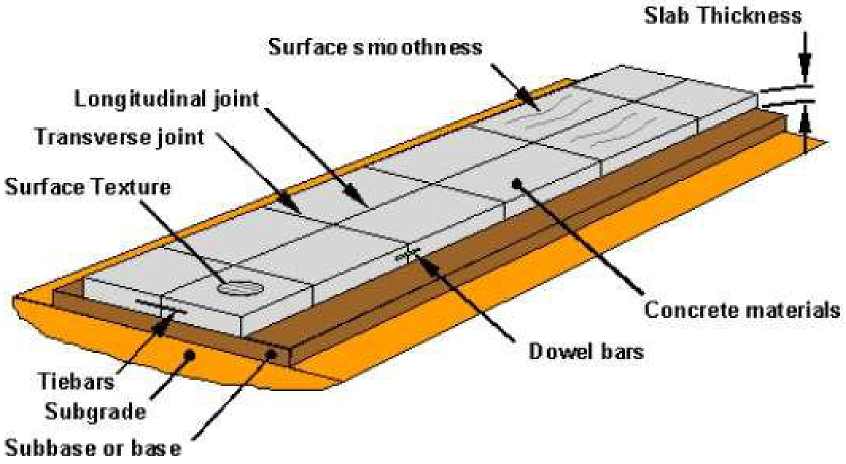
Government of Nepal

Ministry of Physical Infrastructure and Transport

Department of Roads

Chakupat, Lalitpur

PAVEMENT DESIGN GUIDELINES
(Rigid Pavement)



2021

FOREWORD

The largest advantage for using rigid pavement is its durability and ability to hold its shape against traffic and difficult environmental conditions. Design is based on flexural strength or slab action and it carries high flexural strength, no such phenomenon of grain to grain load transfer exists.

It has low repairing cost but completion cost is high, life span is more as compare to flexible (Low Maintenance Cost).

The guideline has been prepared based on IRC: 58-2015 and IRC-101-1988 .The guideline covers the design of plain jointed cement concrete pavement and brief descriptions for the reinforced and pre-stressed cement concrete pavement. The guidelines are applicable for roads having a daily commercial traffic (vehicle laden weight exceeding 3 T) of over 450. They are not applicable to low volume rural roads.

The effort of Dr. Padma Bahadur Shahi, for preparation of the "PAVEMENT DESIGN GUIDELINES (Rigid Pavement) 2021 "; is highly appreciated. The suggestions and experience shared by peer review team ,engineers and experts has been incorporated.

I hope the guideline will lead the Department of Roads to achieve economy of road pavements.

Thank You

....

Er. Arjun Jang Thapa
Director General
Department of Roads

ACKNOWLEDGEMENT

The quality for professional service was taken as the main motto during the preparation engagement in this assignment. The team would like to appreciate Design Branch, Planning Monitoring and Evaluation Unit, Department of Roads for its initiation to prepare the guidelines. I would like to extend my sincere thanks to DDG Mr. Daya Kant Jha, PMEU Chief, SDE Mr. LaxmiDatta Bhatta, and Mr. Ramesh Kumar Singh for their support and trust in doing this professional assignment. Similarly, consultant would like to express thanks to engineers Mr. Pradeep Niraula and Mr. Krishna Bahadur Kunwar for their support during the study. Similarly, I would like to thank Mr. Prabhat Kumar Jha, Mr. Shiva Adhikari and Mr. BinodSapkota for their contribution on finalizing the guidelines after the workshop at DoR.

Dr. Padma Bahadur Shahi,
Pavement Expert

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ABBREVIATIONS

A	Initial number of axles per day in the year when the road is opened to traffic
A_{cs}	Cross-sectional area of one tie bar in mm^2
As	area of steel in mm^2
b	Lane width in m
b_d	Dowel diameter, mm
B^*	Permissible bond stress of concrete in MPa
B	Factor for transverse joint efficiency in top-down cracking
BUC	Bottom-up cracking
C	Cumulative number of axles during the design period
C_s	Spacing of transverse joints, m
CBR	California Bearing Ratio in%
CFD	Cumulative Fatigue Damage
d_t	Diameter of tie bar in mm
DLC	Dry Lean Concrete
E	Modulus of elasticity of concrete in MPa
F_b	Allowable bearing stress in MPa
f	Coefficient of friction
F_{bmax}	Maximum bearing stress in MPa
f_{cr}	Characteristic flexural strength at 28 days in MPa
f'_{cr}	Target average flexural strength at 28 days in MPa
FEM	Finite element method
h	Thickness of slab, m
I_c	Crack infiltration rate m^3/day/m
j	Total number of load groups
k	Modulus of Subgrade Reaction in MPa/m
k_{mds}	Modulus of dowel support in MPa/m
K_p	Rate of infiltration through un-cracked pavement surface (m^3/day/m)
K_{Φ}	Modulus of subgrade reaction (MPa/m) with plate diameter **Φ**
K_{750}	Modulus of subgrade reaction (MPa/m) with plate diameter 750 mm(k)
L	Length of tie bar in mm
l	Radius of relative stiffness in m
LTE	Load Transfer Efficiency, in %
N	Fatigue life
N_{DCP}	Rate of Cone Penetration in mm/blow
n	Design period in years
n_i	Number of predicted repetitions for the i^{th} load group
N_c	Number of longitudinal joints/cracks
N_i	Number of allowable repetitions for the i^{th} load group
P	Single/tandem axle load in kN
P_{ptb}	Perimeter of tie bar in mm
pci	Pound per cubic inches
PQC	Pavement Quality Concrete

q_i	Infiltration rate per unit area,m3/day/m2
R	Flexural stiffness in MNm
r	Annual rate of growth of commercial traffic volume (expressed as decimal)
S_{st}	Allowable working stress of steel in MPa
S	Flexural stress in slab in MPa
SR	Stress Ratio
TCS	Tied Concrete Shoulder
TD	Temperature Differential
TDC	Top-down cracking
W	Weight of slab in kN/m^2
W_c	Length of the transverse cracks or joints, m
W_p	Width of pavement subjected to infiltration, m
Z_a	A factor corresponding to the desired confidence level, which is 1.96 for 5 % Confidence Level
α	Coefficient of thermal expansion in/°C
β	Relative stiffness of dowel bar embedded in concrete in MPa/m
Y	Unit weight of concrete in kN/cum
μ	Poisson's ratio of concrete
σ	Standard deviation of field test samples in MPa
ΔT	Temperature differential in °C

CHAPTER 1 INTRODUCTION

1.1 Introduction

Pavement is one of the important components of road transport infrastructure. It has substantial role for the operational efficiency of the traffic movement. The wheel load distribution to the ground beneath and frictional interaction with the tyres and repetition or cyclic loading natures are the engineering features of the pavement structure. Magnitude of wheel load and the sub-grade soil strength are prime factors for the structural design. Generally, pavements are designed as the flexible type. However, in the case of weak sub-grade or poor drainage system and extremely overloaded vehicular movement are the basic criteria for the option of rigid pavement construction.

Pavement design guidelines for flexible pavement type was published in 2014. The shift from the flexible type into the rigid has been realized by many practicing engineers. The need for the uniformity in design approach and effective utilization of resources are the rationale behind the making of such guidelines.

In these guidelines, general conditions for the selection of pavement type, traffic calculations, sub-grade evaluation, structural design approach and design illustrations have been elaborated.

The document is the guidelines for the practicing engineers, and has the status of departmental approval for the authentic application for the design.

1.2 Scope

The guidelines cover the design of plain jointed cement concrete pavement and brief descriptions for the reinforced and pre-stressed cement concrete pavement. The guidelines are applicable for roads having a daily commercial traffic (vehicle laden weight exceeding 3 T) of over450. They are not applicable to low volume rural roads.

1.3 Pavement design approach

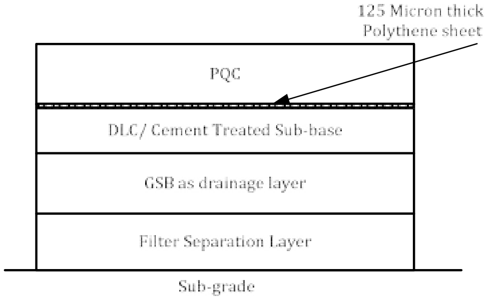
The early approach to design of rigid of rigid pavements was based on 'Westergaard's analysis. However, presently this approach has been advanced by the application of more analytic techniques which may incorporate the effect of present day vehicle fleet, considering cumulative fatigue damage due to the combined effect of load and pavement temperature variations. The guidelines include procedure for design of pavements with widened outer lane, tied concrete shoulder, pavements bonded to cemented sub-base, design of longitudinal joints, expansion and contraction joint. Main features of the guidelines are listed as:

- Design of pavements considering the combined flexural stress under the simultaneous action of load and temperature gradient for different categories of axles,
- Design for bottom-up fatigue cracking caused by single and tandem axle load repetitions,
- Design for top-down fatigue cracking caused by single, tandem and tridem axle load applications,
- Design guidelines for pavements without concrete shoulders and with tied concrete shoulders,
- Consideration of Concrete slabs with unbounded as well as bonded cement bound sub-base and
- Design of pavements with widened outer lanes.

1.4 Types of concrete pavements

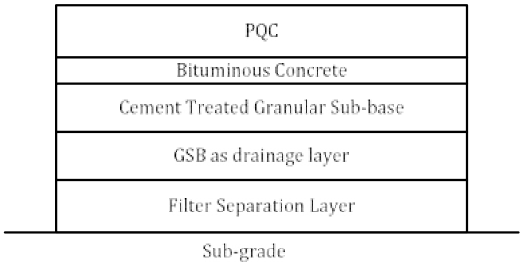
1.4.1 Joint Plain Cement Concrete Pavement (JPCP)

JPCP is the most common type of rigid pavement. JPCP is constructed with longitudinal and transverse joints to control where cracking occurs in the slabs. Tie bars and dowel bars are provided for the transfer of wheel load from one to the neighboring concrete slabs. Dowel bars are placed along the longitudinal direction and across the transverse joints. Similarly, tie bars are placed along the transverse direction and across the longitudinal joints. Typical cross sections may be distinguished as below.



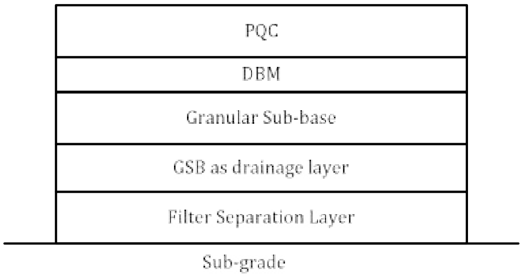
a) Debonding layer of Polythene sheet over Cement treated Sub-base layer

Figure 1 Typical Cross Section of Concrete Pavement -1



b) Debonding layer of 40 mm BC over Cement treated Sub-base layer

Figure 2 Typical Cross Section of Concrete Pavement -2



c) PQC over 100 mm DBM and Granular Sub-base

Figure 3 Typical Cross Section of Concrete Pavement -3

PQC – Pavement Quality Concrete; DLC – Dry Lean Concrete; BC – Bituminous Concrete; DBM – Dense Bituminous Macadam; GSB – Granular Sub-base;

1.4.2 Continuous Reinforced Concrete Pavement (CRCP)

Although this type of pavement is limited in construction. However, CRCP is still a relatively new concept and preferred for construction in High Mountain and High Desert climate regions. Since CRCP uses reinforcing steel rather than weakened plane joints for crack control, saw cutting of transverse joints is not required for CRCP. The continuous reinforcement in the pavement holds the cracks tightly together. CRCP typically costs more initially than JPCP due to the added cost of the reinforcement. However, CRCP is typically more cost-effective over the life of the pavement on high volume routes due to improved long-term performance and reduced maintenance. In CRCP, there are no transverse joins, properly built CRCP should have better ride quality and less it has less maintenance than JPCP. Detail description of the CRCP is given in Chapter 5.

1.4.3 Precast Panel Concrete Pavement (PPCP)

PPCPs use panels that are precast off-site instead of cast-in-place. The precast panels can be linked together with dowel bars and tie bars or can be post-tensioned after placement. PPCP offers the advantages of:

- Improved concrete mixing and curing in a precast yard,
- Reduced pavement thicknesses, which is beneficial when there are profile grade restrictions such as vertical clearances and
- Shorter lane closure times, which is beneficial when there are short construction duration.

Detail explanations and design criteria for the PPCP is given in Chapter 6.

CHAPTER 2 DESIGN FACTORS

The factors governing design consideration are single, tandem axle and tridemloads, their repetition, tire presume and latter placement characteristic of commercial vehicles.

2.1 Axle Load Characteristics

The permissible axle loads in Nepal is taken as 10.2tonnes, 19tonnesand 24 tonnesfor single axles, tandem axles and tridem axles respectively. However, most of freight vehicles plying along the National Highways as well as Feeders Roads carry much more than these legal axle load limits.

The pattern of axle load distribution of commercial vehicles is necessary for the purpose of computation of number of repetitions of single and tandem axles of different weights expected during the design period. Axle load survey is necessary to conductfor the ***continuous for 48 hours, covering minimum sample size of ten percent in both directions of commercial vehicles for exceeding 6000 per day (CPVD), fifteen percent for 3000 to 6000 CVPD and twenty percent for less than 3000 CVPD.*** If the spacing of consecutive axles is more than 2.4 m each axle may be considered as single axle. For the purpose of fatigue damage analysis axle load group is considered as below:

Single axle	10 kN
Tandem Axle	20 kN
Tridem axle	30 kN

Spacing between successive axles of commercial vehicles is necessary to identify the proportion of axles that should be considered for estimating top-down fatigue cracking caused by axle loads during night period when the slab has the tendency of curling up due to negative temperature differential. Data on the spacing ·of axles may be collected during the traffic survey. As discussed in subsequent sections of these guidelines, if the spacing between any pair of axles is less than the spacing of transverse joints, such axles need to be considered in the design traffic for computing top-down fatigue cracking damage. Wheel bases of trucks of different models generally range from 3.6 m to more than 5.0 m whereas the commonly used spacing of transverse joints is 4.5 m. Thus, axles with spacing of more than 4.5 m are not expected to contribute to top-down fatigue cracking. However, if the actual spacing of transverse joints is different from 4.5 m, design traffic for estimation of top- down cracking damage may be selected appropriately. The percentage of commercial vehicles with spacing between the front and the first rear axle less than the proposed spacing of the transverse joints in the concrete slab should be established from axle load survey.

Higher axle loads stimulate high stresses in the pavement and result in the consumption of fatigue resistance of concrete slab. Pavement design should determine the fatigue deterioration caused by the different axle load groups. Stress due to the wheel load also depends upon the tyre pressure as well as the shape of the contact areas. In general, the value of tyre pressure for the commercial vehicles ranges from) 0.7 to 1 MPa. However, stresses due to variation in the tyre pressure (for the given range of 0.7 – 1.0 MPa) are not significant for the slab thickness of 20 cm and above.

In case of limited data on traffic volume count and axle load pattern, typical approach is given in **APPENDIX VII**.

2.2 Design Period

Generally, cement concrete has the life span of 30 years. When the traffic intensity cannot be predicted accurately for a long period of time, and for low volume roads, a design period of 20 years may be considered. However, the design Engineer should use his judgment about the design life taking into consideration the factors, like, traffic volume, the traffic growth rate, the capacity of the road and possibly of growth of capacity.

2.3 Traffic Considerations

2.3.1 Design lane

The lane carrying the maximum number of heavy commercial vehicles is termed as design lane. Each lane of a two-way two-lane highway and the outer lane of multi-lane highways can be considered as design lanes.

2.3.2 Design traffic

Traffic volume should normally be analyzed on seven-day 24-hour count. Actual growth rate for heavy commercial vehicles should be determined after the analysis of previous traffic-count records. However, minimum growth rate may be taken as **5 percent** and maximum of **7.5percent** depending upon the economic development of the region.Night time and day traffic analysis is important for the analysis of top-down and bottom-up cracking analysis respectively.

The edge flexural stress caused by axle loads for **bottom up cracking** is the maximum when the tyre imprint of the outer wheel touches the longitudinal edge. When the tyre position is away even by 150 mm from the longitudinal edge, stress in the edge region is reduced substantially. The edge flexural stress is small when the wheels are close to the transverse joints. Generally, only very few commercial vehicles are making their tyre imprints tangential to the longitudinal edge/joint on two lane two-way roads.Therefore, it is recommended that **25 percent** of the total two-lane two-way commercial traffic may be considered as design traffic for two-lane two-way roads for the analysis of **bottom-up cracking.**In the case of four-lane and other multilane divided highways, **25** percent of the total traffic in the direction of predominant traffic may be considered for design of pavement for bottom-up cracking.

In the case of analyzing **top-down cracking**, the design traffic will be a portion of the design traffic considered for bottom-up cracking analysis. Commercial vehicles with the spacing between the front axle and the first rear axle less than the spacing of transverse joints should be considered for top-down cracking analysis. This ration will be established from the axle load/ traffic survey. A default value of **fifty percent of the design traffic** used for bottom-up cracking analysis may be considered.

Anticipated number of repeated movement of different axle load groups during the design period can be estimated using the details of commercial traffic volume and expected rate of growth of commercial traffic and the information about axle load spectrum and the number of single, tandem and tridem axles obtained from axle load survey. Since front axles (steering axle) with single wheels on either side cause only negligible bottom-up fatigue damage, it is only the **rear axles that may be included in the axle load spectrum**.

In the case of new road links, where no traffic count data is available then the traffic data from the roads of similar category and importance may be used to predict the design traffic intensity.

The cumulative number of repetitions of axle during the design period may be computed from the formula:

$$\mathrm{C} = \frac{365xA\{(1+r)^n - 1\}}{r}$$

Where,

C = cumulative number ofrepetitions of axles during the design period,
r = Annual rate of growth of commercial traffic (expressed in decimals),
A = Initial number of standard axle per day in the year when the road is open to traffic,
n = Design period in years

The design cumulative number of axle load repetitions for fatigue damage can be obtained from the cumulative number of commercial vehicles as mentioned in the previous paragraphs.

2.4 Temperature Differential

Temperature difference between top and bottom of the concrete pavements causes the concrete slab to warp, causing the rise in stresses. The temperature differential depends on the intensity of solar radiation received by the pavement surface at location, losses due to wind velocity etc. and thermal diffusivity of concrete. Therefore, it is affected by geographical features of the pavement location. As far as possible, values of actually anticipated temperature differentials at the location are estimated by using relevant geographical features and material characteristics. In the absence of local data, the values of tentative temperature differentials are given in Table 1.

Table 1 Temperature differential values for various slab thickness

S/N	Region	Temperature differential, ^{o}C/thickness of slab			
		15 cm	20 cm	25 cm	30 cm
1	Hilly region	12.5	13.1	14.3	15.8
2	Terai region	15.6	16.4	16.6	16.8

Temperature differentials are positive when the slab has the tendency to have a convex shape during the day hours and negative with a concave shape during the night. The axle load stresses should becomputed for fatigue analysis when the slab is in a warped state due to the temperature differential during day as well as night hours.

2.5 Characteristics of Sub-grade Soil and Sub-base

2.5.1 Embankment

California Bearing Ratio (CBR) of embankment soil placed below the 500 mm selected subgrade should be determined for estimating the effective CBR of subgrade and its 'k' value for design.

2.5.2 Subgrade

The strength of sub-grade is expressed in terms of modulus of sub-grade reaction k, which is defined as pressure per unit deflection of the foundation as determined by plate bearing tests. As limiting design deflection for cement concrete pavements is taken as 1.25 mm, the k-value is determined from the pressure sustained at the deflection at this deflection. The k-value is necessary to correlate with the soaked CBR test value as shown in Table 2.Table 1

Table 2Approximate k-value corresponding to CBR values homogenous soil sub-grade

Soaked CBR Value, %	2	3	4	5	7	10	15	20	50	100
k-value, MPa/m	21	28	35	42	48	55	62	69	140	220

Note: 100 pci = 2.77kg/cm^3 = 27.2 MPa/m (Source: IRC: 58-2015)

If the CBR of the 500 mm thick compacted subgrade is significantly larger than that of the embankment below it, the effective CBR of the subgrade can be estimated from Figure 4 (IRC:58-2015) .A minimum subgrade CBR of 8 percent is recommended for design.The in-situ CBR of the subgrade soil can also be determined quickly fromthe Dynamic Cone Penetrometer (60° cone) tests using the following relationship:

$$Log_{10}\mathrm{CBR} = 2.465 - 1.12\, Log_{10} N_{DCP}$$ **Equation 1**

Where, N_{DCP}-Rate of cone penetration (mm/blow)

It is recommended to provide filter and drainage layers above the subgrade for drainage of water to prevent (i) excessive softening of subgrade and sub-base and (ii) erosion of the subgrade and sub-base particularly, under adverse moisture condition and heavy dynamic loads. Synthetic geo-composite layer can also be used at the interface of subgrade and granular sub-base layer for filtration and drainage. It will not allow migration of fine particles of subgrade soil to the granular drainage layer above.

If the k-value tested on the wet condition of sub-grade is less than 6.0 kg/cm^2/cm, then concrete pavement should not be laid directly over the sub-grade. A Dry Lean Concrete (DLC) sub-base is generally recommended for modern concrete pavements, particularly those with high traffic intensity.

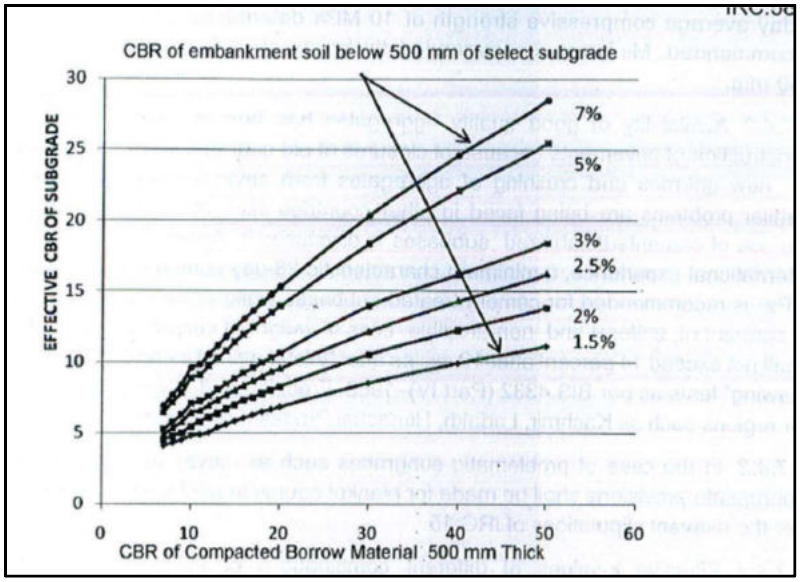


Figure 4 Chart for Estimation of Effective CBR of Sub-grade

2.5.3 Sub-base

The main purpose of the sub-base is to provide a uniform, stable and permanent support to the concrete slab laid over it. It must have sufficient strength so that it is not subjected to disintegration and erosion under heavy traffic and adverse environmental conditions such as excessive moisture, freezing and thawing. In the light of these requirements, sub-base of Dry Lean Concrete (DLC) having a 7-day average compressive strength of 10 MPa is recommended. Minimum recommended thickness of DLC for major highways is150 mm.

Effective k-values of different combinations of subgrade and sub-base (untreated granular and cement treated granular) can be estimated from Table 3.***K-value*** for different combinations of DLC sub-base (with DLC having minimum 7 -day compressive strength of 10 MPa) thicknesses laid over granular sub-base consisting of filter and drainage layers can be adopted fromTable 4. The contribution of granular sub-base placed below the DLC layer can be ignored for estimating the effective modulus of subgrade reaction of the foundation. The values given in Table 4 are based on theoretical analysis and an upper limit of 300 MPa/m is recommended considering the loss of subgrade support expected to be caused by heavy traffic.

Table 3 K-value for Granular and Cement Treated Sub-bases

K-value of sub-grade, (MPa/m)	Effective k (MPa/m) of untreated Granular layer sub-base of thickness in mm			Effective k (MPa/m) of Cement treated sub-base of thickness in mm		
	150	**225**	**300**	**100**	**150**	**200**
28	39	44	53	76	108	141
56	63	75	88	127	173	225
84	92	102	119	-	-	-

Seven day unconfined compressive strength of cement treated granular soil should be minimum of 2.1 MPa. DLC should have minimum compressive strength of 7 MPa at seven days.

Table 4K-values for DLC sub-base

k-value of sub-grade (MPa/m)	**21**	**28**	**42**	**48**	**55**	**62**
Effective k over 100 mm DLC (MPa/m)	56	97	166	208	278	300
Effective k over 150 mm DLC (MPa)	97	138	208	277	300	300

The maximum value of effective k shall be taken as 300 MPa/m

2.6 Separation Layer between sub-base and pavement

Foundation layer below concrete slabs should be smooth to reduce the inter layer friction. A separation membrane of minimum thickness of 125 micron polythene is recommended to reduce the friction between concrete slabs and DLC sub-base.

2.7 Drainage layer

To facilitate the quick disposal of water that is likely to enter the sub-grade, a drainage layer may be provided beneath the pavement throughout road width above sub-grade. An example and Specifications for drainage is given in the **Appendix III** of this guidelines.

2.8 Characteristics of concrete

2.8.1 Design strength

The design of the rigid pavement is based on the flexural stresses of concrete. Flexural strength of concrete can be obtained after testing the concrete beam as per procedure (IS: 516). Alternatively, it can be derived from the characteristic compressive strength using following relationship.

$$f_{cr} = 0.7x\sqrt{f_{ck}}$$ **Equation 2**

Where,

f_{cr} = flexural strength (modulus of rupture), Mpa; f_{ck} = characteristic compressive cube strength of concrete, MPa

S^1= Characteristic flexural strength at 28 days, MPa.

S = Target mean flexural strength at 28 days, MPa.

Z_a = Tolerance factor for the desired confidence level, known as the standard normal variate, which is 1.96 for 5% confidence level.

σ = expected standard deviation of field test samples, MPa

Then the target average flexural strength is given as:

$$S = S^1 + Z_a\sigma$$ **Equation 3**

The values of Standard Normal Variate $Z_a$is given in the table below. The values of $Z_a$depends on the importance of the road. For example it is recommended that the value of $Z_a$may be adopted as 1.96 and for expressways it may be taken as 2.33.

Table 5 Values of Standard Normal Variate, Z_a

Accepted proportion of low results (tolerance)	Standard Normal Variate, Z_a	Quality Level
1 in 15	1.5	Fair
1 in 20	1.65	Good
1 in 40	1.96	Very Good
1 in 100	2.33	Excellent

The values of $Z_a$depends on the importance of the road.

Fair to Good: means construction with semi-mechanized methods and site mixed/semi-automatic batching plant, insertion of tie bar/dowel bars and joint cutting by manualmethod/Joint cutting by machine (usually for low traffic roads).

Good to Very Good: means construction with semi- mechanized/ fixed form pavingmachines and batch mixed concrete with semi-automatic/automatic batching plantinsertion of tie bars and dowel bars by manual method usually for medium traffic roads

Very Good to Excellent: means construction with fixed form/slip form paving machinesand batch mixed concrete with automatic batching plant insertion of tie bars and dowelbars by manual/automatic dowel/tie bar insertion mechanism method usually for heavytraffic roads/expressway

The concrete mix is designed and controlled on the basis of flexural strength. Flexural strength should be determined by modulus of rupture tests under third point loading. The preferred size of the beam should be 15cm x15 cm x 70 cm when the size of the aggregate is more than 20 mm. When the maximum size of the aggregate is less than 20 mm, 10 cm x 10 cm x 50 cm beams may be used.

Determination of flexural strength by correlating with cube strength (compressive strength) shall not be allowed for major projects as the correlation is not well established.

Standard deviation depends upon the degree of quality control, exercised during production of aggregate and concrete mix for major projects using batch type mixing plant with modern aggregates crushing plants, standard deviation will be relatively much less as compared to the locations where mix is prepared using semi-mechanized production process. The values of standard deviation σ used in

Equation 3 for major projects shall according be adopted corresponding to the deviation in flexural strength actually obtained in the field. However, for the initial mix design for major projects value of standard deviation shall be taken as per the table below.

Table 6 Expected values of Standard Deviation

Characteristic flexural strength, MPa	Standard deviation for different degree of control, MPa		
	Very good	Good	Fair
3.0	0.38	0.55	0.6
3.5	0.35	0.50	0.55
4.0	0.32	0.45	0.50
4.5	0.29	0.40	0.45
5	0.26	0.35	0.40

2.8.2 Modulus of Elasticity and Poisson's Ratio of Concrete

The modulus of elasticity (**E**) and the Poisson's ratio (μ) of cement concrete are known to vary with concrete materials and strength. The elastic modulus increases with the increase in strength, and Poisson's ratio decrease with the increase in modulus of elasticity. While it is desirable that the values of these parameters are ascertained experimentally for the concrete mix and materials actually to be used in the construction, this information may not always be available at the design stage. Even a 25 percent variation in **E** and μ values does not have any significant effect on the flexural stresses in the pavement concrete. It is suggested that for design purpose, the following values may be adopted for concrete for the flexural strength of **4.5 MPa**.

Modulus of elasticity of the concrete E = experimentally determined value or 30,000 MPa ($3x10^5$ kg/cm^2)

Poisson's ratio μ = 0.15

2.8.3 Coefficient of thermal expansion

The coefficient of thermal expansion of concrete (α) varies with the type of aggregate. However, for design purpose a value of α=10 x 10^{-6} per ^{o}C may be adopted.

2.8.4 Fatigue behavior of cement concrete

The repeated application of wheel loads create repeated flexural stresses, which results in the progressive fatigue damage in cement concrete slab in the form of gradual development of micro-cracks especially when the applied stress in terms of flexural strength of concrete is high. The ratio between the flexural stressdue to the load and the flexural strength of concrete is termed as the **Stress Ratio (SR)**. If the SR is less than 0.45, the concrete is expected to sustain infinite number of repetitions. As the stress ratio increases, the number of repetitions required to cause cracking decreases. The ratio between fatigue life ***(N)*** and stress ratio is given as:

N = unlimited for SR < 0.45

$$N = \left[\frac{4.2577}{SR-0.4325}\right]^{3.268} \text{ When } 0.45 \le SR \le 0.55 \qquad \text{Equation 4}$$

$$Log_{10}N = \frac{0.9718-SR}{0.0828} \text{ For SR >0.55} \qquad \text{Equation 5}$$

The validity of these fatigue equations is discussed in the **Appendix I.**

The values of fatigue life for different values of stress ratio are given in the table below. Use of fatigue criteria is made on the basis of Miner's hypothesis. Fatigue resistance not consumed by repetitions of one load is available for repetitions of other loads.

Table 7 Stress ratio and allowable repetition for the concrete slab

Stress Ratio	Allowable Repetition	Stress Ratio	Allowable Repetition
0.45	6.279×10^{7}	0.66	5.83×10^{3}
0.46	1.4335×10^{7}	0.67	4.41×10^{3}
0.47	5.2×10^{6}	0.68	3.34×10^{3}
0.48	2.4×10^{6}	0.69	2531
0.49	1.287×10^{6}	0.7	1970
0.50	7.62×10^{5}	0.71	1451
0.51	4.85×10^{5}	0.72	1099
0.52	3.26×10^{5}	0.73	832
0.53	2.29×10^{5}	0.74	630
0.54	1.66×10^{5}	0.75	477
0.55	1.24×10^{5}	0.76	361
0.56	9.41×10^{4}	0.77	274
0.57	7.12×10^{4}	0.78	207
0.58	5.4×10^{4}	0.79	157
0.59	4.08×10^{4}	0.8	119
0.60	3.09×10^{4}	0.81	90
0.61	2.34×10^{4}	0.82	68
0.62	1.77×10^{4}	0.83	52
0.63	1.34×10^{4}	0.84	39
0.64	1.02×10^{4}	0.85	30
0.65	7.7×10^{3}		

CHAPTER 3 DESIGN OF SLAB THICKNESS

3.1 Critical stress conditions

Cement concrete pavements are subjected to stresses due to the variety of factors, acting simultaneously. The severest combinations of different factors that induce the maximum stress in the pavement will give the critical stress conditions. The factors commonly considered for design of pavement thickness are: flexural stress due to traffic loads and temperature differentials between top and bottom fibers of concrete slab, as the two assumed to be additive under critical condition. The effects of moisture changes and are, not normally considered critical to thickness.

The flexural stress at the bottom layer of the concrete slab is the maximum during the day hour; when the axle loads act midway on the pavement slab while there is a positive temperature gradient as illustrated in Figure 5 and Figure 6. This condition is likely to produce bottom-up cracking (BUC).

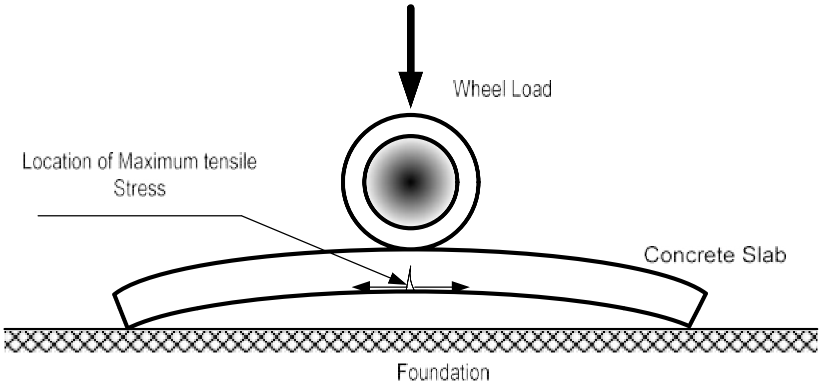


Figure 5 Axle Load Placed at the Middle of the Slab during Mid-day

Locations of points of maximum flexural stress at the bottom of the pavement slab without tied concrete shoulder for single, tandem and tridem axles are shown in Figure 6. The tyre imprints are tangential to the longitudinal edge. For tied concrete shoulders also, the maximum stress occurs at the same locations. Single axles cause highest stress followed by tandem and tridem axles respectively. Spacing between individual axles for tandem and tridem axles varies from 1.30 m to about 1.40 m. There is practically no difference in stresses for axle spacing between 1.30 m and 1.40 m. A spacing of 1.30 m has been used in these guidelines for stress computation.

During the night time, the top surface is cooler than the bottom surface and the ends of the slab curl up resulting in loss of support for the slab as shown in Figure 7. Due to the restraint provided by the self-weight of concrete and by the dowel connections, temperature tensile stresses are caused at the top. Figure 7shows the placement of axle loads close to transverse joints when there is negative temperature gradient during night period causing high flexural stresses in the top layer leading to top-down cracking. Positioning of axles of different configurations on the slab with successive axles placed close to the transverse joints is shown in Figure 8. These axle positions can initiate top-down cracking (TDC) during the night hours when the pavement has the tendency to curl up. Built-in permanent curl induced during the curing of the concrete slab further worsens the problem.

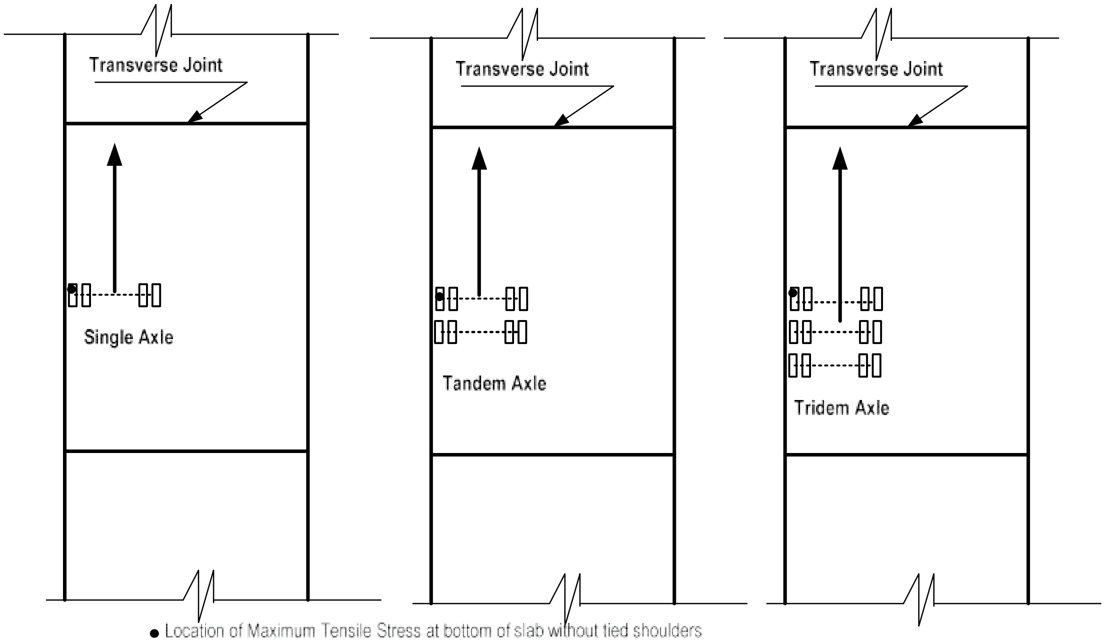


Figure 6 Placement of Axles for Maximum Edge Flexural Stress at the bottom of the slabwithout Tied Concrete Shoulders

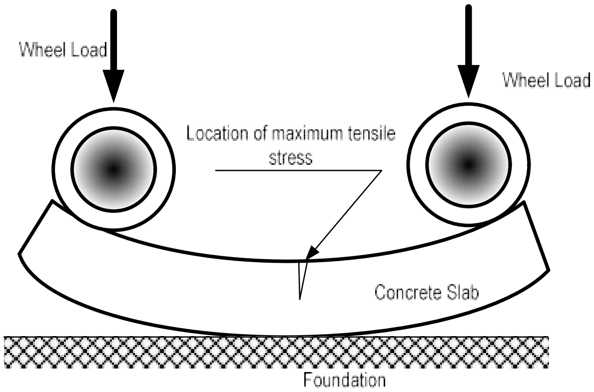


Figure 7 Placement of Two Axles of a Commercial Vehicle on a Slab Curled During Night Hours

3.1 Calculation of flexural stress

Since the loads causing failure of pavements are mostly applied by single,tandem, tridem and other multiple axles, stresses should be determined for theconditions illustrated in Figure 5, Figure 6, Figure 7 and Figure 8. Various computational techniques have been developed based on the Picket and Ray (1951)'s work on computation of stresses in infinite slabs. It is used for the computation of load stress in the edge region of pavements without tied concrete shoulders if there is no temperature gradient in the slab.

