TECHNICAL NOTE NO: 19

Sub: **Design of Rigid Pavements- Relation between thickness and joint spacing in the design of Cement Concrete Pavements for Low Volume Roads – Reg.**

Ref: Observations during inspection of APRRP works by the Project Advisor in different Districts.

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1. Introduction:

CC roads in rural areas are instrumental in fostering economic development, improving living standards, and creating a more connected and accessible environment for the residents. They contribute to the overall progress and well-being of rural communities. Concrete pavements offer an alternative to flexible pavements especially where the soil strength is poor, the aggregates are costly and drainage conditions are bad.

2. Factors Governing Design:

2.1 Wheel Load: The maximum legal load limit on single axle with dual wheels in India being 100 kN, the recommended design load on dual wheel is 50 kN having a spacing of the wheels as 310 mm Centre-to-Centre.

2.2 Tyre Pressure:

The tyre pressure may be taken as 0.8 MPa for a truck carrying a dual wheel load of 50 kN while for a wheel of tractor trailer, the pressure may be taken as 0.5 MPa.

2.3 Design Period:

Concrete pavements designed and constructed as per IRC:SP:62-2014 guidelines will have a design life of 20 years or higher.

2.4 Design Traffic for Thickness Evaluation

- For traffic less than 50 CVPD – Only wheel load stresses for a load of 50kN on dual wheel need be considered.
- For traffic higher than 50 and less than 150 CVPD – Thickness evaluation should be done on the basis of total stresses resulting from wheel load of 50kN and temperature differential.
- For traffic exceeding 150 CVPD – thickness evaluation on the basis of fatigue fracture.

3. Strength of Subgrade:

The minimum CBR of the subgrade shall be 4, in case, it is less than 4 percent the CBR will be improved by stabilization with mechanical / lime-fly ash/ lime/cement so as to bring the CBR not less than 10 percent.

4. Sub- Base

4.1 Sub-base types

Still, some of the PIUs are providing CC 1:4:8 as sub- base under M30 CC pavement, for which there is no provision in the codes. The following types of sub-bases should be provided based on traffic.

4.1.1 Traffic up to 50 CVPD.

75 mm thick: WBM Grade III (WBM III)/WMM may be provided over

100 mm thick: granular subbase made up of gravel, murrum or river bed material with CBR not less than 30 percent, liquid limit less than 25 percent and plasticity Index (PI) less than 6.

Or

150 mm thick: cement/lime/lime-fly ash treated marginal aggregate/soil layer with minimum UCS of 3 MPa at 7 days with cement or at 28 days with lime/lime-fly ash may be used.

4.1.2 Traffic from 50 to 150 CVPD

75 mm thick: WBM Grade III (WBM III)/WMM may be provided over

100 mm thick: granular subbase made up of gravel, murrum or river bed material with CBR not less than 30 percent, liquid limit less than 25 percent and plasticity Index (PI) less than 6.

Or

100 mm thick: cement/lime/lime-fly ash treated marginal aggregate/soil layer with minimum UCS of 3 MPa at 7 days with cement or at 28 days with lime/lime-fly ash over 100 mm thick cementitious naturally available materials with a minimum UCS of 1.5 MPa with cement at 7 days or at 28 days with lime/lime-fly ash may be provided.

4.1.3 Traffic from 150 to 450 CVPD

150 mm thick: WBM Grade III (WBM III)/WMM may be provided over

100 mm thick: granular subbase made up of gravel, murrum or river bed material with CBR not less than 30 percent, liquid limit less than 25 percent and plasticity Index (PI) less than 6.

Alternatively,

100 mm thick: cement/lime/lime-flyash treated marginal aggregate/soil layer with minimum UCS of 3.0 MPa at 7 days with cement or at 28 days with lime/lime-fly ash over 100 mm thick cementitious naturally available materials with a minimum UCS of 1.5 MPa with cement at 7 days or at 28 days with lime/lime-fly ash may be provided.

The granular subbase and WBM layers should meet the requirement of MoRD specifications, Section 400(34)

5. Concrete Strength and Design Mix

Design should be based on flexural strength of concrete. Where there are no facilities for determining the flexural strength, the mix design may be carried out using the compressive strength values.

