SLAB GEOMETRY AND LOAD POSITION EFFECTS ON ULTRA-THIN WHITETOPPINGS: CONSIDERATIONS BASED ON NUMERICAL SOLUTION

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Sumary

The numerical analysis of stresses on ultra-thin whitetopping is just growing now-a-days, specially for defining the needs for concrete properties, as flexural and fatigue resistances. Although concrete strength and shrinkage takes important role on joint the design, the short joint spacing for ultra-thin whitetopping (UTW) deserves more detailed consideration in regard to the bus or truck lane width.

In this study is presented an analysis of flexural stresses considering dimensions of square slabs from 0,60 m to 1,20 m, taking a typical old flexible pavement and loads of single axles ranging from 80 kN to 150 kN. On the basis of this study it is stressed the critical load positions for UTW design.

Further, on the basis of an experimental fatigue relation for concrete it is presented an analysis of load equivalence factors for this kind of concrete overlays, confronting these results to the conventional equivalence law. The numerical model adopted for the study was a modified version of the FEACONS program, namely FEACONS 4.1SI, assembled last year (1997) with the cooperation between Prof. Mang Tia and the Pavement Mechanics Laboratory of University of São Paulo.

1. Introduction

At a first glance, the design of joint spacing for UTW is conditioned by two basic keys. From the structural point of view, when the stress analysis is supported by the Classical Theory of Plates, limits concerning the ratio between slab width and thickness must be considered in order to take note of the hypothesis of such theory. Then, this ratio is generally assumed to be from 20 to 30 by designers.

On the practical field, it must be remembered that special concretes are prior to built UTW, employing high cement content and usually, admixtures such as fly ash and silica fume and also early strength cements due to the nature of this kind of maintenance task. Shrinkage process during hydratation with these particular kinds of concretes are to be taken into account for defining short joint spacing in comparison with ordinary concretes for paving.

Actually, the geometric design of joints for UTW is also depending on the lane width and the axles dimensions for a given use of the pavement.

Considering the ratios between slab width and thickness to the employment of the conventional theory, leaving out of account the effective contribuition of the asphalt layer as an "additional thickness" for the concrete slab, from Table 1 it can be stated that widths from 0,70 m to 2,5 m are limitants for ratios around 20.

As a matter of fact, the surface dimensions of slabs have important role for stresses on concrete, also due to the relative position of loads over the slabs. Field measurements in Mexico showed that deformations on concrete for square slabs 1,20 m width and 90 mm thick were 73 % higher than the measured values for 0,90 m width and 65 mm thick slabs [1].

In USA, an early experiment with UTW carried out at Louisville, Kentucky, had shown to be more advantageous the employment of short joint spacing. After approximately 500.000 equivalent single axle loads, the slabs sawed each 1,80 m have developed corner cracks for almost all the cases; on the contrary, the slabs 0,60 width performed very well for such traffic volume (for both situations the thicknesses were 50 mm) [2].

Another experiment in USA, at Leawood, Kansas, pointed out the better performance of short joints spacings. Slabs 0,90 m width presented less distresses in comparison to slabs 1,20 m width, for the same traffic volume, both of them 50 mm thick [3].

The better behaviour of shorter slabs, for the same concrete, is related to the smaller flexural stresses due to the interaction load/pavement structure. Obviously, the short spacing for joints has a tendency to create a "block pavement system" when the vertical displacements due to loads can take a relevant role for the design. The limit of widths to get such situation could be take as a ratio between slab width and relative stiffness radius of 5 [4], for unbonded slabs.

On the basis of the last statement, taking the value of 28.000 MPa for the modulus of elasticity of the concrete (with Poisson 0,15) and the k-value for subgrade of 100 MPa/m, for instance, the ideal width for a 100 mm UTW, as presented on Table 2, could not exceed 1,90 m, so, yet smaller than values presented on Table 1.

Based on above considerations, it is believable that UTW projects must to limit the joint spacing at values not greater than 1,20; actually this empirical restriction could be enlarged by means of the use of suitable high resistant concretes to face the flexural stresses imposed on larger UTW slabs.

2. Lane Width and Suitable Dimensions

The square-shaped dimensions of UTW, as a common sense, must be the same for all the slabs within a traffic lane. Variable dimensions are not suitable considering design aspects (possible variability on the performance within the lane). It is supposed an "integer number" of slabs for each lane, with identical widths.

On Table 3 are presented the possible number of slabs concerning a range of lane width from 3,60 to 2,50 m, in order to comprise rural and urban ways; the variation of the lane width was tested for intervals of 0,05 m. The dimensions of slabs were verified from 0,60 to 1,20 m, in a step of 0,05 m. Only integer number of slabs are presented (blank cells).

Let's take as a reference axle the dual tyre single axle, and typical tyre inflation pressure of 638 kPa. On Figure 1 are presented the typical dimensions of such an axle and its relative position at the traffic lane. It must taken into account that, for a tandem axle comprising two sequential axles, the second axle, for the most critical position regarding the first axle, shall be over another slab, not the same slab, for joint spacings up to 1,20 m. Moreover, only one extremity of the reference axle will be placed at the same slab 1,20 m width.

