the Districts.

Fig: **Overloaded vehicle plying on the road with raw Granite from quarry to Industries.**

Fig: Location of number of Granite Polishing Industries all along the road

7.1 The influence of VDF values in estimation of ESAL applications based on assumptions and real traffic count data is as follows.

***Case 1:* Without Considering Over- Loaded Vehicles.**

Field data sheet for Traffic Census (Both Directions)- 3 days Average

Sl.No.	Hour	Laden / Un-laden	Average Daily Traffic
1	**2**	**3**	**4**
1	Cars, jeeps, Vans		**20**
2	Scooters/Motor bikes		**23**
3	Buses (HCV)		**5**
4	Light Commercial Vehicles	***Laden***	**14**
		Un-laden	**11**
5	Trucks (MCV)	***Laden***	**8**
		Un-laden	**8**
6	Agricultural Tractors/Trailors(MCV)	***Laden***	**26**
		Un-laden	**23**
7	cycles		**18**
8	Animal Drawn Vehicles	Solid wheel cart	**0**
		Pneumatic type cart	**8**
	Total		**164**

Average Daily Traffic = 164 Nos

Taking 50%, Average Daily Traffic = 82

Average Annual Daily Traffic (AADT) = T+(1.2 n T t)/365

Where, T= 82, n=1, t= 75 (Harvesting season period)

AADT = 82+ (1.2x 1 x 82 x 75)/365 = 102 Nos

Before opening of the road to Traffic AADT = 102 $(1.06)^2$ = 115, assuming an initial annual traffic growth rate of 6%.

From the given traffic data, the proportion of AADT and ADT = 115/82 = 1.4

Type	ADT		50% ADT	Projected AADT	Category
MCV	48	Nos	24	34	Laden- MCV
MCV	42	Nos	21	29	Un Laden - MCV
MCV	0	Nos	0	0	Over Laden- MCV
HCV	5	Nos	3	4	Laden- HCV
HCV	0	Nos	0	0	Un Laden – HCV
HCV	**0**	**Nos**	**0**	**0**	**Over Laden- HCV**

Vehicle Damage Factor

Vehicle	Laden	Un- Laden	Over Laden
For HCV	2.58	0.31	2.86
For MCV	0.31	0.02	0.34

Cumulative ESAL applications over 10 years @ 6% growth rate

ESAL = MCV x VDF + HCV x VDF

= (34x0.31+29x0.02+ 4x2.58)

= 21.44 Nos/ day.

Cumulative ESAL applications = 4811x 21.44

= **103148**

= **T4 – 100000 - 200000**

Pavement Design Adopted: KM 0/0 to 2/5

Avg CBR of Soil = 5.5%

Traffic Category = **T4**

Proposed Surface Course = 25 mm – SDBC

Proposed Base = 150 mm – WMM

Proposed Sub Base = 150 mm - GSB

Existing Crust = 0 mm

ESAL without Considering the Over loaded vehicles = 103148 (T4), Required Crust Thickness: 300 mm.

Case 2: Considering Over loaded Vehicles as per site data.

As observed Trucks are carrying Heavy loads of Raw Granite from the newly developed quarry to the Granite Polishing Industries situated all along the present road.

One of the impacts of this industrial growth is the increase in cases of violations of overloading vehicles, especially goods transport vehicles. Overloading carried out because this behavior can provide benefits such as reducing transportation costs, saving travel time, saving vehicle operating costs, and reducing overhead costs such as administrative costs, permit fees, and user fees. Even though behind all of that, this overload violation has a negative impact on the highway, namely the reduced life of the pavement, it will be studied how the impact of overload on the flexible pavement structure.

Hence , there is a possibility of increase in traffic count in respect of HCVs both Laden (normal and over loaded) and un- Laden in both the directions.

At present Traffic count with HCVs of Laden, Overloaded and Un- Laden in addition to the other traffic mentioned above are considered in arriving the following ESAL calculations.

Field data sheet for Traffic Census (Both Directions)- 3 days Average

Sl.No.	Hour	Laden / Un-laden/overloaded	Average Daily Traffic
1	**2**	**3**	**4**
1	Cars, jeeps, Vans		**20**
2	Scooters/Motor bikes		**23**

3	Buses (HCV)		**5**
4	Trucks (HCV)	Laden	**12**
		Un - Laden	**10**
		Over loaded (20%)	**6**
5	Light Commercial Vehicles	***Laden***	**14**
		Un-laden	**11**
6	Trucks (MCV)	***Laden***	**8**
		Un-laden	**8**
7	Agricultural Tractors/Trailors (MCV)	***Laden***	**26**
		Un-laden	**23**
8	cycles		**18**
9	Cycle Rikshaws		**0**
10	Animal Drawn Vehicles	Solid wheel cart	**0**
		Pneumatic type cart	**8**
	Total		**192**

Average Daily Traffic = 192 Nos

Taking 50%, Average Daily Traffic = 96

Average Annual Daily Traffic (AADT) = T+(1.2 n T t)/365

Where, T= 96, n=1, t= 75 (Harvesting season period)

AADT = 96 + (1.2x 1 x 96 x 75)/365 = 119 Nos

Before opening of the road to Traffic, AADT = 119 $(1.06)^2$ = 134, assuming an initial annual traffic growth rate of 6%.