The following combinations of pavements and loading were considered for the analysis of bottom-up and top-down cracking. **For bottom-up cracking case**, the combination of load and positive non-linear temperature differential (Figure 5) has been considered whereas for **top-down cracking analysis**, the combination of load and negative linear temperature differential (Figure 7) has been taken. For bottom-up cracking analysis, single/tandem axles have been placed on the slab in the positions indicated in Figure 6. In bottom-up cracking case, single axle load causes the largest edge stress followed by tandem and tridem axles. Since the stresses due to tridem axles are small, they were not considered for stress analysis for bottom-up cracking case. For top-down cracking analysis, the load position considered for analysis is as shown in Figure 8. As indicated in the figure, only one axle of single/tandem/tridem axle units has been considered for analysis in combination with front axle. Front axle weight has been assumed to be **50 percent** of the weight of one axle of the rear axle unit (single/tandem/tridem) for analysis.

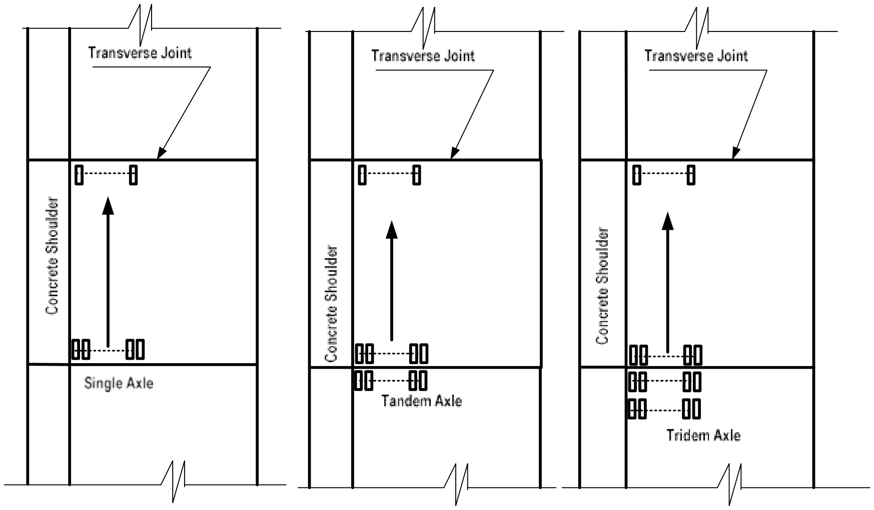


Figure 8 Different Axle Load Positions Causing Stress at the Top Fiber of the Slab with Tied Concrete Shoulder

Following cases shall be considered:

A. Bottom-up cracking

- Pavement with tied concrete shoulders for single rear axle
- Pavement without concrete shoulders for single rear axle
- Pavement with tied concrete shoulders for tandem rear axle
- Pavement without concrete shoulders for tandem rear axle

B. Top-down cracking

Pavements with and without dowel bars having front steering axle with single tyres and the first axle of the rear axle unit (single/tandem/tridem) placed on the same panel as depicted in Figure 8.

For heavy traffic conditions, dowel bars are usually provided across transverse joints for load transfer. Tied concrete shoulders are also necessary for high volume roads. However, for smaller traffic volumes smaller than 450 commercial vehicles per day tied concrete shoulders and dowel bars are not generally warranted. Finite element analysis has been carried out for pavements with and without

- dowelled transverse joints and
- tied concrete shoulders.

Terminal load transfer efficiencies (LTE) for dowelled transverse joints and tied joints between the slab and concrete shoulder shall be taken as 50 percent and 40 percent respectively.

The results of finite element analysis of a large number of concrete pavements with different pavement configurations subjected to various combinations of axle loads and temperature differentials have been presented in the form of Charts in **Appendix-VIII**. The charts can be used to obtain the edge flexural stress caused by a specified magnitude of single/tandem axle (positioned as indicated inFigure 6in combination with a specified positive temperature differential for a given pavement structure. Linear interpolation can be done for obtaining stresses for intermediate loads and temperatures from the charts given in **Appendix-VIII**.

The finite element analysis results have also been used to develop regression equations for estimation of the flexural tensile stress for bottom-up as well as top-down cracking cases. While a single regression equation was found to be adequate for estimation of flexural tensile stress in the slab for top-down case, separate equations were developed for the bottom-up case for different pavement types and foundation strengths. The regression equations are presented in **Appendix-II**.Designers can develop their own excel sheets for analysis and design using these regression equations.

3.2 Cumulative Fatigue Damage Analysis

For a given slab thickness and other design parameters, the pavement willbe checked for cumulative bottom-up and top-down fatigue damage. For bottom-upcracking, the flexural stress at the edge due to the combined action of single or tandemrear axle load and positive temperature differential cycles is considered. This stresscan either be selected from the stress charts given in **Appendix-VIII** or by using theregression equations. Charts explains clearly the interplay ofthickness, modulus of subgrade reactions, axle loads and temperature differentials.Similarly, for assessing the top-down fatigue damage caused by repeated cycles ofaxle loads and negative temperature differential, flexural stress can be estimatedusing the regression equation.

The flexural stress is divided by the design flexural strength (modulus of rupture) of the cement concrete to obtain stress ratio (SR). If the stress ratio (SR) is less than 0.45 then allowable number of cycles of axle load is infinity. For stress ratio values greater than 0.45, allowable cycle of loading (axle load + temperature) can be estimated using Equation 4 and Equation 5. The concrete slab undergoes fatigue damage through crack growth induced by repeated cycles of loading. The cumulative fatigue damage caused to the slab during its service life should be **equal to or less than one.**

Analysis indicates that contribution to cumulative fatigue damage (CFD) for bottom-up cracking is significant only during day time (say 10 AM to 4 PM) because of higher stresses due to simultaneous action of wheel load and positive temperature gradient. Thus, the day hour traffic during the six hour (10 AM to 4 PM) is to be considered for bottom-up cracking analysis. For the top-down cracking analysis, only the CFD caused during the period between 0 AM and 6 AM is important. Hence, the six hour night time traffic (0 AM and 6 AM) only is to be taken for computing CFD for top-down cracking analysis. If the exact proportionsof traffic expected during the specified six-hour periods are not available, it may be assumed that the total night time-traffic is equally distributed among the twelve night hours. Similarly, the total day time traffic may be assumed to be distributed uniformly among the twelve day hours.The Cumulative fatigue damage (CFD) expressions for bottom-up and top-down cracking cases are given by

Equation 6 and Equation 7 shows respectively (Source IRC: 58-2015). The times indicated in the equations will vary depending on the geographical location of the project site but the duration of each period will practically remain the same.

$$CFD(BUC) = \sum_{i}^{j} \left(\frac{n_i}{N_j}\right)(10\ AM\ to\ 4\ PM)$$

Equation 6

$$CFD(TDC) = \sum_{i}^{j} \left(\frac{n_i}{N_j}\right)(0\ AM\ to\ 6\ AM)$$

Equation 7

Where,

N_j = allowable number of load and temperature differential cycles for the wheel load group during the specified six-hour period;

n_i = predicted number of load and temperature differential cycles for the i^{th} load group during the specified six-hour period

j = total number of load groups

3.3 Drainage Layer

Heavy axle loads are very common for major highways in Nepal and therefore, it should be ensured that the unbound layers do not undergo unacceptable permanent deformation under repeated loading. Entrapped water in the subgrade and granular sub-base may cause erosion of the foundation material since pore water pressure generated by tandem and tridem axle loads may be substantially high. It may be mentioned that pavement deflection due to heavy tandem and tridem axles can be as high as 1.0 mm which may result in the formation of voids below the pavement due to the permanent deformation of the foundation material. Presence of excess moisture accumulated in the unbound foundation layers due to infiltration or due to thawing in snow-bound regions is conducive for development of permanent deformation in these layers.

To facilitate the quick disposal of water that is likely to enter the subgrade, a drainage layer together with a filter/separation layer may be provided beneath the sub-base throughout the road width. The filter/separation layer prevents fines from pumping up from the subgrade to the drainage layer. It also provides a platform for the construction of the drainage layer. The amount of water infiltrating into the pavement should be assessed and a drainage layer having the required permeability needs to be designed. In no case should the coefficient of permeability of drainage layer be less than 30 m/day even for low rainfall area. The requirement of the coefficient of permeability can be as high as 300 m/day or more in some cases and it is essential to design the drainage layer appropriately for major highways in areas having annual rainfall in excess of 1000 mm. The drainage layer can be treated with 2 percent cement or 2.5 percent bitumen emulsion so as to permit the construction traffic without any sideway displacement and/or shoving of the aggregates. If granular layers are not needed because of high strength subgrade, synthetic geo-composite with reduced thickness of granular layer can be used over the subgrade to function both as a filter as well as a drainage layer.

An example of the design of a drainage layer is given in the **Appendix III.**

3.4 Tied Concrete Shoulder and Widened Outer Lane

Tied cement concrete shoulders are recommended to protect the edge of high volume highway pavements. These guidelines provide for design of concrete pavements with tied concrete shoulders. Widening of outer lanes of concrete pavement by 0.5 m to 0.6 m can be adopted for two-lane two-way roads to reduce the flexural stresses in the wheel path region. Analysis of typical concrete pavements shows that provision of a widened outer lane functioning as a monolithic concrete shoulder reduces the edge flexural stress by 20 to 30 percent. This will result in reduction of pavement thickness. The total quantity of concrete is likely to be nearly the same as that without shoulder. Rough texture, if provided to the widened part, will bring in additional safety to vehicles particularly during night hours. Thicknesses of pavements with widened outer lane as well as tied concrete shoulder are almost the same. An example of designing concrete pavements with widened outer lanes has been included in **Appendix-IV**.

3.5 Bonded Rigid Pavement

A concrete pavement layer may be laid directly over the DLC layer. In this case PQC and DLC act as monolithic action between layers can be achieved and thickness of the concrete slab can be reduced. DLC surface is made rough by using wire brush. Bounding is achieved by pouring the water and cement slurry before laying the PQC. For pavements constructed with full bonding between the slab and DLC layer, transverse joints may be formed in the DLC layer by cutting grooves to 1 /3rd of its depth at exactly the same locations where transverse joints are to be provided in the upper PQC layer in order to prevent random reflection cracking of upper layer due to cracks in the un-jointed DLC layer. The 7-day compressive strength of the DLC layer in bonded rigid pavement should not be less than 10 MPa.

A granular subbase of 200 mm to 250 mm thickness may be provided below the DLC layer for bonded concrete pavement for filtration and drainage. The effective modulus of subgrade reaction of the subgrade-granular subbase combination can be estimated from Table 3. Total slab thickness (h) over the granular layer is worked out for the given traffic and other design parameters. A part of the PQC of thickness 'h' is to be replaced with 150 mm of DLC so that the combined flexural stiffness of the pavement slab layer (thickness of h_1) and DLC layer (thickness of h_2)

is equal to or greater than the flexural stiffness of the slab of thickness 'h' over the granular layer. Flexural stiffness of a slab of' thickness,h, is given as:

$$\frac{EI}{1-\mu^2} = \frac{Eh^3}{12(1-\mu^2)}$$

Equation 8

Where, ***E, μ, I,h***are the modulus of elasticity, Poisson's ratio, moment of inertia and thickness of the slab respectively. If the design thickness of the slab considering slab over a granular layer and subgrade is "***h***", and if it is proposed to provide a DLC layer of thickness "***h₂***" bonded to the concrete slab of thickness "***h₁***", the thickness of the concrete slab (***h₁***) can be obtained by equating the flexural stiffness of the design slab to the combined flexural stiffness of the DLC layer and concrete slab.Figure 9shows the bonded section with neutral axis in the pavement slab

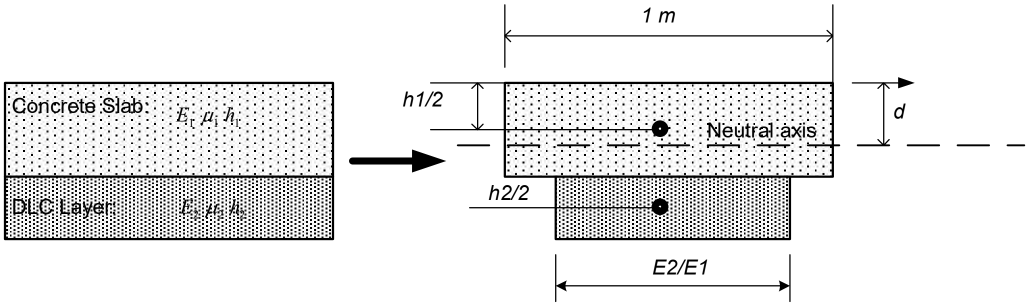


Figure 9 Concept used for Obtaining Combined Flexural Stiffness

The neutral axis depth 'd' can be calculated using the

$$d = \frac{0.5(h_1^2) + \left(\frac{E_2}{E_1}\right) h_2 (h_1 - 0.5h_1)}{h_1 + \left(\frac{E_2}{E_1}\right) h_2}$$

Equation 9

The flexural stiffness of the two layers can be determined using the equations below:

$$Flexural\ stiffness(1, PQC) = \frac{E_1 \left(\left(\frac{h_1^3}{12}\right) + h_1 (d - 0.5h_1)^2 \right)}{1 - \mu_1^2}$$

Equation 10

$$Flexural\ stiffness(2, DLC) = \frac{E_2 \left[\frac{\left(\frac{E_2}{E_1}\right) h_2^3}{12} + \left(\frac{E_2}{E_1}\right) h_2 \left(h_1 + \frac{h_2}{2} - d\right)^2 \right]}{(1 - \mu_2^2)}$$

Equation 11

The combined flexural stiffness of two layers should be equal to or more than the requirement of design flexural stiffness given by the Equation 8. 28-day strength of DLC may be taken as 13.6 MPa. The ***'É'*** of DLC layer may be taken as 13600 MPa. Poisson's ratio of DLC is taken as 0.2.

3.6 Recommended procedure for Slab design

The Concrete Pavement slab is recommended to adopt the following steps. Example of design is given in the **Appendix IV.**

Step 1: Specify design values for the various parameters related to the traffic calculation, subgrade strength and temperature variations at night and day-time and etc.

Step 2: Select a trial design thickness of pavement slab

Step 3: Compute the repetitions of axle loads of different magnitudes and different Categories during the design life

Step 4: Find the proportions of axle load repetitions operating during the day and Night periods

Step 5: Estimate the axle load repetitions in the specified six-hour-period during the day time. The maximum temperature differential is assumed to remain constant during the 6 hours for analysis of **bottom-up cracking**

Step 6: Estimate the axle load repetitions in the specified six-hour period during the night time. The maximum negative temperature differential during night is taken as half of day-time maximum temperature differential. Built in negative temperature differential of 50°C developed during the setting of the concrete is to be added to the temperature differential for the analysis of **top-down cracking**. Only those vehicles with spacing between the front (steering) axle and the first rear axle less than the transverse joint spacing need to be considered for top-down cracking analysis.

Step 7: Compute the flexural stresses at the edge due to the single and tandem axle loads for the combined effect of axle loads and positive temperature differential during the day time. Determine the stress ratio (Flexural stress/ Modulus of Rupture) and evaluate the cumulative fatigue damage (CFD) for single and tandem axle loads. Sum of the two CFDs should be less than 1.0 for the slab to be safe against bottom-up cracking.

Step 8: Compute the flexural stress in the central area of the pavement slab with the front axle near the approaching transverse joint and the rear axle close to the following joint in the same panel under negative temperature differential. Determine the stress ratio and evaluate the CFD for different axle loads for the analysis of top-down cracking. CFD should be less than 1.0 for top-down cracking design

CHAPTER 4 DESIGN OF JOINTS

4.1 Spacing and layout

Design and construction of joints in the cement concrete pavement is very crucial item of work because these joints are at critical locations having significant effect on pavement performance. The joints also need to be effectively sealed and maintained well. Various types of joints in Cement Concrete Pavements are shown in Figure 10.

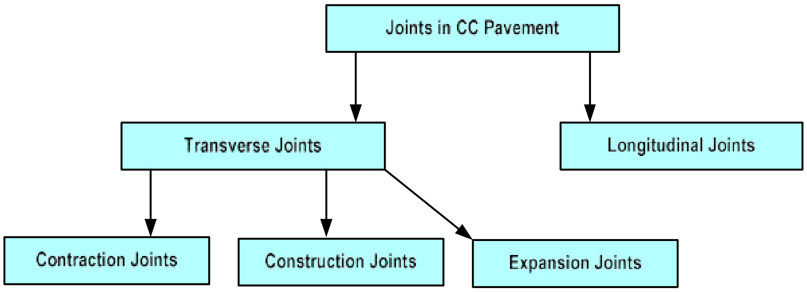


Figure 10 Types of CC Pavements

Contraction joints are transverse joints which release the tensile stresses in concrete pavements. The joint spacing of a concrete pavement depends upon the type of coarse aggregates and the average temperature fluctuation in different seasons. The spacing of contraction joints should be limited to 4.5 m to prevent top-down cracking during the night hours.

Expansion joints are transverse joints to allow expansion of concrete slab due to rise in average temperature in summer months. These joints are difficult to maintain and they get filled up with dirt and other incompressible materials causing locking of the joints and preventing expansion of concrete slabs. They are, therefore, no longer in use except near permanent structure like bridges and culverts.

Construction joints should, as far as possible, be placed at the location of contraction joints except in case of emergency when a key joint may be used.Longitudinal joints are required in pavements of width greater than 4.5 m to allow for transverse contraction and warping.
Typical details of contraction joint, longitudinal joint and expansion joint are shown in Figure 11, Figure 12, Figure 13.

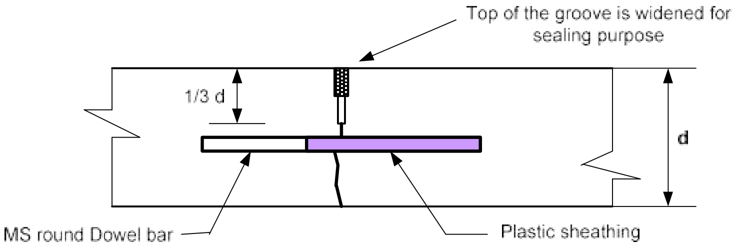


Figure 11 Contraction joint with Dowel bar

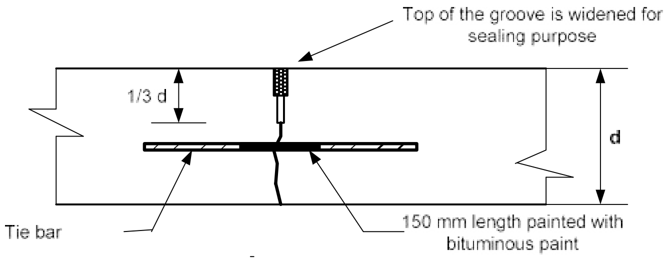


Figure 12 Longitudinal joint with tie rod between two lanes

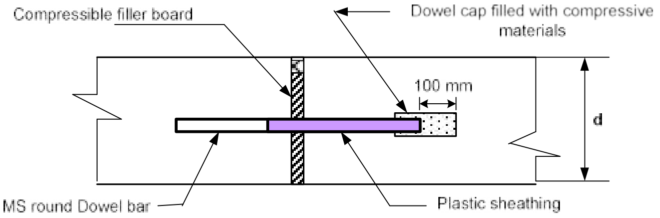


Figure 13 Expansion joint with dowel bar

4.2 Load Transfer at Transverse Joints

Load transfer to relieve part of the load stresses in edge and corner regionsof pavement slab at transverse joints is provided by means of mild steel round dowelbars. In the areas of high rainfall, coated/corrosion resistant dowel bars are oftenused to provide long term load transfer. The coating may be zinc or lead based paint orepoxy coating. Dowel bars enable good riding quality to be maintained by preventingfaulting at the joints.

The bearing stress in the concrete that is responsible for the performance of dowel bars at the joints. High concrete bearing stress can fracture the concrete surrounding the dowel bars, leading to the looseness of the dowel bar and the deterioration of the load transfer system with eventual faulting of the slab. Larger diameter dowel bars are found to provide better performance. Maximum bearing stress (***F_{bmax}***) between the concrete and dowel bar is obtained fromEquation 12.

$$F_{bmax} = \frac{k_{mds} P_t (2 + \beta Z)}{4\beta^3 EI}$$ **Equation 12**

Where,

β= Relative stiffness of the bar embedded in concrete, mm = $\sqrt[4]{\frac{K_{mds} b_d}{4EI}}$

k_{mds}= Modulus of dowel support, MPa/m

b_d= diameter of the dowel bar, mm

Z = Joint width (5 mm for contraction joint and 20 mm for expansion joint), in mm

E = Modulus of elasticity of the dowel bar, MPa

I = Moment of inertia of the dowel bar, mm^4

P_t = load transfer by designed dowel bar, kN

The modulus of dowel support ranges from 80,000 to 415,000 MPa/m. A typical value of 415,000 MPa/m may be adopted for design since only the fourth root of the ***k-value*** affects the computation of$\boldsymbol{\beta}$.

Each dowel bar should be designed for the maximum load being transferredby it for the allowable bearing pressure. Based on the expression givenby the American Concrete Institute (ACI) Committee, Equation 13may be used for calculationof the allowable bearing stress on concrete.

$$F_b = \frac{(101.6 - b_d) f_{ck}}{95.25}$$ **Equation 13**

Where,

F_b = allowable bearing stress, MPa

b_d = dowel diameter, mm

f_{ck} = Characteristic compressive strength of the concrete, MPa (For M 35 concrete, f_{ck} = 35 MPa (28 days); = 42 MPa (90 days)

Since the initial load transfer efficiency (LTE) at the transverse joint is almost 100 percent and it takes a long time for the LTE to decrease with traffic repetitions, 90 day compressive strength can safely be used for the computation of allowable bearing stress.

For heavy traffic, greater than 450 CVPD, dowels are to be provided at thecontraction joints since aggregate inter-lock cannot be relied upon to effect loadtransfer across the joint to prevent faulting due to the repeated loading of heavy axles.Joint widths of 5 mm and 20 mm may be taken for stress computation in dowel bar atcontraction and expansion joint respectively. Recommended diameter and length of dowel bar is given in the table below.

Table 8 Recommended Dimensions of Dowel bars

Slab thickness	Dowel bar details		
	Diameter, mm	Length, mm	Spacing, mm
200	25	360	300
230	30	400	300
250	32	450	300
280	36	450	300
300	38	500	300
350	38	500	300

Note: Dowel bars for the slabs of thickness less than 200 mm is not recommended to provide.The recommended table is suitable for concrete grade M40. If the concrete used for slab is of grade less than M40, then dowel bars shall be provided only after design as in the **Appendix V**.

4.3 Dowel group action

When loads are applied at a joint, a portion of the load is transferred to the other side of the slab through the dowel bars. If the load is near the joint of a pavement slab tied to a concrete shoulder, a part of the load is transferred to the shoulder also. The dowel bar immediately below the wheel load carries maximum amount of loadand other dowel bars transfer progressively smaller magnitudes of loads. Repeated loading causes some looseness between the dowel bars and the concrete slab andrecent studies indicate that the dowel bars within a distance of one radius of relativestiffness (***1.0 l***)from the point of load application participate in load transfer. Assuminga linear variation of the load carded by different dowel bars within ***1.0 l***, the maximumload carried by a dowel bar can be computed. Example of the design of dowel bars is given in **Appendix V.**

4.4 Design of Tie Bars for Longitudinal Joints

The longitudinal joint is expected to open up during the service period (in case of heavy traffic, expansive subgrades, etc.). The area of steel required per meter length of joint may be computed using the following equation.

$$A_s = \frac{bfW}{S_{st}}$$ **Equation 14**

Where,

A_s = area of steel in mm^2, required permeter length of joint;
b = lane width in meter;
f = coefficient of friction between pavement and the subbase/base (usually taken as 1.5)
W = weight of slab in kN/m^2 and
S_{st}= allowable working stress of steel in MPa

The length of any tie bar should be at least twice that required to develop a bond strength equal to the working stress of the steel. The formula for estimating the length of the tie bar is given as in the Equation below.

$$L = \frac{2\, S_{st} A_{cs}}{B^{*} P_{ptb}}$$ **Equation 15**

Where;

L = length of tie bar (mm)
S_{st} = allowable working stress in steel (MPa)
A_{cs} = cross-sectional area of one tie bar (mm^2)
P_{ptb}= perimeter of tie bar (mm), and
B = permissible bond stress of concrete; (for deformed tie bars = 2.46 MPa; for plain tie bars- 1. 75 MPa.)

Reinforced Cement Concrete needs to be provided in pavement panels in curved portions of radius less than 45 m and at underpasses, on steep gradients, and for slabs having man-hole cover slab having L/B (length to breadth) ratio more than 1.5 and in other similar situations.

To permit warping at the joint, the maximum diameter of tie bars may be limited to 16 mm, and to avoid concentration of tensile stress they should not be spaced more than 750 mm apart. The calculated length, L, may be increased by 50 to 80 mm to account for any inaccuracy that may occur in the placement during construction. Anexample of design of tie bar is given in **Appendix VI.**

Typical tie bar details for use at central longitudinal joint in double-lane rigidpavements with a lane width of 3.50 m are given in Table 9. The same specificationsmay be used for the tied concrete shoulder also.

Table 9 Recommendations for Tie Bars for Longitudinal Joint of Two-Lane Rigid Pavements

Slab thickness	Tie bar details				
	Diameter (d) mm	Maximum Spacing, mm		Minimum length, mm	
		Plain	Deformed	Plain	Deformed
150	8	330	530	440	480
	10	520	830	510	560
200	10	390	620	510	560
	12	560	900	580	640
250	12	450	720	580	640
300	12	370	600	580	640
	16	660	1060	720	800
350	12	320	510	580	640
	16	570	910	720	800

Note: The recommended details are based on the following values of different design parameters: S = 125 MPa for plain bars, 200 MPa for deformed bars; bond stress for plain bars = 1.75 MPa, for deformed bars = 2.46 MPa as per IRC: 58:2015.

4.5 Reinforcement in Cement Concrete Slab to Control Cracking

Reinforcement in concrete pavements, is intended to hold the cracked faces tightly together, so as to prevent opening of the cracks and to maintain aggregate inter-lock required for load transfer. It does not increase the flexural strength of unbroken slab when used in quantities which are considered economical.

Reinforcement in concrete slabs, when provided, is designed to counteract the tensile stresses caused by shrinkage and contraction due to temperature or moisture changes. The maximum tension in the steel across the crack equals the force required to overcome friction between the pavement and its foundation, from the crack to the nearest joint or free edge. This force is the greatest in the middle of the slab where the cracks occur first. Reinforcement is designed for this critical location. However, for practical reasons reinforcement is kept uniform throughout the length for short slabs.
The amount of longitudinal and transverse steel required per meter width or length of slab is computed by the following formula:

$$A_s = \frac{L_d f W}{2S_{st}}$$

Equation 16

Where,

As = area of steel in mm^2 required per m width or length of slab;
L$_d$=distance (m) between free transverse joints (for longitudinal steel) or freelongitudinal joints (for transverse steel)
f = coefficient of friction between pavement and sub-base/base (usually takenas 1.5)
W = weight of the slab in kN/m^2 and
S$_{st}$= allowable working stress in steel in MPa (usually taken as 50 to 60 percentof the minimum yield stress of steel.

Since reinforcement in the concrete slabs is not intended to contribute towards its flexural strength, its position within the slab is not important except that it should be adequately protected from corrosion. Since cracks starting from the top surface are more critical because of ingress of water when they open up, the general preference is for the placing of reinforcement about 50 to 60 mm below the top surface. Reinforcement is often continued across longitudinal joints to serve the same purpose as tie bars, but it is kept at least 50 mm away from the face of the transverse joints and edge. In special cases, the steel reinforcement shall be provided in acute curve portions, under passes, steep gradients and slabs having man-hole covers and slabs having length to breadth ratio more than 1.5 and at acute angled corners.

CHAPTER 5 COUNTINUOUSLY REINFORCED CONCRETE PAVEMENT

5.1 Introduction

The technique of Continuously Reinforced Concrete Pavement (CRCP) does not require the expansion and contraction joints, thus permitting very long slab lengths with improved riding comfort and reduced maintenance as compared to plain concrete pavements. Conventional CRCP requires relatively high percentage of steel ranging from 0.7 to 1.0 percent of concrete cross-section. The technique of CRCP construction with elastic joints (CRCP-EJ) facilitates significant reduction in quantity of steel required (0.4 - 0.5 percent) and also eliminates the random cracks which occur in conventional continuously reinforced concrete pavements.

The provision of continuous reinforcement in CRCP of the conventional type results in the formation of transverse cracks in the pavement which are held tightly closed by the steel without impairment of structural strength. The closely held cracks ensure load transfer across the cracks through aggregate interlocking and also prevent the ingress of water and grit into the cracks. The width and spacing of such cracks are dependent on the amount of steel reinforcement provided. The greater the amount of steel, the closer is the spacing of the cracks and the smaller is their opening. An optimum amount of longitudinal reinforcement is called for so that the cracks are neither too widely spaced with resulting over-stressing of steel, loss in load transfer provided by aggregate interlock and accelerated corrosion of steel; nor too closely spaced so as to cause disintegration of the slab.

The elastic joints consist of dummy contraction joints with the reinforcement continuous through them. The reinforcement is painted with a bond-breaking medium over a specified design length on either side of the joint groove to provide adequate gauge length for limiting the steel strains due to joint movement.

The use of elastic joints, apart from resulting in reduction of steel stresses by about 50 per cent and enabling the use of less quantity of steel, also preclude the random cracking associated with conventional construction, since the weakened plane provided at such joints localizes the cracking. The usual spacing of such joints works out to about 4 to 5 m.

5.2 Design

Calculation for Steel Percentage and Stresses in Steel and Concrete due to Continuity at Elastic Joints

The continuity of steel at elastic joints leads to restraint in the slab movement due to shrinkage and temperature change, and thus induces stresses in both steel and concrete. However, if steel is provided at mid-depth of the slab, as is the usual practice, no stress will develop in it due to wheel load and warping.

The stresses (due to continuity of steel at elastic joints) in steel, (σs), and concrete, (σc), in the vicinity of elastic joints may be calculated from ***Eisenann*** equations which are given below:

$$\sigma_s = \frac{100(\alpha.\Delta_T.h.E_0.E_s)}{f_s E_s(1-\lambda) + (100.h.E_c.\lambda)} kg/cm^2$$

and

$$\sigma_c = \frac{\alpha.\Delta_T.h.E_c.E_s}{f_s.E_s(1-\lambda)+(100.h.E_c.\lambda)}\ kg/cm^2$$

where

α = Coefficient of thermal expansion of concrete per °C,

$\boldsymbol{\Delta_T}$ = Difference between the mean temperatures of the slab at the time of construction and the coldest period in °C,

Δt = Maximum temperature differential between top and bottom of the slab as given in Table 1 of this guidelines,

Note: While finding out the temperature stress at the edge, Δt is different from $\boldsymbol{\Delta_T}$ which is used in these equations to designate temperature difference between the minimum of minimums and the mean temperature at the time of construction. $\boldsymbol{\Delta_T}$ is not a function of slab thickness whereas Δt the temperature differential depends on the thickness of slab.

h = Slab thickness in cm

E_c = Modulus of elasticity of concrete in kg/cm^2

E_s = Modulus of elasticity of steel in kg/cm^2

f_s = Cross-section of steel in 1 m width of the slab in cm^2

λ = Ratio of free, unbonded length of the steel to the slab length between two consecutive elastic joints.

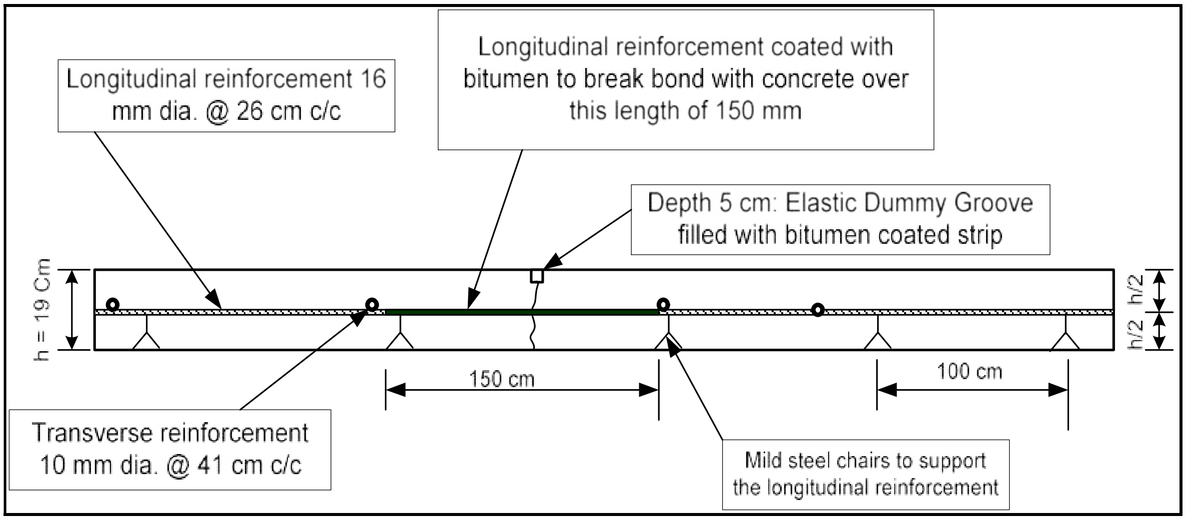


Figure 144 Details of Elastic Joint Section

The stresses developed in steel and concrete per °C of ΔT for steel percentage range of 0.1 - 0.6 and for ratio, λ range of 0.1-0.4. of are shown in the charts below. The steel stresses so determined should not exceed the permissible value of 1400 kg/cm^2. The concrete stresses are additive to the load and temperature warping stresses and are required to be taken into account while designing the pavement. The transverse steel may be taken as 25 per cent of longitudinal steel.

The provision of steel enables some increase in the effective slab thickness and its continuity at elastic joints provides additional load transfer over and above that provided by conventional dummy contraction joint. At the same time, the percentage of steel is small enough not to induce any restraint to bending of the slab at elastic joints due to effect of wheel load and temperature warping.

While in CRCP without elastic joints the permissible stress in steel in 2800 kg/cm^2 (i.e. the steel is allowed to be stressed up to the yield point), the permissible value in CRCP with elastic joints is restricted to 1400 kg/cm^2 only (i.e. normal working stress in steel used in conventional structures). The lower permissible stress in steel in CRCP with elastic joints enables taking advantage of the effective increase in concrete slab thickness due to provision of steel, while the permissible yield stress limit in steel in the case of CRCP without elastic joint prevents such increase.

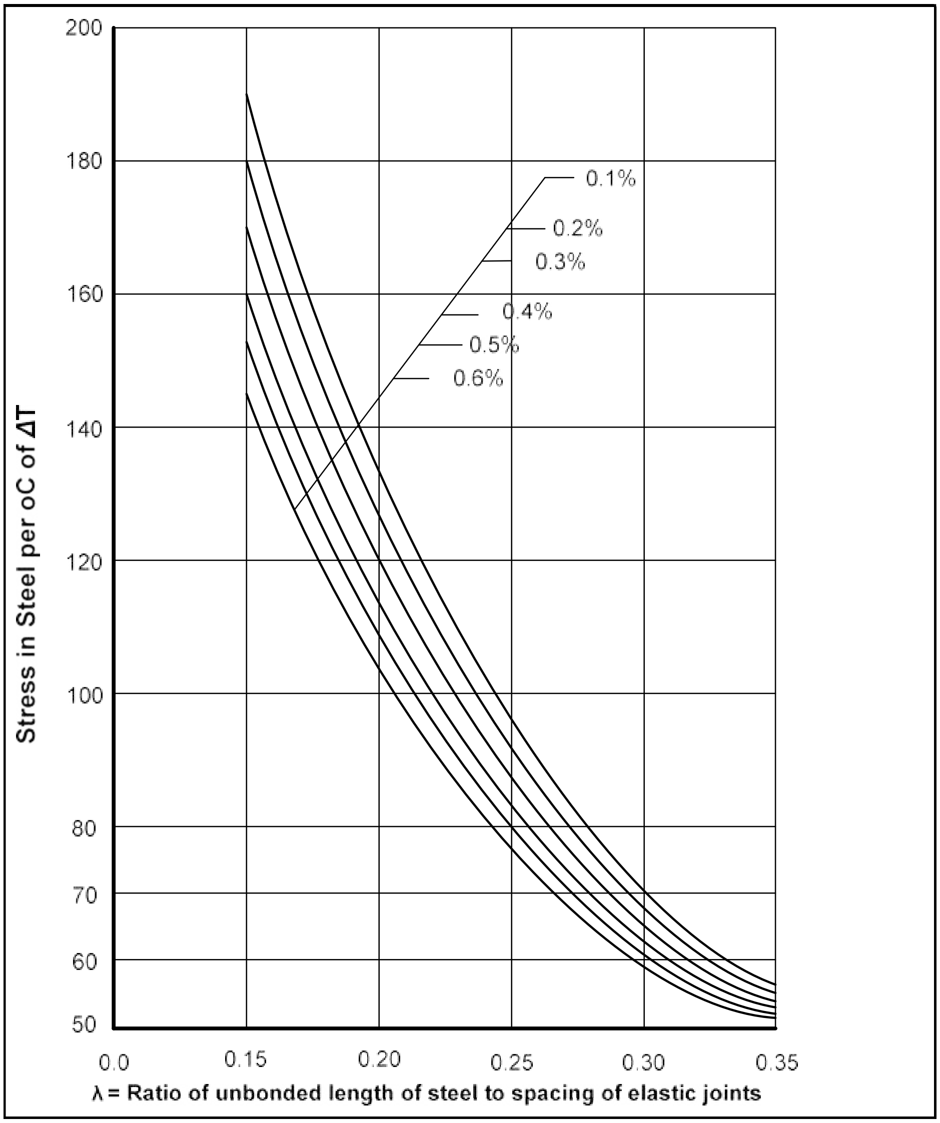


Figure 15: Design Charts for calculation of stresses in Steel

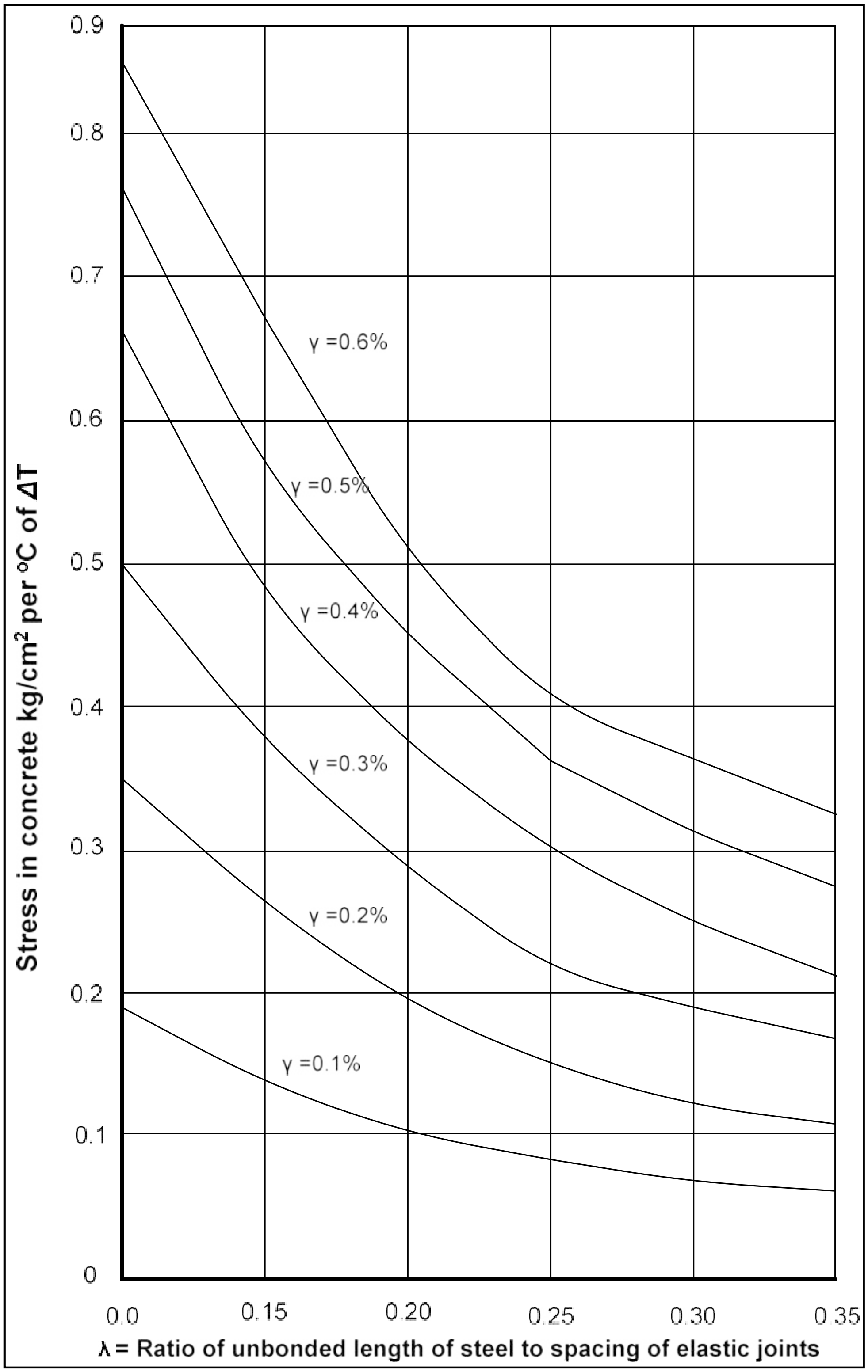


Figure 16 Design charts for calculation of stresses in concrete

5.3 Design of Slab Thickness

Initially, the thickness of plain cement concrete pavement should be worked out considering PCCP. While working out the thickness, the additional concrete tensile stress should be accounted for as indicated in Figure 15 and Figure 16.

