PAVEMENT DESIGN FOR LARGE ELEMENT PAVING SLABS

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ABSTRACT

Segmental paving slabs are seeing increased use in the U.S. and Canada in municipal, commercial and residential vehicular applications. Currently, there are no structural design guidelines in North America for such applications. In addition, there are no structural guidelines for precast concrete ‘planks’ (long, thin units), thin paving units (sometimes called tile pavers), or large-format units (sometimes called mega-slabs). The lack of rational design data likely places manufacturers, contractors and purchasers at risk, increasing the probability of failures.

This paper outlines the results of a literature survey and finite element modelling that was completed for a series of combinations of experimental variables that induced tensile stresses and slab deflections resulting from the combination of material properties, slab dimension, and support structure for typical vehicle/loading levels. The stresses were compared to various flexural strengths to determine a stress ratio matrix. The matrix provides design guidance for the use of large element paving slabs for both flexible (slabs over a granular base) and composite (slabs over a lean concrete base) for pedestrian, low, moderate and higher traffic levels. Details on the modelling method and parameters including a parametric study of load positioning are provided. Design charts are provided for various configurations of square, rectangular and plank paving elements.

The results of this study provide a logical and defendable approach to the structural design of pedestrian and roadway designs surfaced with large element paving slabs and tiles. While the approach taken is considered to be conservative, the validity of the designs would benefit through validation based on field observation or accelerated load testing.

Keywords: Large element paving slabs, finite element modelling, paving slab design.

INTRODUCTION

Segmental paving slabs are seeing increased use in the U.S. and Canada in municipal, commercial and residential vehicular applications. These slabs generally have aspect ratios of 2:1 or greater and can have lengths and widths of anywhere from 75 to 300 mm and lengths of 300 to 1,200 mm with thicknesses varying from 50 to 125 mm. The composition of the slabs can be cut natural stone or manufactured products through the use of slab presses. Examples of large element paving slabs are shown in Figure 1.

Figure 1. Examples of Large Element Paving Slabs.

Currently, there are no structural design guidelines in North America for such applications. In addition, there are no structural guidelines for precast concrete ‘planks’ (long, thin units), thin paving units (sometimes called tile pavers), or large-format units (sometimes called mega-slabs). The lack of rational design data likely places manufacturers, contractors and purchasers at risk, increasing the probability of failures.

A review of literature on the modeling of paving slabs was completed to develop recommended parameters and finite element modeling (FEM) in support of the use of square, rectangular, plank and thin tile paving slabs. As anticipated, there has not been a significant amount of work done in this area in North America.

Blab, et al (Blab 2012), constructed pavement test sections in a test pit (6.4 m long and 5.0 m wide). Two slabs and two of the blocks were instrumented in the wheelpath with strain gauges, soil pressure cells and thermocouples to determine the response under loading conditions. The test program included visual inspection, Falling Weight Deflectometer (FWD) measurements and response measurements. Accelerated pavement testing was carried out through the Mobile Load Simulator MLS10. MLS10 was equipped with Goodyear 455/40 R22.5 super single tires with a tire pressure of 1.06 N/mm^2 and a wheel load of 65kN. A total of 1,189,353 load applications were distributed over the seven sections in 31 days of testing. A finite element model was developed to validate the sensor data from MLS 10. The results of the modelling compared reasonably well with the strain gauges on the bottom of the slabs and the soil pressure gauges placed on the top of the base aggregate and top of the subgrade.

Bull, J.W., (Bull 1989), describes the result of finite element modeling completed for the structural design of slab pavements in the U.K. The research showed that the maximum concrete tensile stresses occurred when the truck wheel was placed at the center of one edge of the paving slab. The maximum vertical compressive soil bearing pressure was achieved when the wheel was placed at the corner of the paving slab. A total of 800 elements were used to model the pavement and vertical compressive soil bearing pressure of the paving was determined. To determine the maximum concrete and soil stress a standard 80kN axle load was adopted. Maximum concrete stress was determined when the wheels were placed at the center of one edge and maximum vertical compressive soil bearing pressure was obtained when the wheel was at a corner of the paving slab.

This reference also provided a relation to determine the number of load applications that would cause overstressing of the subgrade soil (N – 80 kN standard axles), the allowable soil bearing pressure (B) at the top of the subgrade and the CBR (C) of the subgrade as follows:

$$N = [(280 \times C)/B]^4$$

The work described a stress ratio concept for the number of load application until overstressing of the concrete slabs cause them to crack. The relationship is as follows:

$$\text{Log } N = 111.78 - 12.11 \times (\text{stress/modulus of rupture})$$

For a stress ratio of < 0.5, the number of load applications to failure is assumed to be infinity. The research completed a number of iterations to determine the sensitivity of the concrete stress.