From the given traffic data, the proportion of AADT and ADT = 134/96 = 1.4

Type	**ADT**		**50% ADT**	**Projected AADT**	**Category**
MCV	48	Nos	24	34	Laden- MCV
MCV	42	Nos	21	29	Un Laden - MCV
MCV	0	Nos	0	0	Over Laden- MCV
HCV	17	Nos	9	13	Laden- HCV
HCV	10	Nos	5	7	**Un Laden - HCV**
HCV	6	Nos	3	4	**Over Laden- HCV**

Vehicle Damage Factor

Vehicle	Laden	Un- Laden	Over Laden with 20%
For HCV	2.58	0.31	5.35 (Cl 3.4.4 iii)
For MCV	0.31	0.02	0.65

Cumulative ESAL applications over 10 years @ 6% growth rate

ESAL = MCV x VDF + HCV x VDF

= (34x0.31) + (29x0.02) +(13x2.58) + (7x0.31) + (4x5.35)

= 68.23 Nos/ day.

Cumulative ESAL applications = 4811x 68.23

= **328255**

= **T6** – (>300000 – 600000) – Clause 3.5 of IRC: SP:72-2015

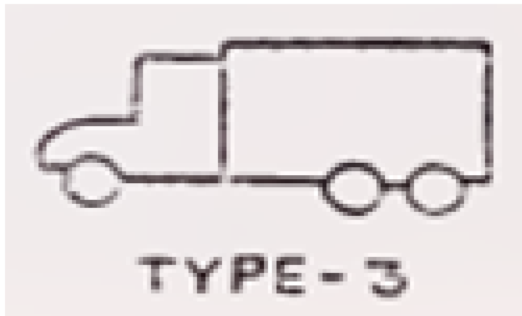
ESAL duly Considering the Over loaded vehicles = 328255 (T6), Required Crust Thickness: 375 mm.

As seen from the above ESAL applications, when comparing case 1 and case 2, it is evident that there will certainly be an impact on the VDF values of overloaded vehicles. This is because the traffic category changes from **T4 to T6** when 20% overload of all trucks (HCV) is considered."

Furthermore, there is a chance of an increase in the number of vehicles, particularly **multi-axle trucks** (HCVs), to carry heavy loads such as raw granite from the quarries.

The VDF values mentioned in IRC: SP:72-2015 are based on a rear axle load of 10.2 tonnes (Dual Tyre) and a front axle load (Single Tyre) of about 5 tonnes in the case of laden HCVs. Due to the increase in trucks with multi-axles, the VDF values mentioned in the IRC: SP:72 cannot be used directly in arriving at the ESAL applications. The VDF values will be calculated based on the number of axles, as shown below as case 3.

Case 3: For the same traffic count mentioned above , if we consider Type- 3 (Vehicle type) vehicles as HCV (Laden- Overloaded- multi Axle) which are common in use to transport coarse and fine aggregate by the contractors during road construction process.



Considering Trucks (HCV- Loaded) with **2 Rear Axles with Dual Tyres** and **Front Axle with Single Tyre** in the design, which we come across normally in Rural Roads during construction time also.

The images of the Trucks as stated above are as shown below carrying Aggregate and Sand from quarries during construction of Roads.

Fig: HCVs with Rear Two Axles with Dual Tyres and Front Single Axle with Single tyre

Calculation of VDF value for the Heavy Commercial vehicles (Case 2- Over Laden : 4 vehicles) with Multi Axles (Rear Two Axles with Dual Tyres) and Over load as per site condition – for the above Traffic mentioned in Case 1&2.

Rear Axle load allowed for HCV = 10.2 T – Cl 3.4.4 of IRC: SP-72-2015.

Front Axle load allowed for HCV = 5.00 T - Cl 3.4.4 of IRC: SP-72-2015.

Details of Trucks with multi-Axles plying on the road from Granite Quarries and Crushers.