The effective increase in slab thickness due to provision of steel reinforcement may be worked out by using Mallinger's chart given in Fig. 17. The equivalent CRCP slab thickness may then be calculated by reducing the thickness calculated above, by the amount of the effective increase in slab thickness using Figure **17** the average of steel in longitudinal and transverse direction may be taken.

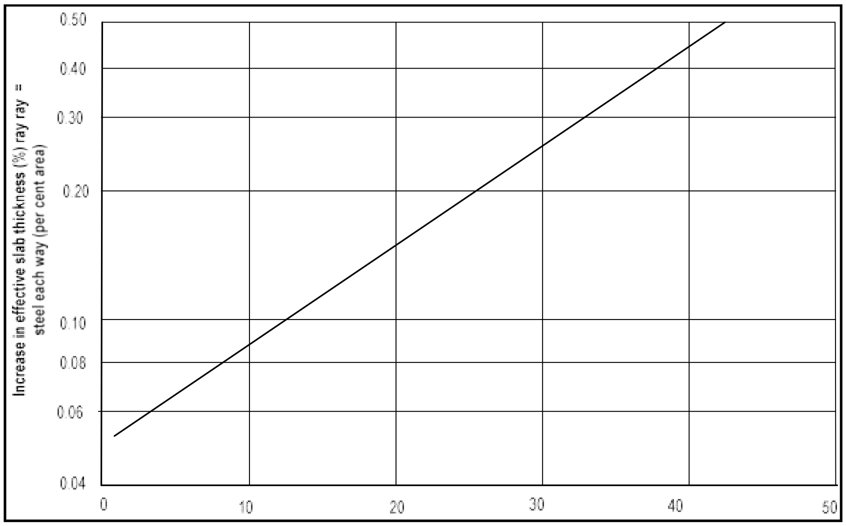


Figure 17 Malinger's chart showing the effect of reinforcement on rigid pavements

5.4 Outline of Design procedure

Design of continuous reinforced concrete pavement with elastic joints shall be done according to the following steps:

Step I: Assume a thickness and examine wheel load and temperature stresses as per this guideline,

Step II: For a proposed value, choose a steel percentage Figure 15 such that the steel stress is within the permissible value. Calculate the concrete stress from Figure 16. In calculating these stresses the ordinates are to be multiplied by the corresponding value of ***t***, as applicable to the particular location.

Step III: Add the concrete stress calculated in **Step II** to the value obtained in **Step I** and the final total stresses should be within the flexural strength of concrete. The trials may be repeated till the assumed thickness in **Step I** meets the requirement.

Step IV: Calculate the effective increase in slab thickness due to provision of reinforcement as per 17 and reduce the thickness obtained in **Step III** to account for the increase.

5.5 Cement Concrete Mix Design

The mix should be designed on the basis of absolute volume method as per IRC:44 - "Tentative Guidelines for Cement Concrete Mix Design". The flexural strength of concrete at 28 days in the field should not be less 40 kg/cm^2.

5.5.1 Materials

Cement: Should conform to IS: 269 or IS: 8112.

Coarse and Fine Aggregate: Should conform to IS: 383.

Steel: The diameter of steel bars should be so chosen as to keep the spacing, between bars around 25 to 35 cm. Steel should conform to IS: 432 (Part I)- Mild Steel.

Water: Water used for both mixing and curing should be clean and free from injurious amount of deleterious matter and should conform to IS:456. Potable water is generally considered satisfactory.

5.6 Construction Details

The construction details are the same as in the case of plain cement concrete pavements (vide IRC: 15) except the following.

5.6.1 Construction of Joints

Elastic joints

These are dummy type joints which should be induced at intervals similar to that for dummy contraction joints. The joint grooves may be formed as in the case of conventional dummy joint, and filled with sealing compound. Alternatively, bitumen-coated plywood strips of 50 mm width and 3 mm thickness may be inserted therein. On either side of the elastic joint, steel should be coated with bitumen for a length of 1/3 - 1/4 joint spacing in order to break the bond of steel with concrete and to provide greater length for elongation of the steel due to joint opening for reducing the stress in the reinforcing steel.

Expansion joints:

The expansion joints are provided only at the ends of the CRCP-EJ sections and there is no need of providing these in-between. The width of such expansion joints is kept upto double that of conventional concrete pavement to accommodate the greater end movements. Details of these joints should be as shown in IRC: 15.

5.7. Reinforcement

The steel mats, assembled at site, are placed over suitable chairs at mid depth of the slab before concreting is done. The bars should be continuous across elastic joints and any construction joints. Where overlap of bars is required, a minimum overlap of 30 diameters should be provided. Such overlaps should be staggered. It should also be ensured that no overlap of steel bars is provided at the location of elastic joints.

CHAPTER 6 PRECAST PANEL CONCRETE PAVEENT

6.1 Introduction

Generally, precast pavement technology comprises new and innovative construction methods that can be used to meet the need for rapid pavement repair and construction. Precast pavement components are fabricated or assembled offsite, transported to the project site, and installed on a prepared foundation (existing pavement or re-graded foundation). The system components require minimal field curing time to achieve strength before opening to traffic. These systems are primarily used for rapid repair, rehabilitation, and reconstruction of both asphalt and cement concrete pavements in high-volume-traffic roadways. The precast technology can be used for intermittent repairs or full-scale, continuous rehabilitation. In intermittent repair of concrete pavement, isolated full-depth repairs at joints and cracks or full-panel replacements are conducted using precast concrete panels. The repairs are typically full-lane width. The process is similar for full-depth repairs and full-panel replacement. One technology developed for continuous applications is precast pre-stressed concrete pavement (PPCP). Use of precast concrete pavements for reconstruction and rehabilitation is a very viable alternative to conventional cast-in-place concrete pavement construction, especially in situations where high traffic volumes and consideration of the delay costs to users due to lane closures favor reconstruction and rehabilitation solutions that allow expedited opening to traffic. Precastconcrete also offers the advantage of being “factory made” in a more controlled environment than cast in-place construction and thus is potentially more durable and less susceptible to construction and material variability.

6.2 Precast Panel Concrete Pavement System

The basic precast pre-stressed pavement concept consists of a series of individual precast panels that are post-tensioned together in the longitudinal direction after installation on site. Each panel can be pre-tensioned in the transverse direction (long axis of the panel) during fabrication, and ducts for longitudinal post-tensioning are cast into each of the panels. The basic features (typical) of the PPCP system are as follows:

- Panel size: up to 11.6 m wide, typically 3 m long, and 178 mm to 203 mm thick (or as per design).
- Panel types: Base, joint, and central stressing panels (as originally developed).
- Tongue-and-groove transverse epoxied joints
- Post-tensioning details: a. 15 mm diameter 7-wire mono-strand tendons, typically spaced at 600 mm. b. Tendon load: 75 percent of ultimate tendon load, typically. c. Pre-stress force: sufficient to ensure about 1.0 to 1.4 MPa residual pre-stress at the mid-point of each series of pre-stressed panels. D. Grouted post-tensioning ducts.
- Expansion joint spacing: about 76 m, typically.
- Base type: a. Hot-mix asphalt concrete base with polyethylene sheet over base or asphalt concrete interlayer in the case of an overlay application. b. Permeable base (as used in the Missouri demonstration project). c. Lean concrete base, d. Aggregate base
- Injection of bedding grout to firmly seat panels (after post-tensioning).

6.3 Design Considerations of PPCP

The following factors need to be considered:

a. The PPCP systems require placement of the panels on a smooth base or interlayer to ensure that the friction between panel and base is as low as possible. Otherwise, a larger portion of the pre-stressing force is consumed in overcoming this friction.
b. The PPCP base and the foundation need to be of high quality and stiff to minimize slab deflections at the expansion joint.
c. The PPCP can be designed to achieve a minimum residual pre-stress of about 1.0 to 1.4 MPa at mid-length of the series of posttensioned slabs. This residual pre-stress adds to the concrete’s flexural strength and allows use of PPCP systems that are about 75 to 100 mm less in thickness than conventional concrete pavements for the same traffic loading and environmental conditions.

d. The PPCP systems can be designed to incorporate expansion joints at 50 to 75 m. The longer joint spacing requires use of more pre-stressing tendons (more pre-stressing force) to balance the higher pre-stress losses due to longer pre-stressing lengths involved.
e. The pre-stressing tendon size (diameter) and spacing should be selected to achieve the desired stress level at slab ends and at mid-length of the posttensioned panels. Generally it is kept as 15 mm diameter, Grade 270 7-wire stress-relieved tendons for highway applications.
f. The AASHTO (2004) mechanistic–empirical design procedure can be used to determine the required thickness of the PPCP using only the "fatigue cracking" distress criteria. The flexural strength used should be the concrete's flexural strength plus the residual pre-stress at mid-length of the post-tensioned series of the panels.
g. The expansion joint should be designed to allow for large slab end movements (typically 51 to 76 mm], depending on environmental conditions) and to provide desired load transfer across the wider joints.

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APPENDIX I: VALIDITY OF FATIGUE EQUATIONS

The fatigue equation adopted in the Mechanistic Empirical Pavement Design Guide (MEPDG) recently developed USA (NCHRP, 2004) for a reliability of 90 percent gives fatigue lives that are practically the same compared to those obtained by using the fatigue equations adopted in the present guidelines. The design thicknesses obtained for a typical concrete pavement using the fatigue criteria adopted by MEPDG (NCHRP, 2004) and the fatigue criteria adopted in these guidelines are practically the same. The MEPDG fatigue equation for concrete is

$$Log_{10} N_r = \left[\frac{-SR_r{}^{-10.24}\{Log_{10}\,(1-P)\}}{0.0112}\right]^{0.217}$$

Equation 17

Where,

N**r*= fatigue life at load level ***r

***SR**r*= stress ratio at load level$\boldsymbol{r} = \frac{stresscausedatloadlevelr}{modulusruptureofconcrete}$

P = probability of 10 percent fatigue cracking failure at the end of designperiod (in decimal)

Reliability = 1- p

Suggested reliability values for different types of roads are:

Type of Roads	Reliability
Village roads	60 %
District Roads	70 %
Feeder Roads	80 %
National Highways	90 %

APPENDIX II: EQUATIONS FOR FLEXURAL STRESS IN CONCRETE SLAB

Regressions equations are given in this appendix for estimation of the maximum tensile stress in the slab in the edge region due to the combined effect of axle loads and temperature differential. The equations are given for bottom-up cracking and for top-down case. Flexural stress for bottom-up case has been computed for non-linear positive temperature differential occurring in the slab during day time. The stress for top-down cracking case is for the combination of axle loads and linear negative temperature differential in the slab occurring during night time.

For the computation of stress for bottom-up cracking analysis, only the rear axles (single as well as tandem) with two wheels (dual wheel sets) on either side of each axle have been considered as the front axles do not contribute to any significant fatigue damage. For top-down cracking, rear axle is considered at one end and the front axle at the other end. Only one axle of the tandem and tridem axles is assumed to be placed on the slab under consideration. Thus, for a tandem axle, ***50 percent*** of the tandem axle weight is considered for analysis. For a tridem axle, ***33 percent*** of the tridem axle weight may be taken for analysis. The corresponding front axle is taken as ***50 percent*** of the rear axle, (***25 percent*** of rear tandem axle and ***one sixth*** of rear tridem axle).

1) Expressions for maximum tensile stress at the bottom of the slab (for bottom-up cracking case)

I. Single axle - Pavement with tied concrete shoulders

a) K ≤ 80 MPa/m

$$S = 0.008 - 6.12\left[\frac{\gamma h^2}{kl^2}\right] + 2.36\left[\frac{Ph}{kl^4}\right] + 0.0266\Delta T$$

b) K > 80 MPa/m, k ≤ 150 MPa

$$S = 0.08 - 9.69\left[\frac{\gamma h^2}{kl^2}\right] + 2.09\left[\frac{Ph}{kl^4}\right] + 0.0409\Delta T$$

c) K> 150 MPa

$$S = 0.042 + 3.26\left[\frac{\gamma h^2}{kl^2}\right] + 1.62\left[\frac{Ph}{kl^4}\right] + 0.0522\Delta T$$

II. Single axle - Pavement without concrete shoulders

a) k ≤ 80 MPa/m

$$S = -0.149 - 2.60\left[\frac{\gamma h^2}{kl^2}\right] + 3.13\left[\frac{Ph}{kl^4}\right] + 0.0297\Delta T$$

b) k > 80 MPa/m, k ≤ 150 MPa

$$S = -0.119 - 2.99\left[\frac{\gamma h^2}{kl^2}\right] + 2.78\left[\frac{Ph}{kl^4}\right] + 0.0456\Delta T$$

c) k> 150 MPa

$$S = -0.238 + 7.02\left[\frac{\gamma h^2}{kl^2}\right] + 2.41\left[\frac{Ph}{kl^4}\right] + 0.0585\Delta T$$

III. Tandem axle - Pavement with tied concrete shoulders

a) k ≤ 80 MPa/m

$$S = -0.188 + 0.93\left[\frac{\gamma h^2}{kl^2}\right] + 1.025\left[\frac{Ph}{kl^4}\right] + 0.0207\Delta T$$

b) k > 80 MPa/m, k ≤ 150 MPa

$$S = -0.174 + 1.21\left[\frac{\gamma h^2}{kl^2}\right] + 0.87\left[\frac{Ph}{kl^4}\right] + 0.0364\Delta T$$

c) k> 150 MPa

$$S = -0.210 + 3.88\left[\frac{\gamma h^2}{kl^2}\right] + 0.73\left[\frac{Ph}{kl^4}\right] + 0.0506\Delta T$$

IV. Tandem axle - Pavement without tied concrete shoulders

a) k ≤ 80 MPa/m

$$S = -0.223 + 2.73\left[\frac{\gamma h^2}{kl^2}\right] + 1.335\left[\frac{Ph}{kl^4}\right] + 0.0229\Delta T$$

b) k > 80 MPa/m, k ≤ 150 MPa

$$S = -0.276 + 5.78\left[\frac{\gamma h^2}{kl^2}\right] + 1.14\left[\frac{Ph}{kl^4}\right] + 0.0404\Delta T$$

c) k> 150 MPa

$$S = -0.3 + 9.88\left[\frac{\gamma h^2}{kl^2}\right] + 0.956\left[\frac{Ph}{kl^4}\right] + 0.0543\Delta T$$

2) Expression for maximum tensile stress at the top of the slab (for top-down cracking case)

Top-down cracking analysis is performed only with the consideration of rear axle load. Front axle load is assumed be 50% of the rear axle load (tandem/tridem).

$$S = -0.219 + 1.686\left[\frac{BPh}{kl^4}\right] + 168.48\left[\frac{h^2}{kl^2}\right] + 0.1089\Delta T$$

The symbols in the equations have the following meaning:

S = flexural stress in slab, MPa
Δ***T***= maximum temperature differential in °C during day time for bottom-upcracking
(Sum of the maximum night time negative temperature differential and built-in negative temperature differential in °C for top-down cracking)
h = thickness of slab, m
k = effective modulus of subgrade reaction of foundation, MPa/m
l = radius of relative stiffness,m

$$l = \sqrt[4]{\frac{Eh^3}{12k(1-\mu^2)}}$$

E = elastic modulus of concrete, MPa
μ= Poisson's ratio of concrete
γ = unit weight of concrete (24 kN/m3)
P = For Bottom-up cracking analysis: single/tandem rear axle load (kN). Nofatigue damage estimated for front (steering) axles for bottom-up crackingcase
P = For Top-down cracking analysis: 100 percent of rear single axle, 50 percent of rear tandem axle, 33 percent of rear tridem axle. No front axle weight is required to be given as input for top-down cracking. 50 percent of rear single axle, 25 percent of rear tandem axle, 16.5 percent of rear tridem axle, have been considered in the finite element analysis as the front axle weights for single, tandem and tridem rear axles respectively.

B = 0.66 for transverse joint with dowel bars (load transfer efficiency was taken as 50 percent)
= 0.90 for transverse joint without dowel bars (load transfer efficiency was taken as 10 percent)

APPENDIX III: EXAMPLE FOR THE DESIGN OF DRAINAGE LAYER

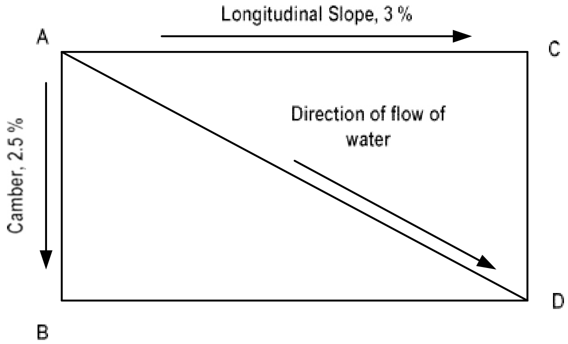
A four-lane divided cement concrete pavement will be constructed for a high traffic volume road in an area having an annual rainfall of 1500 mm/year. The width of each carriageway will be 7.0 m. 2.5 m wide (1.5 m concrete, 1.0 m unpaved) shoulders will be provided. Transverse joint spacing will be 4.5 m. The highway has a longitudinal gradient of 3 percent and a camber of 2.5 percent. Side slopes of embankment are 2:1 (horizontal to vertical). The pavement has a 300 mm thick concrete slab placed over 150 mm thick DLC layer. Estimate the requirement of permeability of the drainage layer material to be used if the layer thickness is 150 mm.

Solution:-

- Combined thickness of the slab and DLC layer = 300 + 150 = 450 mm
- The drainage layer will be provided below the DLC layer at a depth of 450 mm from pavement surface. The drainage layer will be extended to the full width of embankment.
- Width of drainage layer= 7 m (pavement)+ 2.5 m (shoulder)+ 2 x 0.45 m = 10.4 m
- The figure below indicates the direction of flow of water along AD (diagonal)
- In this figure, AB = 10.4 m; AC = 10.4 x (0.03/0.025) = 12.48 m;

$$AD = \sqrt{AC^2 + CD^2} = \sqrt{10.4^2 + 12.48^2} = 16.24$$

- Drop of elevation along AC = 12.48 x 0.03 = 0.37 4 m; Elevation drop alongCD = 10.4 x 0.025 = 0.26 m; Elevation drop along AD = 0.37 4 + 0.260 = 0.634 m
- Gradient along AD = I = drop along AD/length pf AD= 0.634/16.24.= 0.039



- The infiltration rate per unit area q_i can be estimated using following. The equation is reproduced here for convenience.

$$q_i = I_c \left(\frac{N_c}{W_p} + \frac{W_c}{C_s W_p} \right) + K_p$$

Where;

I_c = crack infiltration rate = 0.223 m3/day/m

Nc = number of longitudinal joints/cracks = 3 (joints between lanes, between lane and shoulder and paved shoulder edge)

Wp= width of pavement subjected to infiltration= 7.0 + 2.5 = 9.5 m

We =length of the transverse cracks or joints = 7.0 + 1.5 = 8.5 m

Cs =spacing of transverse joints= 4.5 m

K = rate of infiltration through un-cracked pavement surface = 0 m^3/day/m which is almost negligible for cement concrete pavement.

- Thus, the rate of infiltration of water into pavement, $\boldsymbol{q_i}$= 0.115 m^3/day/m
- Amount of infiltrated water per meter length flowing along the path AD of the drainage layer,
- Q = 16.24x 0.12=1.949 m^3/day/m
- Rate of flow through drainage layer,
- Q = KIA. Since ***I*** = 0.039, KA=1.949/0.039 = 49.97; A=1x0.15=0.15m2
- Hence, the required coefficient of permeability, K = 49.97/0.15 = 333 m/day

Considering the coefficient of permeability values adopted by AASHTO (1993) for different aggregate gradations it can be expected that the grading I, II, and III of the coarse graded granular sub-base material will have permeability values larger than 300 m/day. The AASHTO gradations and the corresponding coefficient of permeability values are given in table below. The percentage fines passing 0.075 mm sieve should be less than 2 percent for ensuring good permeability. If the subgrade is erodible with high content of fine grained material and subjected to high moisture contents, close graded granular sub-base material is recommended below the coarse graded drainage layer to act as a filter.

Sieve Size, mm	**% passing the sieve**					
	Grading 1	**Grading 2**	**Grading 3**	**Grading 4**	**Grading 5**	**Grading 6**
20	100	100	100	100	100	100
12.5	85	84	83	81.5	79.5	75
9.5	77.5	76	74	72.5	69.5	63
4.76	58.3	56	52.2	49	43.5	32
2.36	42.5	39	34	29.5	22	5.8
2.00	39	35	30	25	17	0
0.84	26.5	22	15.5	9.8	0	0
0.42	18.2	13.3	6.3	0	0	0
0.25	13.0	7.5	0	0	0	0
0.105	6.0	0	0	0	0	0
0.075	0	0	0	0	0	0
Coefficient Of permeability m/day	3	35	100	350	850	950

APPENDIX IV: EXAMPLE FOR THE DESIGN OF SLAB THICKNESS

A cement concrete pavement is to be designed for a ***four-lane divided*** National Highway with two lanes in each direction in plain terrain. Design the pavement for a period of 30 years. Lane width is 3.5 m; transverse joint spacing is 4.5 m.

It is expected that the road will carry in the year of completion of construction, about ***2000 commercial vehicles per day*** in ***both direction***. Traffic growth rate is assumed as ***6.5 %*** per annum. Axle load survey of commercial vehicles indicated that the percentages of front single (steering) axle, rear single axle, rear tandem axle and rear tridem axle are 31 percent, 9 percent, 28percent and 32 percent respectively. The percentage of commercial vehicles with spacing between the front axle and the first rear axle less than 4.5 m ***is 55 percent***. Traffic count indicates that 30 percent of the commercial vehicles travel during night hours (6 PM to 6 AM). The percentage of day time traffic for six hours (10 AM – 4 AM) is assumed as 75 % of the total day time traffic. Details of axle load spectrum of rear single, tandem and tridem axles are given in the table below. Front (steering) axles are not included. The average number of axles per commercial vehicle is 2.5 (due to the presence of multi-axle vehicles). Effective CBR of sub-grade is 6%.

Solution:

a)	Selection of modulus of sub-grade reaction:	Values	Explanation
1	CBR of compacted subgrade, %	6	Given value
2	Modulus of Sub-grade reaction, MPa/m (Table 2)	44.18	Interpolated
3	Thickness of granular sub-base (provided), mm	150	Assumed thickness
4	Thickness of DLC sub-base with a minimum 7 day compressive strength of 10 MPa, mm	150	Assumed thickness
5	Effective modulus of subgrade reaction of combined foundation of subgrade + granular sub-base and DLC sub-base (from Table 4), MPa/m	238.55	Interpolated Value
6	Polythene sheet of 125 micron thickness between DLC and concrete slab	Yes	Adopted provision

b)	Selection of Concrete: (M35)		
7	28-day compressive strength of cement concrete, MPa	35	Standard Value
8	28-day Flexural strength of cement concrete, MPa	4.14	Formula
9	90-day Flexural strength of cement concrete, MPa	4.56	10 % more than 28-day strength
10	Elastic Modulus of concrete, E , MPa	30000	
11	Poisson's ratio of concrete, μ = 0.15	0.15	
12	Unit weight of concrete, γ = kN/m3	24	
13	Max. day-time Temperature Differential in slab (for bottom-up cracking), °C for plain area	16.8	
14	Night-time Temperature Differential in slab (for top-down cracking) = day-time.	13.4	

c)	Traffic Calculation for design period		
15	Design period , years	30.00	Given Value
16	Annual rate of growth of commercial traffic (expressed in decimal)	0.065	Assumed as 6.5 %
17	Two-way commercial traffic volume per day (in the year of completion of construction)	2,000.00	Tow way atraffic
18	% of traffic in predominant direction percent	0.50	Percentage of Traffic in Design lane

19	Traffic in predominant direction, commercial traffic volume per day	1,000.00	Design traffic
20	Average number of standard axles (steering/single/tandem/tridem) per commercial vehicle	2.50	Data from axle load survey and analysis
21	Number of standard axles in predominant direction (in the year of completion of construction)	2,500	
22	Growth Factor	86	Growth factor formula
23	Cumulative number of standard axles during design period in predominant direction	78,817,063	Consideration of Growth factor
24	Total day time (12 hour) traffic % of Total traffic in predominant direction (number of standard axle)	70.0%	
25	Total day time Traffic (number of standard Axle)	55,171,944	
26	Six hour day time traffic (10 AM - 4PM)	41,378,958	
27	Design Traffic (for Bottom-up Cracking) % of standard axle in predominant direction for six hour day time	0.25	Standard percentage value of Design traffic for BUC
28	Design number of standard axles (25 percent of predominant direction traffic for four lane divided highways)	10,344,740	
29	Design number of standard axles axle repetitions for Bottom up Cracking analysis **(K)**	**10,344,740**	
30	Total Night time (12-hour) traffic % of Total traffic in predominant direction (number of standard axle)	30.0%	
31	Total Night time (12-hour) traffic in predominant direction (number of standard axle)	23,645,119	
32	6-hour night time traffic in predominant direction (number of standard axles)	11,822,560	Assumption 50% of total night time traffic
33	Six hour night time traffic having wheel base less than 4.5 m (55% of six hour night time traffic (number of standard axle) **(J)**	**6,502,408**	

Pavement Option I - Concrete pavement without tied concrete shoulder with Dowel bars across transverse joints		Values	Explanations
1	Trial thickness of the slab, m	0.32	Trial Thickness
2	Radius of relative stiffness, m	0.77	Calculated
3	Load transfer factor for Dowel bars through the transverse joints	0.66	Standard given value

Axle category	Ratio of total
Front single axel (N1)	0.31
Rear single axle (N2)	0.09
Tandem axle (N3)	0.28
Tridem axle (N4)	0.32
Total	**1.00**

Design Axle Load Repetitions for Fatigue Analysis	
For Bottom-up Cracking Analysis	
Front single (steering) Axles not considered	0
Rear single Axles = K* N2	931,027
Tandem Axles = K * N3	2,896,527
Tridem Axles = K * N4	3,310,317
For Top-Down Cracking Analysis	
Front single (steering) Axles not considered	0
Rear single Axles = J * N2	585,217
Tandem Axles = J * N3	1,820,674
Tridem Axles = J * N4	2,080,770

Axle Load Spectrum Data								
Rear Single Axle			**Rear Tandem Axle**			**Rear Tridem Axle**		
Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)	Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)	Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)
185-195	190	0.00	380 - 400	390	0.00	530-560	545	0
175-185	180	0.00	360 - 380	370	0.00	500-530	515	0
165-175	170	2.00	340 - 360	350	0.00	470-500	485	0
155-165	160	3.00	320 - 340	330	0.00	440-470	455	0
145-155	150	10.00	300 - 320	310	0.00	410-440	425	0
135-145	140	12.00	280 - 300	290	1.00	380-410	395	1
125-135	130	10.00	260 - 280	270	6.00	350-380	365	4
115-125	120	20.00	240 - 260	250	10.00	320-350	335	5
105-115	110	16.00	220 - 240	230	28.00	290-320	305	26
95-105	100	10.00	200 - 220	210	25.00	260-290	275	30
85-95	90	7.00	180 - 200	190	18.00	230-260	245	16
< 85	80	10.00	< 180	170	12.00	< 230	215	18
		100.00			**100.00**			**100.00**

Fatigue damage Analysis of concrete slab

Bottom-up Cracking Fatigue Analysis for Day time traffic									
Rear Single Axles					**Rear Tandem Axles**				
Expected Repetitions (ni)	Flex Stress MPa	Stress Ratio (SR)	Allowable Repetitions (Ni)	Fatigue Damage (ni/Ni)	Expected Repetitions (ni)	Flex Stress MPa	Stress Ratio (SR)	Allowable Repetitions (Ni)	Fatigue Damage (ni/Ni)
0	2.615	0.574	63554	0.000	0	2.221	0.488	1483099.008	0.000
0	2.523	0.554	111458	0.000	0	2.1473	0.471	4623131.042	0.000
18621	2.431	0.534	202879	0.092	0	2.0736	0.455	26823814.01	0.000
27931	2.339	0.513	420010	0.067	0	1.9999	0.439	infinite	0.000
93103	2.247	0.493	1072570	0.087	0	1.9262	0.423	infinite	0.000
111723	2.155	0.473	4014459	0.028	28965	1.8525	0.407	infinite	0.000
93103	2.063	0.453	38073316	0.002	173792	1.7788	0.390	infinite	0.000
186205	1.971	0.433	infinite	0.000	289653	1.7051	0.374	infinite	0.000
148964	1.879	0.412	infinite	0.000	811028	1.6315	0.358	infinite	0.000
93103	1.787	0.392	infinite	0.000	724132	1.5578	0.342	infinite	0.000
65172	1.695	0.372	infinite	0.000	521375	1.4841	0.326	infinite	0.000
93103	1.603	0.352	infinite	0.000	347583	1.4104	0.310	infinite	0.000
931027	**Fat Dam from Single Axles =**			**0.28**	**2896527**	**Fat Dam from Tandem Axles =**			**0.000**

Total Bottom-up Fatigue Damage due to Single and Tandem axle loads =	0.28	+	0.00	=	0.28

Top-Down Cracking Fatigue Analysis for Night-time (6 hour) traffic and Negative Temperature Differential														
Rear Single Axles					**Rear Tandem Axles (Stress computed for 50% of axle load)**					**Rear Tridem Axles (Stress computed for 33% of axle load)**				
Expected Repetitions (ni)	**Flex Stress MPa**	**Stress Ratio (SR)**	**Allowable Repetitions (Ni)**	**Fatigue Damage (ni/Ni)**	**Expected Repetitions (ni)**	**Flex Stress MPa**	**Stress Ratio (SR)**	**Allowable Repetitions (Ni)**	**Fatigue Damage (ni/Ni)**	**Expected Repetitions (ni)**	**Flex Stress MPa**	**Stress Ratio (SR)**	**Allowable Repetitions (Ni)**	**Fatigue Damage (ni/Ni)**
0	2.170	0.476	3139926	0.000	0	2.1908	0.481	2255332	0.000	0	2.1342	0.468	5948737	0.000
0	2.127	0.467	6872054	0.000	0	2.1483	0.472	4537702	0.000	0	2.0917	0.459	15853629	0.000
11704	2.085	0.458	19292053	0.001	0	2.1058	0.462	11056201	0.000	0	2.0492	0.450	infinite	0.000
17557	2.042	0.448	infinite	0.000	0	2.0633	0.453	37754449	0.000	0	2.0067	0.441	infinite	0.000
58522	2.000	0.439	infinite	0.000	0	2.0209	0.444	infinite	0.000	0	1.9642	0.431	infinite	0.000
70226	1.957	0.430	infinite	0.000	18207	1.9784	0.434	infinite	0.000	20808	1.9217	0.422	infinite	0.000
58522	1.915	0.420	infinite	0.000	109240	1.9359	0.425	infinite	0.000	83231	1.8792	0.413	infinite	0.000
117043	1.872	0.411	infinite	0.000	182067	1.8934	0.416	infinite	0.000	104039	1.8367	0.403	infinite	0.000
93635	1.830	0.402	infinite	0.000	509789	1.8509	0.406	infinite	0.000	541000	1.7943	0.394	infinite	0.000
58522	1.787	0.392	infinite	0.000	455169	1.8084	0.397	infinite	0.000	624231	1.7518	0.385	infinite	0.000
40965	1.745	0.383	infinite	0.000	327721	1.7659	0.388	infinite	0.000	332923	1.7093	0.375	infinite	0.000
58522	1.702	0.374	infinite	0.000	218481	1.7234	0.378	infinite	0.000	374539	1.6668	0.366	infinite	0.000
585217	Fat Dam from Sing. Axles =			0.001	1820674	Fat Dam from Tand Axles =			0.000	2080770	Fat Dam from Tridem Axles =			0.000
Total Top-Down Fatigue Damage =								**0.001**	**+**	**0.000**	**+**	**0.000**	**=**	**0.001**

Sum of CFD for BUC & TDC=	0.28+0.001 = 0.281
Design is safe Since CFD for BUC and TDC <1	

APPENDIX V: DESIGN OF DOWEL BARS

Input data for Design of Dowel

Modulus of Elasticity of concrete, Ec, Mpa	30000.00	$l = \sqrt[4]{\frac{E * h^3}{12(1-\mu^2)k}}$
Poisson's Ration, μ	0.15	
Slab Thickness, h, m	0.30	
Joint width, z mm (contraction joint)	20.00	
Modulus of Sub-grade reaction, k, Mpa/m	80.00	
Radius of relative stiffness, ***mm; l***	963.88	

Solution:

Modulus of Elasticity, E for Dowel bar, MPa	200000	
Modulus of Dowel support, ***K_{mds},*** MPa/m	415000	
Maximum single axle load, kN	180	
Maximum Single wheel load , kN	90	
Assume a load transfer of 30 % at terminal stage to the tied concrete shoulder or to the side slab. If no concrete shoulders are provided, no load transfer to shoulder may be assumed		
Wheel Load to be considered for Dowel bar design (95x0.7), kN	63.0	$F_b = \frac{(101.6 - b_d)f_{ck}}{95.25}$
Assume the percentage of load transfer through dowel bar is 50%	31.5	
Permissible bearing stress in concrete is calculated as***: F_b***		

Where,	
F_{ck} - Compressive strength of Concrete, MPa (for M35 Grade)	35
b_d- diameter of dowel bars assume, mm	38
F_b - Permissible bearing stress in concrete, MPa	**23.37**
Spacing of dowel bars, mm (assume)	300
First dowel bar is placed at a distance of 150 mm from the pavement edge	
Assume the length of dowel bar, mm	500
Dowel bars up to a distance of 1.0 x radius of relative stiffness (l) from the point of load application are effective in load transfer	
Number of dowel bars participating in load transfer when the wheel load is just over the dowel bar close to the edge of the slab = 1+l/spacing = 1+(963.88/300) = 4 nos.	
Assuming that the load transferred by the first dowel is P_t and that the load on dowel bar at a distance of l from the first dowel bar is zero, the total load transferred by the dowel bar system is P	

$$P = \left(1 + \frac{l-300}{l} + \frac{l-600}{l} + \frac{l-900}{l}\right)P_t$$

Coefficient to the Pt	2.13	
Load carried by the outer dowel bar, P_t	14.77	
Check for Bearing Stress		$\beta = 4\sqrt{\frac{K_{mds}b_d}{4EI}}$
Relative stiffness of dowel bar embedded in the concrete, ***β***	0.0210	
Moment of inertia of dowel, ***I,*** mm4	102301.985	$I = \frac{\pi\,(b_d)^4}{64}$
Bearing stress in dowel bar ***F_{bmax},***	19.17	$F_{bmax} = \frac{(P_t * k_{mds}) * (2 + \beta z)}{4\beta^3 EI}$
Bearing stress developed in dowel bar < permissible stress in concrete	***F_{bmax}***<F_b	

Hence, the dowel bar spacing and diameter assumed are safe.

APPENDIX VI: DESIGN OF TIE BARS

Input Data	
Slab thickness, m	0.3
Lane width, b, m	3.5
Weight of the slab in kN/m2, W	7.92
Coefficient of friction, f	1.5
Density of concrete, kN/m3	24
Allowable tensile stress in plain bars, S_{st}, MPa	125
Allowable tensile stress in deformed bars, MPa	200
Allowable bond stress for plain tie bars, B, MPa	1.75
Allowable bond stress for deformed tie bars, B, MPa	2.46

Design of Plain Tie bars		
Assumed diameter of tie bar d_1, mm	12	
Area of plain steel bar required per meter width of joint to resist the frictional force at slab bottom, A_s, mm^2/m	332.64	$A_s = \frac{b * f * W}{S_{st}}$
Cross sectional area of the tie bar A, mm2	113.04	$A = \frac{\pi d^2}{4}$
Perimeter of tie bar, P_{ptb}, mm	37.68	$P_{ptb} = \pi d$
Spacing of tie bar, mm (A/As)	339.83	
Provide spacing of 340 mm c/c		
Length of the bar, L, mm	428.57	$L = \frac{2 * S_{st} * A}{B * P_{ptb}}$
Increase length by 100 mm for loss of bond due to painting and another 50 mm for tolerance in placement. Therefore, the required length of tie bar	578 mm adopt **600 mm**	

Design of Deformed Tie Bars

Assumed diameter of tie bar d_1, mm	12
Area of plain steel bar required per meter width of joint to resist the frictional force at slab bottom, As, mm2/m	207.9
Cross sectional area of the tie bar A, mm2	113.04
Perimeter of tie bar, P_{ptb}, mm	37.68
Spacing of tie bar, mm (A/As)	543.72
Provide spacing of 550 mm c/c	
Length of the tie bar, L, mm	487.80
Increase length by 100 mm for loss of bond due to painting and another 50 mm for tolerance in placement.	637.8
Calculated thickness (487+100+50 = 637 mm); adopt required length of tie bar 637 mm and adopt 640 mm	

Design parameters:

1. Slab Thickness: 32 cm of concrete M35 Grade
2. Dowel bars: 32 mm Dia, 50 Cm long, 30 cm c/c spacing, first bar 15 cm from the edge of the slab
3. Tie bars: 12 mm Dia, 60 cm long, 35 cm c/c spacing, first bar 15 cm from the edge of the slab,
4. Layout is given in the Fig.