Shackel and Pearson (Shackel 2000) visited various European paving associations and slab manufacturers during 1998 and 1999 including Britain, Belgium, Germany, Austria, Denmark and Sweden. In Belgium, it was reported that slabs 400 x 400 mm or 500 x 500 mm break under traffic and that, to ensure good service, a maximum size of 300 x 300 mm was recommended. In Britain, the maximum slab size for trafficked pavements has been specified to be 450 x 450 mm. Austria implied a maximum slab size of 450 x 450 x 70 mm.

In some countries, the strengths required for slabs are independent of their dimensions. The Belgium standard specifies flexural strengths of 5 MPa for individual units with a mean value of 6 MPa. Scandinavia specifies a minimum flexural strength of 6 MPa. A detailed review of the design procedure was completed. Design parameters like traffic, slab properties, base thickness were determined. This design review was restricted to the use of square slab only. Theoretical analysis was performed to observe the relationship between the slab dimension, thickness and tensile strength to ensure that slab would not crack under traffic. Design charts were prepared for different pavement bases and traffic to determine the base thickness.

A draft bridge standard (British 2014), provides structural design guidance for clay, natural stone and interlocking concrete pavers and square paving slabs up to a maximum dimension of 450 x 450 mm. Structural design tables permit the user to determine the appropriate pavement thickness depending on traffic category, base/subbase and subgrade type and support capability. Details are provided for unit tolerances as well as examples of how to use the standard to design the pavement.

Transpavé (Transpavé 2015), outlines products and technical recommendations for the use of large dimension urban pavers. They are introducing what is called “Pavers Flexural Capacity” to compare the relative flexural strength of “pavers” to select the most effective product for the vehicular load type. The document uses the flexural strength of a paver expressed in Newtons compared to a “safe minimum” flexural strength of 4.5 MPa to compare pavers to one another. The document compares the flexural capacity of the products marketed by Transpavé and classifies their use for pedestrian only, light, heavy and very heavy traffic types.

METHODOLOGY

Based on the review of the technical literature the recommended configuration parameters for the finite element modeling were as follows:

- Paving slab category (square, rectangle, plank)
- Dimensions in mm: 300 x 300, 600 x 600, 900 x 900 and 1,200 x 1,200 for square;
- 300 x 450, 300 x 600, 500 x 600, 525 x 750, 600 x 900, 600 x 1,200, 900 x 1,200 for rectangles; and 300 x 75, 600 x 100, 900 x 150, 300, 450, 600, 750, 900 and 1,200 mm lengths by 75, 100, 125 and 150 mm widths for planks
- Thickness (50, 75, 100 and 125 mm)

- Thin “tile pavers”: 100 x 200 mm by 20 mm, 30 mm, and 40 mm thick
- Slab material properties (flexural strength 4.5, 4.8 and 5.2 MPa as determined per the draft ASTM paving slab standard.
- Slab unit weight = 2,400 kg/ m^3, Modulus of elasticity = 40,000 MPa, Poisson’s ratio = 0.2, Lateral Modulus of Reaction = 150 MN/m3
- Joint sand material, unit weight = 1,800 kg/ m^3, Modulus of elasticity 1,000 MPa, Poisson’s ratio = 0.3, Lateral Modulus of Reaction = 150 MN/ m^3
- Bedding unit weight = 1,800 kg/ m^3, sand 25 mm thick, modulus of elasticity 1,000 MPa, Poisson’s ratio = 0.3, Lateral Modulus of Reaction = 150 MN/ m^3
- Base material unit weight = 2,100 kg/ m^3, modulus of elasticity = 250 MPa, Poisson’s ratio = 0.15
- Cement treated base unit weight = 1,800 kg/ m^3, modulus of elasticity = 16,000 MPa, Poisson’s ratio = 0.2, Lateral Modulus of Reaction = 150 MN/ m^3
- Concrete base unit weight = 2,400 kg/ m^3, modulus of elasticity = 26,250 MPa, Poisson’s ratio = 0.2, Lateral Modulus of Reaction = 150 MN/ m^3
- Subgrade unit weight = 1,500 kg/m^3, 35 MPa, 50 MPa, 60 MPa, 80 MPa, Poisson’s ratio = 0.4, Lateral Modulus of Reaction = 150 MN/m^3
- Loading = North American Standard Dual Wheel radial tires, ½ axle load = 40 kN, tire pressure (hot) = 0.827 MPa
- Location of critical load may be center, edge, or corner depending on slab dimensions

A factorial experiment was designed to incorporate all feasible combinations of the above-listed variables. The output generated for each of the combinations of the experimental variables induced tensile stresses and slab deflections resulting from the combination of material properties, slab dimension, and support structure for the vehicle/loading levels.