No of Rear Axles = 2

No of Front Axles = 1

Allowable load (2*10.2+1*5) = 25.4 T – Cl 3.4.4 (i) of IRC: SP:72-2015

Actual average load observed = 35 T (At site)

Overload in Tonnage = 9.6 T

Percentage of Overload = 100x (9.6/25.4) = 37.79 or say 38%.

VDF Value Calculations with 38% Overload

Axle equivalency factor = (W/Ws) ^4 - Cl 3.4.3 of IRC: SP:72-2015

Where,

W = Axle load of the vehicle in question

Ws = Standard Axle load = 80 kN or 8.16 T

(As per Table in Cl 3.4.3 of IRC: SP-72-2015)

For 10.2 T axles (10.2*1.38/8.16) ^4 = 8.85

For 5.0 T axles (5*1.38/8.16) ^4 = 0.51

VDF = with 38 % overload for 100% overladen HCV = 9.36

The VDF value of 9.36 is proposed as per site condition and the pavement design is modified accordingly.

Vehicle Damage Factor

Vehicle Type	Laden	Un- Laden	Overladen with Multi- Axles
HCV	2.58	0.31	9.36
MCV	0.31	0.02	0.34

Cumulative ESAL applications over 10 years @ 6% growth rate

ESAL = MCV x VDF + HCV x VDF

= (34x0.31) + (29x0.02) +(13 x2.58) + (7x0.31) + (**4 x 9.36**)

= 84.27 Nos/ day.

Cumulative ESAL applications = 4811x 84.27

= **405423**

= **T6** – (>300000 – 600000)

Thickness required = 375 mm

8. Conclusions and Recommendations:

Based on the three different traffic studies as explained above in case 1,2 & 3, the variation in VDF values leads to change in the design thickness of pavement for the said road as shown below.

S.No	Case/ Traffic Count details	Traffic Category & ESAL	Pavement Thickness in mm	Remarks
1	Case 1: Normal Traffic	T4 & 103148	300	T4: 100000-200000
2	Case 2: With 20% over loading (HCV)	T6 & 328255	375	T6: 300000 - 600000
3	Case 3: Multi-Axles with actual overloading (HCV)	T6 & 405423	375	T6: 300000 - 600000

As seen from the above designs of flexible pavements, the traffic Category changes **from T4 to T6** when actual overloaded vehicles with multi-axle HCVs are considered during traffic counts.

Since the concept of estimating actual traffic census is not addressed by most designers in their estimates, the roads may deteriorate within the defect liability period.

Hence, the pavement design of the following category of roads should duly consider Heavy Commercial Vehicles (HCV) trucks (laden) with **multi-axles** and account for observed **overloading** during traffic counts.

- Roads connecting two NHs – since there is a possibility of diverting traffic from NHs to VRs due to traffic disruptions in NHs.
- Roads connecting two SHs and MDRs - since there is a possibility of diverting traffic from SHs/MDRs to VRs due to traffic disruptions in said roads.
- Roads connecting SEZs and Industrial Corridors
- Roads connecting Quarries, crushers etc.

8. Adverse effects of Wrong VDF values:

If the wrong VDF is adopted in the design of pavements, it can lead to various adverse effects. Here are some potential consequences:

Pavement Distress: Using an incorrect VDF can result in underestimating or overestimating the actual damage caused by traffic loads. This can lead to pavement distress, such as rutting, cracking, and fatigue failure. Inadequate pavement design may necessitate premature maintenance or rehabilitation.

Reduced Pavement Service Life: Pavements designed with an inaccurate VDF may have a shorter service life than anticipated. The pavement may deteriorate more quickly, leading to increased maintenance costs and disruptions.

Safety Concerns: Pavements that fail prematurely due to inaccurate design may pose safety risks to road users. Distresses like potholes and cracks can contribute to accidents and increase the likelihood of skidding.

Increased Maintenance Costs: If the pavement design is based on a VDF that underestimates the damage caused by traffic loads, it may lead to frequent and costly maintenance. On the other hand, overestimating the damage may result in unnecessary and expensive construction of overly robust pavements.

Financial Implications: Inaccurate pavement design can have financial repercussions for transportation agencies and governments. Unforeseen maintenance and rehabilitation needs may strain budgets and hinder the implementation of other infrastructure projects.

To mitigate these consequences, it's essential to ensure **accurate** calculations of **VDF values** based on the specific characteristics of the vehicles using the road. Regular updates to design standards and methodologies can help address changes in vehicle configurations and axle loads over time. Additionally, periodic monitoring and reassessment of pavement conditions can help identify any discrepancies early on and allow for timely corrective measures.

Hence, it's important to note that designing for **overloaded and multi axle vehicles** requires a balance between accommodating heavy loads and ensuring the long-term sustainability of the road infrastructure.

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