Adopt a 28-day compressive strength of 30 MPa. (f_{ck})

28-day flexural strength = $f_f = 0.7 \sqrt{f_{ck}}$ = 3.834 MPa

90-day flexural strength = 1.10x3.834 MPa = **4.22 MPa**.

Where,

f_f = flexural strength, MPa

f_{ck} = Characteristic compressive cube strength, MPa.

5.1 Flexural Strength and Compressive Strength

For rural roads, it is recommended that the characteristic 28-day compressive strength should be at least **30 MPa** and corresponding flexural strength shall not be less than **3.8 MPa**.

6. Recommended Temperature Differentials for Concrete Slabs

Table 1. gives default values of temperature differentials of **zone iii** in which **Andhra Pradesh State** falls as recommended by CRRI. If data is available, local values of the temperature differential may be used.

Table 1. Recommended Temperature Differentials for Concrete Slabs

Zone	State	Temperature Differential ^0C in Slabs of Thickness		
		150 mm	200 mm	250 mm
iii)	Andhra Pradesh	17.3	19.0	20.3

7. Pavement Design

A programmed excel sheet is provided by IRC along with **SP:62-2014** for quick computation of thickness of pavements instead of doing manually. Minimum pavement thickness shall be taken as 150 mm. Three cases are considered in the excel sheets for pavement design **up to 450 CVPD for Low Volume Roads**.

Traffic greater than 450 CVPD – IRC:58 deals with design of concrete pavements for major roads carrying an average daily traffic exceeding 450 CVPD with laden weight exceeding 30 kN.

Case 1

Traffic less than 50 CVPD – Stresses due to 50 kN dual wheel load only. Thickness values for a dual wheel load of 60kN are 160 mm for all the joint spacing of 2.50 m, 3.25 m and 4.00 m with effective k value over WBM is taken as 42 MPa/m (35+20 percent of 35 MPa/m). For other k values, excel sheet can be used to get the thickness. The outcome of results is **"Safe"** with the following input parameters in the excel sheet.

Trial Thickness: 160 mm

CVPD : 45 < 50 – Case1

Joint Spacing : 3.25 m

DESIGN OF CONCRETE PAVEMENTS FOR RURAL ROADS AS PER IRC:SP 62-2014.

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data					
Case 1 /2/3	1	Tyre (**1**- single/**2** - dual)	2	Transverse joint spacing,m	3.25
Temperature Zone (1 to 6)	3	Spacing of wheels Sd (mm)	310	Ratio of L/l	NO NEED TO CALC TEMP STRESS
Modulus of the subgrade reaction, k Mpa/m	58.66	wheel load, P kN	50	Co-efficient of thermal expansion	0.00001
Elastic modulus of concrete E, Mpa	30000	Tyre pressure, q MPa	0.8	Correction factor C	
Poisson Ratio of the concrete, µ	0.15	Radius of contact, a (mm)	180.565	Design life of pavement, yrs	20
Temperature differntial, ΔT oC	17.6	Trial thickness, h m	0.16	Rate of increase of traffic	0.06
Modulus of rupture of concrete, fcr	4.22	No. of commercial vehicels per day	45	Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION

Case 1	
Radius of relative stiffness, l m	650.0702375
Stress developed, σ, Mpa	3.726889403
Design is	Safe

RESULTS FOR WHEEL LOAD AND TEMPARATURE

Case 2	
temparature stress at edge, Mpa	
Wheel load Stresses at edge, Mpa	
Total stresses, σ, Mpa	
Design is	

Case 2

Traffic **greater than 50 and less than 150 CVPD** – Combined stresses due to 50 kN dual wheel load and temperature gradient.

Table 2 gives slab thickness for traffic 50 to 150 CVPD as per SP:62-2014. A subbase of 75mm WBM over 100 mm GSB is considered.

Table 2. Concrete pavement thickness for traffic between 50 and 150 CVPD and a subgrade CBR of 4%.

Joint Spacing in Metres	Pavement Thickness (mm)
	Wheel Load-50 kN
	Zone III (Andhra Pradesh)
4.00	190
3.25	170
2.50	160

Case 3

Traffic **greater than 150 CVPD and less than 450 CVPD** – Fatigue analysis for stresses due to 50 kN dual wheel load and temperature stresses are considered and the thicknesses are shown in Table 3.

Table 3. Concrete pavement thickness over for a traffic of 150 CVPD (subgrade CBR=8%).