Prior to the commencement of the full-scale modeling, a parametric study was completed to determine the most efficient finite element mesh size to maximize value and minimize run time and to determine critical locations for the wheel load on the paving slabs to identify the location for maximum tensile stress.

A plan view of the paving slab layout using a running bond, with half paver offset is shown in Figure 2. This configuration was used for all dimensions of paving slabs.

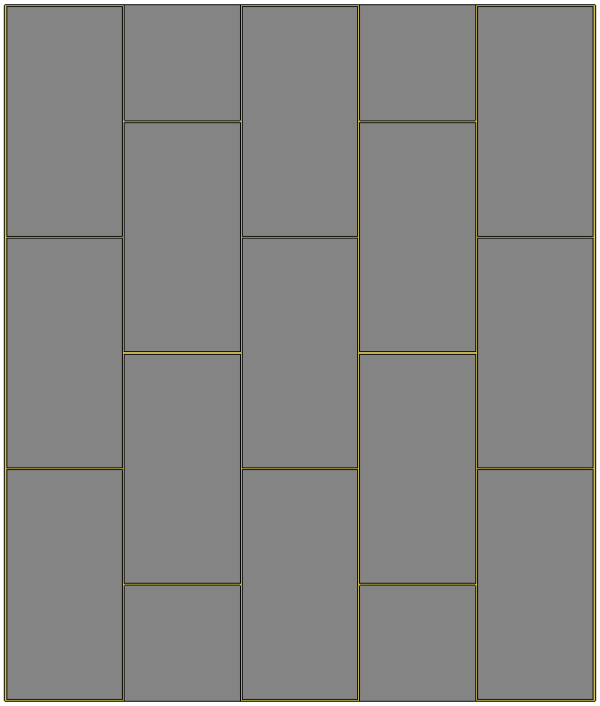


Figure 2. Plan View of Paving Slab Layout

The model was assumed to be a fixed container on the sides and bottom. The pavement materials were permitted to slide freely against the container with a coefficient of friction of 0.35. The loading was applied as a variable pressure across dual tires until it reached a constant stress. The contact modeling between the sand bedding and the underlying base utilized a static coefficient of friction of 0.35.

The loading applied simulates the load due to a single pair of North American Standard truck dual wheel radial tires. The tires are oriented so the direction of travel is across the smaller dimension of the pavers. An analysis of the contact pressure of the tires was used to develop appropriate loading for the model. The tire imprint (Figure 3) was developed from information published by the Michelin Tire Company [Al-Qadi 2004]. The tread shapes are approximated as rectangles and the tread widths are extended to fill the tread gaps. By holding the tread length ratios, and tread contact pressure ratios constant, the required contact pressure and tread lengths can then be calculated given the total load and the total contact area (Table 1).

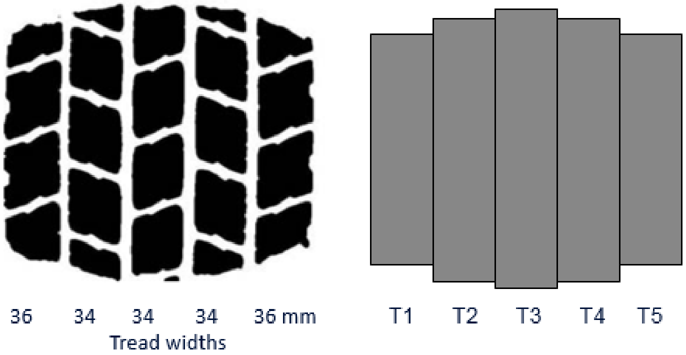


Figure 3. Tire Contact Patch

Table 1. Contact Area for Tire Pressure Calculations

	T1	T2	T3	T4	T5	Total
Tread width (mm)	36	34	34	34	36	174
Tread width – scaled	41.8	39.5	39.5	39.5	41.8	202
Tread length (mm)	146	172	179	172	146	
Contact Area (mm²) Rectangular tread	6,100	6,790	7,070	6,790	6,100	32,850

Once the loading configuration was established, an analysis of the maximum principal stresses under a single paver was completed. This was done to “fine tune” the finite element mesh size to optimize the computer run time. An example of the results for a 10 mm mesh size is shown in Figure 4.