On Figure 1 are presented some referencial position variables concerned to the location of the axle at the lane width by taking the y axis as referential. The variables have the following meanings:

Lw = lane width
Aw = axle width (measured from geometric centers of the pairs of loads)
Sw = slab width for UTW
Tp = truck external position related to longitudinal edge
Tp'= truck internal position related to the oposite longitudinal edge
Av = lateral displacement for the axle, from the central position at the lane, taken as 0,30 m.

The free width (Fw) out of the axle extension within the traffic lane can be calculated by:

$$Fw = Lw - Aw = Lw - 1{,}80$$

On the same way, the maximal and minimal truck <u>external</u> position related to longitudinal edge are gotten by:

$$Tp_{max} = Lw - Aw - (Fw / 2) + Av$$

$$Tp_{min} = Lw - Aw - (Fw / 2) - Av$$

For the maximal and minimal truck internal position related to the oposite pair of wheels, are given by:

$$Tp'_{max} = Tp_{min} + Aw$$

$$Tp'_{min} = Tp_{max} + Aw$$

For a centered position of the axle at the traffic lane, the truck positions related to external and internal loads are:

$$Tp_{center} = Fw / 2$$

$$Tp'_{center} = (Fw / 2) + Aw$$

Taking the above relations it becomes possible to define all the possible positions for the geometric center of dual tyre loads, and it is presented on Table 4, where all the mentioned lane widths (from 3,60 to 2,50 m) were considered.

Through the crossing of data presented on Tables 3 and 4, it is allowed to define the distance from the geometric center of a pair of tyres to each of the position of longitudinal joints resulted for any possible slab width and for any lane width (comprising the cases presented on Table 3).

These distances are finally presented on Table 5, where it was considered three possibilities: axle centered at the lane; positive variation of the axle from the central position; and negative variation of the axle from the central position. The values for distances between the geometric center of a dual tyre load and the joints on Table 5 can be analysed with the help of Figure 2 which shows the three situations for the loads.

On case (a) the pair of tyres are located in an way that the external tyre is tangent to the corner of the slab. For case (b), the geometric center of loads is located exactly at the longitudinal joint and the tyres are tangents to transversal joint; case (c) draws the situation when the center of loads is 0,30 m far from the longitudinal joint. For design purposes, all the mentioned cases could be considered as corner loads.

Consulting Table 5 its is easily verified that for all posibilities there is at least one distance between longitudinal joint and center of load little or equal to 0,30 m, *i.e*., for any situation of lane width and number of slabs occurs at least a corner load condition, and then, the design shall be done taking the corner load as a typical condition.

Indeed, the last statement is also supported by the fact that the corner loads induce the greater flexural stresses on UTW. Just to show this condition better, for instance, let’s to introduce a numerical simulation for a dual tyre load at three locations: center, transversal joint and corner of the UTW slab.

It was taken 1,20 by 1,20 m slabs for a concrete with elasticity modulus of 30.000 MPa and the asphalt layer supposed to have an elasticity modulus of 3.000 MPa and thickness of 70 mm. The pressure for the loaded area was 639 kPa for a total dual tyre load of 50 kN. The k-value of 50 MPa/m was assumed.

From such simulation, the resulting flexural stresses for the taken location of loads were: 4,28 MPa for the corner case (top stress); 3,57 MPa for the transversal joint case (bottom stress); and 3,62 MPa for the center of slab case (bottom stress). These received results agree well with previous field measurements [5] in terms of critical stresses for the slabs, *i.e.*, loads at free edges resulting the higher stresses and similar stresses for transversal joint and center of slab loads. At last, it must be stressed that the corner case must be taken as the critical location, both in geometric and mechanical terms, for the design of UTW.

3. Load Equivalence Factors

The employment of load equivalence factors (LEFs) to resume the forecasted axles in terms of a standard axle is a common design technique. The choice of convenient LEFs can be rationally done through two basic steps: to define a mechanictic way to compute the damage due to each load solicitation and its link to an empirical or experimental model relating the distress (rupture mode) to the number of load repetitions.

The recent studies related to UTW [2,5] describes the predominat rupture mode for the concrete: corner cracks. These distresses could be taken as result of stresses greater than the concrete strength or the fatigue consumption of concrete under flexural solicitations.

In order to verify the realibility of appling the "fourth power law" for UTW, concerning the fatigue behaviour as the rupture mode, in this study it was taken the fatigue relation proposed by Darter [6], given by the following expression:

$$SR = 0{,}943 - 0{,}057 \log_{10} N$$

where SR is the ratio between flexural stress and the ultimate flexural strength for the concrete and N is the number of load applications to fatigue.