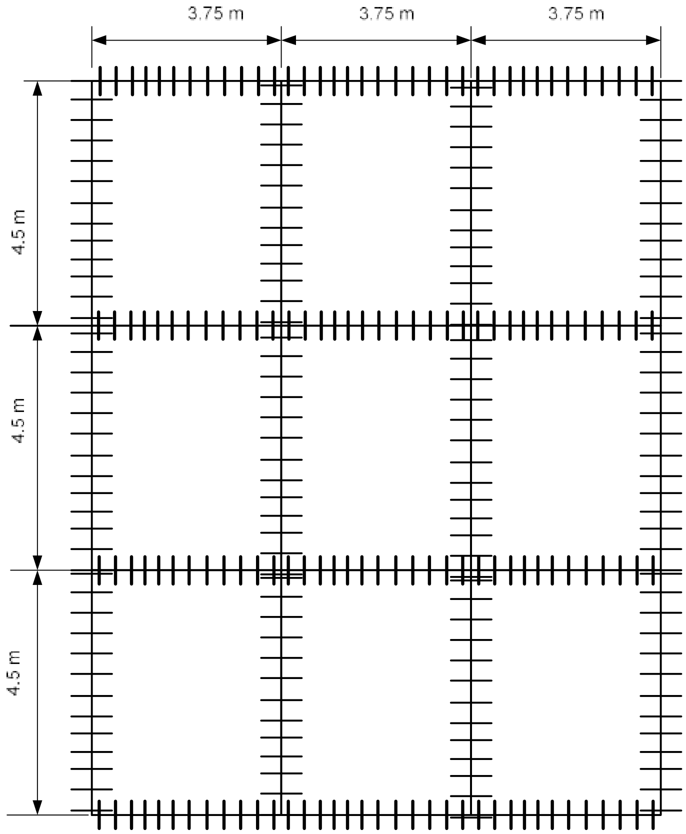


Figure 15 Typical layout of the dowel and tie bars

APPENDIX VII: TYPICAL DESIGNS IN THE CASE OF LIMITED TRAFFIC DATA

The design of Jointed Plain Concrete Pavement requires traffic data in terms of its volume as well as axle loading spectrum. However, to get such data is resource consuming. In the case of limited traffic and axle load data following assumptions could be helpful for design of concrete slab.

a. Consideronly the commercial vehicles from the ‘Traffic count data available at DoR’. The total number of AADT commercial vehicles in both direction shall be taken.
b. Determine the design traffic volume for the predominant traffic direction.
c. For conversion of average number of axles for commercial vehicle take the multiply by:

Busy highways	3.2
Feeder road	2.1

d. The percentage of front single, rear single, tandem and tridem axle may be taken as 31, 9, 28 and 32 respectively.
e. The load spectrum can be taken as:

Rear Single Axle			Rear Tandem Axle			Rear Tridem Axle		
Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)	Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)	Load Group (kN)	Mid-Point of Load Group (kN)	Frequency (%)
185-195	190	1.00	380 - 400	390	0.00	530-560	545	0
175-185	180	1.00	360 - 380	370	0.00	500-530	515	0
165-175	170	2.00	340 - 360	350	1.20	470-500	485	0.5
155-165	160	5.00	320 - 340	330	1.50	440-470	455	1
145-155	150	10.00	300 - 320	310	1.50	410-440	425	4
135-145	140	12.00	280 - 300	290	2.00	380-410	395	5
125-135	130	10.00	260 - 280	270	12.00	350-380	365	10
115-125	120	20.00	240 - 260	250	14.80	320-350	335	11
105-115	110	10.00	220 - 240	230	20.00	290-320	305	16
95-105	100	10.00	200 - 220	210	22.00	260-290	275	18
85-95	90	7.00	180 - 200	190	15.00	230-260	245	20
< 85	80	12.00	< 180	170	10.00	< 230	215	14.5
		100.00			100.00			100

f. Stress due to axle loading may be determined from the charts given in this guidelines or may be calculated using the regression equations.

APPENDIX VIII: SAMPLE DESIGN TEMPLATE OF DEPTH OF CONCRETE SLAB

1. Design of depth of cement concrete slab with the given design conditions in the Appendix IV are given in the table below:

Both-way traffic, cvpd	CBR, %				
	6.00	**8.00**	**10.00**	**12.00**	**15.00**
500	30	30	30	30	30
750	30	30	30	30	30
1000	30	30	30	30	30
1500	32	32	30	30	30
2000	32	32	32	32	32
2500	32	32	32	32	32
3000	32	32	32	32	32

2. Other design trials can be generated with the help of Excel Sheet developed during the preparation of this design guidelines.
3.

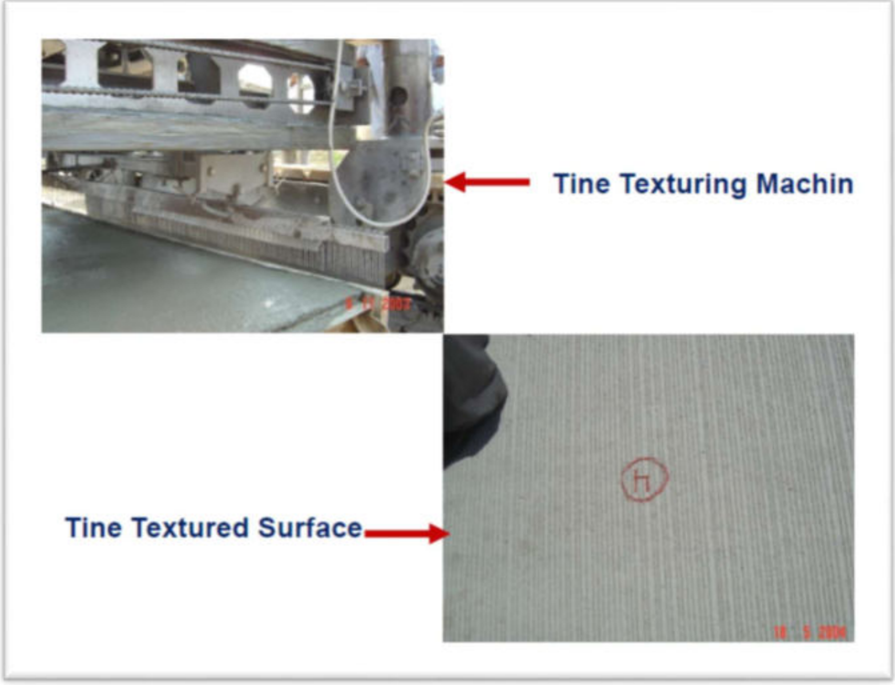
APPENDIX IX: SOME FIGURS FOR CONSTRUCTION TECHNOLOGY OF PCCP SLAB

Dowel Chairs Fixed into Sub-base before Concrete Pouring

60% Dowel Length Covered With Plastic Sheathing and Dowel Chairs Designed Properly

Tie Bars Painted in Middle 150 mm

Properly aligned Tie Bars Placed in Side Form Holes



Tine Texturing Machin

Tine Textured Surface

APPENDIX X: STRESS CHARTS FOR BOTTOM UP CRACK ANALYSIS

APPENDIX XI: AN ILLUSTRATIVE EXAMPLE OF DESIGN OF SLAB THICKNESS

1. **Design Parameters:**

Design Wheel Load, P : 5100 kg
Present Traffic Intensity : 300 veh/day
Design Tyre Pressure, p : 7.2 kg/cm^2
Foundation Strength, k : 6 kg/cm^2
Concrete Flexural Strength, f_R : 40 kg/cm^2
E_c = 3.0 x 10 5 kg/cm 2
μ = 0.15
$\alpha = 10 \times 10^{-4}$ / °C
Δt = 14.3 °C against thickness of 25 cm

2. **Design Procedure:**

Step I : Assume h = 25 cm, spacing of elastic joints = 4.5 m
As per IRC:58-1988
σle = 18.50 kg/cm^2
σte = 15.50 kg/cm^2
σ Total = 34.00 kg/cm^2

Step II : For λ = 0.33 and Δ_T = 20°C
r = 0.4 per cent (Steel reinforcement)
From Fig. 2, σ_s = 56 x 20 - 1 1 20 kg/cm^2
< 1400 kg/cm^2
OK
From Fig. 2, $\sigma c = 0.235 \times 20 = 4.7$ kg/cm^2

Step III : From Step I total σ = 34.00 kg/cm^2
From Step II σc = $\underline{4.70 \text{ kg/cm}^2}$
Total σ = 38.70 kg/cm say 39.00 kg/cm 2

The total stress 39.00 kg/cm^2 is less than the flexural strength of concrete 40 kg/cm^2 and therefore the thickness of 25 cm is O.K.

Step IV : Average steel reinforcement (r_{av})

$$= \frac{0.004 + 25\% \text{ of } 0.004\ 0.005}{2} = \frac{0.005}{2}$$ = 0.25 per cent

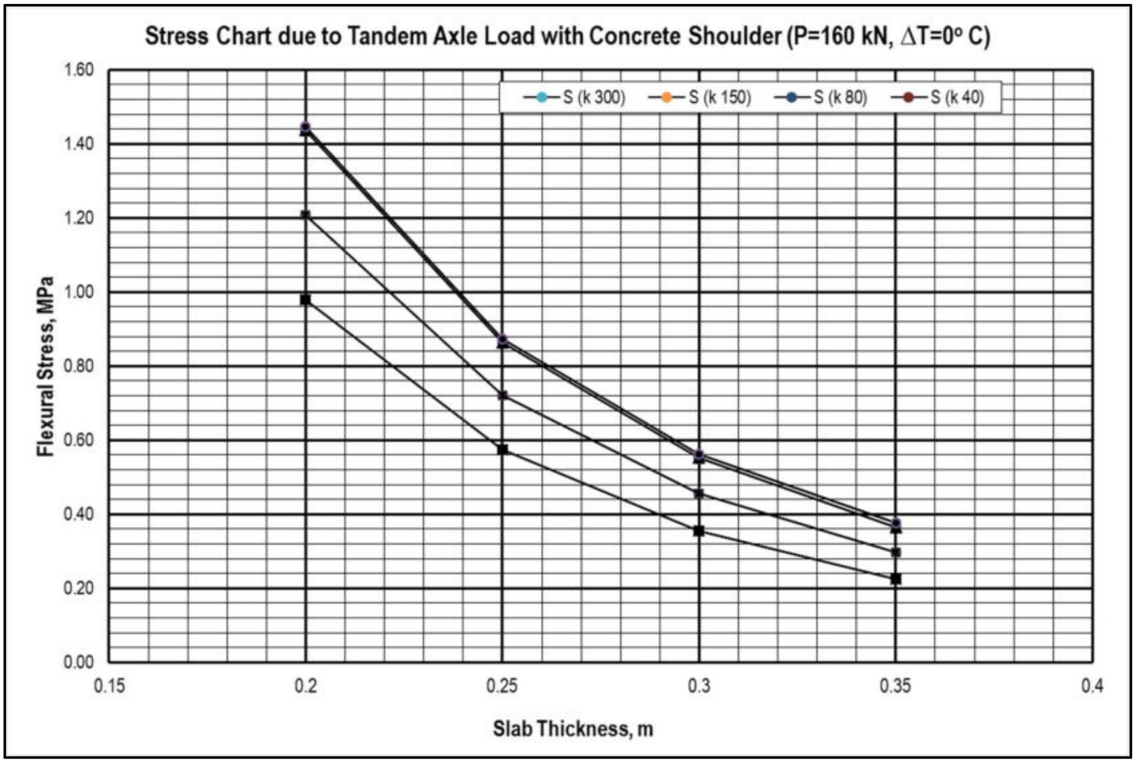
From Figure 17, for r a = 0.25%, the effective increase in slab thickness is 31%.

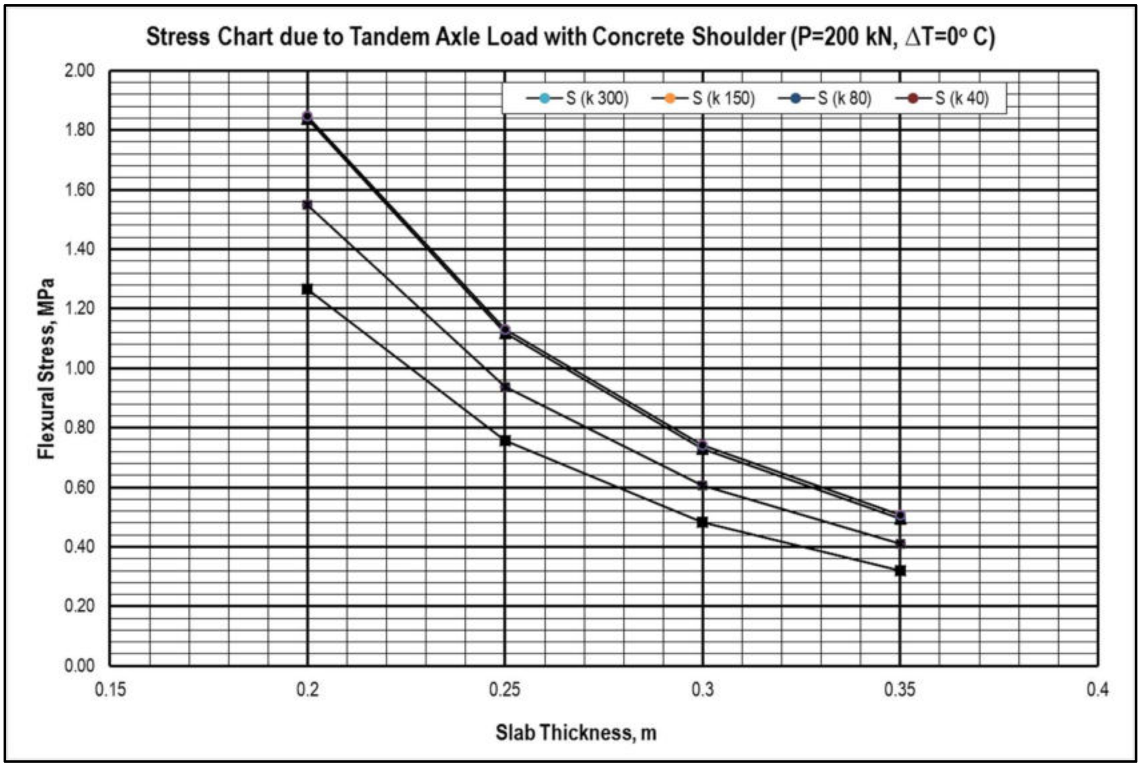
Reducing the thickness proportionately

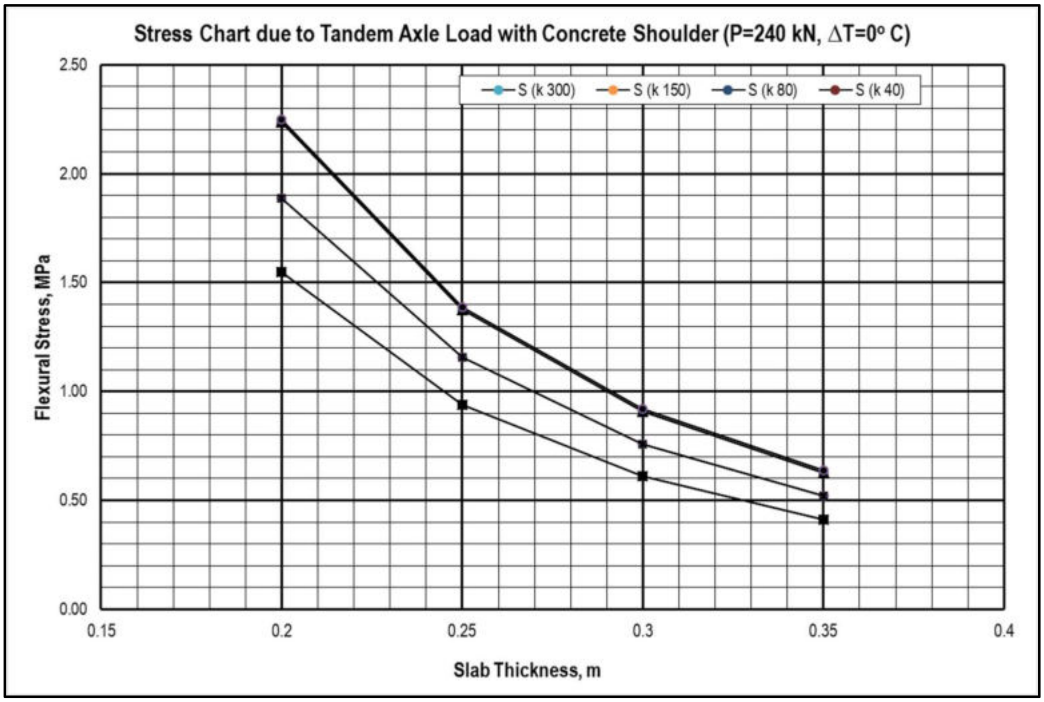
$h_r = \frac{25}{1+0.31}$ = 19.08 cm

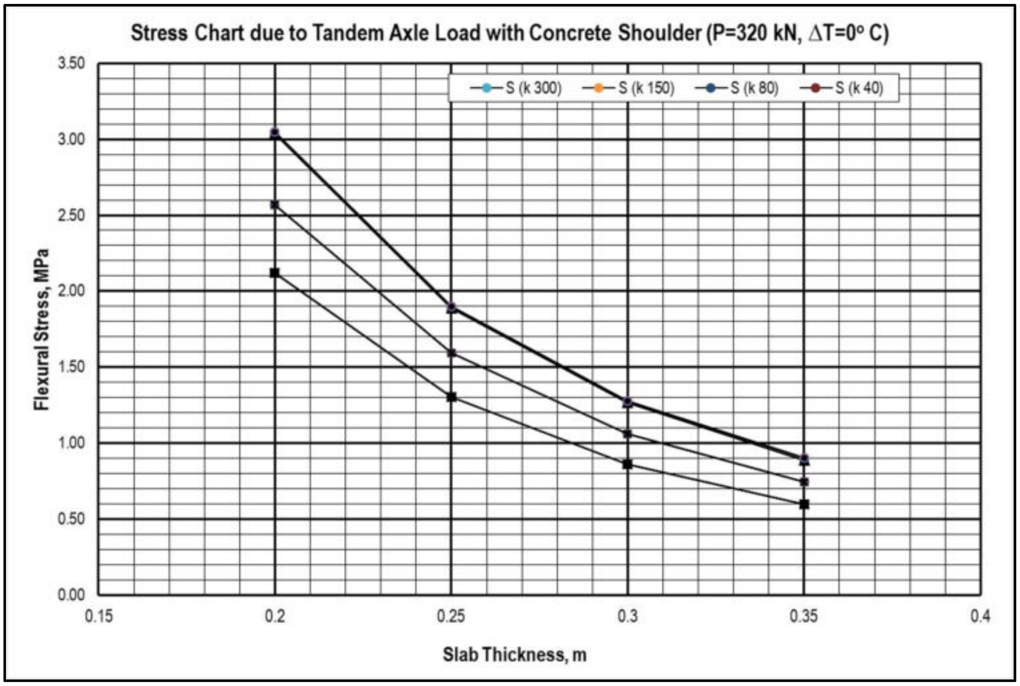
Design thickness of pavement slab = 19 cm

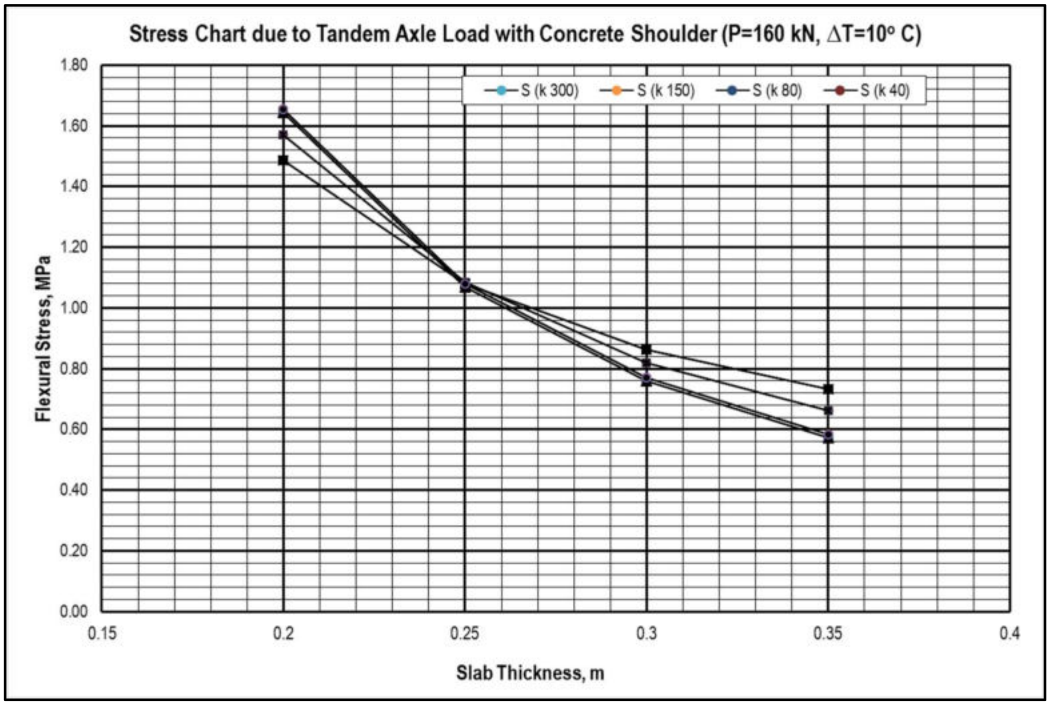
CHARTS FOR FLEXURAL STRESS (BUC): Tandem Axle

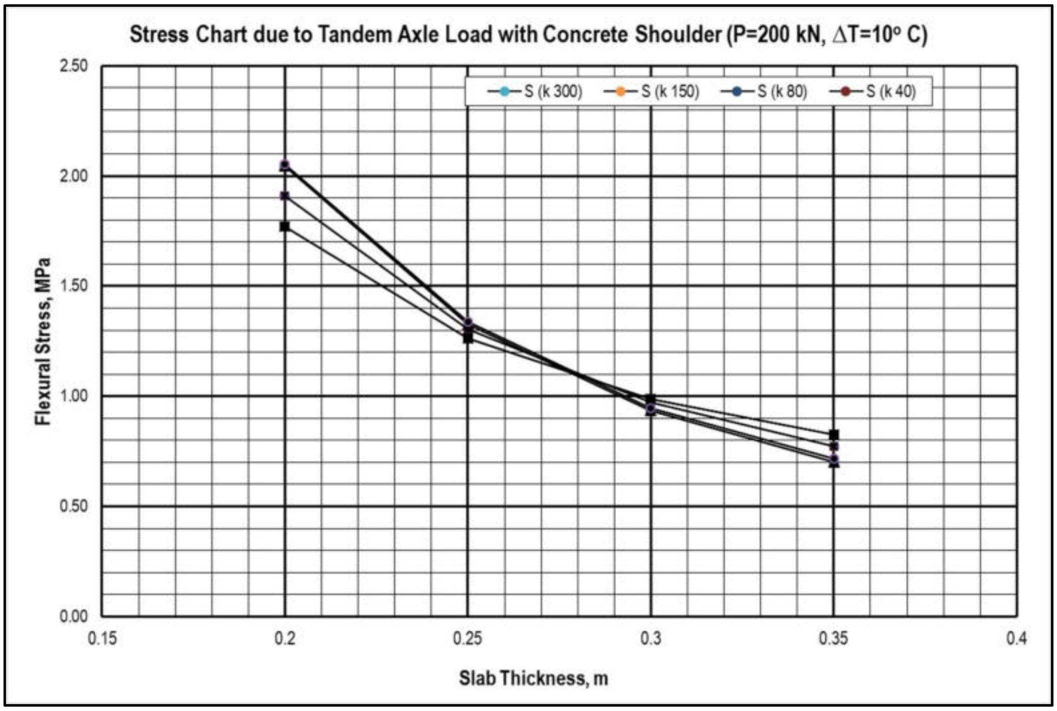


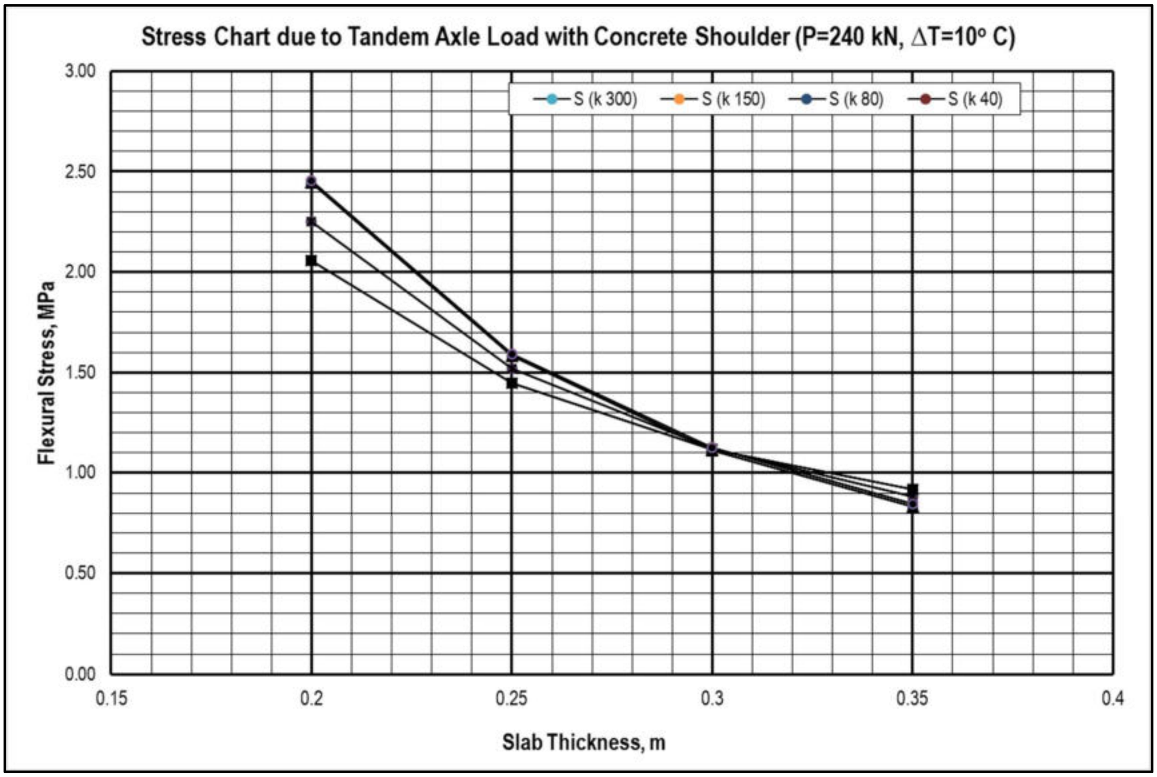


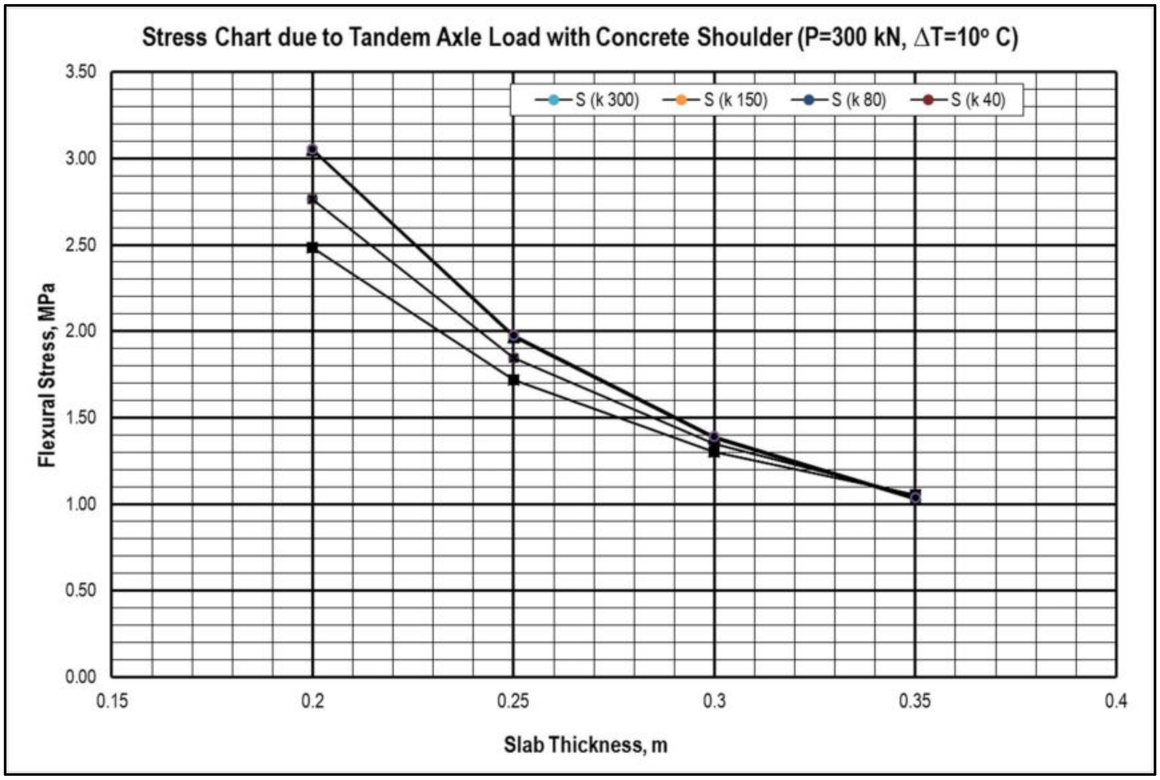

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=240 kN, ΔT=0° C)

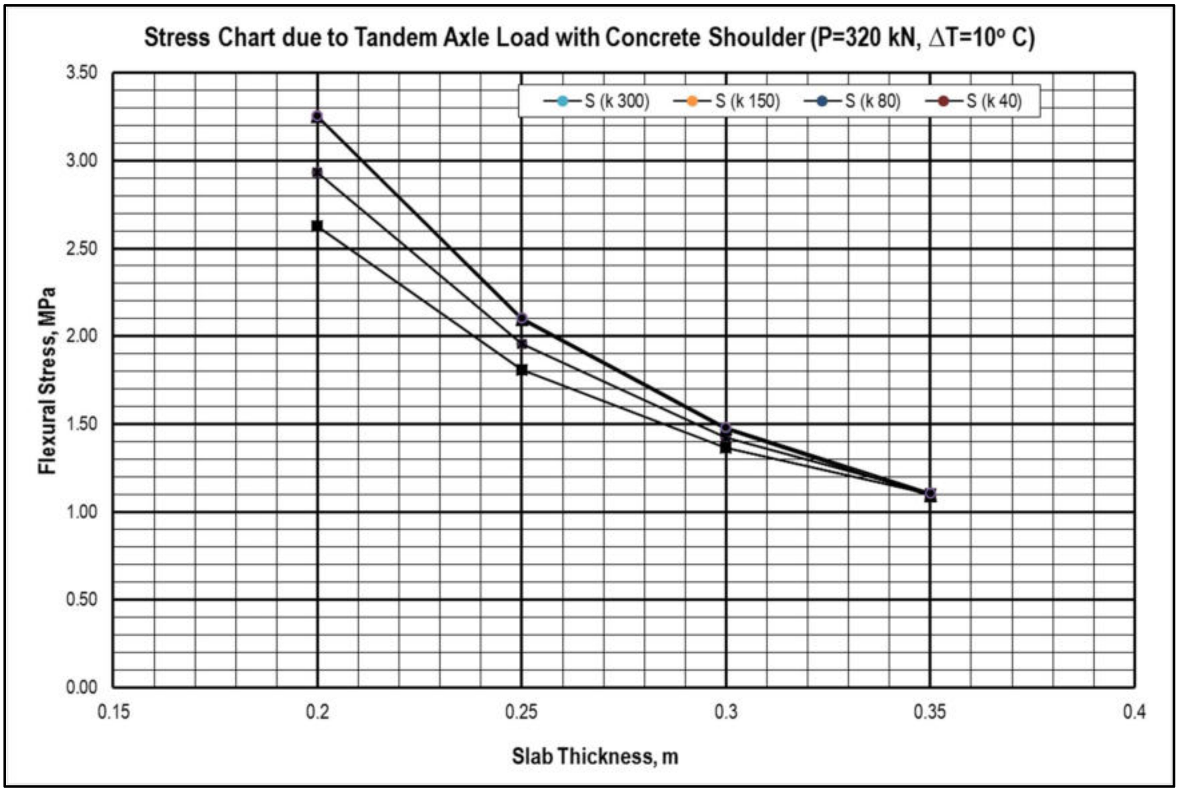

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=320 kN, ΔT=0° C)

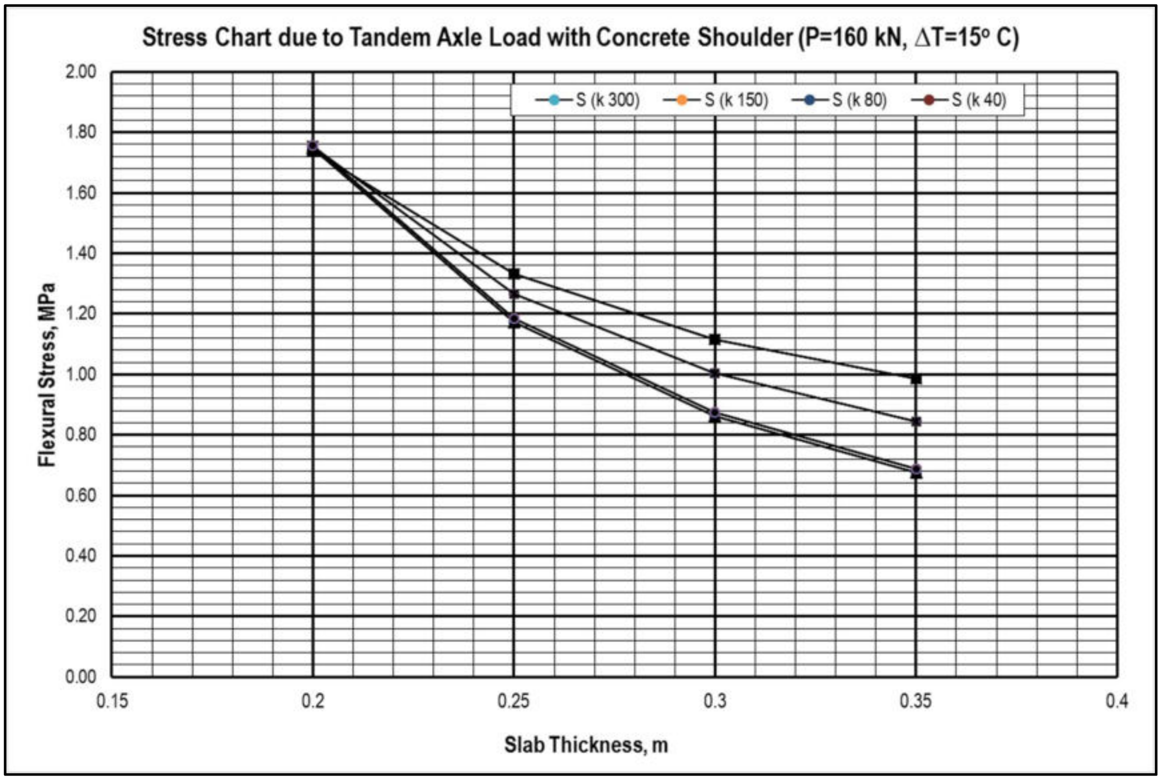

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=160 kN, ΔT=10° C)

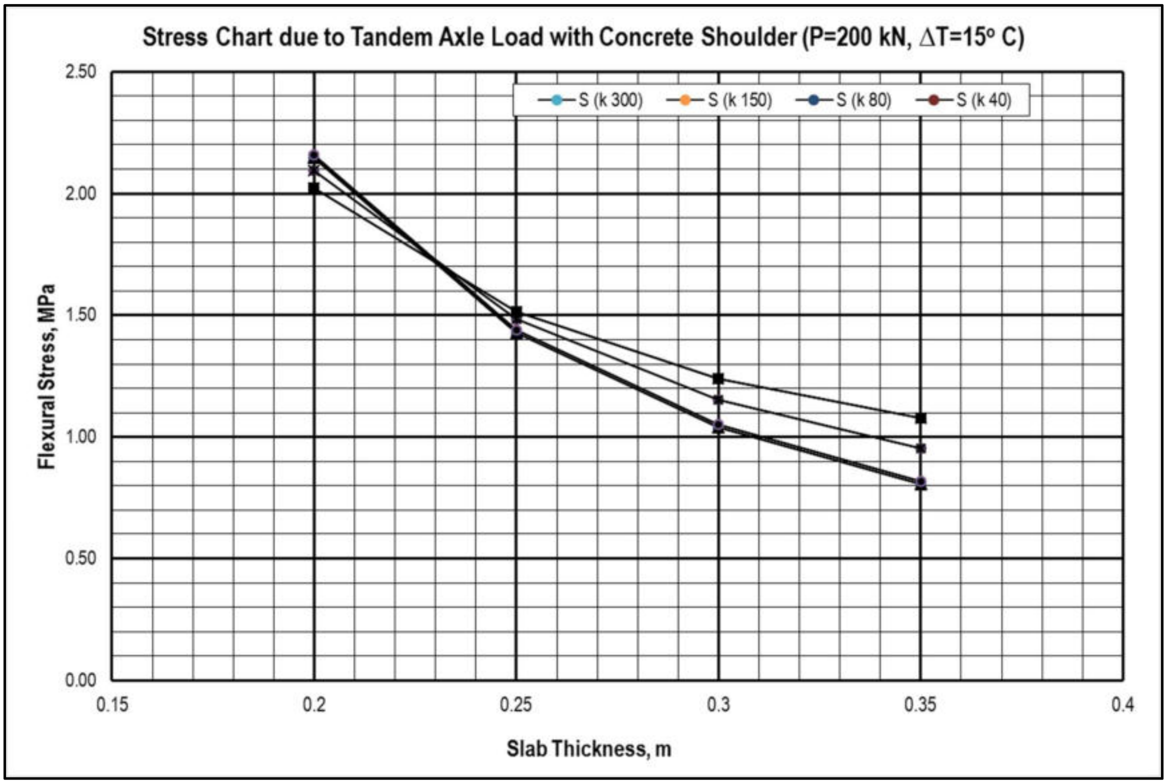

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=200 kN, ΔT=10° C)


Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=240 kN, ∆T=10° C)

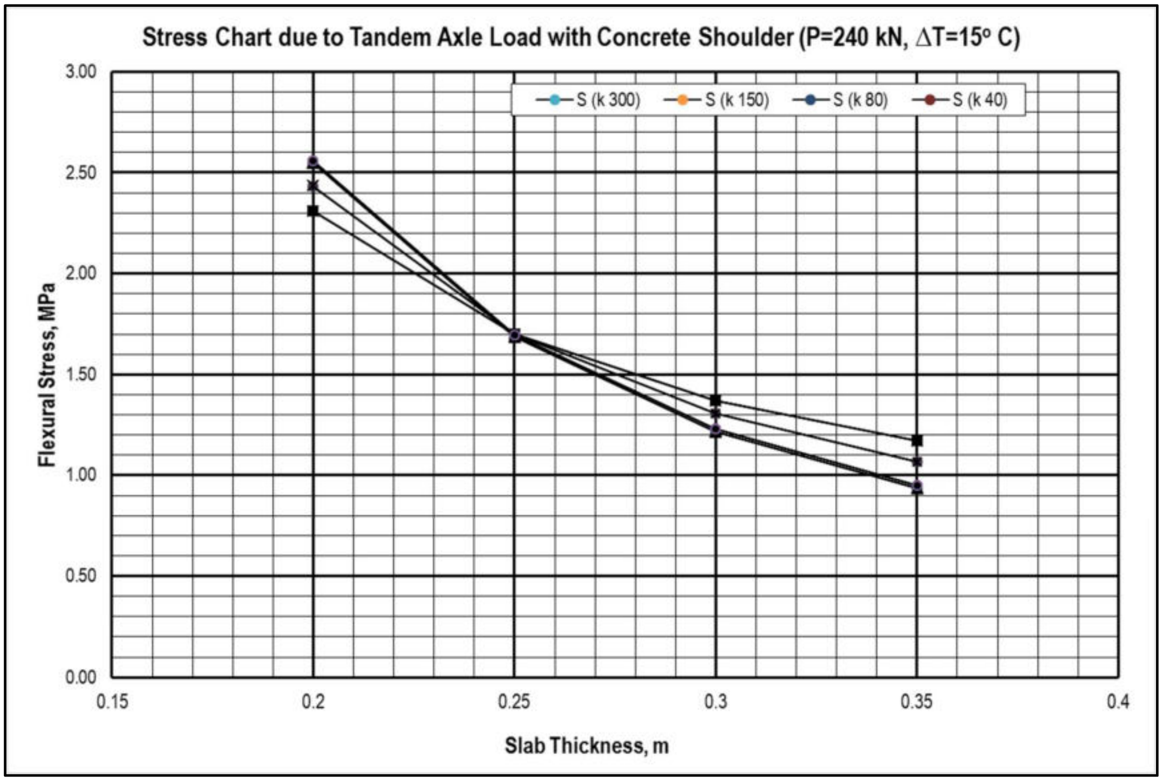

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=300 kN, ∆T=10° C)


Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=320 kN, ΔT=10° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

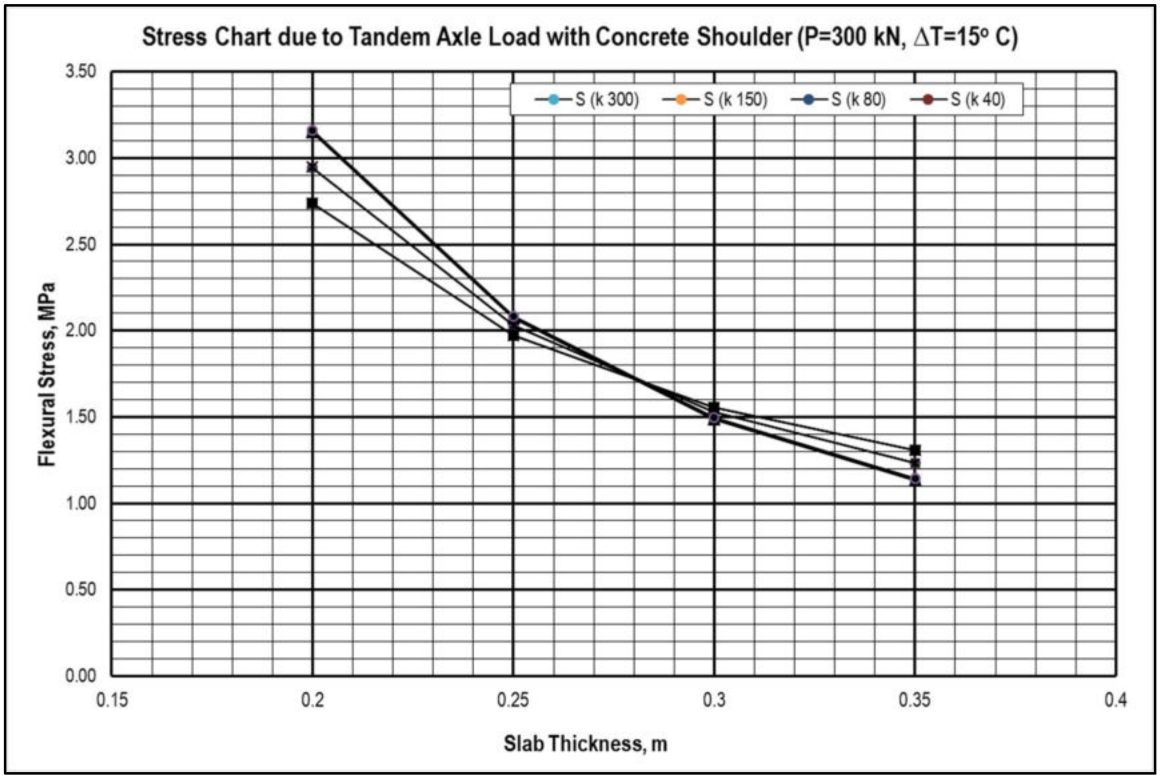

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=160 kN, ΔT=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

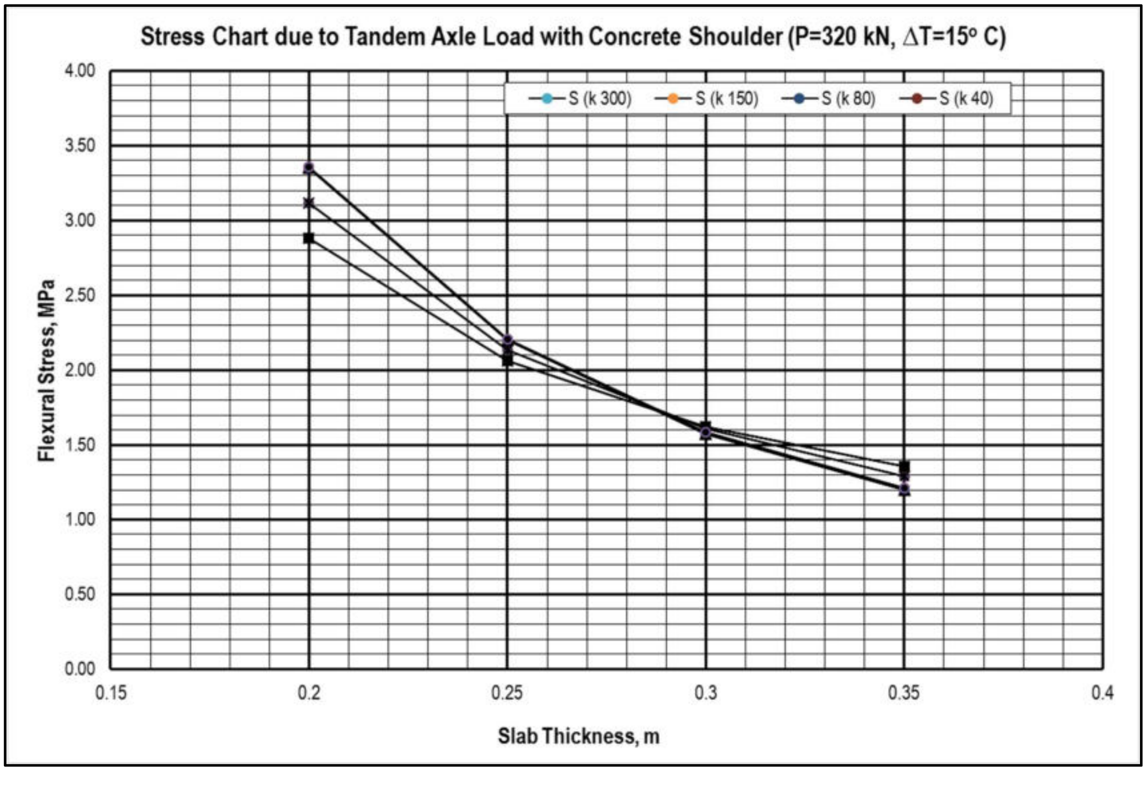


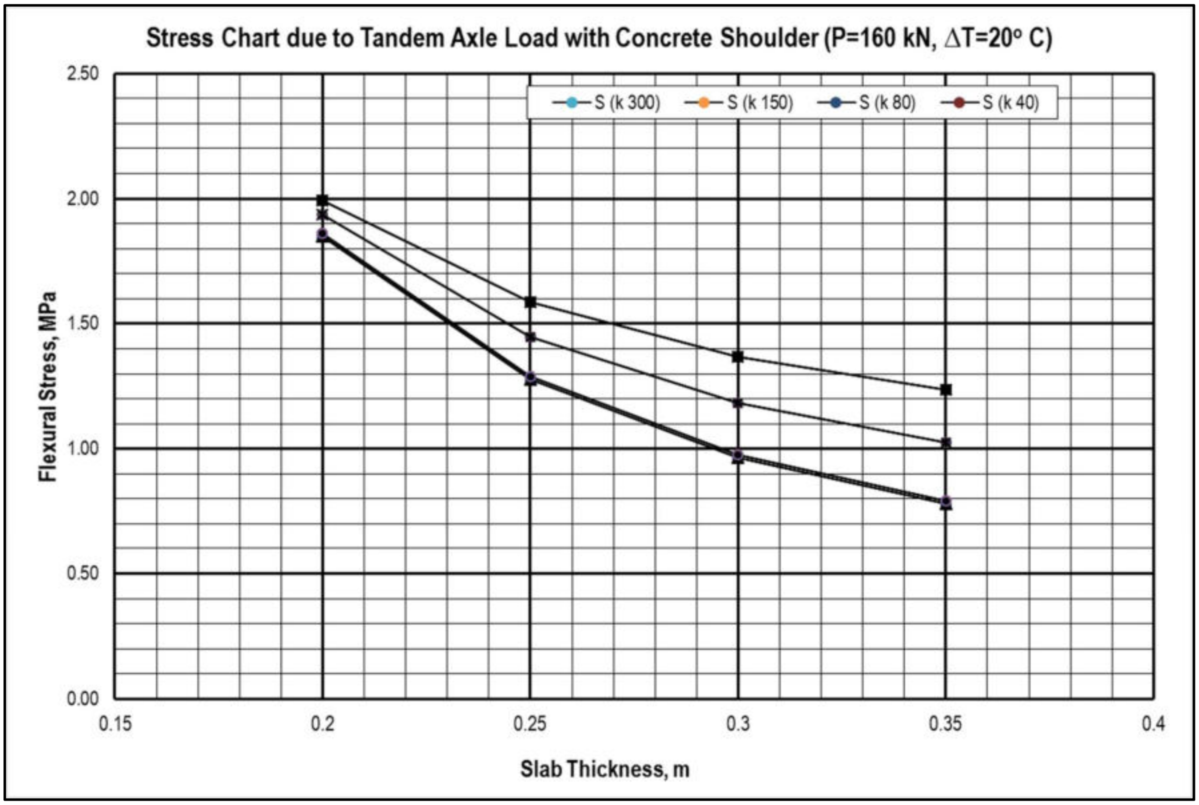
Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=200 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

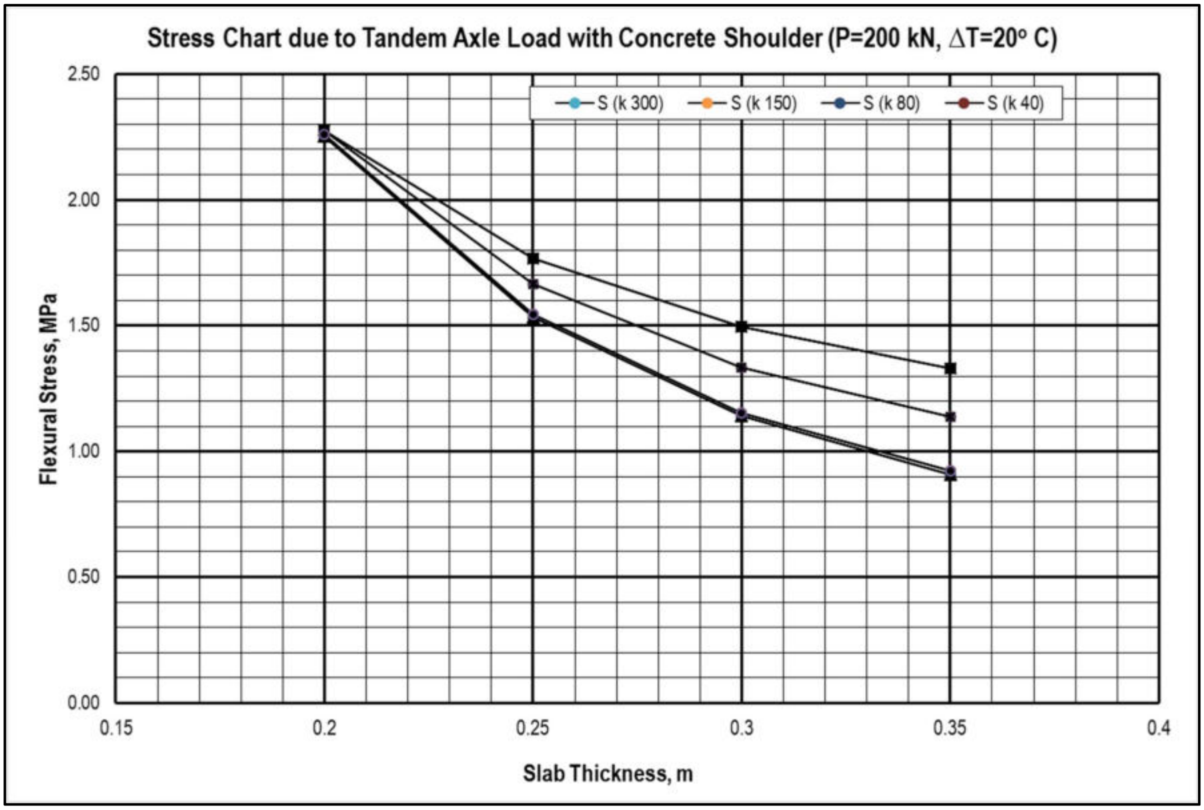


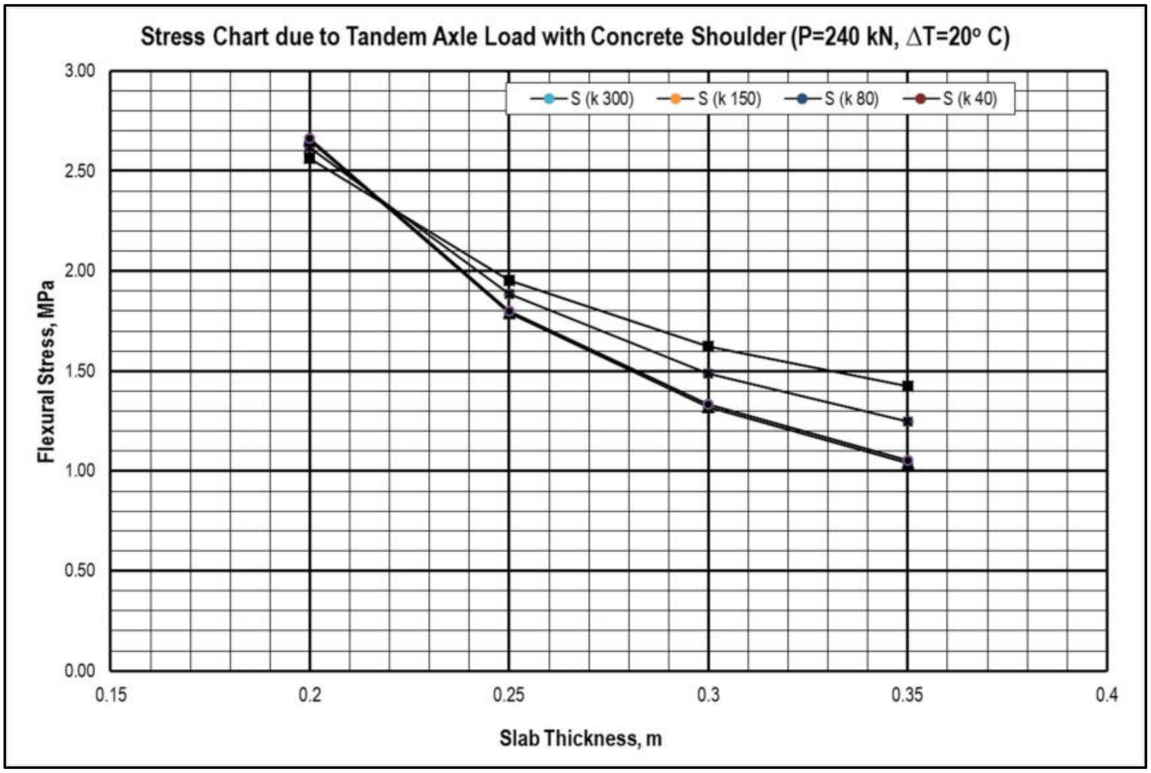
Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=240 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

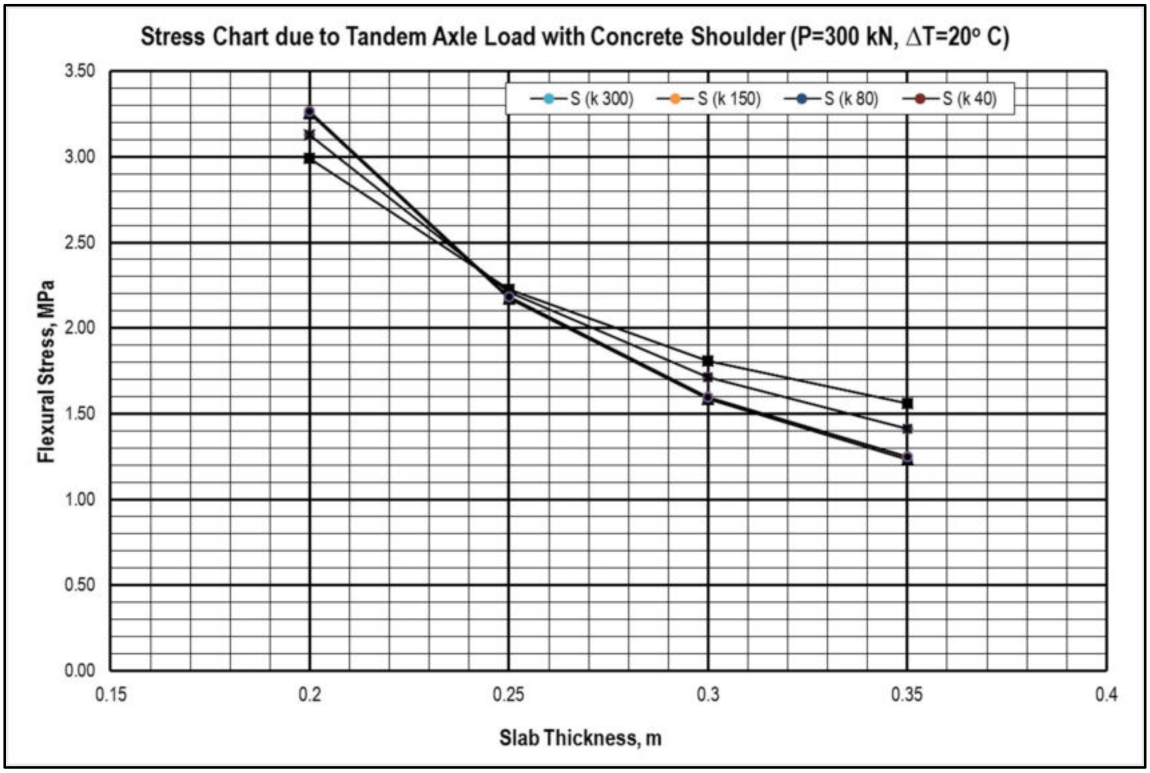

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=300 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

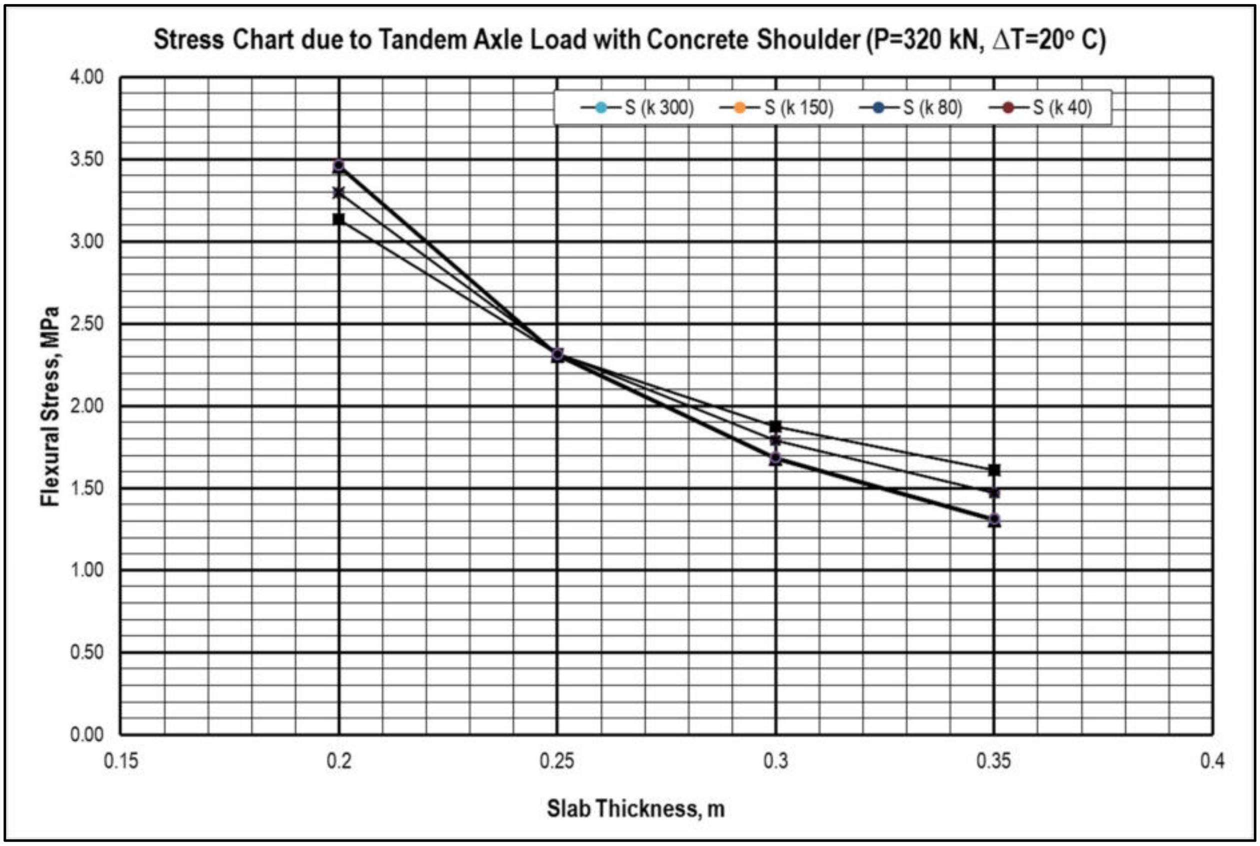

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=320 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

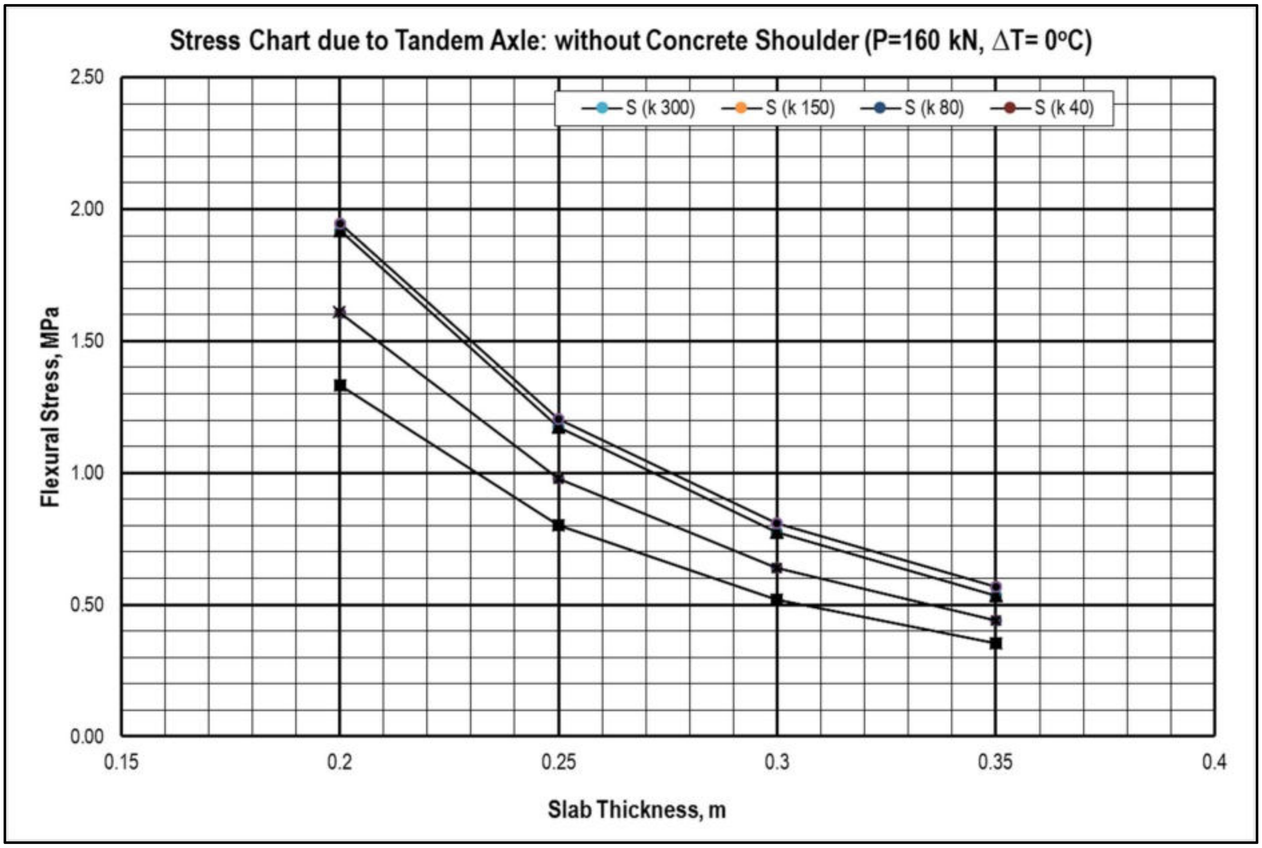

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=160 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
Slab Thickness, m
0.15
0.2
0.25
0.3
0.35
0.4

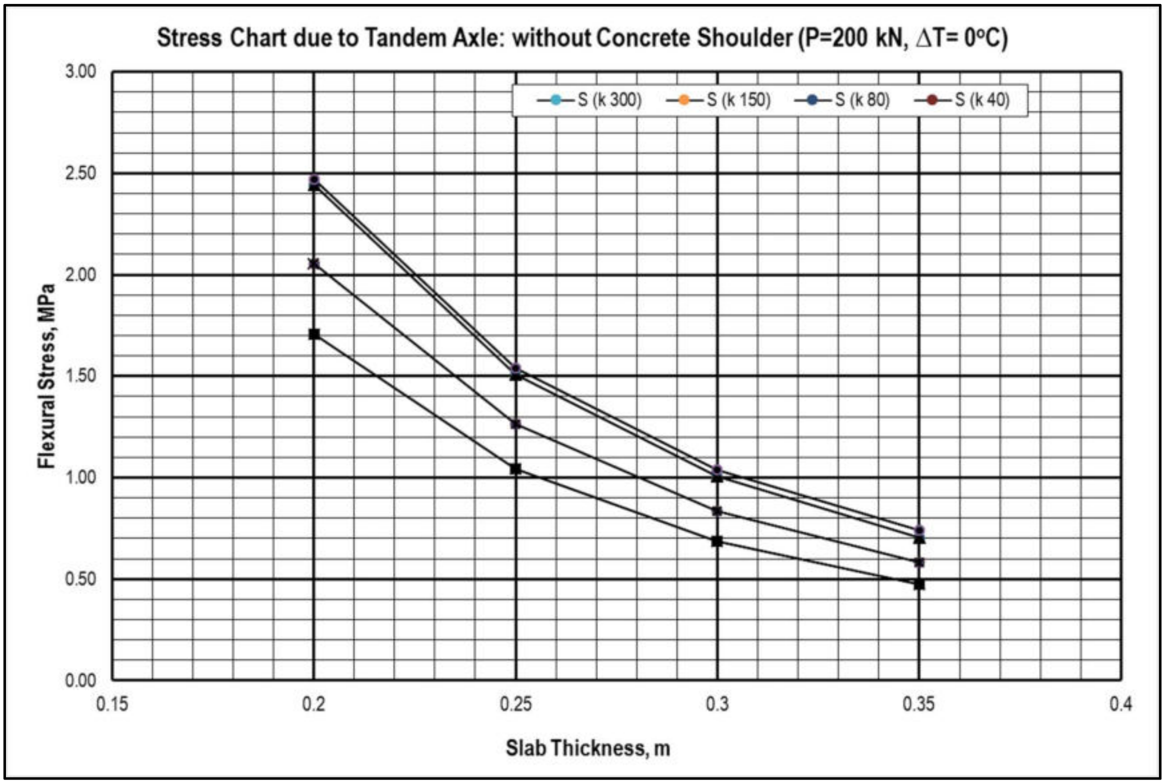

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=200 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
Slab Thickness, m
0.15
0.2
0.25
0.3
0.35
0.4

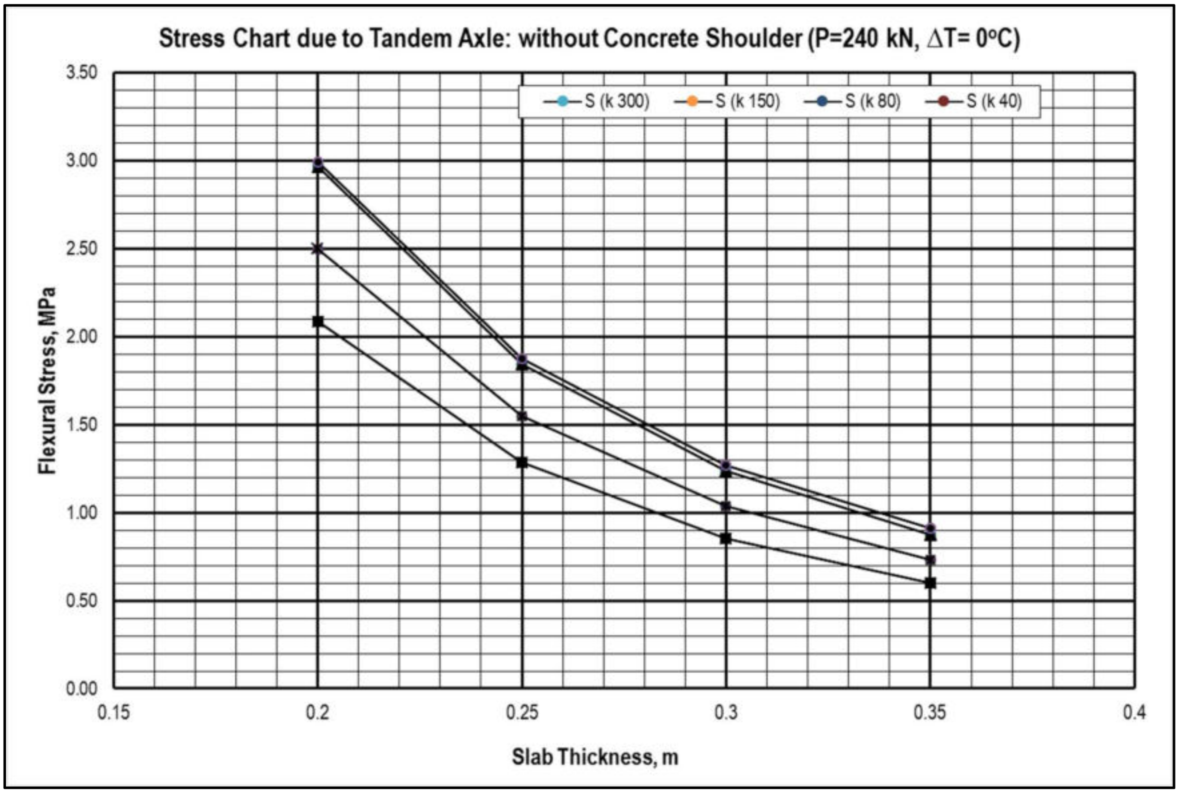

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=240 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

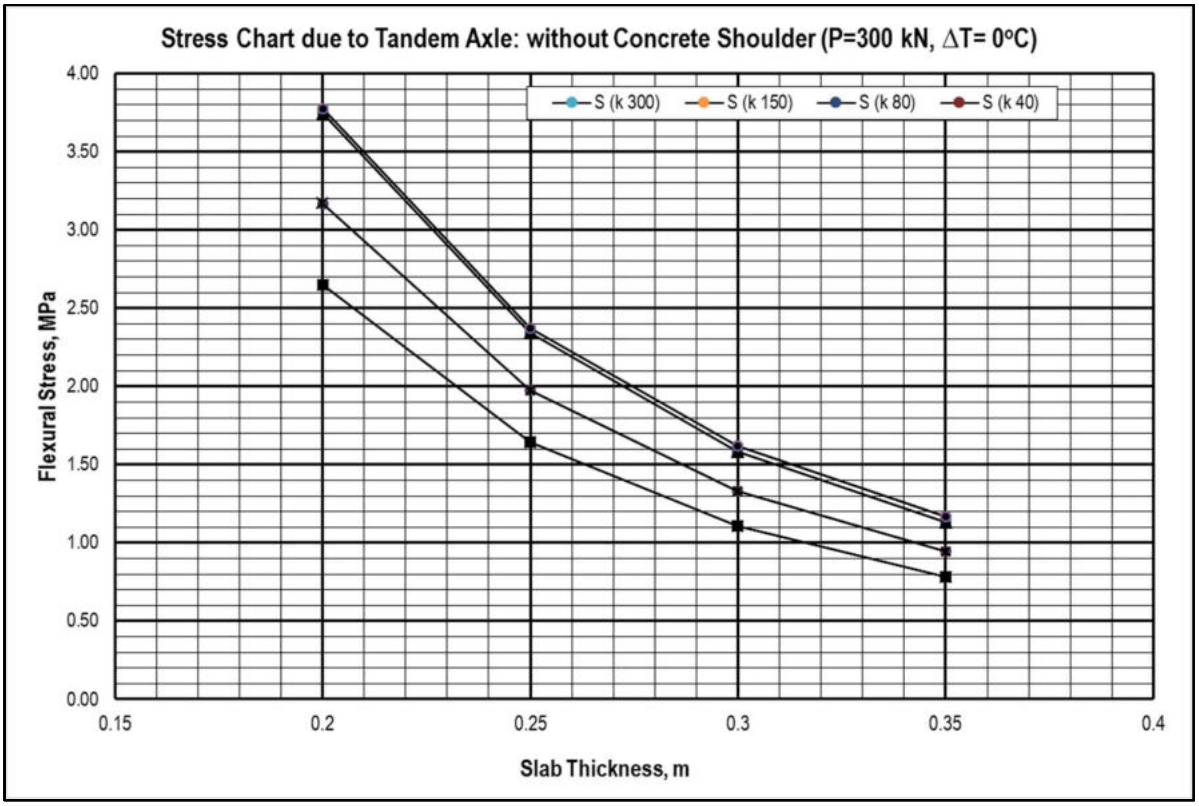

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=300 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

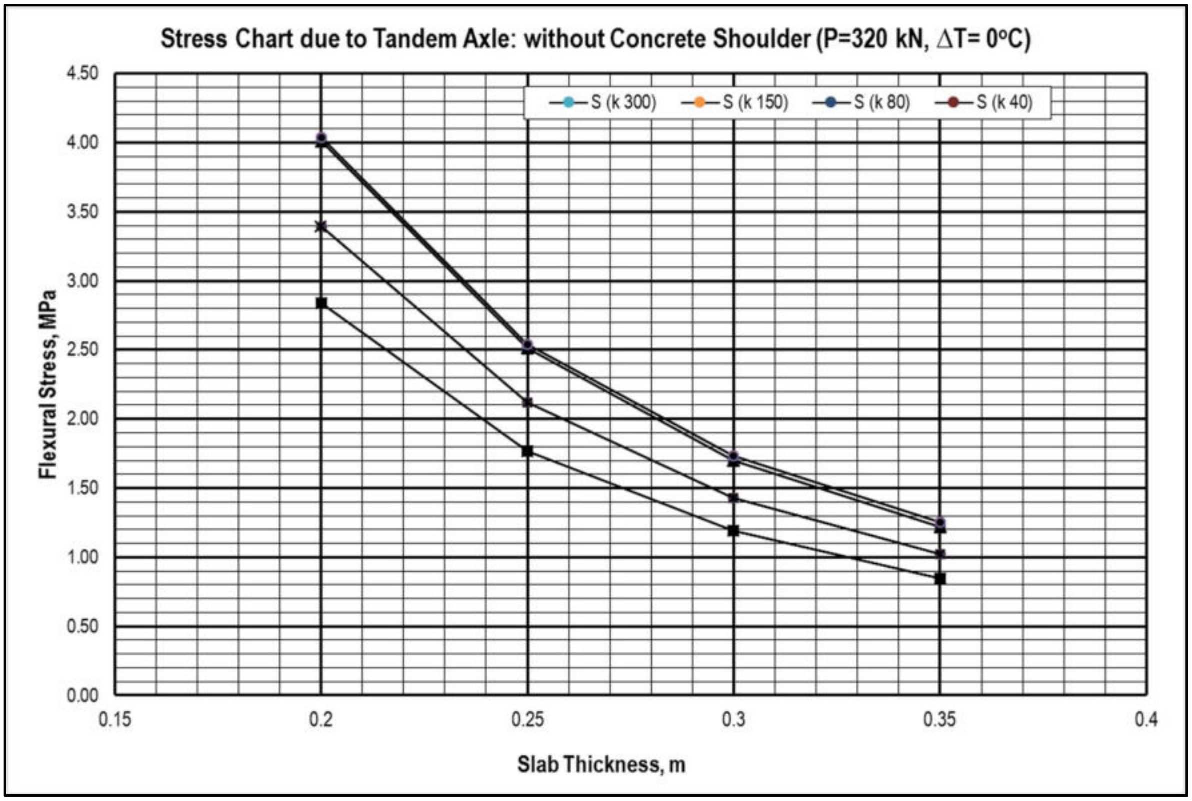

Stress Chart due to Tandem Axle Load with Concrete Shoulder (P=320 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