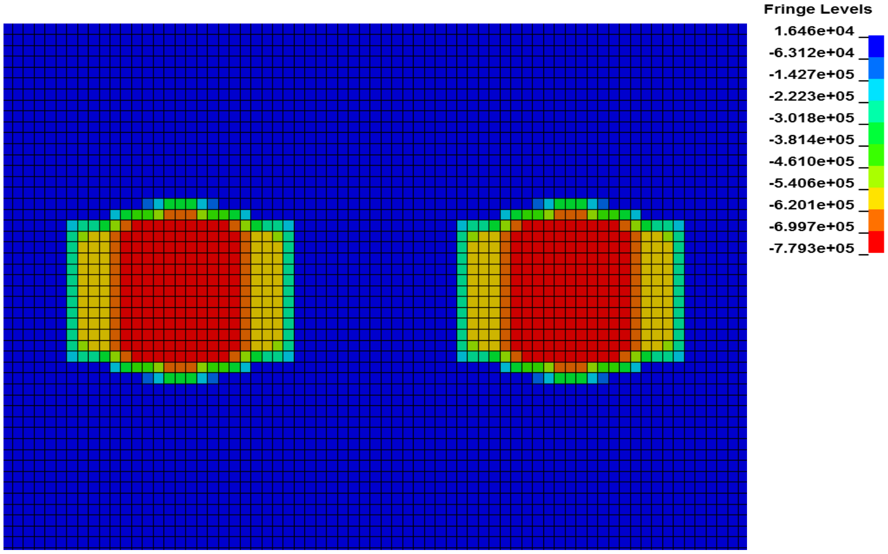
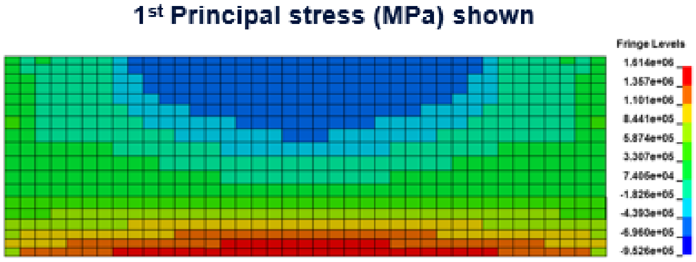
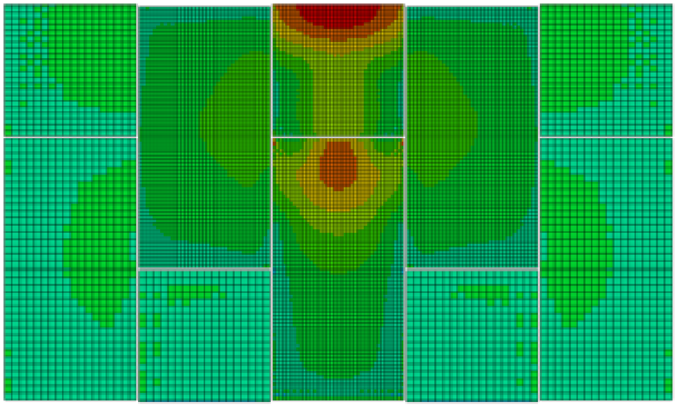


Figure 4. Principal Stresses for 10 mm Mesh Size (Top of Paving Slab)

A cross section and bottom view of the stresses at the bottom of the paving slabs are shown in Figure 5.