The LEF is defined as the ratio of the unit damage caused by one application of any kind of load (du_j) to the unit damage due to an arbitrary standard load (du_s). The final condition for the distress evolution must be the same for any kind of load. The relation for LEF can be written as follows:

$$LEF = du_j / du_s$$

The unit damage can abstractly be defined as the ratio between the total damage (damage final situation) and the number of load applications associated to this condition. As the total damage must obbligatory be the same for any kind of load (axle or vehicle), then the LEF could be taken as:

$$LEF = N_s / N_j$$

LEFs are an interesting option to describe the sensivity of a given type of pavement structure to loads, and so, are often employed for road design to convert all the anticipate axles in terms of a standart axle. The most common and plain expression for the LEFs is as follows:

$$LEF = (W_j / W_s)^{\gamma}$$

where W_j is the total weight over a given axle, W_s is the weight of the standard axle and the exponent γ is a regression coefficient for the expression defined from a damage criteria for a traffic profile. In such expression, in fact exponent γ is the "thermometer" to verify the sensivity of a given pavement structure to loads (for a given rupture mode).

On Table 6 are presented analysis carried out in order to define values of exponent γ for some cases of UTW. For such analysis the following parameters had been taken: slab widths of 0,90 m and 1,20 m; k-value of 60 MPa/m; modulus of elasticity of 30.000 MPa and 3.000 MPa for concrete and asphalt mix layer, respectively; tyre pressures of 639 kPa; thickness of asphalt mixture of 70 mm. The ultimate flexural strength of concrete is assumed 6,0 MPa (high strength concrete).

From the received results it can be inferred that the thinner the slab is, more sensitive the UTW layer shall be to the loads: the exponent γ grows as the slab thickness decreases (averages for γ are 6,3 and 11 respectively for slab thicknesses of 100 mm and 60 mm). As the thickness grows, step by step the value of the exponent γ will approach the "fourth power law" for thicknesses greater than 100 mm, but in a thickness zone not concerned to UTW.

By the other hand, as larger the slab is, greater shall be the exponent γ (averages for γ are 3,4 and 8,9 respectively for slab widths of 0,90 m and 1,20 m, 80 mm thick). Then, as larger the slab is, more sensitive to loads becomes the UTW, considering the fatigue failure of the concrete as the main damage mode.

These results agree with others that could be taken from the recent American developments on UTW numerical modelling. From the guideline procedure proposed by Mack *et alli* [5] it can be backcalculated the exponent γ resulting from their numerical model for computing the flexural stresses on UTW. From the design example presented in that paper, for a slab width of 1,22 m and 65 mm thick, the exponent γ ranged from 10 to 13. Then, for UTW the old rule ("fourth power law") could not be applied because will induce the risk of underdesign for concrete thicknesses.

4. Conclusions

In order to decrease flexural stresses on UTW and to take advantage of its vertical displacement behaviour the slabs must to be shorter than traditional slabs for plain concrete pavements. There are empirical evidences pointing out the maximum joint spacing to values close to 1,20 m; the mechanistic approach has agreed to this observation.

For slab widths from 0,60 m to 1,20 m and conventional truck axles, the geometric location possibilities for loads point out the corner load as an unavoidable design situation. Indeed, the greater top flexural stresses due to corner loads compels to take this situation as the critical for the design of UTW, considering the discussed geometric aspects.

In regard to the conversion of the anticipate traffic for an equivalent number of single axle loads (for design purposes), the employment of "fourth power law" must be avoided. The exponent γ for computing load equivalent factors can range from 6 to 11 for a slab width of 1,20 m, and, in such way it is stressed the needs for definition of mechanistic values for this parameter; this could be reached on the basis of experimental or empirical models concerning concrete failure.

From the results presented above, it is very easy to conclude that the smaller the slab is less sensitive to the loads concerning flexural stresses it becomes, and so, the slabs shall be working more in terms of vertical displacements. At last, it is found by numerical modelling that short joint spacing, little than 1,20 m, will be more advantageous for design, construction costs and performance, ratifing the recent field results experienced in USA.

Nevertheless, the question could be more clarified in future through the progress on high performance concrete researches concerning its fatigue behaviour, once the employment of such concretes seems to be obbligatory to achieve long-lasting service for UTW.

References

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Table 1 Dimensions for UTW based on several ratios between width and thickness

UTW width (mm)	Dimensions for UTW (m)				
	Ratio width / thickness				
	15	**17,5**	**20**	**25**	**30**
40	0,6	0,7	0,8	1	1,2
50	0,75	0,875	1	1,25	1,5
60	0,9	1,05	1,2	1,5	1,8
70	1,05	1,225	1,4	1,75	2,1
80	1,2	1,4	1,6	2	2,4
90	1,35	1,575	1,8	2,25	2,7
100	1,5	1,75	2	2,5	3

Table 2 Width limits in order to decrement flexural stresses.