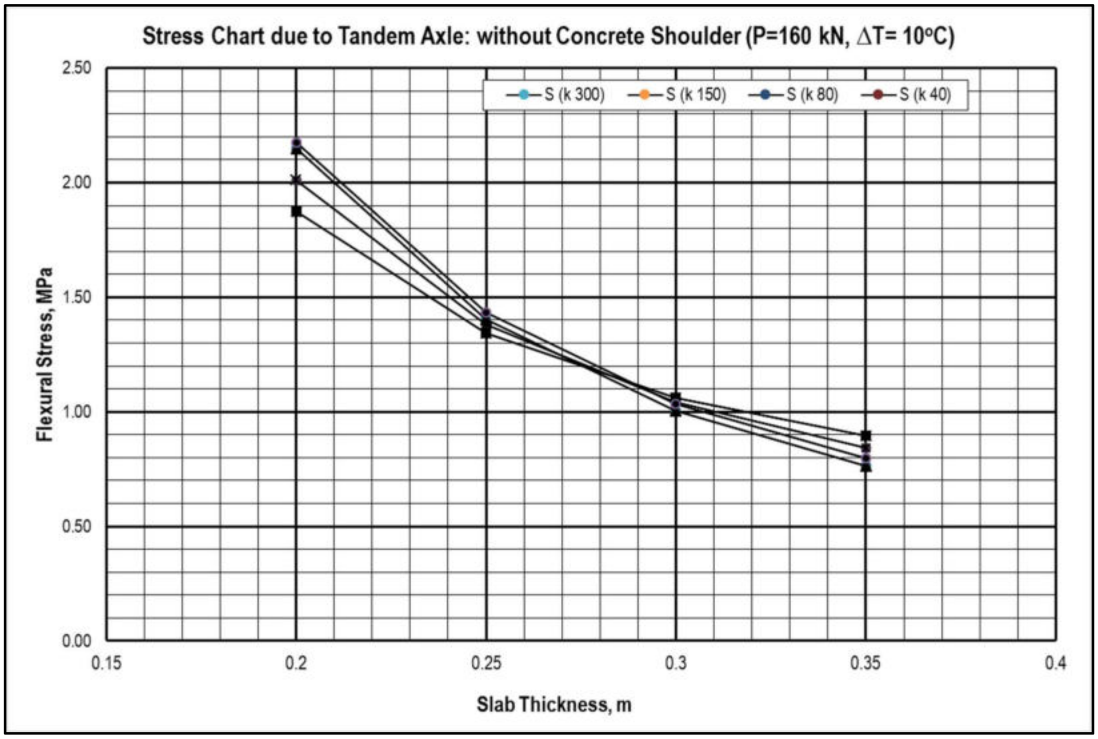

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=160 kN, ∆T= 0°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

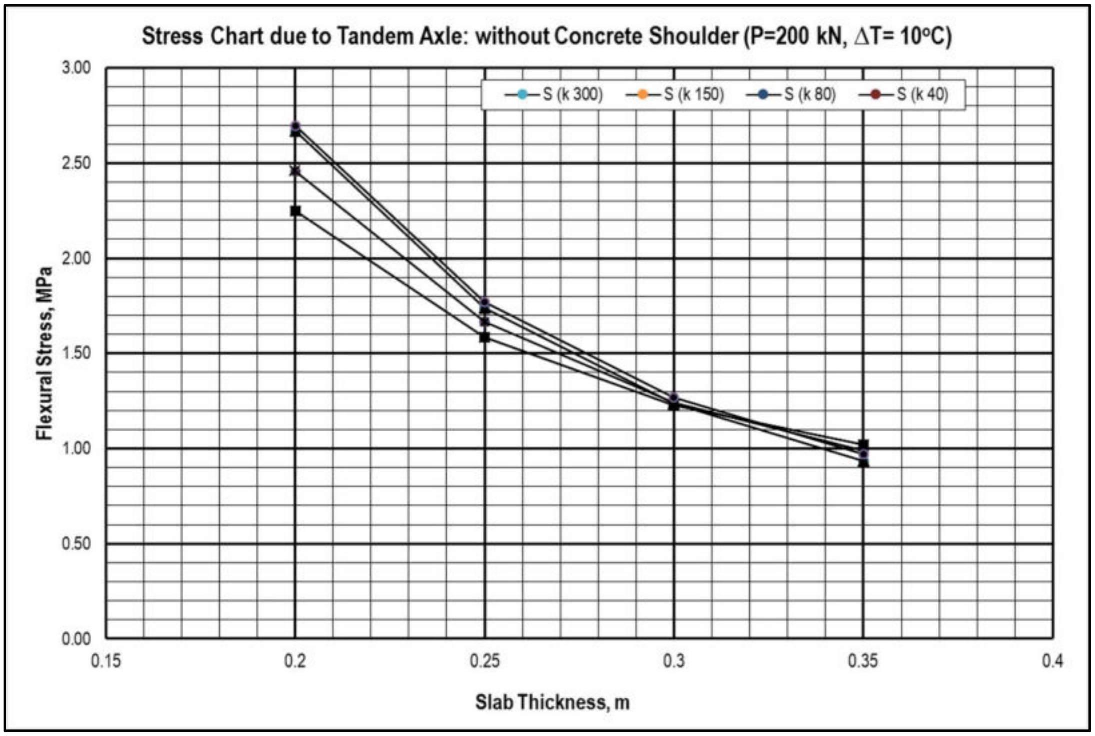

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=200 kN, ∆T= 0°C)

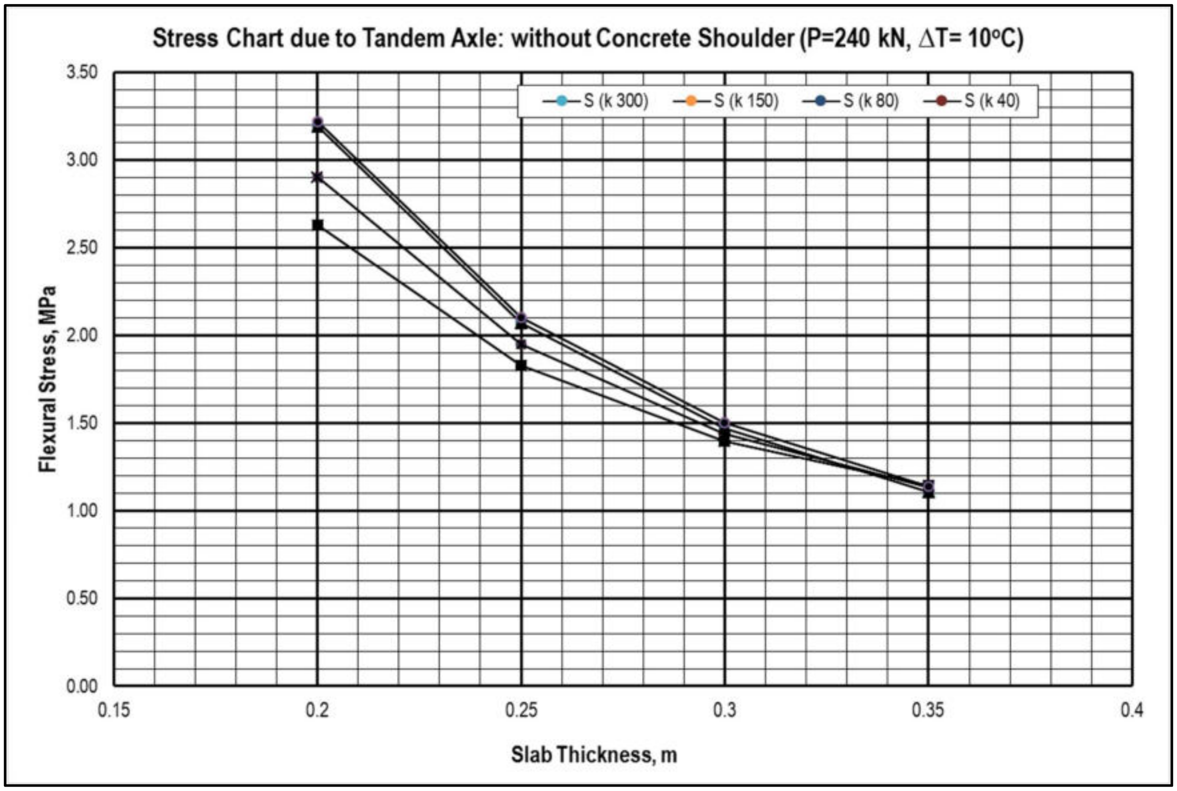

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=240 kN, ∆T= 0°C)

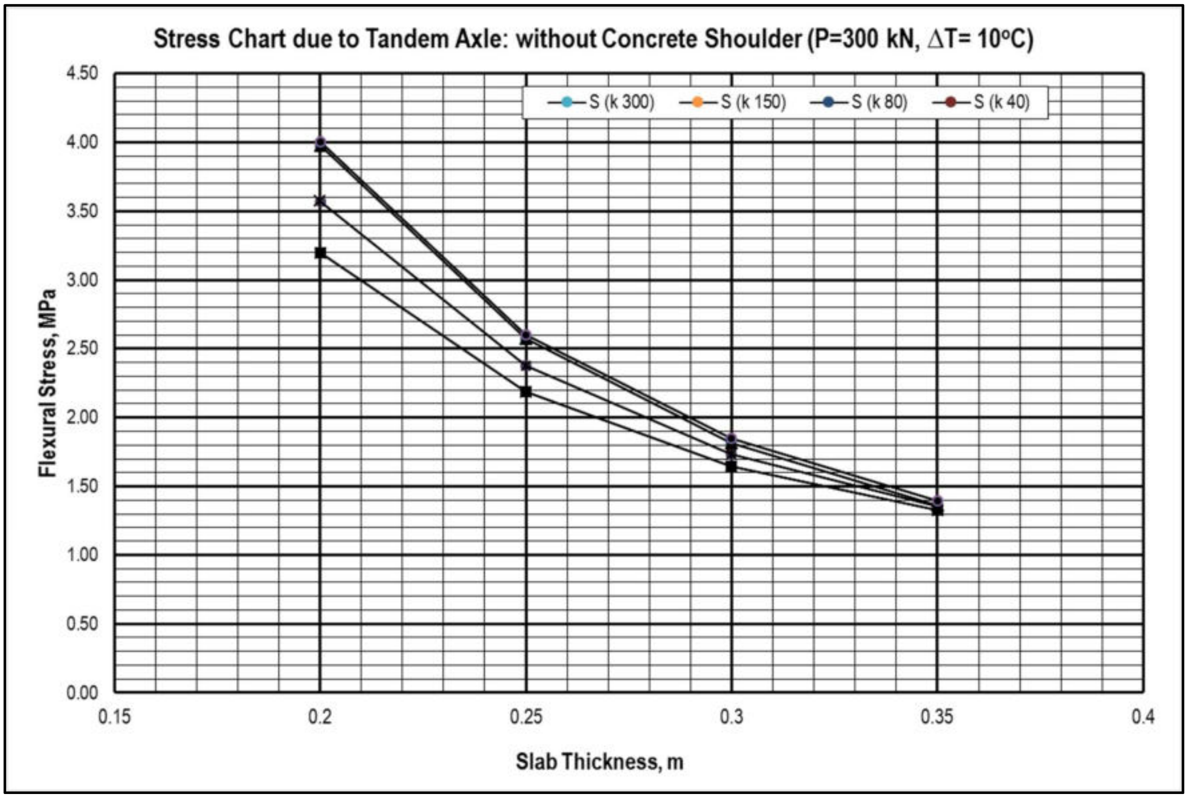

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=300 kN, ∆T= 0°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

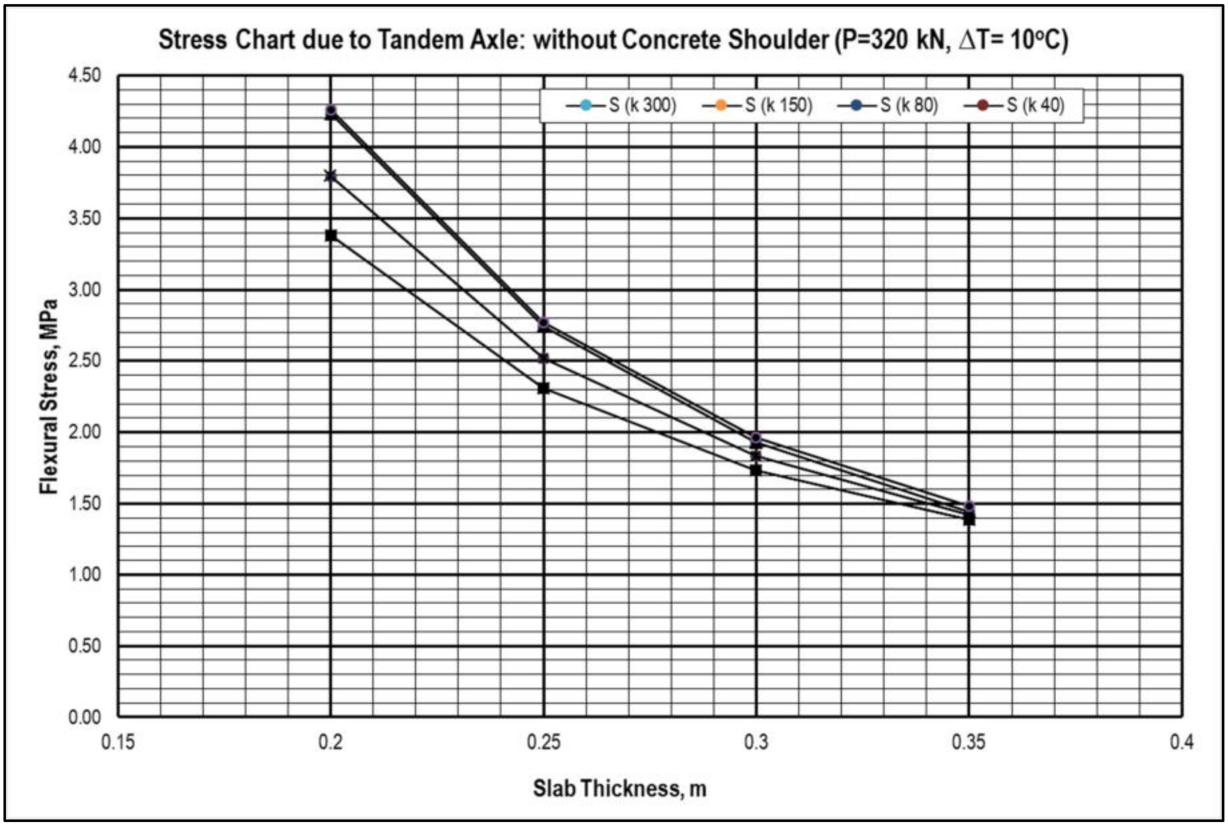

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=320 kN, ∆T= 0°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

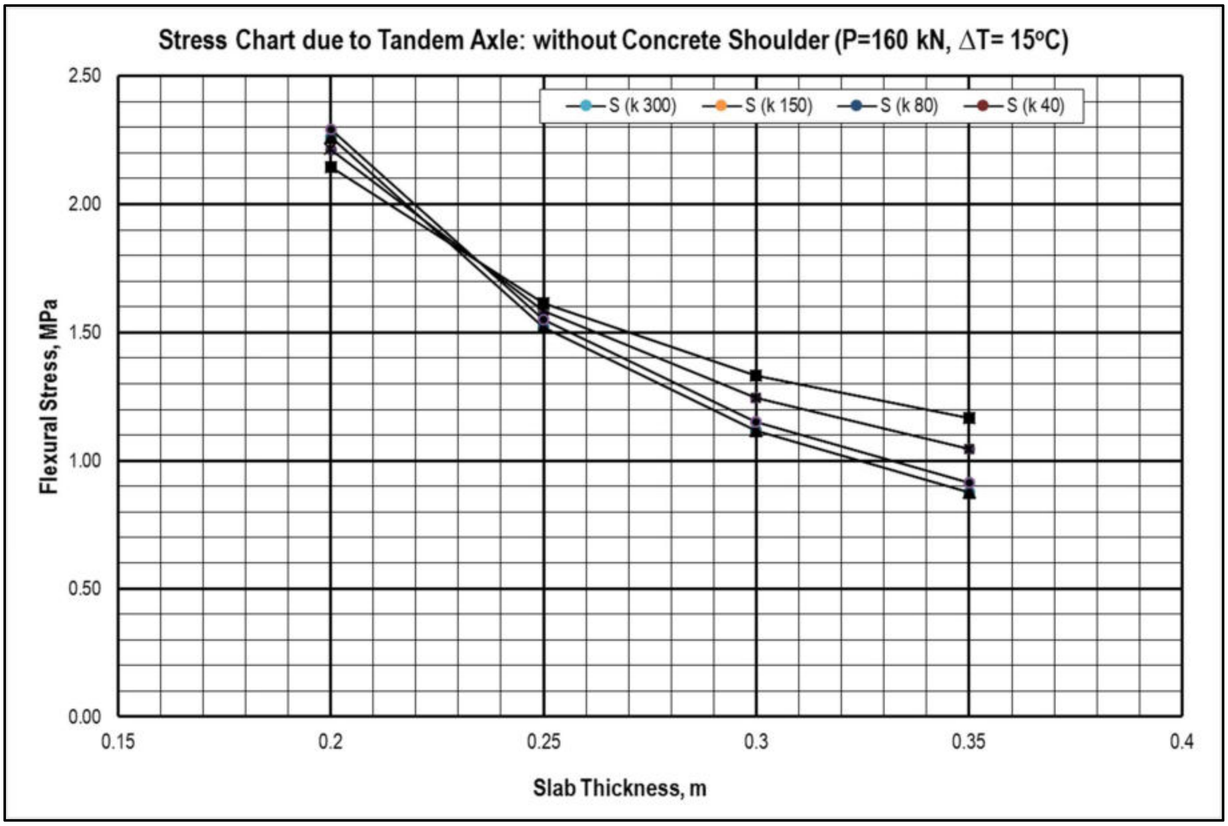

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=160 kN, ∆T= 10°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
0.00
0.50
1.00
1.50
2.00
2.50
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

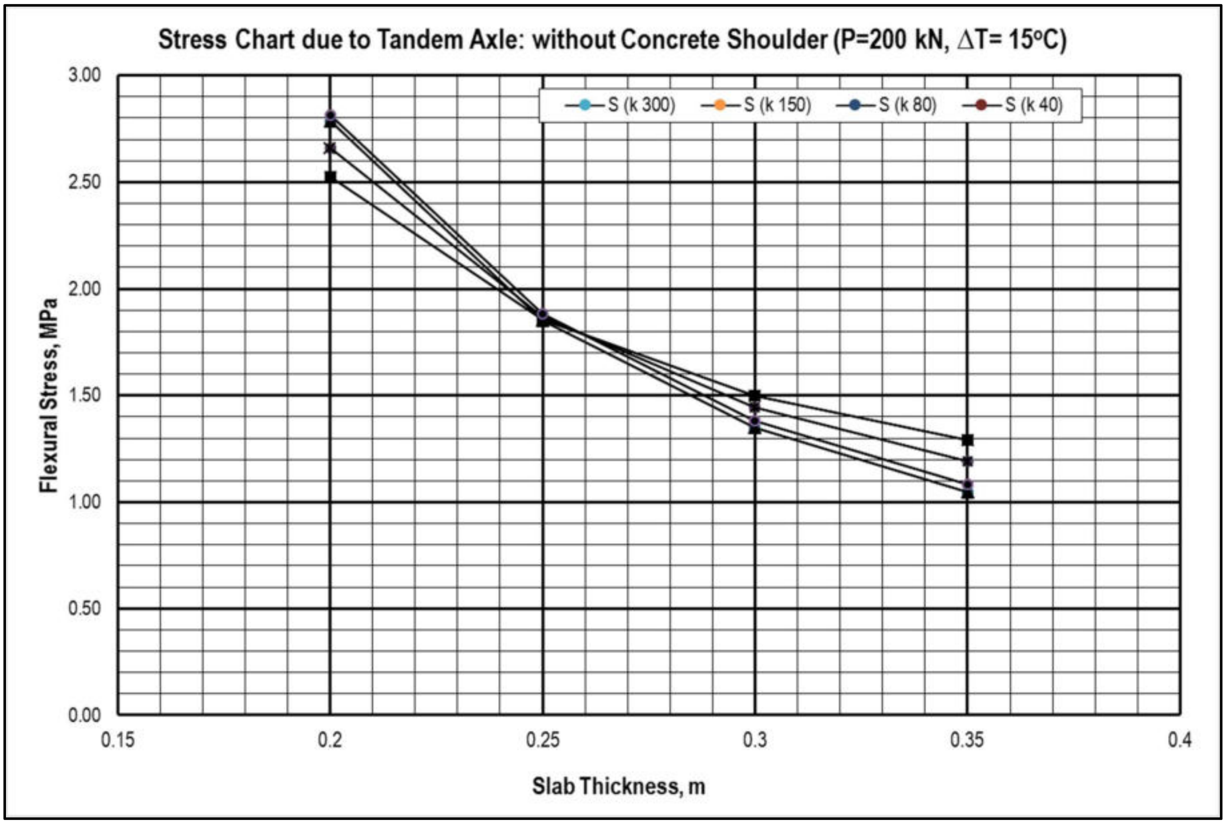

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=200 kN, ∆T= 10°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
0.00
0.50
1.00
1.50
2.00
2.50
3.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

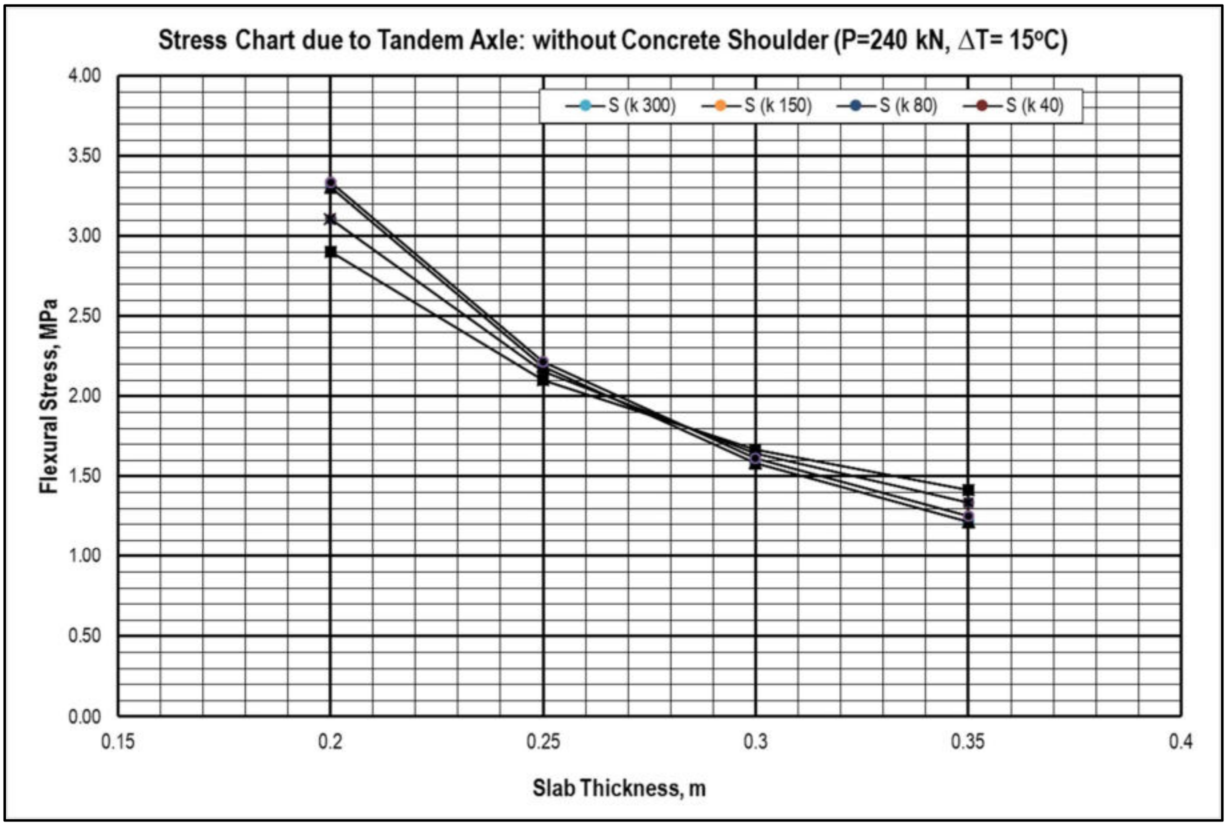

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=240 kN, ∆T= 10°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

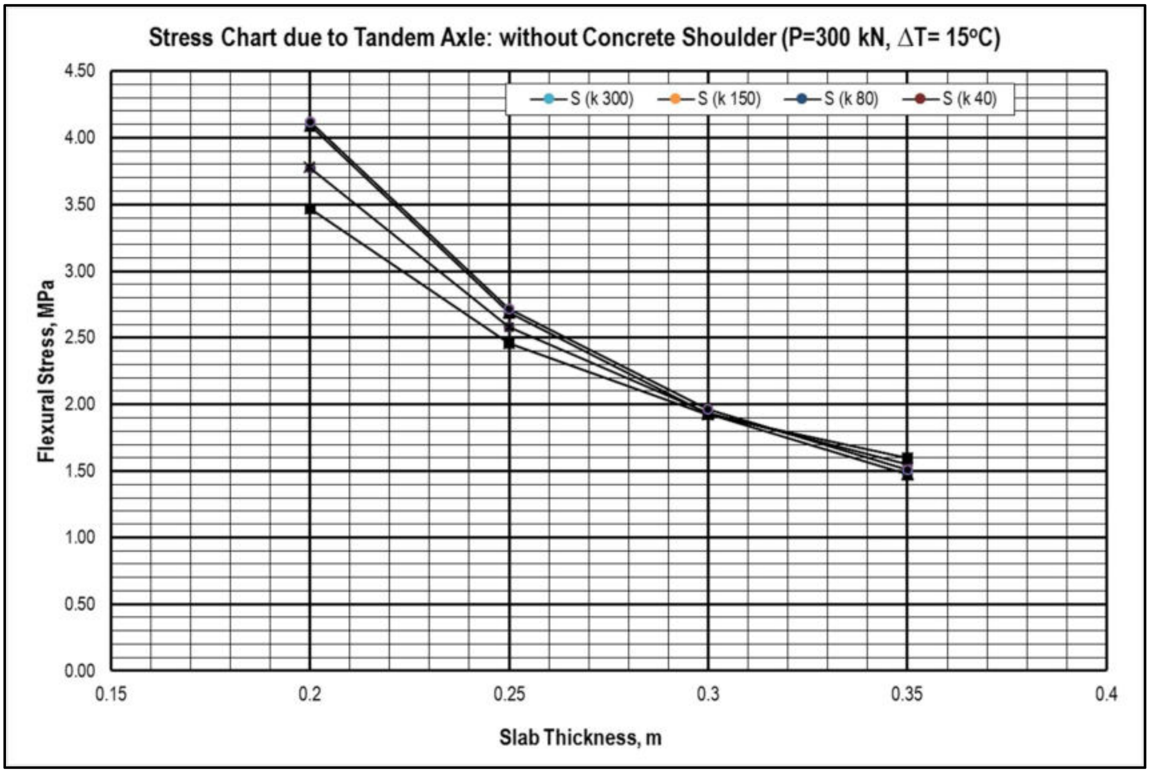

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=300 kN, ∆T= 10°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

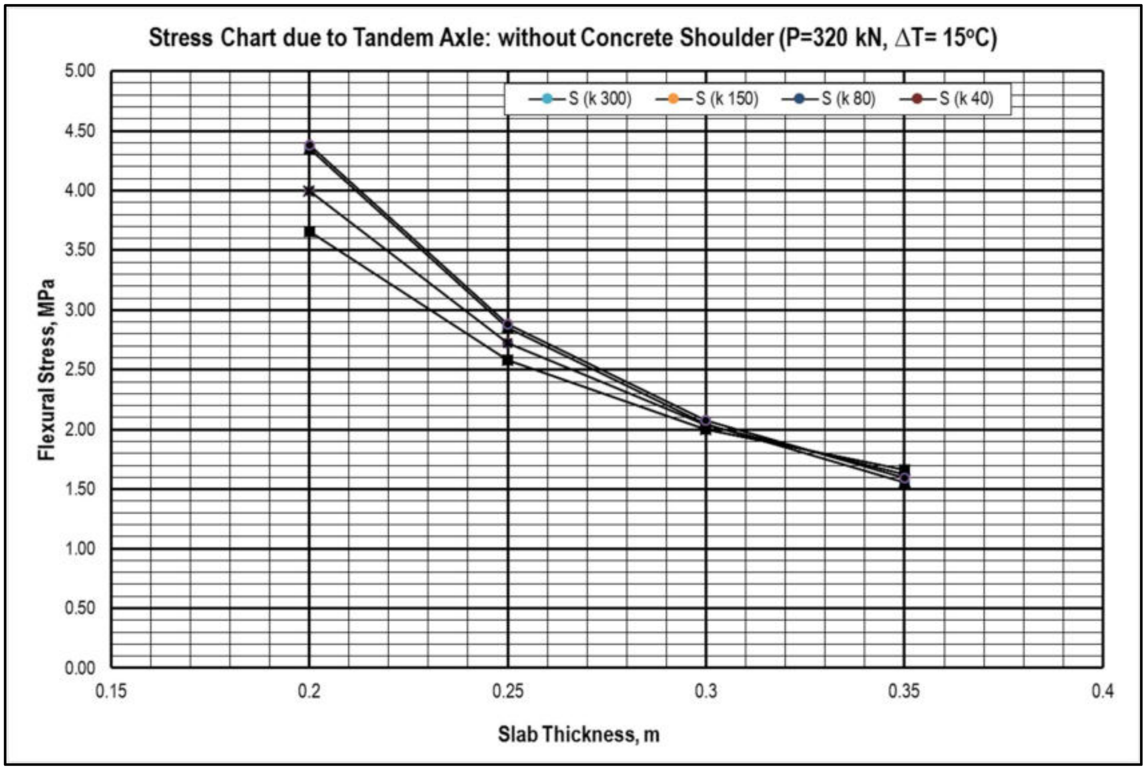

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=320 kN, ∆T= 10°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

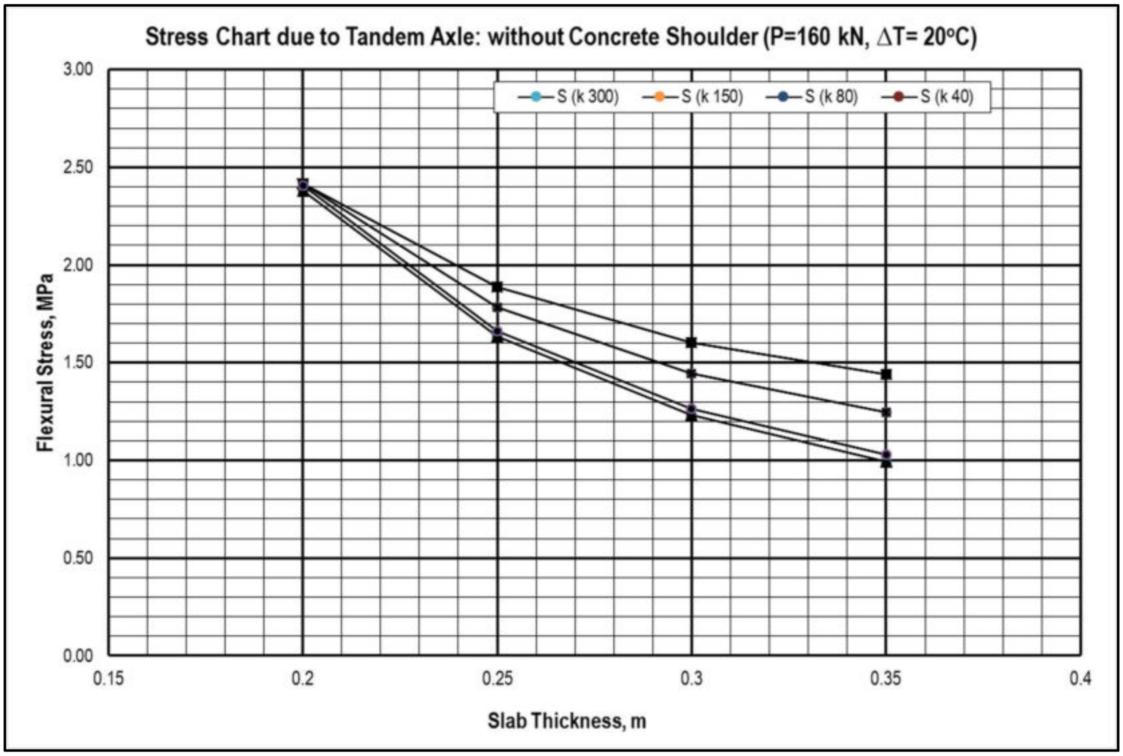

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=160 kN, ∆T= 15°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

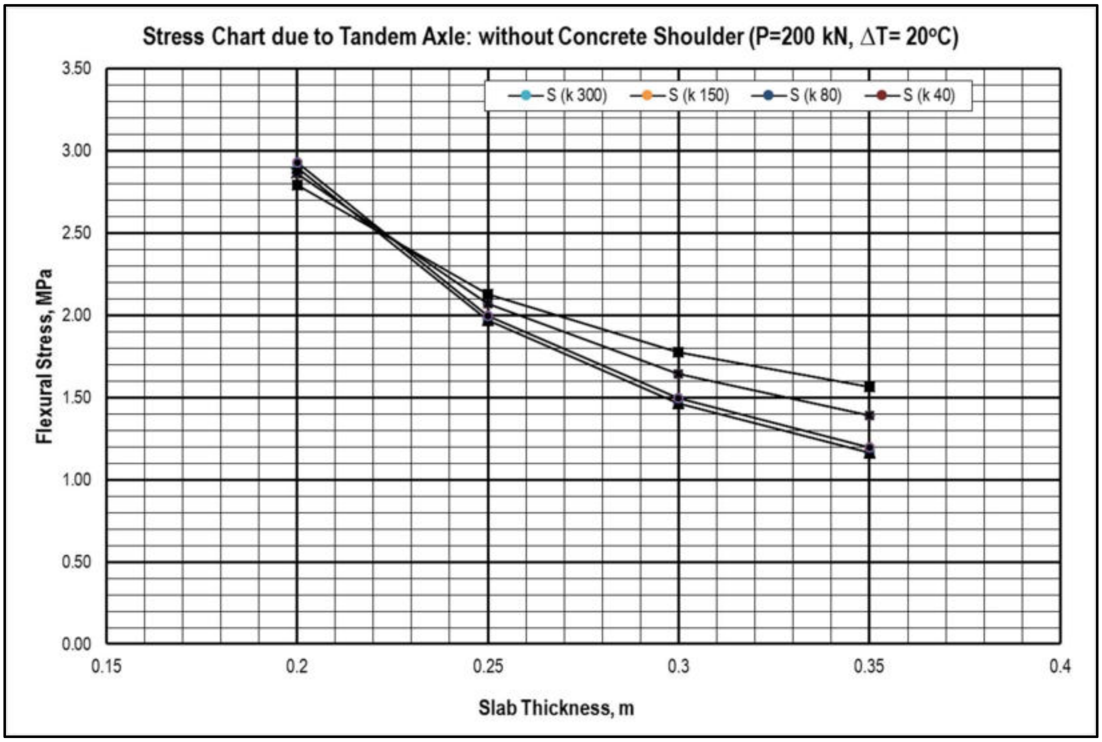

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=200 kN, ΔT= 15°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

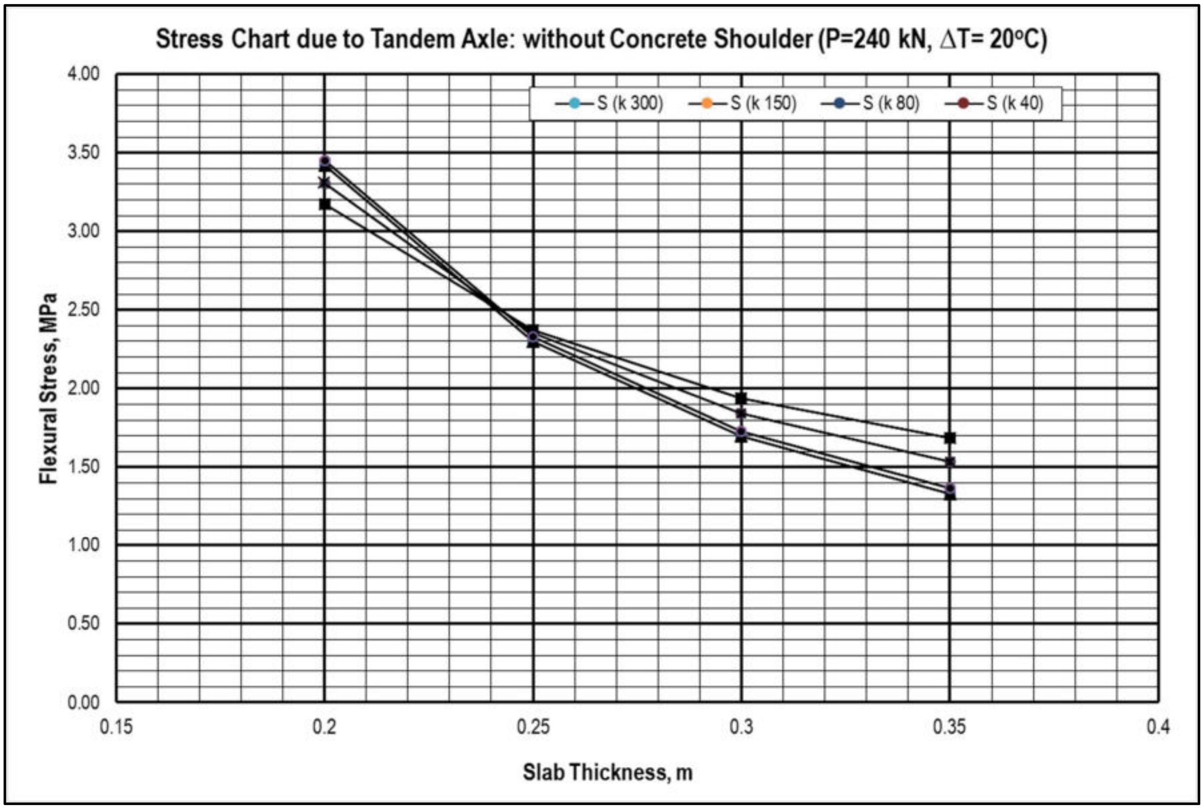

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=240 kN, ΔT= 15°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m