Joint Spacing in Metres	Pavement Thickness (mm)
	Wheel Load-50 kN
	Zone III (Andhra Pradesh)
4.00	260
3.25	240
2.50	210

Input Parameters:

Trial Thickness: 0.25 m

No of CVPD : 172 > 150 – Case 3

Transverse Joint spacing : 4.0 m

Result : **" Safe"** as shown below since the fatigue damage is 0.824 which is less than 1.

DESIGN OF CONCRETE PAVEMENTS FOR RURAL ROADS AS PER IRC:SP 62-2014.

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data	
Case 1/2/3	3
Temperature Zone (1 to 6)	3
odulus of the subgrade reaction, k Mpa	58.66
Elastic modulus of concrete E, Mpa	30000
Poisson Ratio of the concrete, μ	0.15
Temperature differntial, ΔT oC	20.3
Modulus of rupture of concrete, fcr	4.22

Tyre (1- single/2 - dual)	2
Spacing of wheels Sd (mm)	310
wheel load, P kN	50
Tyre pressure, q MPa	0.8
Radius of contact, a (mm)	180.565
Trial thickness, h m	0.25
No. of commercial vehicles per day	172

Transverse joint spacing,m	4
Ratio of L/l	NEED TO CALC TEMP STR
o-efficient of thermal expansio	0.00001
Correction factor C	
Design life of pavement, yrs	20
Rate of increase of traffic	0.06
Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION

Case 1	
Radius of relative stiffness, l m	908.5007758
Stress developed, σ, Mpa	
Design is	

RESULTS FOR WHEEL LOAD AND TEMPARATURE

Case 2		
temparature stress at edge, Mpa		2
Wheel load Stresses at edge, Mpa		
Total stresses, σ, Mpa		
Design is		

RESULTS FOR FATIGUE ANALYSIS

Case 3	
Design No.of vehicles for fatigue analysis	461879.8832
Stresses due to wheel load,σ, Mpa	1.866259616
Ratio of L/l	4.402858101
Correction factor C	0.600144497
stresses due to temparature,σ, Mpa	1.224384795
egative stress due to nonlinear temparature diffrential,σ, Mp	0.519181586
Total stress for Fatigue calculation,σ, Mpa	2.571462825
stress ratio	0.60935138
Allowable repetititons	559963.8662
Design is	Safe
Cummulative fatigue damage	0.824838728

As observed in the tables and Excel sheets above, the thickness of the pavement is directly proportional to the joint spacing. To comply with the specified codal requirements, the pavement should be laid continuously without any joints, except for a construction joint during the day's work. Transverse contraction joints will be cut at designed intervals to meet these specifications.A designer can exercise various options of joint spacing using the spread sheet and adopt the thickness and transverse joint spacing according his/her resources.

8. Study of Contraction Joint Spacing and Thickness of Pavement

Example: 1

The excel sheet will run with the input parameters like pavement thickness: **170mm**, designed contraction joint spacing :**3.25 m**. Traffic: **50 to 150 CVPD**. The outcome of result is " **Safe"** as shown below.

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data					
Case 1 /2/3	2	Tyre (1- single/2 - dual)	2	Transverse joint spacing,m	3.25
Temperature Zone (1 to 6)	3	Spacing of wheels Sd (mm)	310	Ratio of L/l	4.777232453
Modulus of the subgrade reaction, k Mpa/m	58.66	wheel load, P kN	50	Co-efficient of thermal expansion	0.00001
Elastic modulus of concrete E, Mpa	30000	Tyre pressure, q MPa	0.8	Correction factor C	0.7020702
Poisson Ratio of the concrete, μ	0.15	Radius of contact, a (mm)	180.565	Design life of pavement, yrs	20
Temperature differntial, ΔT oC	18.0	Trial thickness, h m	0.17	Rate of increase of traffic	0.06
Modulus of rupture of concrete, fcr	4.22	No. of commercial vehicels per day	145	Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION	
Case 1	
Radius of relative stiffness, l m	680.3102072
Stress developed, σ, Mpa	
Design is	

RESULTS FOR WHEEL LOAD AND TEMPARATURE	
Case 2	
temparature stress at edge, Mpa	0.813542051
Wheel load Stresses at edge, Mpa	3.399638154
Total stresses, σ, Mpa	4.213180205
Design is	Safe