UTW thickness (mm)	Relative Stiffness Radius	Width limit (m)
50	0,23	1,15
60	0,27	1,35
70	0,30	1,50
80	0,33	1,65
90	0,36	1,80
100	0,39	1,90

Table 3 Number of slabs as a function of lane width and joint spacing

	Joint spacing (m)												
Lane width (m)	**0,60**	**0,65**	**0,70**	**0,75**	**0,80**	**0,85**	**0,90**	**0,95**	**1,00**	**1,05**	**1,10**	**1,15**	**1,20**
3,60	6						4						3
3,50			5										
3,45												3	
3,40						4							
3,30											3		
3,25		5											
3,20					4								
3,15										3			
3,00	5			4					3				
2,85								3					
2,80			4										
2,70							3						
2,60		4											
2,55						3							

Table 4 Position of the geometric center of loads referred to the external longitudinal joint (report to Figure 1) - values in meters

Lw	Aw	Fw/2	Av	Tp_{max}	Tp_{min}	$T'p_{max}$	Tp'_{min}	Tp_{cen}	Tp'_{cen}
3,60	1,80	0,90	0,30	1,20	0,60	2,40	3,00	0,90	2,70
3,55	1,80	0,88	0,30	1,18	0,58	2,38	2,98	0,88	2,68
3,50	1,80	0,85	0,30	1,15	0,55	2,35	2,95	0,85	2,65
3,45	1,80	0,83	0,30	1,13	0,53	2,33	2,93	0,83	2,63
3,40	1,80	0,80	0,30	1,10	0,50	2,30	2,90	0,80	2,60
3,35	1,80	0,78	0,30	1,08	0,48	2,28	2,88	0,78	2,58
3,30	1,80	0,75	0,30	1,05	0,45	2,25	2,85	0,75	2,55
3,25	1,80	0,73	0,30	1,03	0,43	2,23	2,83	0,73	2,53
3,20	1,80	0,70	0,30	1,00	0,40	2,20	2,80	0,70	2,50
3,15	1,80	0,68	0,30	0,98	0,38	2,18	2,78	0,68	2,48
3,10	1,80	0,65	0,30	0,95	0,35	2,15	2,75	0,65	2,45
3,05	1,80	0,63	0,30	0,93	0,33	2,13	2,73	0,63	2,43
3,00	1,80	0,60	0,30	0,90	0,30	2,10	2,70	0,60	2,40
2,95	1,80	0,58	0,30	0,88	0,28	2,08	2,68	0,58	2,38
2,90	1,80	0,55	0,30	0,85	0,25	2,05	2,65	0,55	2,35
2,85	1,80	0,53	0,30	0,83	0,23	2,03	2,63	0,53	2,33
2,80	1,80	0,50	0,30	0,80	0,20	2,00	2,60	0,50	2,30
2,75	1,80	0,48	0,30	0,78	0,18	1,98	2,58	0,48	2,28
2,70	1,80	0,45	0,30	0,75	0,15	1,95	2,55	0,45	2,25
2,65	1,80	0,43	0,30	0,73	0,13	1,93	2,53	0,43	2,23
2,60	1,80	0,40	0,30	0,70	0,10	1,90	2,50	0,40	2,20
2,55	1,80	0,38	0,30	0,68	0,07	1,88	2,48	0,38	2,18
2,50	1,80	0,35	0,30	0,65	0,05	1,85	2,45	0,35	2,15

Table 5 Distances from the geometric center of dual tyres to any longitudinal joint (*in italics*) - values in meters