Section View of Center of Paving Slabs

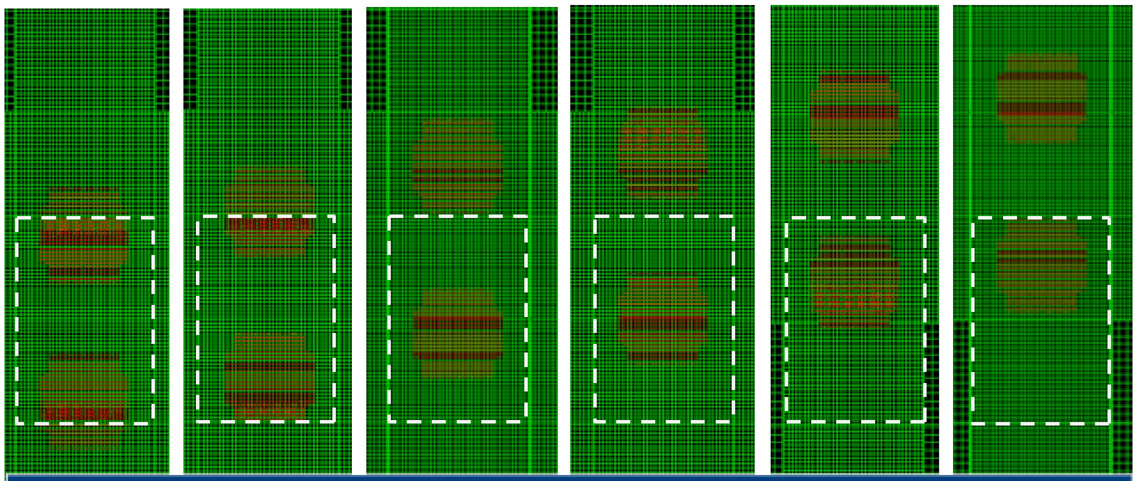


Bottom View of Paving Slabs

Figure 5. Principal Stresses for 10 mm Mesh Size

Finally, a load positioning study was completed. The objective was to determine where to position the tire load in order to maximize the 1st principal stress in the paving slab. (i.e., find the worst case scenario for paving slab tensile stress. Simulations were performed for multiple paver sizes varying the load location in order to look for trends. An example is shown on Figure 6. The figure shows the top view of a section of the paving slabs. The brown areas indicate the location of tire contact (applied pressure). The single paving slab where stresses are being determined is indicated by the dashed square. In this example, a 300 x 300 x 100 mm paving slab was used. The findings of the load position simulations indicated:

- For pavers where their width is less than or nearly equal to the dual tire width, the maximum stress occurs with a single tire on the paver somewhere between the locations:
    1. where a tire is centered on the paver, and
    2. where a tire is at the edge of the paver.
- For pavers where the paver length is significantly greater than the length of the tire load (2-3x), there are two locations where local maximum occur:
    3. the outer edge of a tire is against the edge of the paver
    4. the inner edge of a tire is against the edge of the paver.



Max. Principal Stress (MPa)					
1.23	1.26	1.37	1.48	1.56	1.37

Figure 6. Stress Analysis for Offset Load Locations

For larger paving slabs included in this study, plate bending in both the transverse and longitudinal directions significantly contributes to the maximum principal stress. An example for the 1,200 x 1,200 x 100 mm paving slab is shown in Figure 7. The load location was varied in both directions to see if an off-center placement could result in higher stress.

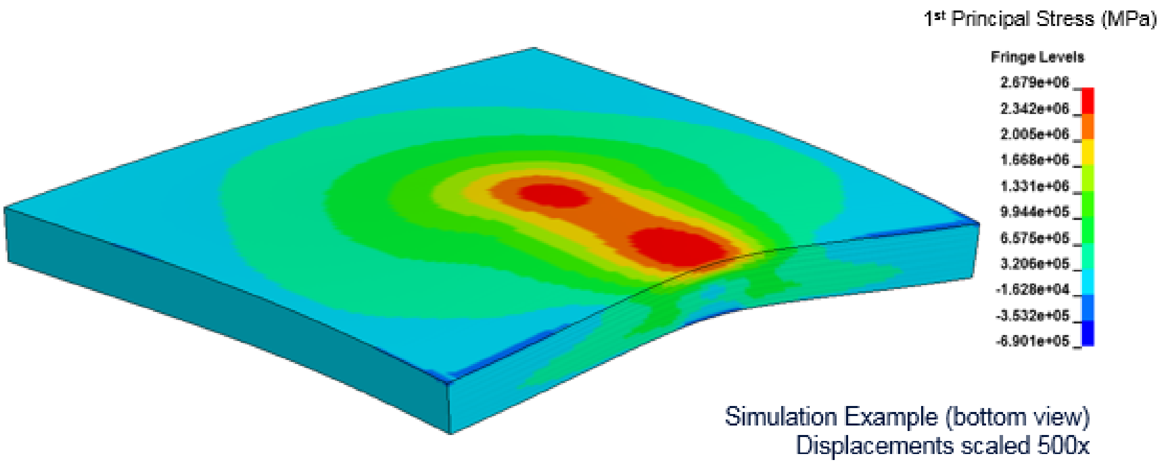


Figure 7. Principal Stresses for Large Paving Slab

The results of the load positioning analysis indicated that the position of highest stress may change depending on the size of the paving element. By selecting one common location for each paving element, it would not be possible to isolate the highest stress level for input to the design matrix. This could result in a non-conservative (risky) design. As such, the analysis of multiple locations in the vicinity of the approximate locations of highest stress found for maximum stress for all paving slabs and material combinations. While the exact location of the highest stress may not have been located, running 4 locations for each configuration provided good confidence in knowing the highest stress value.