RESULTS FOR FATIGUE ANALYSIS

Example:2

For the **same traffic category**, change the input parameter of Joint spacing to **4.00 m ,** without modifying the thickness . The outcome will be as shown below , which gives " **Un safe "** result, which indicates that the provided thickness is not sufficient for the joint spacing of **4.00 m** since the total of wheel load and the temperature stresses due to 50 kN dual wheel load= 4.62 > 4.22 MPa and hence the design is unsafe. **Hence 170 mm thickness is safe for the joint spacing of 3.25 m only.**

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data	
Case 1 /2/3	2
Temperature Zone (1 to 6)	3
Modulus of the subgrade reaction, k Mpa/m	58.66
Elastic modulus of concrete E, Mpa	30000
Poisson Ratio of the concrete, µ	0.15
Temperature differntial, ΔT oC	18.0
Modulus of rupture of concrete, fcr	4.22

Tyre (**1**- single/**2** - dual)	2
Spacing of wheels Sd (mm)	310
wheel load, P kN	50
Tyre pressure, q MPa	0.8
Radius of contact, a (mm)	180.565
Trial thickness, h m	0.17
No. of commercial vehicels per day	145

Transverse joint spacing,m	4
Ratio of L/l	5.879670712
Co-efficient of thermal expansion	0.00001
Correction factor C	0.932207675
Design life of pavement, yrs	20
Rate of increase of traffic	0.06
Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION

Case 1	
Radius of relative stiffness, l m	680.3102072
Stress developed, σ, Mpa	
Design is	

RESULTS FOR WHEEL LOAD AND TEMPARATURE

Case 2	
temparature stress at edge, Mpa	1.229398166
Wheel load Stresses at edge, Mpa	3.399638154
Total stresses, σ, Mpa	4.62903632
Design is	Unsafe

RESULTS FOR FATIGUE ANALYSIS

Example:3

Further if the joint spacing is modified to **3.30 m** without altering the thickness, the result will still be **'UN Safe**,' as indicated below. This demonstrates that even a slight modification in the joint spacing will have a significant impact on the designed thickness.

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data	
Case 1 /2/3	2
Temperature Zone (1 to 6)	3
Modulus of the subgrade reaction, k Mpa/m	58.66
Elastic modulus of concrete E, Mpa	30000
Poisson Ratio of the concrete, µ	0.15
Temperature differntial, ΔT oC	18.0
Modulus of rupture of concrete, fcr	4.22

Tyre (**1**- single/**2** - dual)	2
Spacing of wheels Sd (mm)	310
wheel load, P kN	50
Tyre pressure, q MPa	0.8
Radius of contact, a (mm)	180.565
Trial thickness, h m	0.17
No. of commercial vehicels per day	145

Transverse joint spacing,m	3.3
Ratio of L/l	4.850728337
Co-efficient of thermal expansion	0.00001
Correction factor C	0.720664489
Design life of pavement, yrs	20
Rate of increase of traffic	0.06
Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION

Case 1	
Radius of relative stiffness, l m	680.3102072
Stress developed, σ, Mpa	
Design is	

RESULTS FOR WHEEL LOAD AND TEMPARATURE

Case 2	
temparature stress at edge, Mpa	0.847141744
Wheel load Stresses at edge, Mpa	3.399638154
Total stresses, σ, Mpa	4.246779899
Design is	Unsafe

RESULTS FOR FATIGUE ANALYSIS

During the inspection of CC roads in the districts, it was observed that contraction joints were cut beyond the designed spacing due to negligence and a lack of knowledge.

The following road was designed for a thickness of **170 mm** with a joint spacing of **3.25 m**, intended for traffic categories between 50 and 150 CVPD. The contraction joint spacing was observed to be **4.00 m**, in contrast to the sanctioned **3.0 m** (Pkg 30- Kalavagunta Road in Chittoor Dist), exceeding the designed spacing."

The specified thickness for the mentioned road was **170 mm**, intended to accommodate a contraction joint spacing of up to **3.25 m and executed with 170 mm thick only**. However, the actual executed contraction joint spacing was **4.0 m**, necessitating a thickness of **190 mm**, as calculated in the Excel sheet provided below.

DESIGN OF CONCRETE PAVEMENTS FOR RURAL ROADS AS PER IRC:SP 62-2014.