Slab width (m)	Possible Lw (m)	Number of slabs	Longitudinal joint position (m)	Position of geometric center of loads related to external joint (m) – Central Position – Ext. Tyres	Central Position – Int. Tyres	Positive Displacement – Ext. Tyres	Positive Displacement – Int. Tyres	Negative Displacement – Ext. Tyres	Negative Displacement – Int. Tyres
0,6	**3,60**			**0,90**	**2,70**	**1,20**	**3,00**	**0,60**	**2,40**
		6	**0,00**	*0,90*	*2,70*	*1,20*	*3,00*	*0,60*	*2,40*
			0,60	*0,30*	*2,10*	*0,60*	*2,40*	***0,00***	*1,80*
			1,20	*-0,30*	*1,50*	***0,00***	*1,80*	*-0,60*	*1,20*
			1,80	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,40	*-1,50*	*0,30*	*-1,20*	*0,60*	*-1,80*	***0,00***
			3,00	*-2,10*	*-0,30*	*-1,80*	***0,00***	*-2,40*	*-0,60*
			3,60	*-2,70*	*-0,90*	*-2,40*	*-0,60*	*-3,00*	*-1,20*
	3,00			**0,60**	**2,40**	**0,90**	**2,70**	**0,30**	**2,10**
		5	**0,00**	*0,60*	*2,40*	*0,90*	*2,70*	*0,30*	*2,10*
			0,60	***0,00***	*1,80*	*0,30*	*2,10*	*-0,30*	*1,50*
			1,20	*-0,60*	*1,20*	*-0,30*	*1,50*	*-0,90*	*0,90*
			1,80	*-1,20*	*0,60*	*-0,90*	*0,90*	*-1,50*	*0,30*
			2,40	*-1,80*	***0,00***	*-1,50*	*0,30*	*-2,10*	*-0,30*
			3,00	*-2,40*	*-0,60*	*-2,10*	*-0,30*	*-2,70*	*-0,90*
0,65	**3,25**			**0,73**	**2,53**	**1,03**	**2,83**	**0,43**	**2,23**
		5	**0,00**	*0,73*	*2,53*	*1,03*	*2,83*	*0,43*	*2,23*
			0,65	***0,08***	*1,88*	*0,38*	*2,18*	*-0,22*	*1,58*
			1,30	*-0,57*	*1,23*	*-0,27*	*1,53*	*-0,87*	*0,93*
			1,95	*-1,22*	*0,58*	*-0,92*	*0,88*	*-1,52*	*0,28*
			2,60	*-1,87*	***-0,07***	*-1,57*	*0,23*	*-2,17*	*-0,37*
			3,25	*-2,52*	*-0,72*	*-2,22*	*-0,42*	*-2,82*	*-1,02*
	2,60			**0,40**	**2,20**	**0,70**	**2,50**	**0,10**	**1,90**
		4	**0,00**	*0,40*	*2,20*	*0,70*	*2,50*	***0,10***	*1,90*
			0,65	*-0,25*	*1,55*	***0,05***	*1,85*	*-0,55*	*1,25*
			1,30	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			1,95	*-1,55*	*0,25*	*-1,25*	*0,55*	*-1,85*	***-0,05***
			2,60	*-2,20*	*-0,40*	*-1,90*	***-0,10***	*-2,50*	*-0,70*
0,70	**3,50**			**0,85**	**2,65**	**1,15**	**2,95**	**0,55**	**2,35**
		5	**0,00**	*0,85*	*2,65*	*1,15*	*2,95*	*0,55*	*2,35*
			0,70	*0,15*	*1,95*	*0,45*	*2,25*	***-0,15***	*1,65*
			1,40	*-0,55*	*1,25*	*-0,25*	*1,55*	*-0,85*	*0,95*
			2,10	*-1,25*	*0,55*	*-0,95*	*0,85*	*-1,55*	*0,25*
			2,80	*-1,95*	*-0,15*	*-1,65*	***0,15***	*-2,25*	*-0,45*
			3,50	*-2,65*	*-0,85*	*-2,35*	*-0,55*	*-2,95*	*-1,15*

Table 5 Distances from the geometric center of dual tyres to any longitudinal joint (*in italics*) - values in meters - ***continuation***

Slab width (m)	Possible Lw (m)	Number of slabs	Longitudinal joint position (m)	Position of geometric center of loads related to external joint (m)					
				Central Position		Positive Displacement		Negative Displacement	
				Ext. Tyres	Int. Tyres	Ext. Tyres	Int. Tyres	Ext. Tyres	Int. Tyres
	2,80			**0,50**	**2,30**	**0,80**	**2,60**	**0,20**	**2,00**
		4	**0,00**	*0,50*	*2,30*	*0,80*	*2,60*	*0,20*	*2,00*
			0,70	*-0,20*	*1,60*	***0,10***	*1,90*	*-0,50*	*1,30*
			1,40	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,10	*-1,60*	*0,20*	*-1,30*	*0,50*	*-1,90*	***-0,10***
			2,80	*-2,30*	*-0,50*	*-2,00*	*-0,20*	*-2,60*	*-0,80*
0,75	**3,00**			**0,60**	**2,40**	**0,90**	**2,70**	**0,30**	**2,10**
		4	**0,00**	*0,60*	*2,40*	*0,90*	*2,70*	*0,30*	*2,10*
			0,75	***-0,15***	*1,65*	***0,15***	*1,95*	*-0,45*	*1,35*
			1,50	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,25	*-1,65*	***0,15***	*-1,35*	*0,45*	*-1,95*	***-0,15***
			3,00	*-2,40*	*-0,60*	*-2,10*	*-0,30*	*-2,70*	*-0,90*
0,80	**3,20**			**0,70**	**2,50**	**1,00**	**2,80**	**0,40**	**2,20**
		4	**0,00**	*0,70*	*2,50*	*1,00*	*2,80*	*0,40*	*2,20*
			0,80	***-0,10***	*1,70*	*0,20*	*2,00*	*-0,40*	*1,40*
			1,60	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,40	*-1,70*	***0,10***	*-1,40*	*0,40*	*-2,00*	*-0,20*
			3,20	*-2,50*	*-0,70*	*-2,20*	*-0,40*	*-2,80*	*-1,00*
0,85	**3,40**			**0,80**	**2,60**	**1,10**	**2,90**	**0,50**	**2,30**
		4	**0,00**	*0,80*	*2,60*	*1,10*	*2,90*	*0,50*	*2,30*
			0,85	***-0,05***	*1,75*	*0,25*	*2,05*	*-0,35*	*1,45*
			1,70	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,55	*-1,75*	***0,05***	*-1,45*	*0,35*	*-2,05*	*-0,25*
			3,40	*-2,60*	*-0,80*	*-2,30*	*-0,50*	*-2,90*	*-1,10*
	2,55			**0,38**	**2,18**	**0,68**	**2,48**	**0,07**	**1,88**
		3	**0,00**	*0,38*	*2,18*	*0,68*	*2,48*	***0,07***	*1,88*
			0,85	*-0,47*	*1,33*	*-0,17*	*1,63*	*-0,78*	*1,03*
			1,70	*-1,32*	*0,48*	*-1,02*	*0,78*	*-1,63*	*0,18*
			2,55	*-2,17*	*-0,37*	*-1,87*	***-0,07***	*-2,48*	*-0,67*
0,90	**3,60**			**0,90**	**2,70**	**1,20**	**3,00**	**0,60**	**2,40**
		4	**0,00**	*0,90*	*2,70*	*1,20*	*3,00*	*0,60*	*2,40*
			0,90	***0,00***	*1,80*	***0,30***	*2,10*	***-0,30***	*1,50*
			1,80	*-0,90*	*0,90*	*-0,60*	*1,20*	*-1,20*	*0,60*
			2,70	*-1,80*	***0,00***	*-1,50*	***0,30***	*-2,10*	***-0,30***
			3,60	*-2,70*	*-0,90*	*-2,40*	*-0,60*	*-3,00*	*-1,20*