Stress Chart due to Tandem Axle: without Concrete Shoulder (P=300 kN, ∆T= 15°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

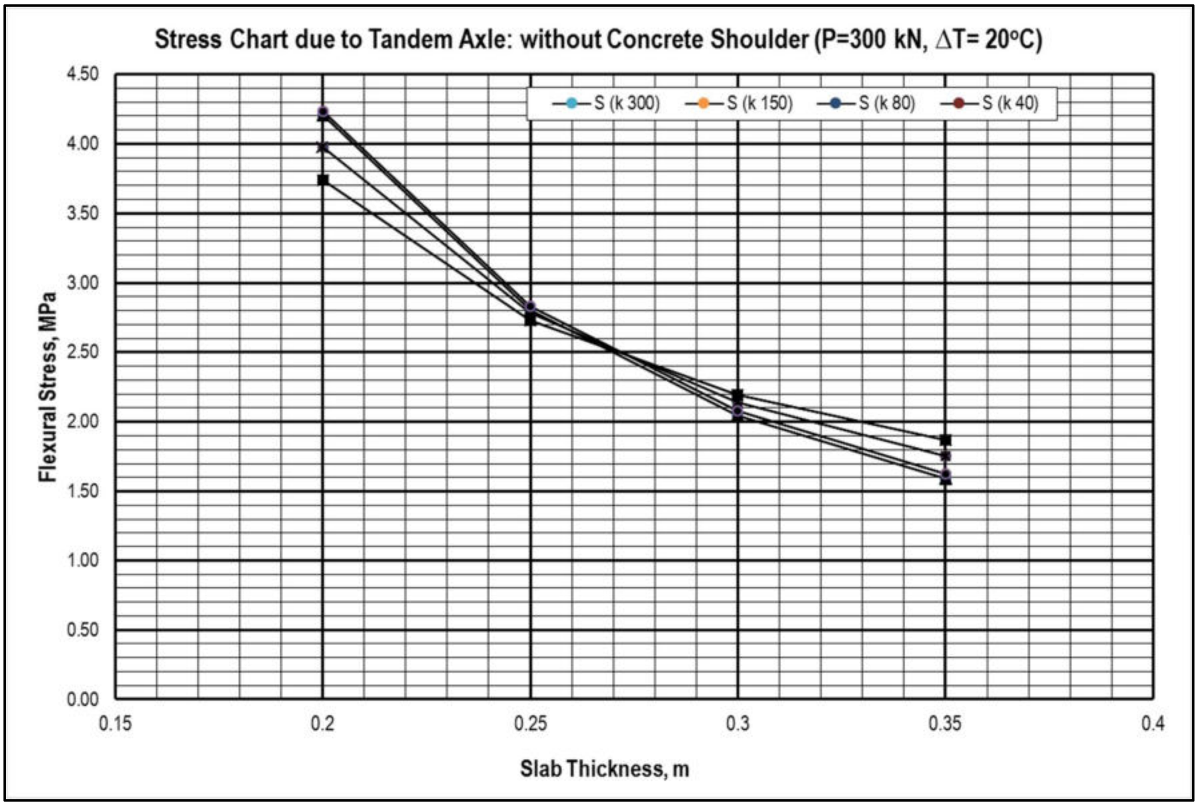

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=320 kN, ∆T= 15°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m


Stress Chart due to Tandem Axle: without Concrete Shoulder (P=160 kN, ∆T= 20°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

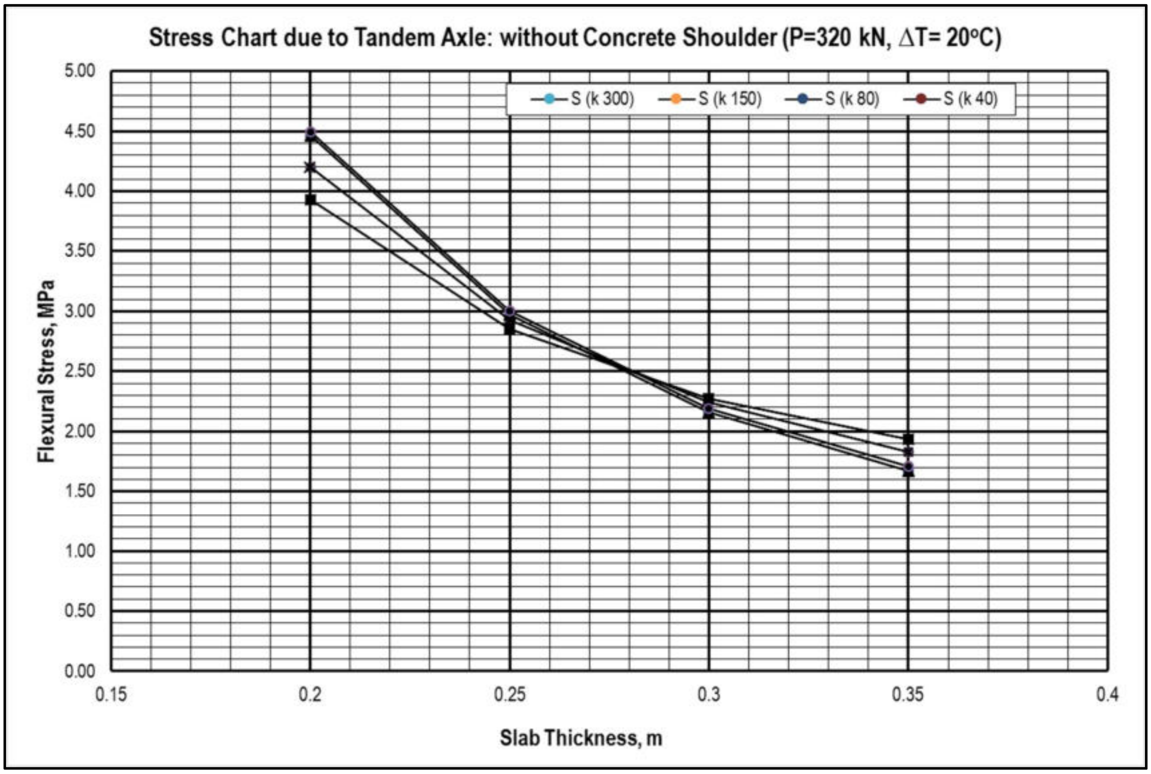

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=200 kN, ∆T= 20°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m



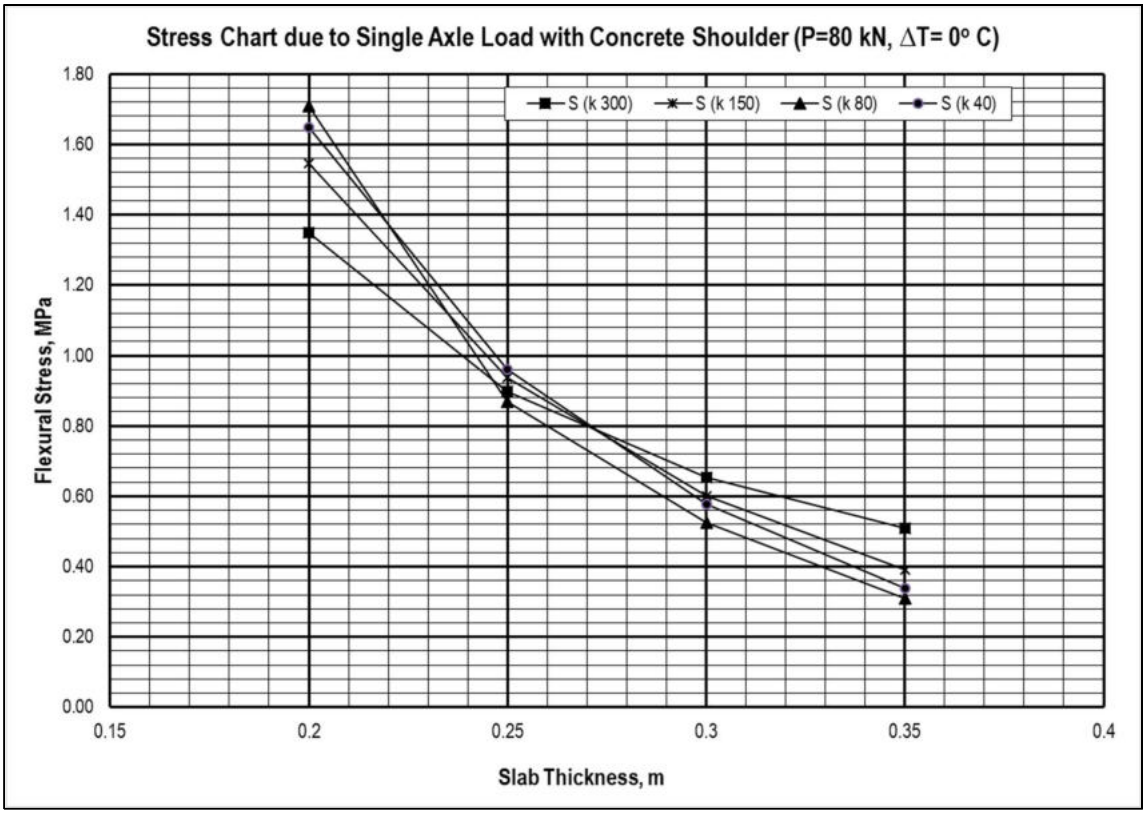
Stress Chart due to Tandem Axle: without Concrete Shoulder (P=240 kN, ∆T= 20ºC)

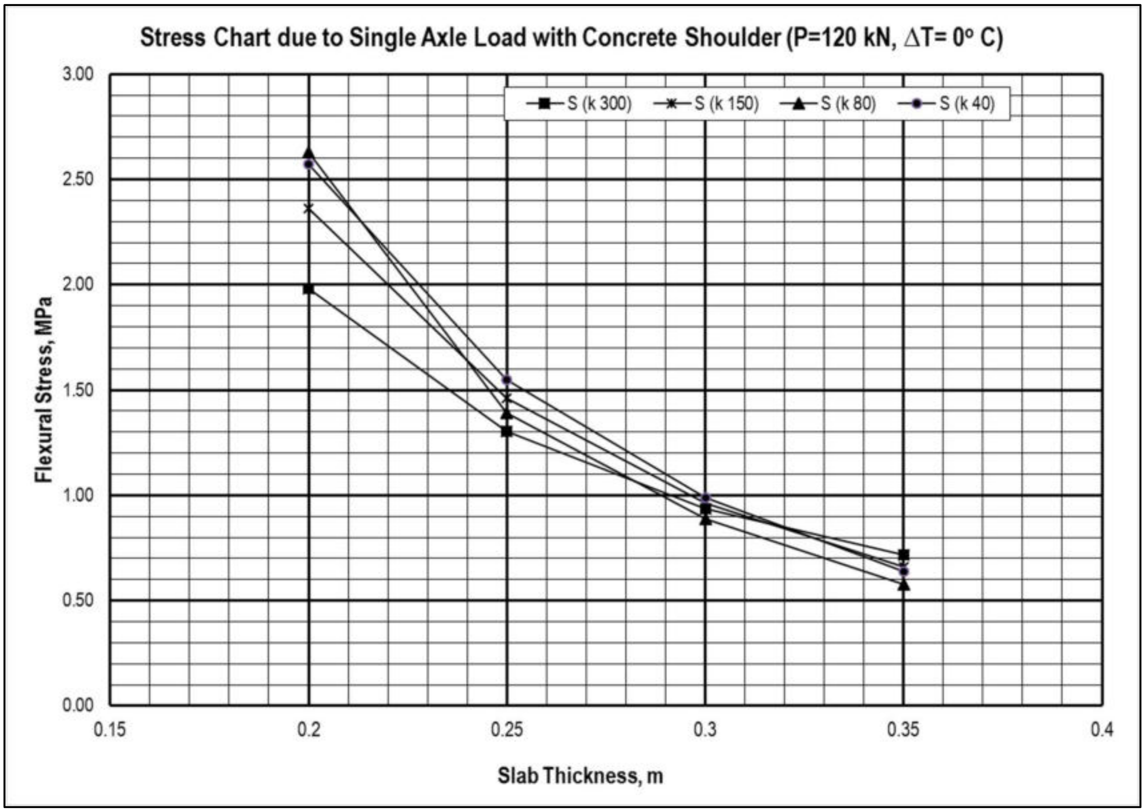


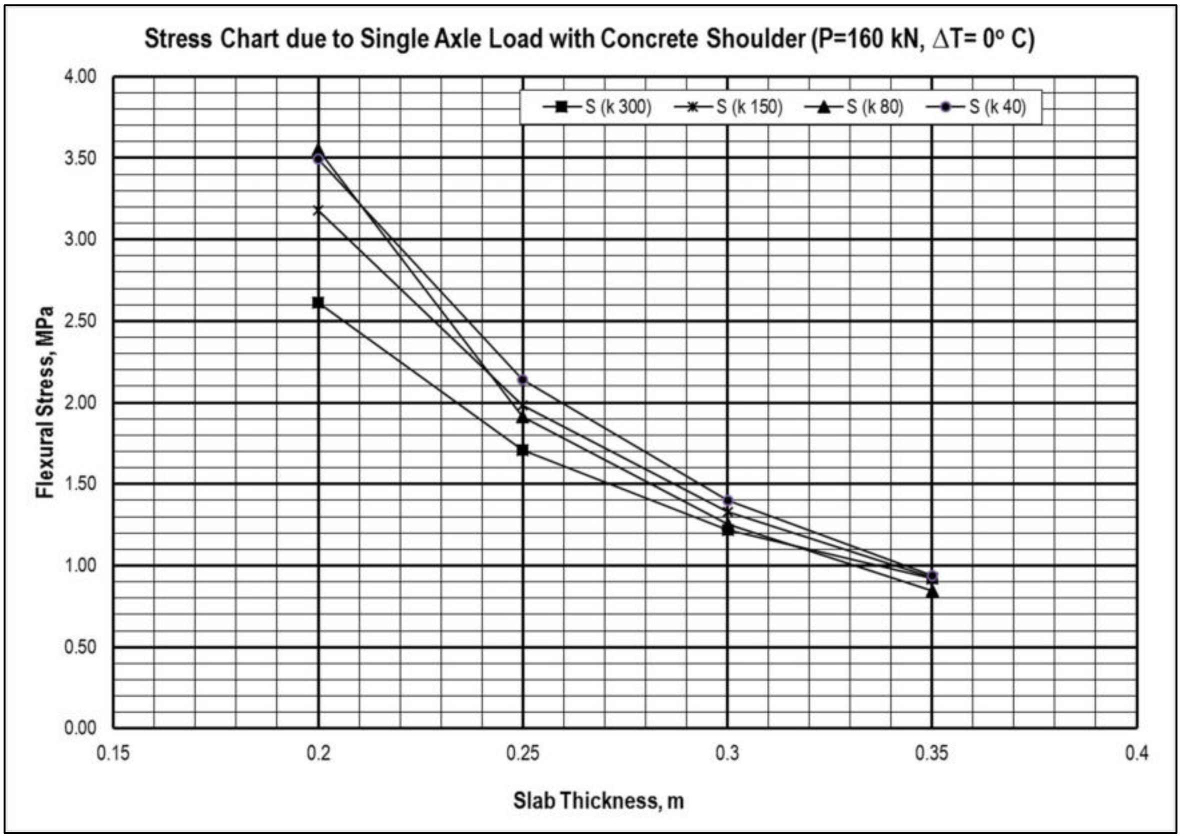
Stress Chart due to Tandem Axle: without Concrete Shoulder (P=300 kN, ∆T= 20ºC)

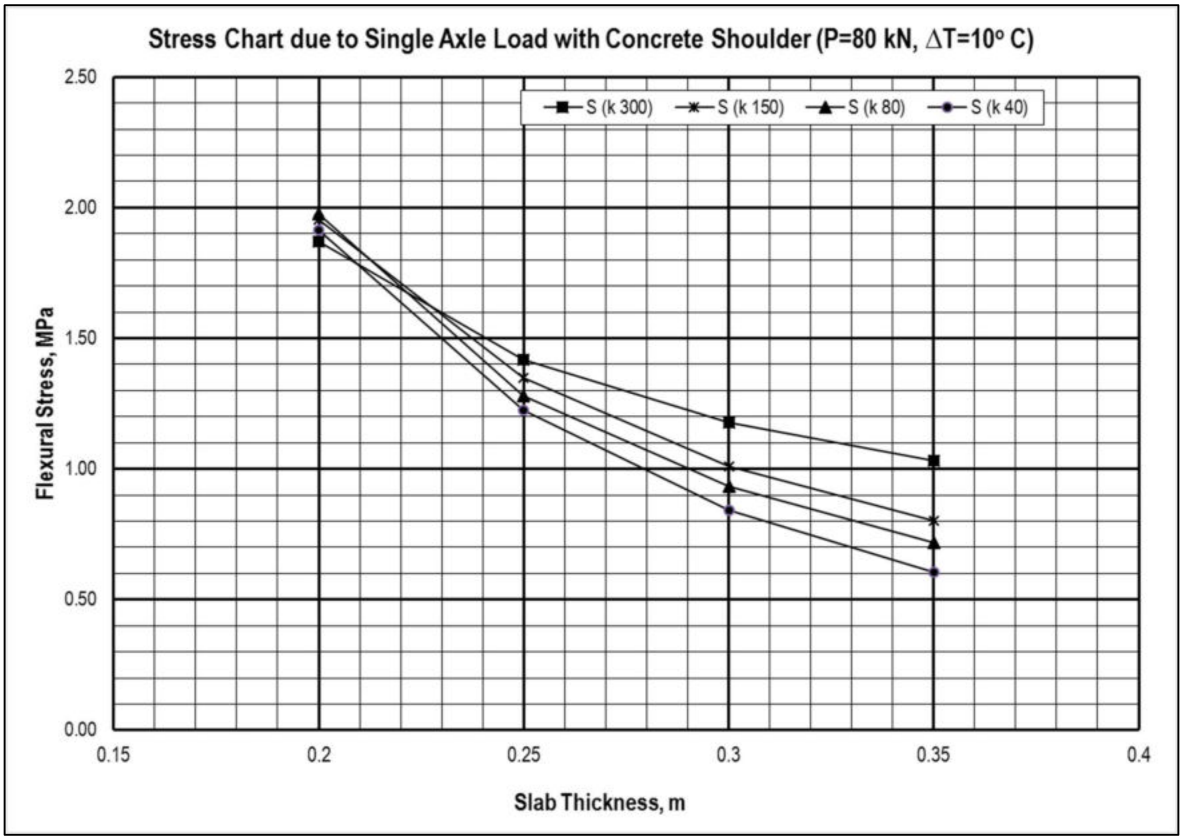

Stress Chart due to Tandem Axle: without Concrete Shoulder (P=320 kN, ∆T= 20°C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

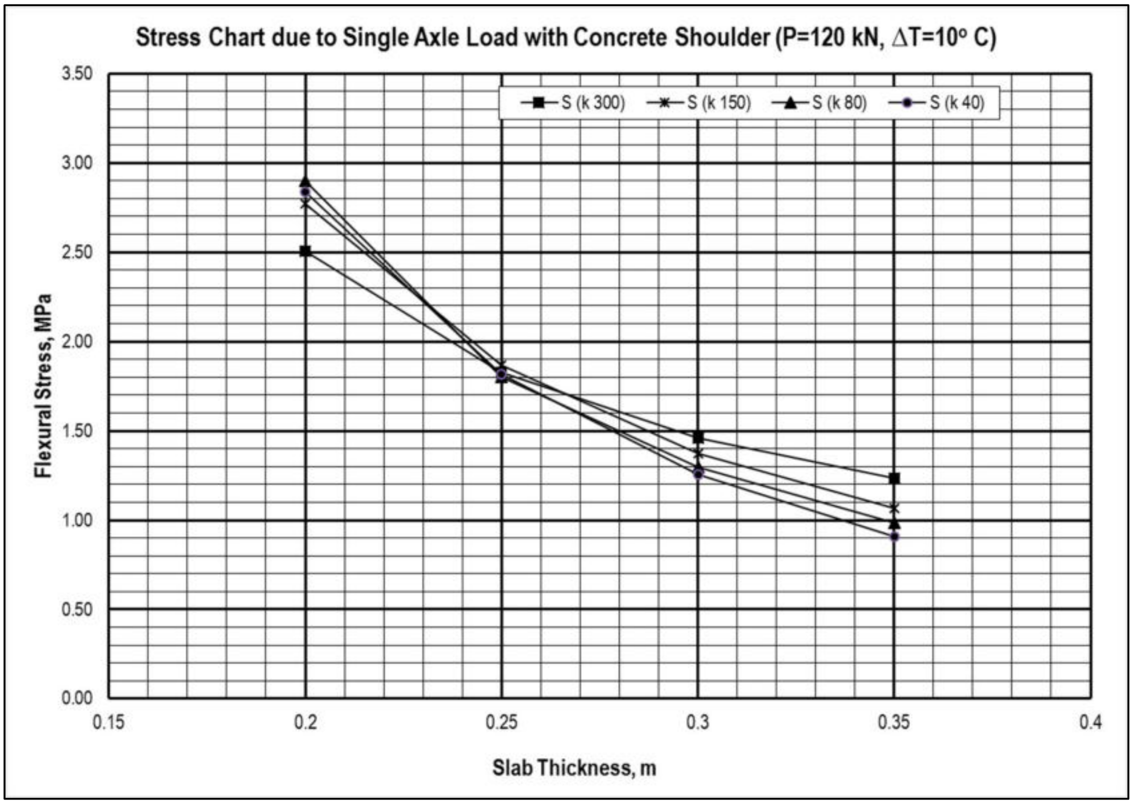
CHARTS FOR FLEXURAL STRESS: Single Axle loading with concrete shoulder

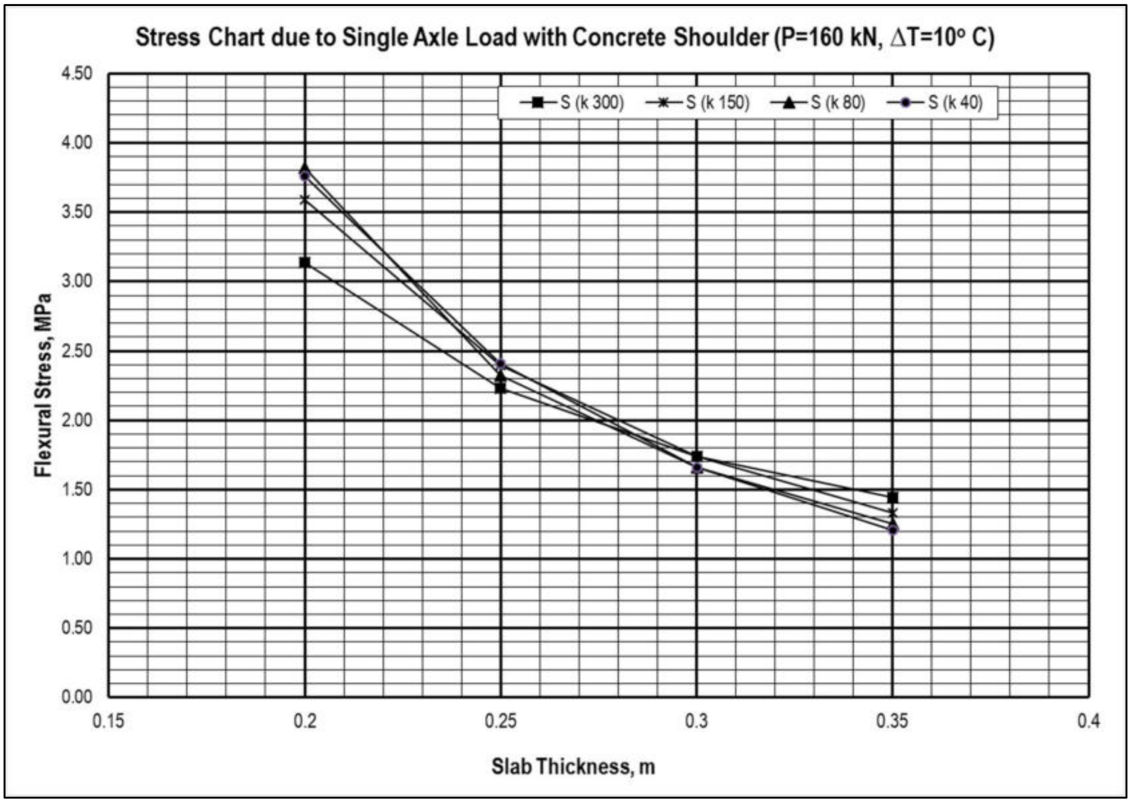


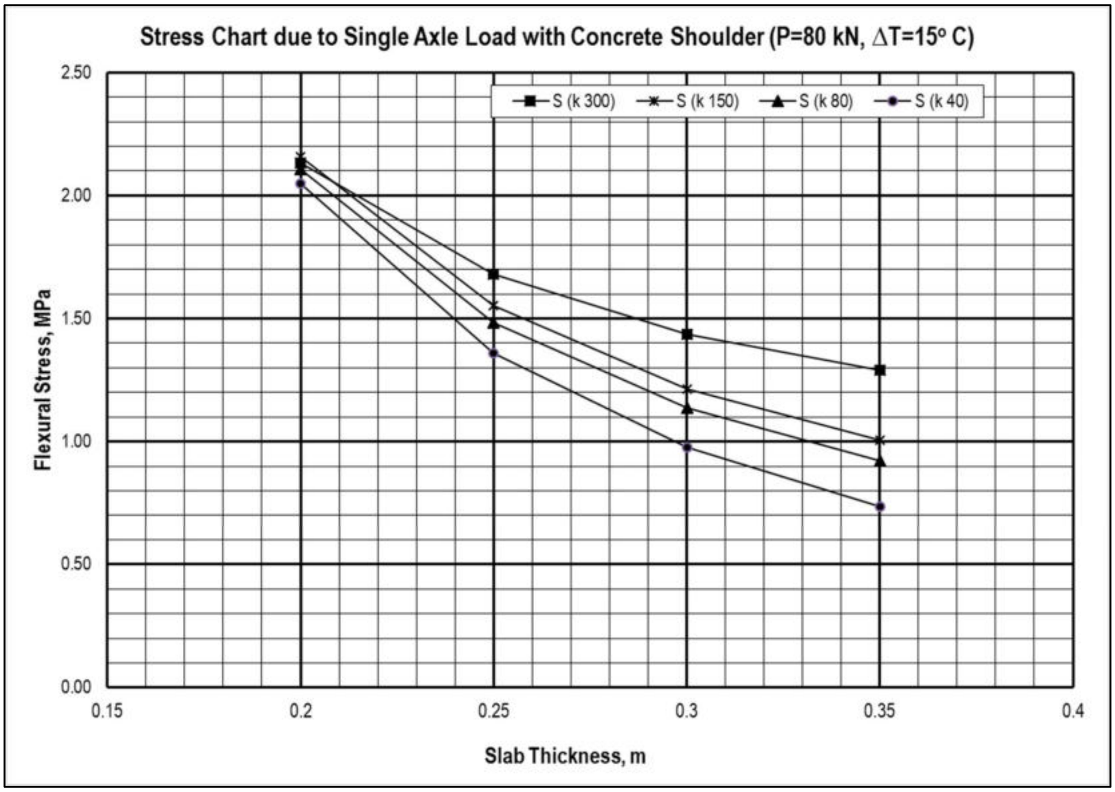


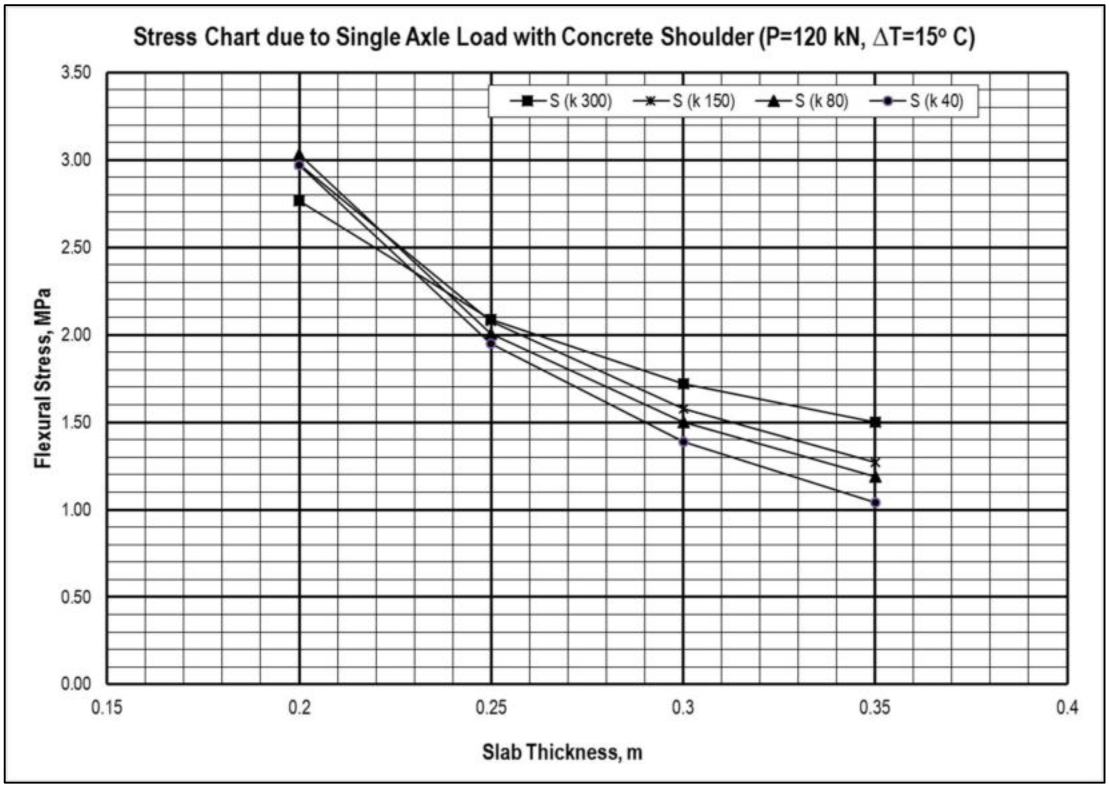

Stress Chart due to Single Axle Load with Concrete Shoulder (P=160 kN, ∆T= 0° C)

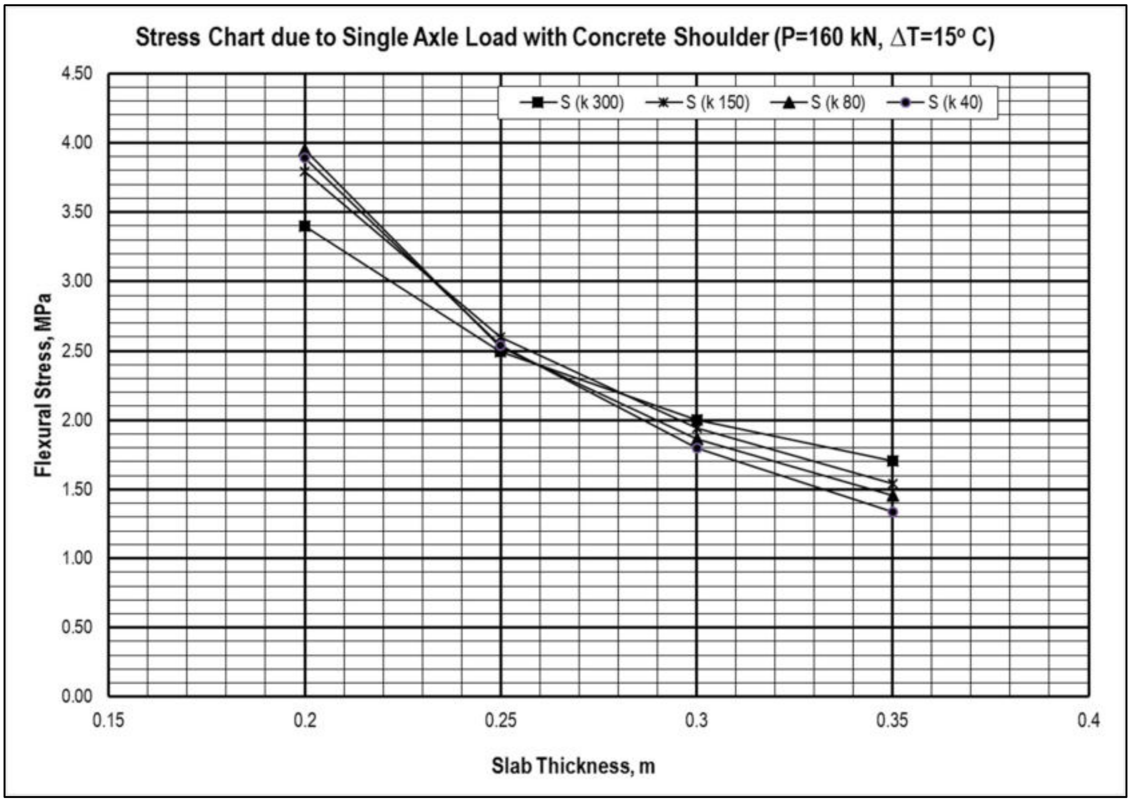

Stress Chart due to Single Axle Load with Concrete Shoulder (P=80 kN, ∆T=10° C)

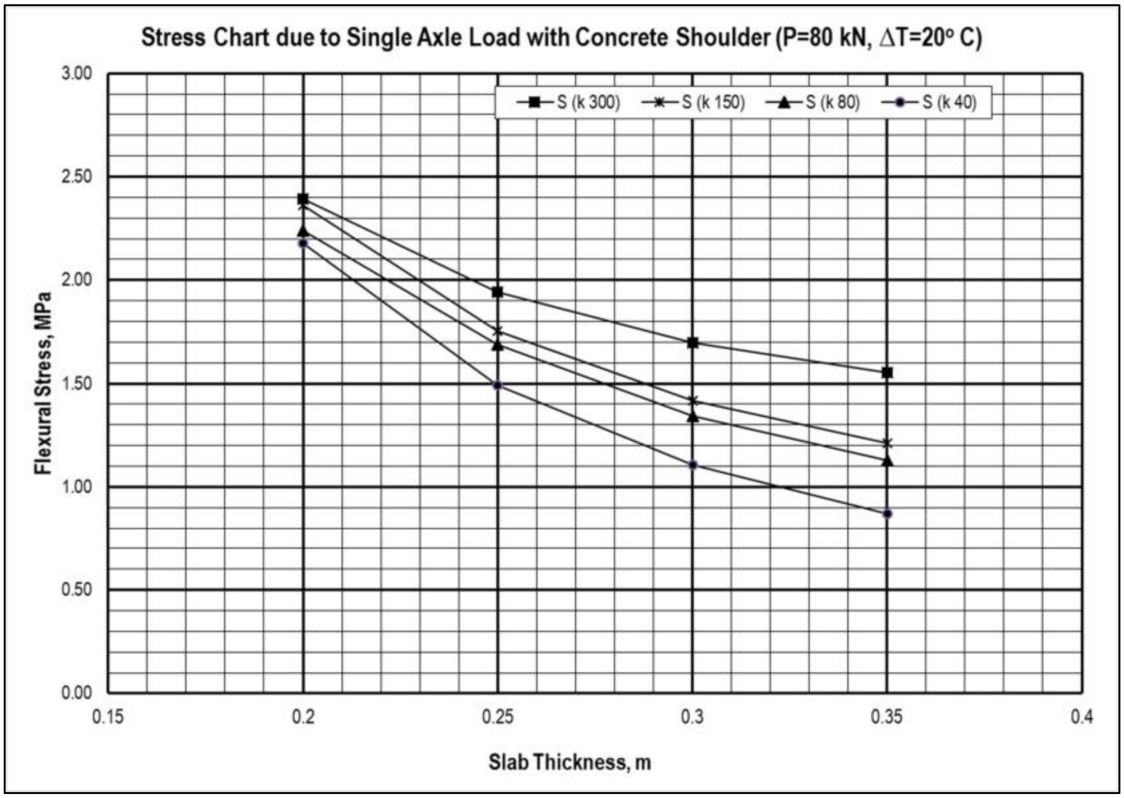

Stress Chart due to Single Axle Load with Concrete Shoulder (P=120 kN, ∆T=10° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

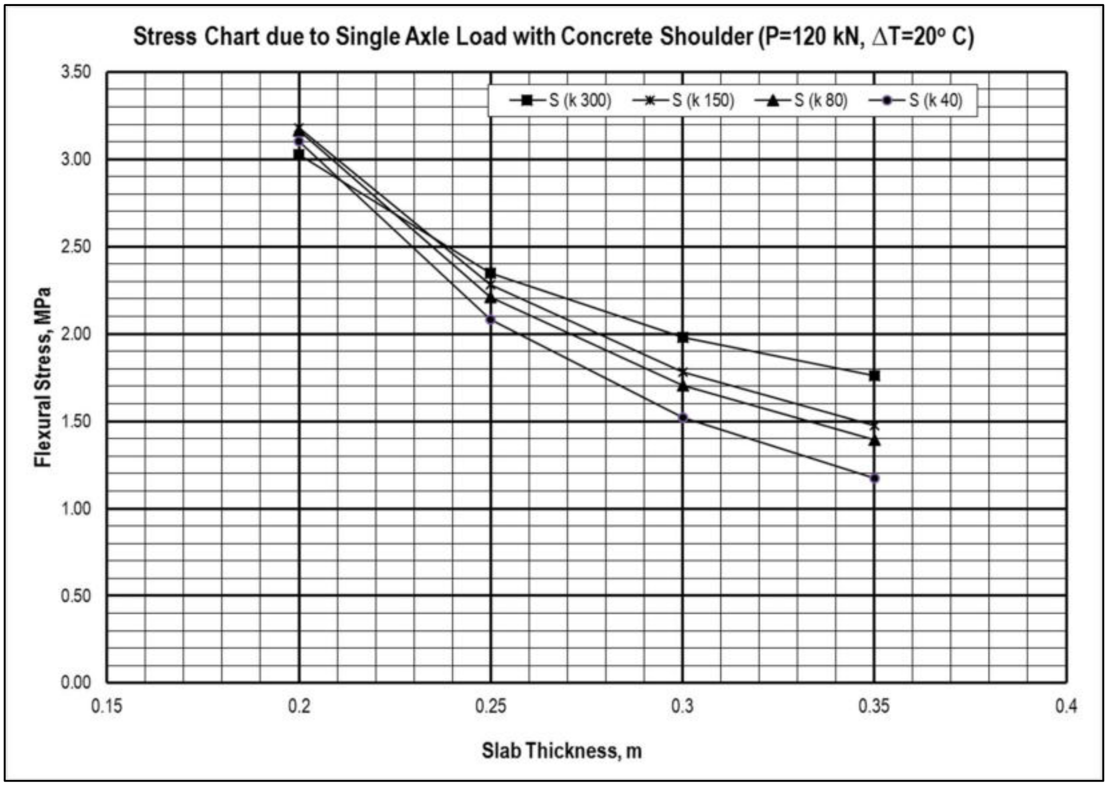

Stress Chart due to Single Axle Load with Concrete Shoulder (P=160 kN, ∆T=10° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