The conclusions from the stress location study indicated that:

- The maximum stress did not occur with the load centered on the slab (single or dual tire)
- For slab widths less than or nearly equal to the dual tire width, the maximum stress occurred from a single tire between the center and edge of the slab.
- For slab lengths of 2 to 3 times greater than the length of the tire load, the maximum stresses occurred at the outer edge of a tire against the slab edge, or the inner edge of a tire against the slab edge.

SIMULATION RESULTS

The simulation results provided the maximum principal stress applied to the slab along with the maximum pressure from the wheel loading and the maximum vertical displacement under the load. Of particular interest is the maximum vertical stress under slab bending. An example of the modelling output for 1,200 x 75 x 50 mm in planks is shown in Figure 8. The figure shows the highest principal stresses between the wheels and on the units extending laterally from the point of load application.

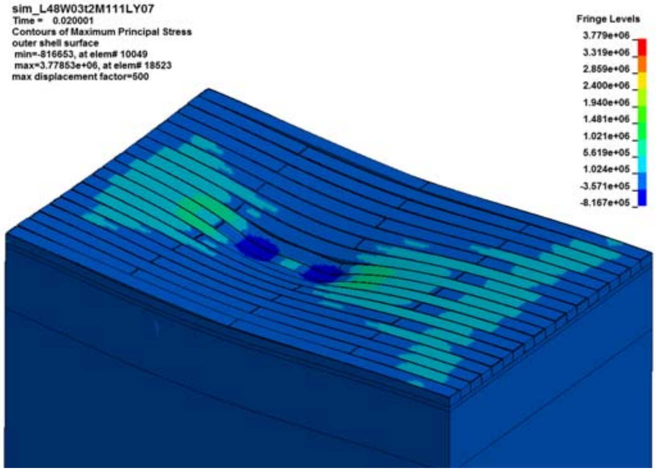


Figure 8. Principal Stresses for 1,200 x 75 x 50 mm Planks.

The general results of the modeling are summarized below:

Square and Rectangle Slabs

- The maximum principal stresses ranged from 1.1 to 4.5 MPa for the slabs on a granular base to 0.9 to 2.2 MPa for the slabs on a lean concrete base and 0.7 to 1.8 for slabs on a concrete base.
- The highest principal stresses for the thin units (50 mm) ranging from 3 to 4.5 MPa.
- Stress increases as the size of the units go upwards.

- Stresses for the thicker units (100 and 125 mm) are about a third of the stresses for the thin units.
- Larger sized units are more sensitive to changes in subgrade support capability.
- The use of a lean concrete base reduces the principal stress by about 50 percent compared to the granular base.
- The use of a conventional concrete base reduces the principal stress by a further 15 percent compared to the lean concrete base.

Planks

- The maximum principal stresses ranged from 0.9 to 3.8 MPa for the planks on a granular base and 1.0 to 2.0 MPa for the planks on a lean concrete base and 0.7 to 1.3 for planks on a concrete base.
- The highest principal stresses are for thin units (50 mm). The planks are more susceptible to changes in flexural strength and subgrade support capability, particularly for longer units.
- The use of a lean concrete or conventional concrete base can reduce the maximum principal stress by 100 percent.

Tiles

- Thin tile slabs experienced high stresses (3 to 4 MPa) when used with a granular base.

The modelling indicated that thin tile slabs over a lean concrete or concrete base reduced stresses due to the thin layer effect. Since the tiles are very thin, the loading tends to push the entire tile downward resulting in decreased bending of the tile and therefore lower stresses.

DESIGN TABLES

The results of the FEM analysis were used to develop design tables for the slabs and tiles. The stress ratio concept was used to develop ranges of traffic limits for each of the slabs and tiles. Lower stress ratios were selected for higher vehicular loading as outlined in Table 2.

Table 2. Stress Ratio Criteria for Paving Slabs and Tiles.

Traffic Limits	Category	Stress Ratio	20 yr ESALs*	Equivalent Heavy Vehicles/Day**
Do Not Use	No	1	0	0
Primarily Pedestrian	P	0.7	1,000	0.1
Cars	C	0.5	7,500	0.5
Cars and Light Trucks	LT	0.4	30,000	2.0
Cars and Occasional Heavy Vehicles	OHV	0.3	75,000	5.0

* ESALs = 80 kN equivalent single axle loads.

** Heavy vehicles/day assumes 2 ESALs per heavy vehicle.

The stress ratio is calculate by dividing the maximum principal stress for each slab, base and subgrade configuration by the flexural strength of the concrete. This is the standard concept used in the concrete slab design for the American Association of State Highway and Transportation Officials (AASHTO) 1993 Guide for the Design of Pavement Structures [AASHTO 1993].