Table 5 Distances from the geometric center of dual tyres to any longitudinal joint (*in italics*) - values in meters - ***continuation***

Slab	Possible	Number	Longitudinal	Position of geometric center of loads related to external joint (m)					
width	Lw	of	joint	Central	Position	Positive Displacement		Negative Displacement	
(m)	(m)	slabs	position (m)	Ext. Tyres	Int. Tyres	Ext. Tyres	Int. Tyres	Ext. Tyres	Int. Tyres
	2,70			**0,45**	**2,25**	**0,75**	**2,55**	**0,15**	**1,95**
		3	**0,00**	*0,45*	*2,25*	*0,75*	*2,55*	***0,15***	*1,95*
			0,90	*-0,45*	*1,35*	***-0,15***	*1,65*	*-0,75*	*1,05*
			1,80	*-1,35*	*0,45*	*-1,05*	*0,75*	*-1,65*	***0,15***
			2,70	*-2,25*	*-0,45*	*-1,95*	***-0,15***	*-2,55*	*-0,75*
0,95	**2,85**			**0,53**	**2,33**	**0,83**	**2,63**	**0,23**	**2,03**
		3	**0,00**	*0,53*	*2,33*	*0,83*	*2,63*	*0,23*	*2,03*
			0,95	*-0,42*	*1,38*	***-0,12***	*1,68*	*-0,72*	*1,08*
			1,90	*-1,37*	*0,43*	*-1,07*	*0,73*	*-1,67*	***0,13***
			2,85	*-2,32*	*-0,52*	*-2,02*	*-0,22*	*-2,62*	*-0,82*
1,00	**3,00**			**0,60**	**2,40**	**0,90**	**2,70**	**0,30**	**2,10**
		3	**0,00**	*0,60*	*2,40*	*0,90*	*2,70*	*0,30*	*2,10*
			1,00	*-0,40*	*1,40*	***-0,10***	*1,70*	*-0,70*	*1,10*
			2,00	*-1,40*	*0,40*	*-1,10*	*0,70*	*-1,70*	***0,10***
			3,00	*-2,40*	*-0,60*	*-2,10*	*-0,30*	*-2,70*	*-0,90*
1,05	**3,15**			**0,68**	**2,48**	**0,98**	**2,78**	**0,38**	**2,18**
		3	**0,00**	*0,68*	*2,48*	*0,98*	*2,78*	*0,38*	*2,18*
			1,05	*-0,37*	*1,43*	***-0,07***	*1,73*	*-0,67*	*1,13*
			2,10	*-1,42*	*0,38*	*-1,12*	*0,68*	*-1,72*	***0,08***
			3,15	*-2,47*	*-0,67*	*-2,17*	*-0,37*	*-2,77*	*-0,97*
1,10	**3,30**			**0,75**	**2,55**	**1,05**	**2,85**	**0,45**	**2,25**
		3	**0,00**	*0,75*	*2,55*	*1,05*	*2,85*	*0,45*	*2,25*
			1,10	*-0,35*	*1,45*	***-0,05***	*1,75*	*-0,65*	*1,15*
			2,20	*-1,45*	*0,35*	*-1,15*	*0,65*	*-1,75*	***0,05***
			3,30	*-2,55*	*-0,75*	*-2,25*	*-0,45*	*-2,85*	*-1,05*
1,15	**3,45**			**0,83**	**2,63**	**1,13**	**2,93**	**0,53**	**2,33**
		3	**0,00**	*0,83*	*2,63*	*1,13*	*2,93*	*0,53*	*2,33*
			1,15	*-0,32*	*1,48*	***-0,02***	*1,78*	*-0,62*	*1,18*
			2,30	*-1,47*	*0,33*	*-1,17*	*0,63*	*-1,77*	***0,03***
			3,45	*-2,62*	*-0,82*	*-2,32*	*-0,52*	*-2,92*	*-1,12*
1,20	**3,60**			**0,90**	**2,70**	**1,20**	**3,00**	**0,60**	**2,40**
		3	**0,00**	*0,90*	*2,70*	*1,20*	*3,00*	*0,60*	*2,40*
			1,2	*-0,30*	*1,50*	***0,00***	*1,80*	*-0,60*	*1,20*
			2,4	*-1,50*	*0,30*	*-1,20*	*0,60*	*-1,80*	***0,00***
			3,6	*-2,70*	*-0,90*	*-2,40*	*-0,60*	*-3,00*	*-1,20*