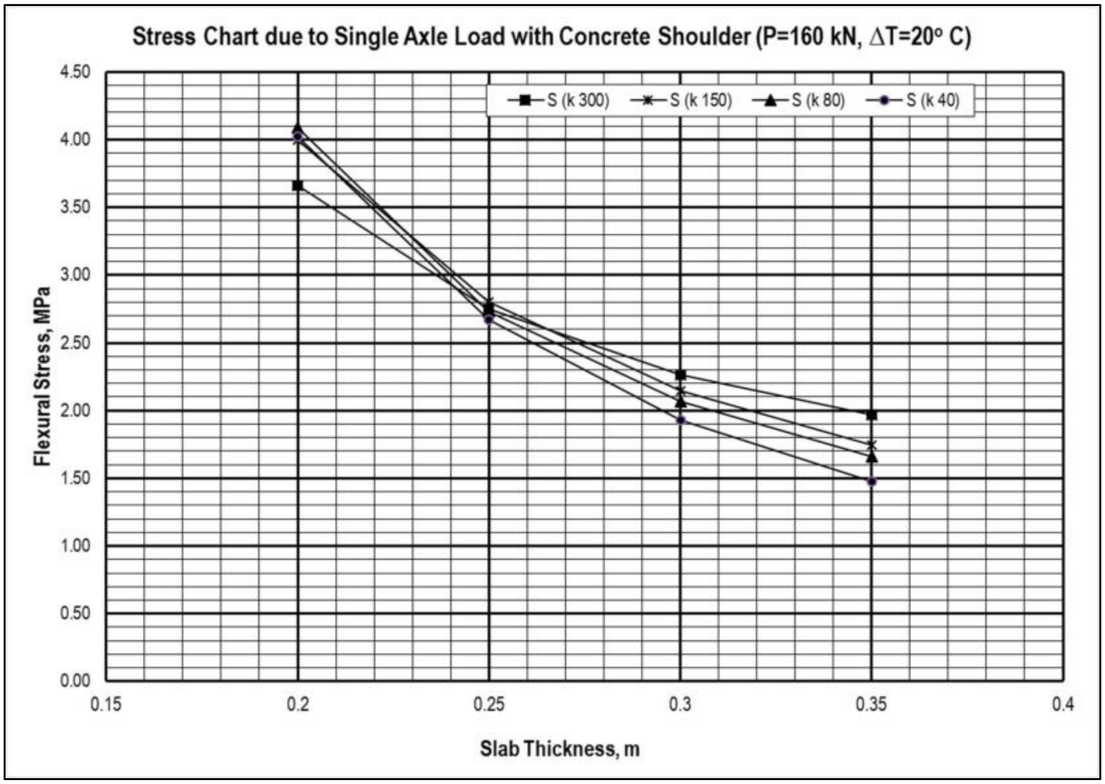

Stress Chart due to Single Axle Load with Concrete Shoulder (P=80 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m


Stress Chart due to Single Axle Load with Concrete Shoulder (P=120 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

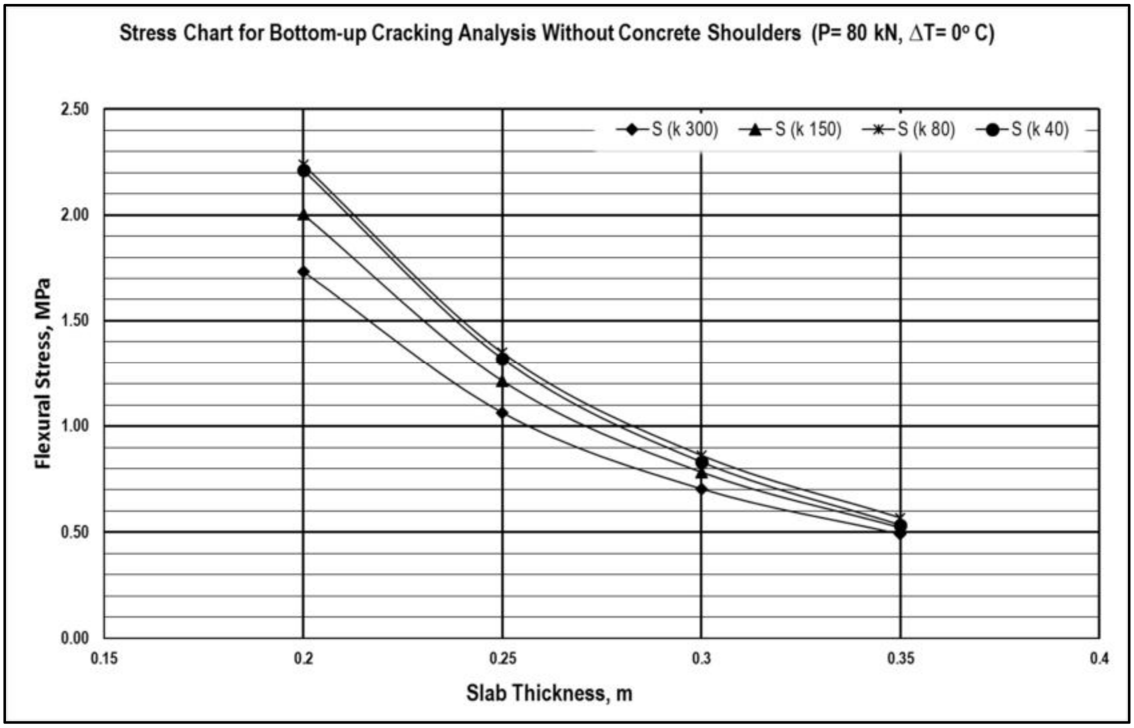

Stress Chart due to Single Axle Load with Concrete Shoulder (P=160 kN, ∆T=15° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

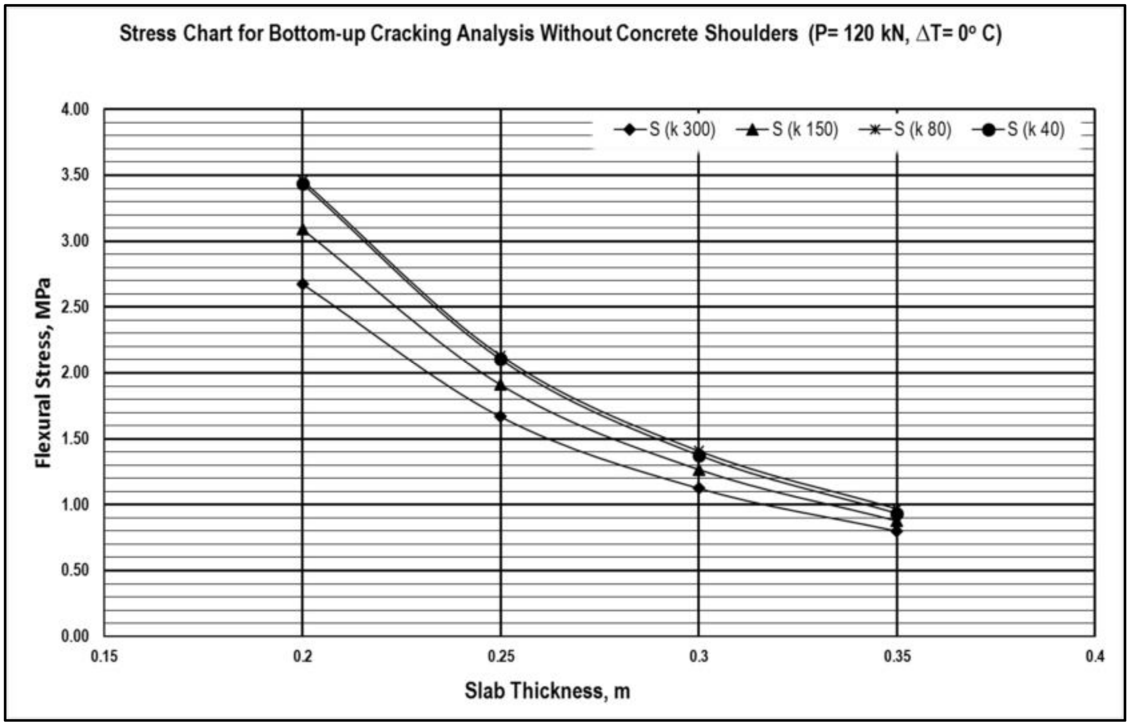

Stress Chart due to Single Axle Load with Concrete Shoulder (P=80 kN, ∆T=20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

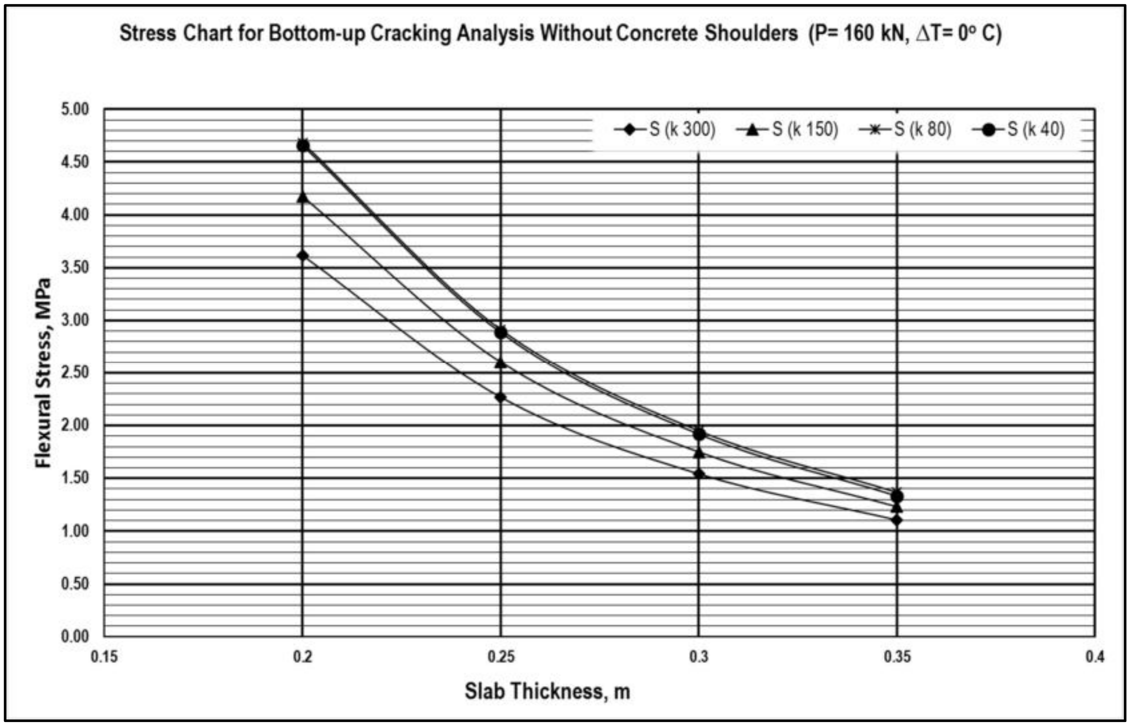

Stress Chart due to Single Axle Load with Concrete Shoulder (P=120 kN, ∆T=20° C)

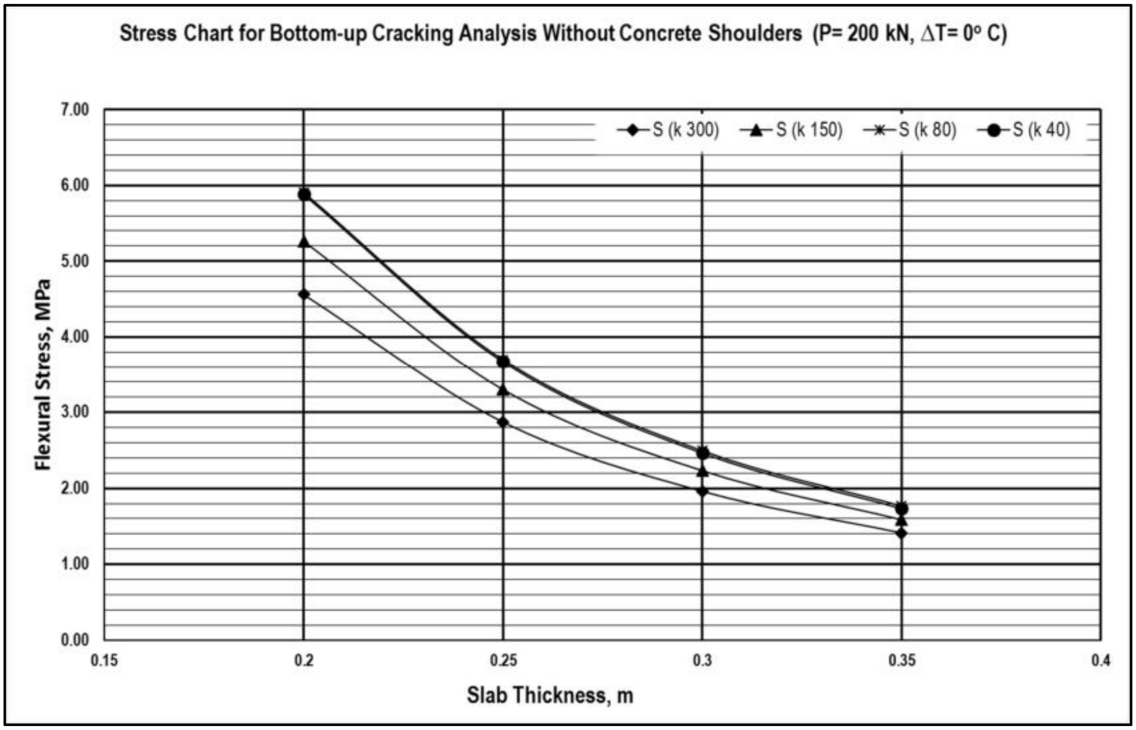

Stress Chart due to Single Axle Load with Concrete Shoulder (P=160 kN, ∆T=20° C)

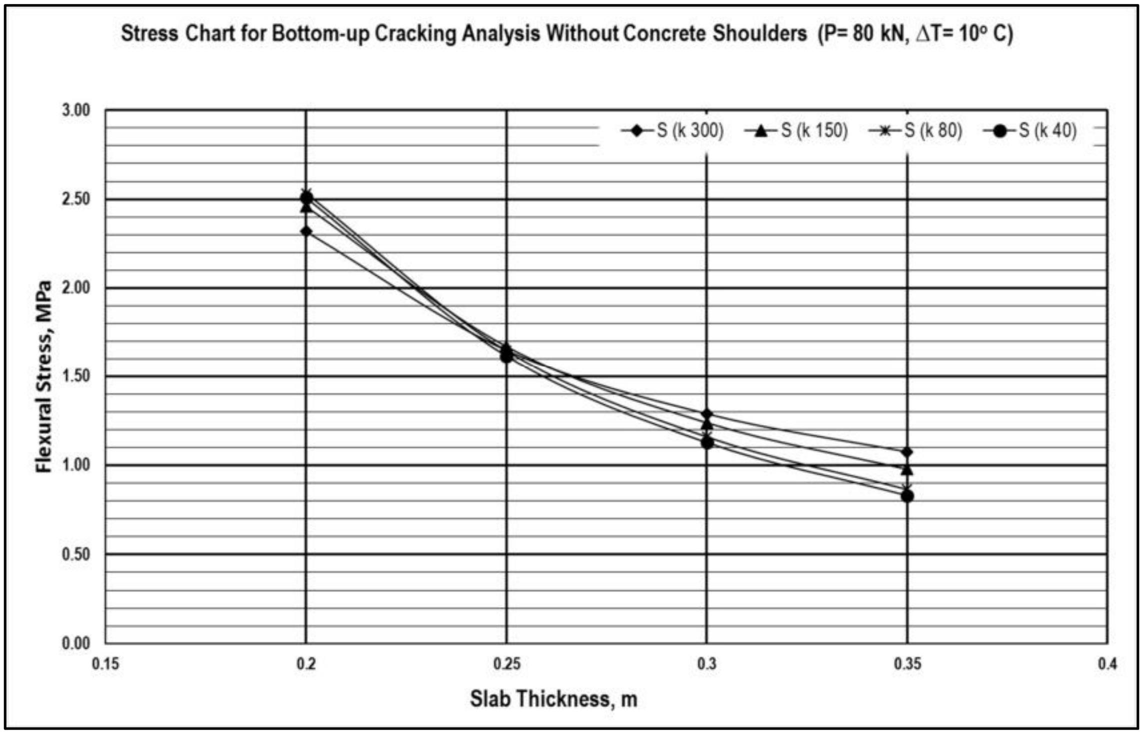
CHARTS FOR FLEXURAL STRESS: Single Axle loading without concrete shoulder

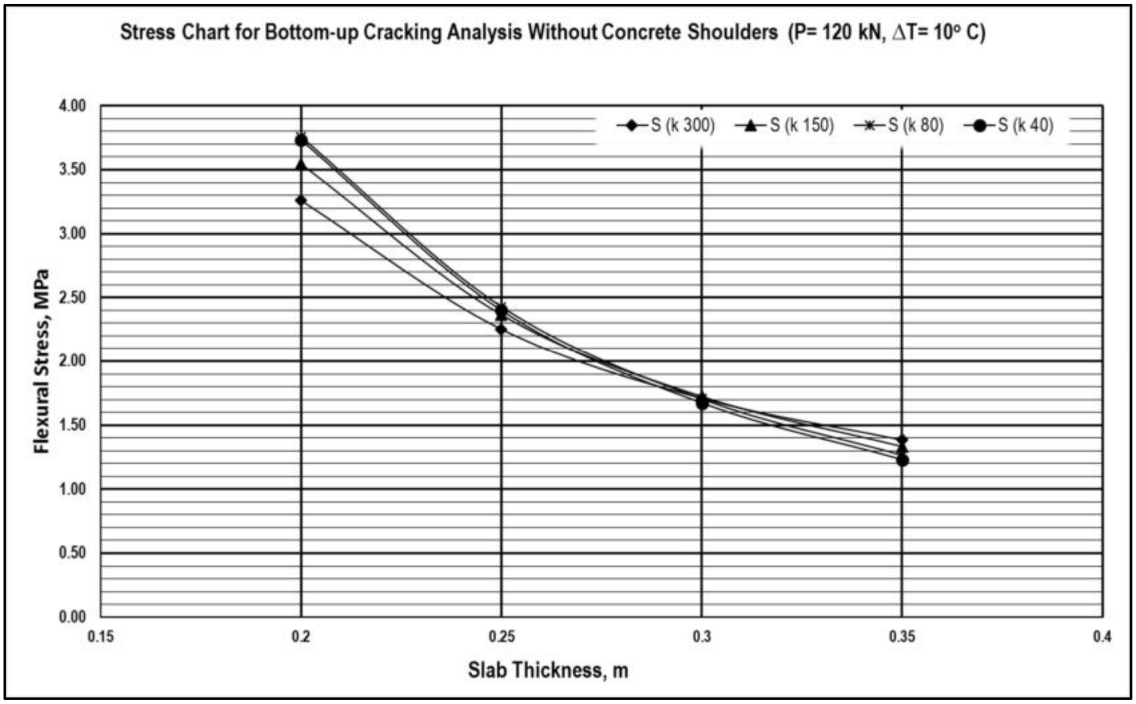


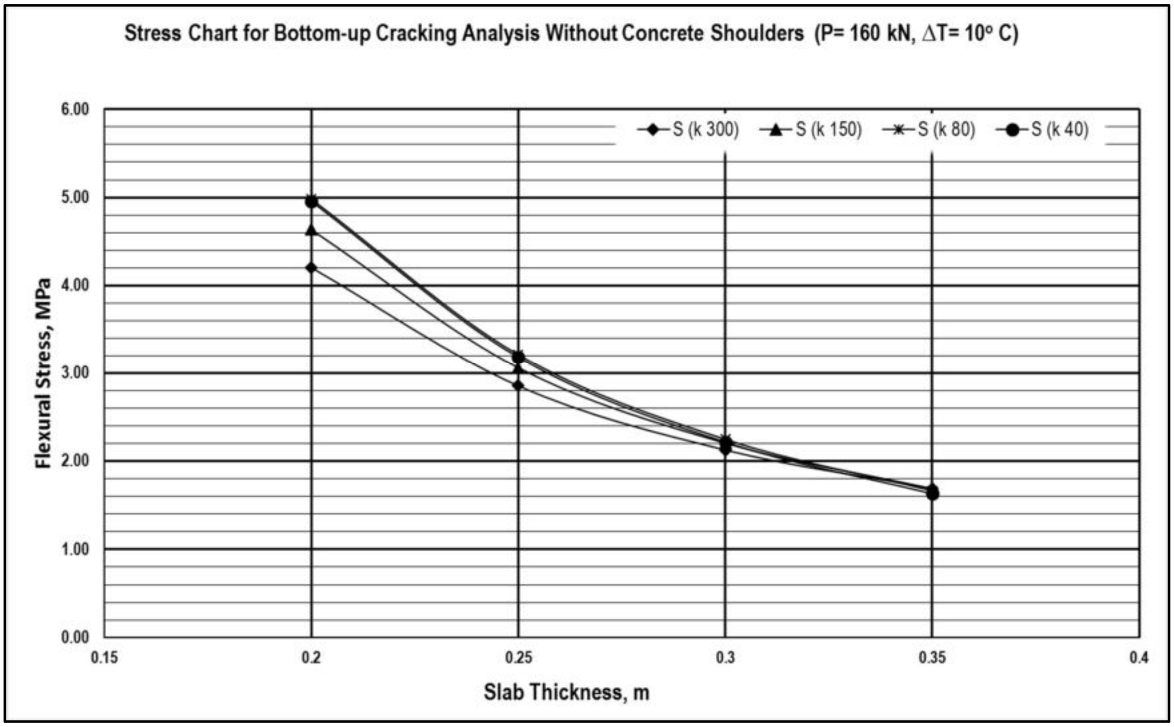



Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 160 kN, ΔT= 0° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m

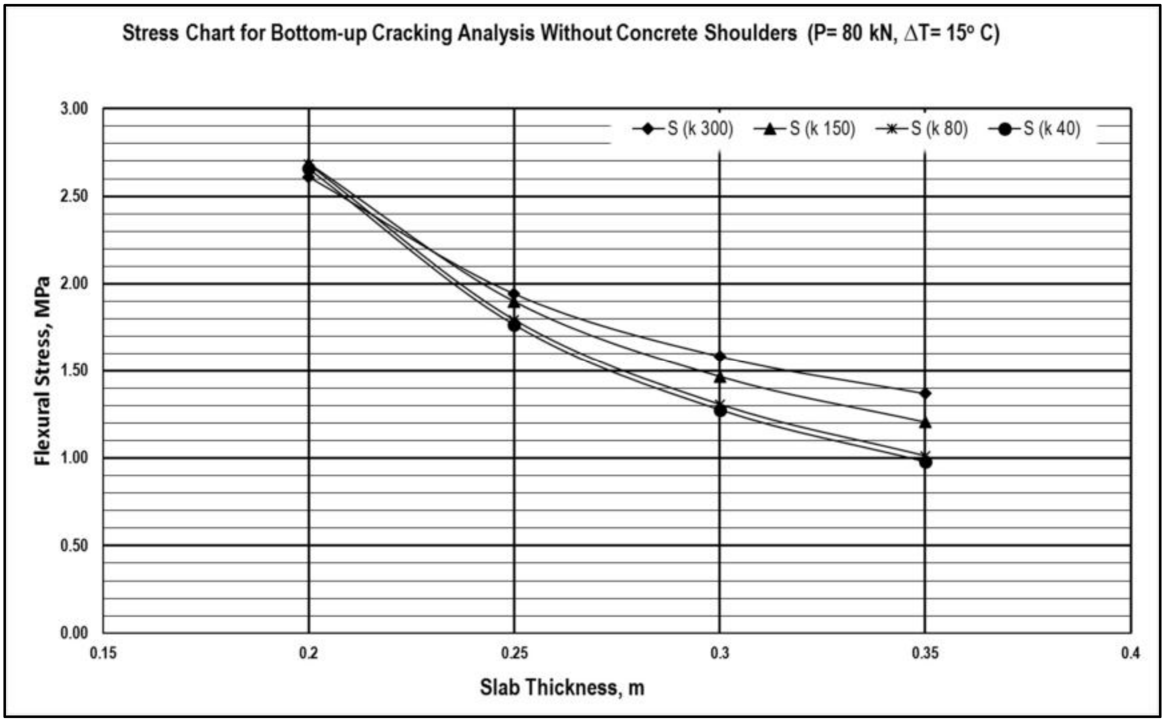

Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 200 kN, ΔT= 0° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 80 kN, ∆T= 10° C)

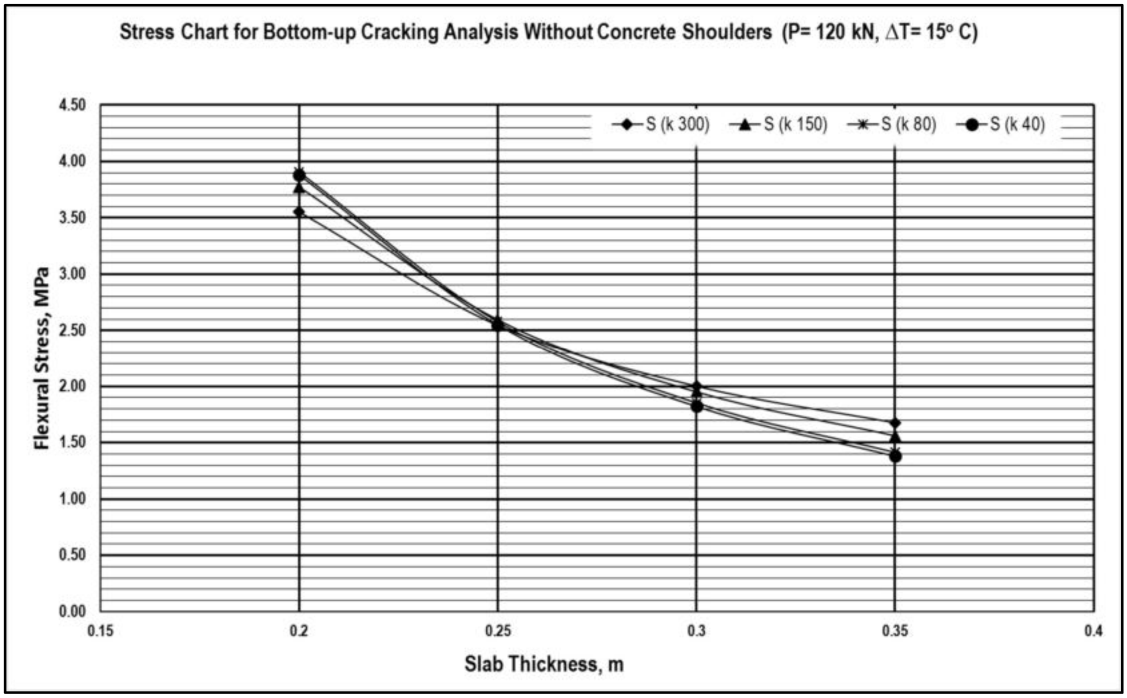

Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 120 kN, ∆T= 10° C)

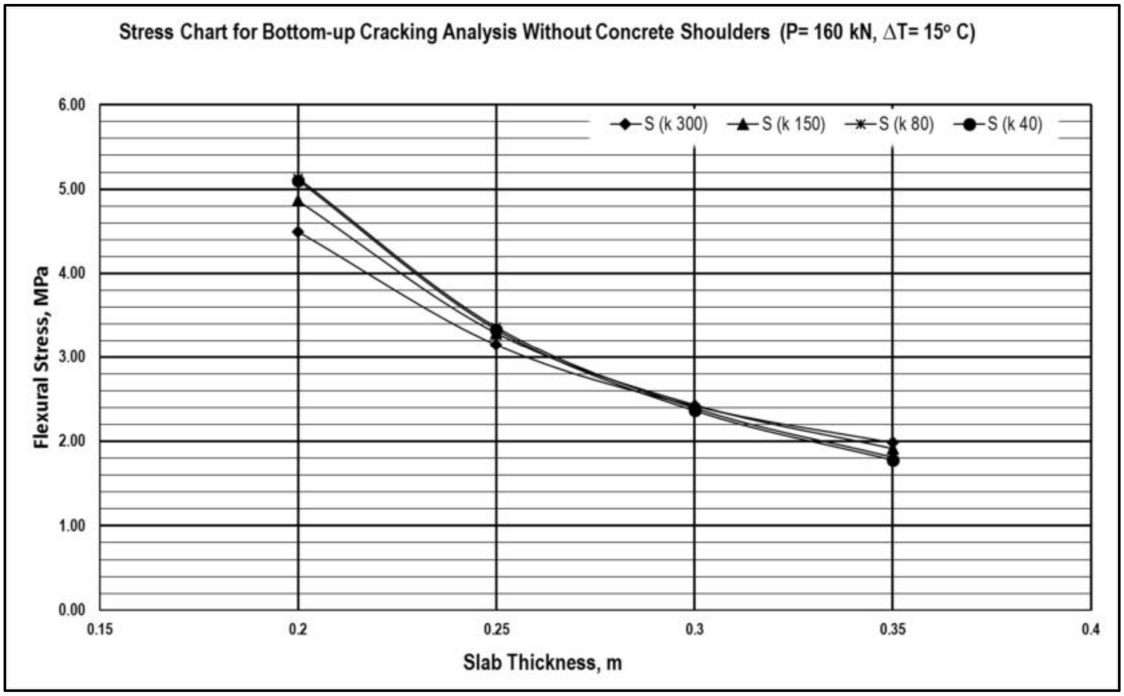


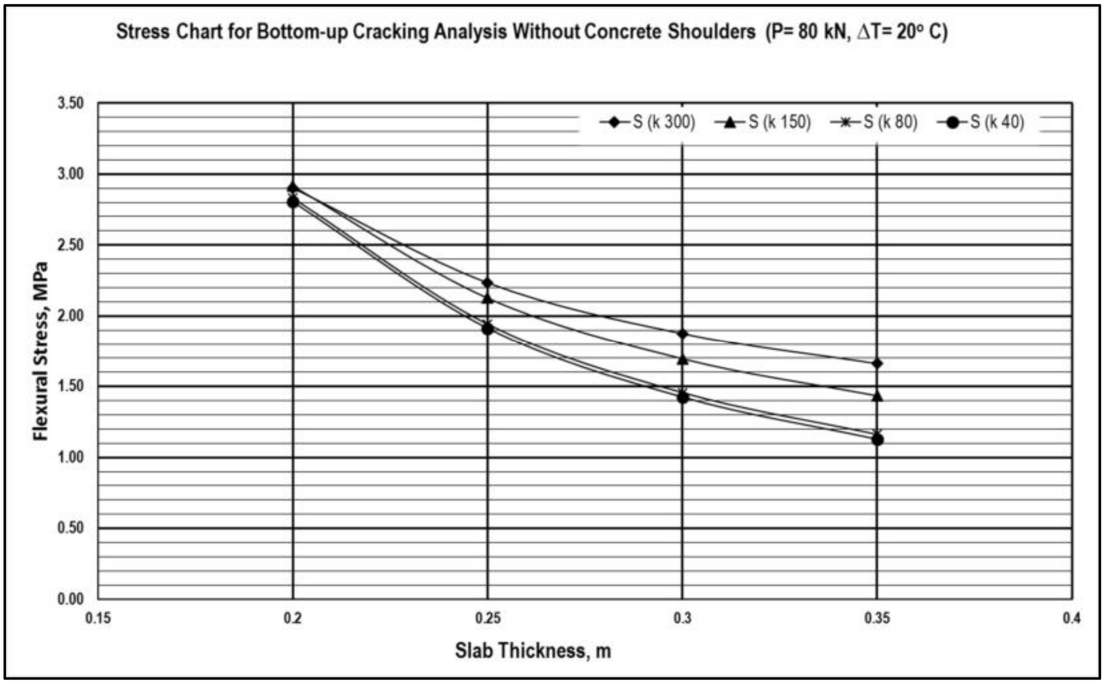
Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 160 kN, ∆T= 10° C)

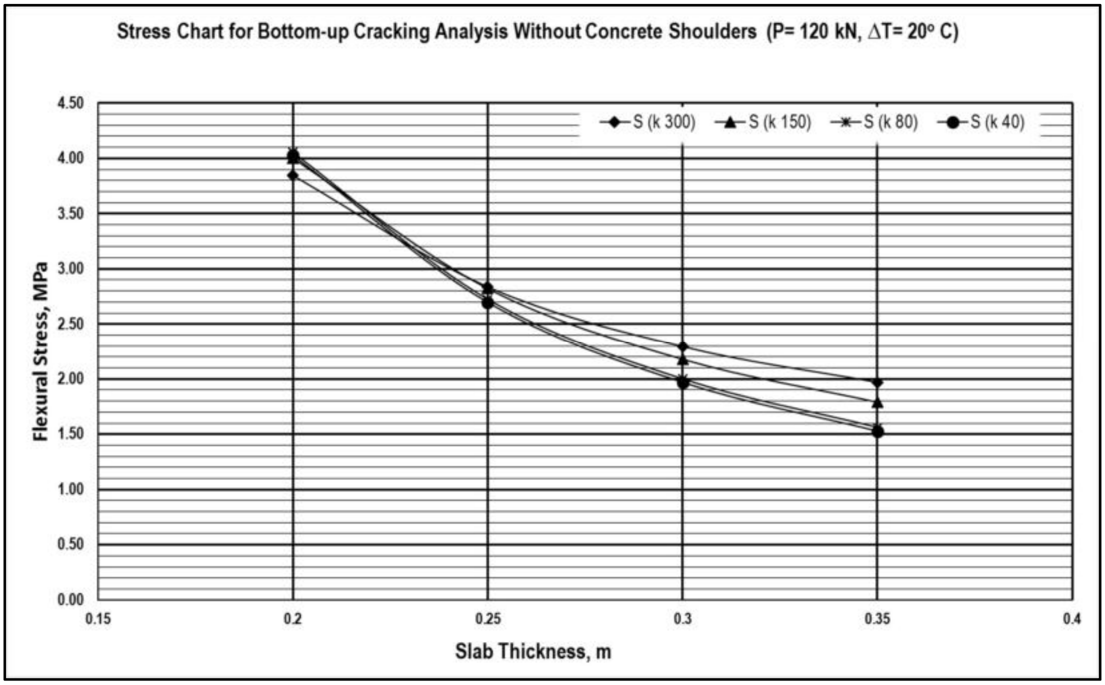


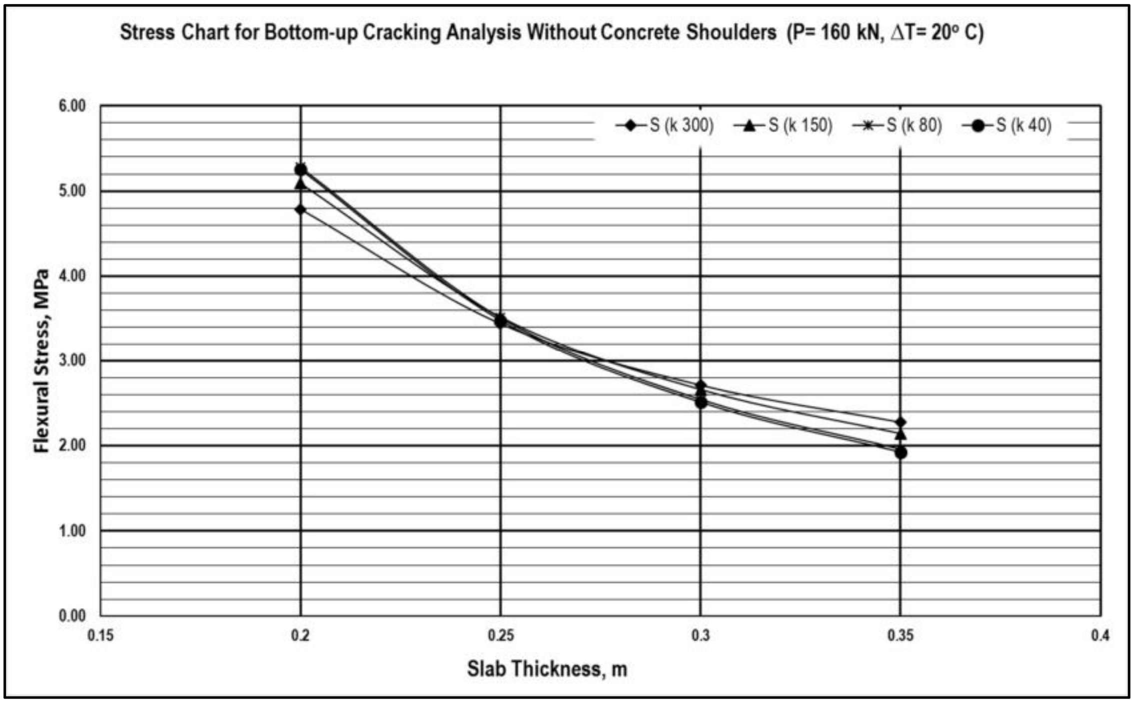
Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 80 kN, ∆T= 15° C)


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 120 kN, ∆T= 15° C)


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 160 kN, ∆T= 15° C)


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 80 kN, ∆T= 20° C)


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 120 kN, ∆T= 20° C)


Stress Chart for Bottom-up Cracking Analysis Without Concrete Shoulders (P= 160 kN, ΔT= 20° C)
S (k 300)
S (k 150)
S (k 80)
S (k 40)
Flexural Stress, MPa
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.15
0.2
0.25
0.3
0.35
0.4
Slab Thickness, m