Case 1 Only wheel load stress : Case 2 Temperature and wheel load stresses without fatigue: Case 3 fatigue analysis considering load and temperature

Case 1: design traffic is <50cvpd Case 2 : traffic is in between 50 to 150 cvpd Case 3 traffic is >150 cvpd

Enter the Data					
Case 1 /2/3	2	Tyre (**1**- single/**2** - dual)	2	Transverse joint spacing,m	4
Temperature Zone (1 to 6)	3	Spacing of wheels Sd (mm)	310	Ratio of L/l	5.409093575
Modulus of the subgrade reaction, k Mpa/m	58.66	wheel load, P kN	50	Co-efficient of thermal expansion	0.00001
Elastic modulus of concrete E, Mpa	30000	Tyre pressure, q MPa	0.8	Correction factor C	0.846758803
Poisson Ratio of the concrete, µ	0.15	Radius of contact, a (mm)	180.5648	Design life of pavement, yrs	20
Temperature differntial, ΔT oC	18.7	Trial thickness, h m	0.19	Rate of increase of traffic	0.06
Modulus of rupture of concrete, fcr	4.22	No. of commercial vehicels per day	150	Truck with 50kN Wheel load,%	20

RESULTS FOR ONLY WHEEL LOAD CONSIDERATION	
Case 1	
Radius of relative stiffness, l m	739.4954338
Stress developed, σ, Mpa	
Design is	

RESULTS FOR WHEEL LOAD AND TEMPARATURE		
Case 2		
temparature stress at edge, Mpa	1.115648925	2
Wheel load Stresses at edge, Mpa	2.867031057	
Total stresses, σ, Mpa	3.982679982	
Design is	Safe	

Furthermore, some estimates were approved with a **200 mm** thick CC pavement, despite the specified maximum thickness for rural roads in the traffic category ranging from **50 to 150 CVPD** being only **190 mm**, with a contraction joint spacing of **4.0 m (max) (Table 4.2 of IRC: SP:62-2014).** This leads to an unnecessary escalation of the estimated cost.

8. Adverse effects of excessive contraction joint spacing

Contraction joints are intentional gaps or spaces provided in concrete pavements to control cracking caused by the natural contraction of the concrete as it cures and cools. However, excessive contraction joint spacing in the design of concrete pavements can lead to several adverse effects. Here are some of the potential issues:

Increased Cracking: The primary purpose of contraction joints is to control and localize cracking in concrete pavements. If the joint spacing is excessive, there may be inadequate control of the natural cracking process, leading to increased random cracking throughout the pavement. This can compromise the structural integrity and durability of the pavement.

Pavement Distress: Wide joint spacing may result in distress in the form of transverse and longitudinal cracking, which can eventually lead to the development of faults and rough surfaces. This distress not only affects the appearance of the pavement but also contributes to reduced load-bearing capacity and functional performance.

Reduced Load Transfer Efficiency: Contraction joints are designed to transfer loads across the joints and prevent differential settlement or heaving of adjacent slabs. If the joints are spaced too far apart, load transfer efficiency decreases, leading to uneven stress distribution and increased risk of joint faulting. This can result in a rougher ride for vehicles and accelerated pavement deterioration.

Increased Maintenance Costs: Pavements with excessive contraction joint spacing may require more frequent maintenance and repairs due to the increased occurrence of cracking and other distresses. Maintenance costs can escalate over the life of the pavement, impacting the overall lifecycle cost of the infrastructure.

Safety Concerns: Cracked and distressed pavements can pose safety hazards for road users. The presence of wide cracks may lead to water infiltration, freeze-thaw damage, and increased skid resistance, all of which can contribute to a less safe driving environment.

Accelerated Deterioration: Excessive joint spacing may accelerate the deterioration of the pavement, reducing its overall service life. This can result in the need for premature rehabilitation or replacement of the concrete pavement, leading to increased costs and disruptions.

To avoid these adverse effects, it is crucial to follow IRC guidelines and best practices when designing contraction joint spacing in concrete pavements. The appropriate joint spacing depends on various factors, including the type of pavement, environmental conditions, and traffic loads.

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1. IRC: SP:62-2014: Guidelines for design and construction of cement concrete pavements for low volume roads (First Revision).
2. MoRd- 2014 (First Revision).