Table 6 Sensivity analysis of exponent γ for fatigue failure on UTW

UTW thickness (m)	Slab width (m)	Total Axle Load (kN)	Wj/Ws	Flexural stress (MPa)	SN relation	Allowed N	LEF	γ
0,06	0,90	60	0,750	2,044	0,34	4,09E+10	0,246	4,8712
		70	0,875	2,219	0,37	1,25E+10	0,808	1,5956
		80	1,000	2,251	0,38	1,01E+10	1,000	
		90	1,125	2,337	0,39	5,64E+09	1,786	4,9265
		100	1,250	2,457	0,41	2,50E+09	4,025	6,2403
		110	1,375	2,481	0,41	2,13E+09	4,737	4,8840
		120	1,500	2,618	0,44	8,44E+08	11,950	6,1183
		130	1,625	2,602	0,43	9,39E+08	10,739	4,8894
		140	1,750	2,615	0,44	8,60E+08	11,726	4,3991
		150	1,875	2,726	0,45	4,08E+08	24,737	5,1038
0,06	1,20	60	0,750	2,846	0,47	1,80E+08	0,041	10,9211
		70	0,875	3,079	0,51	3,74E+07	0,199	11,9446
		80	1,000	3,318	0,55	7,44E+06	1,000	
		90	1,125	3,490	0,58	2,33E+06	3,192	10,7531
		100	1,250	3,727	0,62	4,70E+05	15,827	12,8109
		110	1,375	3,927	0,65	1,22E+05	61,100	13,1493
		120	1,500	3,896	0,65	1,49E+05	49,794	9,9504
		130	1,625	4,078	0,68	4,37E+04	170,415	10,6469
		140	1,750	4,087	0,68	4,11E+04	181,058	9,4425
		150	1,875	4,198	0,70	1,95E+04	382,307	9,6809
0,08	0,90	60	0,750	1,550	0,26	1,15E+12	0,277	4,4631
		70	0,875	1,653	0,28	5,72E+11	0,555	4,4132
		80	1,000	1,740	0,29	3,18E+11	1,000	
		90	1,125	1,807	0,30	2,02E+11	1,573	3,8439
		100	1,250	1,793	0,30	2,22E+11	1,430	1,6018
		110	1,375	1,893	0,32	1,13E+11	2,801	3,2345
		120	1,500	1,926	0,32	9,06E+10	3,504	3,0928
		130	1,625	2,052	0,34	3,86E+10	8,217	4,3382
		140	1,750	1,946	0,32	7,94E+10	4,001	2,4776
		150	1,875	2,023	0,34	4,71E+10	6,739	3,0351
0,08	1,20	60	0,750	2,117	0,35	2,48E+10	0,078	8,7223
		70	0,875	2,324	0,39	6,15E+09	0,317	8,4959
		80	1,000	2,494	0,42	1,95E+09	1,000	
		90	1,125	2,619	0,44	8,36E+08	2,331	7,8415
		100	1,250	2,842	0,47	1,86E+08	10,474	10,8958
		110	1,375	2,919	0,49	1,11E+08	17,619	9,1732
		120	1,500	3,060	0,51	4,25E+07	45,830	9,7392
		130	1,625	3,101	0,52	3,23E+07	60,339	8,4955
		140	1,750	3,232	0,54	1,33E+07	146,190	9,0540
		150	1,875	3,215	0,54	1,49E+07	130,458	7,9305

Table 6 Sensivity analysis of exponent γ for fatigue failure on UTW - ***continuation***

UTW thickness (m)	Slab width (m)	Total Axle Load (kN)	Wj/Ws	Flexural stress (MPa)	SN relation	Allowed N	LEF	γ
		60	0,750	1,150	0,19	1,72E+13	0,329	3,8641
		70	0,875	1,236	0,21	9,57E+12	0,590	3,9541
		80	1,000	1,315	0,22	5,64E+12	1,000	
		90	1,125	1,343	0,22	4,67E+12	1,209	1,6119
0,10	**0,90**	100	1,250	1,380	0,23	3,62E+12	1,560	1,9925
		110	1,375	1,447	0,24	2,31E+12	2,444	2,8058
		120	1,500	1,432	0,24	2,55E+12	2,213	1,9592
		130	1,625	1,525	0,25	1,36E+12	4,136	2,9240
		140	1,750	1,470	0,25	1,97E+12	2,862	1,8792
		150	1,875	1,506	0,25	1,55E+12	3,639	2,0549
		60	0,750	1,638	0,27	6,34E+11	0,140	6,7487
		70	0,875	1,773	0,30	2,55E+11	0,347	7,8178
		80	1,000	1,929	0,32	8,85E+10	1,000	
		90	1,125	1,983	0,33	6,17E+10	1,434	3,3385
0,10	**1,20**	100	1,250	2,178	0,36	1,65E+10	5,358	7,7863
		110	1,375	2,269	0,38	8,95E+09	9,895	7,3284
		120	1,500	2,283	0,38	8,10E+09	10,929	6,0891
		130	1,625	2,320	0,39	6,33E+09	13,978	5,4651
		140	1,750	2,419	0,40	3,24E+09	27,339	6,0088
		150	1,875	2,498	0,42	1,89E+09	46,719	6,2586

Figure 1 Dimensions and locations of the reference axle over the trafic lane.

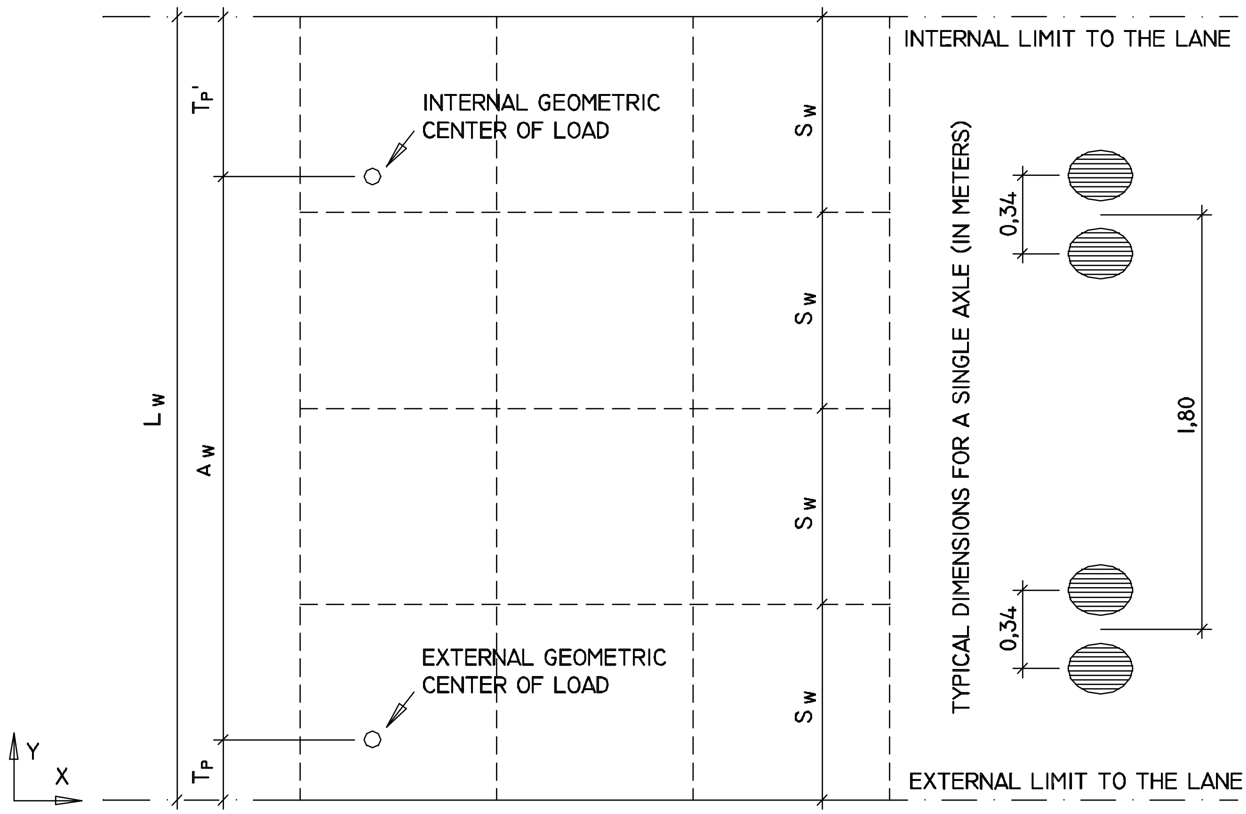

Figure 2 Locations of loads near the slab corner