Figure 9 shows the sensitivity of 300 x 300 x 75 mm square slabs over a granular base to changes in subgrade strength and flexural strength of the slabs. The figure shows that the stress ratio is very sensitive to the flexural strength of the slab And somewhat less sensitive to the subgrade strength.

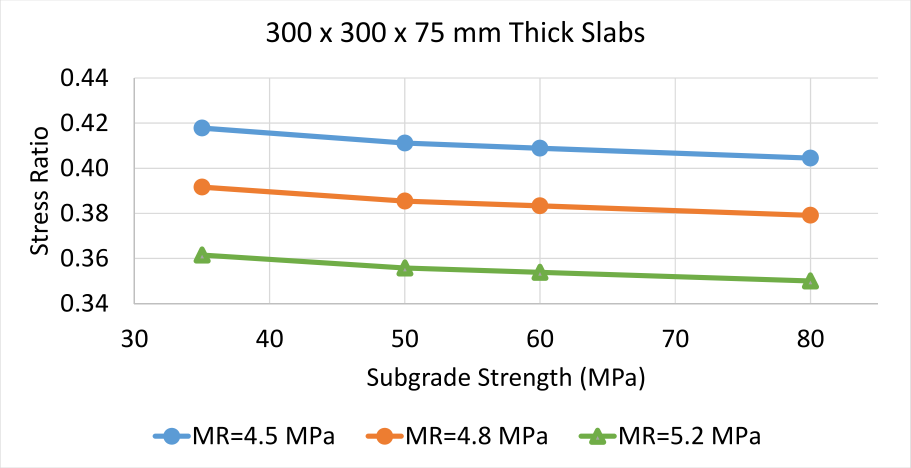


Figure 9. Stress Ratio Sensitivity to Subgrade Support and Flexural Strength of the Slabs.

DESIGN TABLES

Based on the information outlined above, design tables were developed for the length/width/thickness, subgrade strength and flexural strength and base type (granular, lean concrete and concrete) permutations and combinations included in the study. The design tables for the granular base alternatives are shown in Tables 3 through 5.

Table 3. Design Table for Square and Rectangular Pavers

Length (mm)	Width (mm)	Thickness (mm)	Square and Rectangle Pavers - Suitability for Use in Granular Base											
			Subgrade Modulus (MPa)											
			35			50			60			80		
			Flexural Strength (MPa)											
			4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2
300	300	50	P	P	C	P	P	C	P	P	C	P	P	C
300	300	75	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
300	300	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	300	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
400	400	50	No	No	P	No	No	P	No	No	P	No	No	P
400	400	75	C	C	LT	C	C	LT	C	LT	LT	C	LT	LT
400	400	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV

Table 3. Design Table for Square and Rectangular Pavers

400	400	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	300	50	P	P	P	P	P	C	P	P	C	P	P	C
450	300	75	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
450	300	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	300	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	450	50	No	No	No	No	No	No	No	No	No	No	No	P
450	450	75	P	C	C	C	C	C	C	C	LT	C	C	LT
450	450	100	LT	OHV	OHV	OHV	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV
450	450	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	300	50	No	P	P	P	P	P	P	P	C	P	P	C
600	300	75	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
600	300	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	300	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	400	50	No	No	No	No	No	No	No	No	No	No	No	P
600	400	75	C	C	LT	C	LT	LT	C	LT	LT	C	LT	LT
600	400	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	400	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	600	50	No	No	No	No	No	No	No	No	No	No	No	No
600	600	75	P	P	C	P	P	C	P	P	C	P	P	C
600	600	100	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
600	600	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
900	900	50	No	No	No	No	No	No	No	No	No	No	No	No
900	900	75	No	P	P	No	P	P	No	P	P	P	P	C
900	900	100	C	C	LT	C	C	LT	C	C	LT	C	LT	LT
900	900	125	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV
1200	1200	50	No	No	No	No	No	No	No	No	No	No	No	No
1200	1200	75	No	No	P	No	P	P	No	P	P	No	P	P
1200	1200	100	C	C	C	C	C	LT	C	C	LT	C	C	LT
1200	1200	125	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV	LT	OHV	OHV
750	500	50	No	No	No	No	No	No	No	No	No	No	No	No
750	500	75	P	C	C	P	C	C	C	C	C	C	C	C
750	500	100	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
750	500	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
900	600	50	No	No	No	No	No	No	No	No	No	No	No	No
900	600	75	P	P	C	P	P	C	P	C	C	P	C	C
900	600	100	LT	LT	LT	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV
900	600	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
1200	600	50	No	No	No	No	No	No	No	No	No	No	No	No
1200	600	75	P	P	C	P	P	C	P	P	C	P	C	C
1200	600	100	LT	LT	LT	LT	LT	LT	LT	LT	OHV	LT	LT	OHV
1200	600	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
1200	900	50	No	No	No	No	No	No	No	No	No	No	No	No
1200	900	75	No	No	P	No	P	P	No	P	P	P	P	P
1200	900	100	C	C	LT	C	C	LT	C	C	LT	C	C	LT
1200	900	125	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV

P = Pedestrian, C = Passenger Cars, LT = Light Trucks, OHV = Occasional Heavy Vehicles

Table 4. Design Table for Concrete Plank Pavers

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Length (mm)	Width (mm)	Thickness (mm)	Plank Pavers Suitability for Use in Granular Base											
			Subgrade Modulus (MPa)											
			35			50			60			80		
			Flexural Strength (MPa)											
			4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2
300	75	50	No	No	P	No	No	P	No	No	P	No	No	P
300	75	75	C	C	LT	C	LT	LT	C	LT	LT	C	LT	LT
300	75	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	75	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	100	50	No	P	P	No	P	P	P	P	P	P	P	C
300	100	75	LT	LT	LT	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV
300	100	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	100	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	125	50	P	P	C	P	P	C	P	P	C	P	P	C
300	125	75	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
300	125	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	125	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	150	50	P	P	C	P	P	C	P	P	C	P	P	C
300	150	75	LT	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	150	100	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
300	150	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	75	50	No	No	No	No	No	No	No	No	No	No	No	No
450	75	75	P	P	C	P	P	C	P	P	C	P	P	C
450	75	100	C	C	LT	C	C	LT	C	LT	LT	C	LT	LT
450	75	125	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV
450	100	50	No	No	P	No	No	P	No	No	P	No	No	P
450	100	75	P	C	C	P	C	C	C	C	C	C	C	C
450	100	100	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	OHV
450	100	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	125	50	No	No	P	No	No	P	No	No	P	No	P	P
450	125	75	C	C	C	C	C	C	C	C	LT	C	C	LT
450	125	100	LT	LT	LT	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV
450	125	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
450	150	50	No	No	P	No	No	P	No	No	P	No	No	P
450	150	75	C	C	C	C	C	LT	C	C	LT	C	C	LT
450	150	100	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV
450	150	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	75	50	No	No	No	No	No	No	No	No	No	No	No	No
600	75	75	P	P	C	P	P	C	P	P	C	P	P	C
600	75	100	C	C	C	C	C	C	C	C	LT	C	C	LT
600	75	125	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT

Table 4. Design Table for Concrete Plank Pavers

600	100	50	No	No	P	No	No	P	No	No	P	No	No	P
600	100	75	P	C	C	P	C	C	P	C	C	P	C	C
600	100	100	C	LT	LT	C	LT	LT	C	LT	LT	LT	LT	LT
600	100	125	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
600	125	50	No	No	P	No	No	P	No	No	P	No	P	P
600	125	75	P	C	C	P	C	C	C	C	C	C	C	C
600	125	100	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
600	125	125	LT	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
600	150	50	No	No	P	No	No	P	No	No	P	No	No	P
600	150	75	C	C	C	C	C	C	C	C	C	C	C	LT
600	150	100	LT	LT	LT	LT	LT	LT	LT	LT	OHV	LT	LT	OHV
600	150	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
750	75	50	No	P	P	No	P	P	No	P	P	No	P	P
750	75	75	P	P	C	P	C	C	P	C	C	P	C	C
750	75	100	C	C	C	C	C	LT	C	C	LT	C	C	LT
750	75	125	C	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
750	100	50	No	P	P	No	P	P	No	P	P	No	P	P
750	100	75	P	C	C	P	C	C	C	C	C	C	C	C
750	100	100	C	LT	LT	C	LT	LT	C	LT	LT	LT	LT	LT
750	100	125	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
750	125	50	No	No	P	No	No	P	No	No	P	No	P	P
750	125	75	P	C	C	P	C	C	P	C	C	C	C	C
750	125	100	C	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
750	125	125	LT	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
750	150	50	No	No	P	No	No	P	No	No	P	No	No	P
750	150	75	P	C	C	P	C	C	P	C	C	C	C	C
750	150	100	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	OHV
750	150	125	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV	OHV
900	75	50	No	No	P	No	No	P	No	No	P	No	No	P
900	75	75	P	P	C	P	C	C	P	C	C	P	C	C
900	75	100	C	C	LT	C	C	LT	C	LT	LT	C	LT	LT
900	75	125	LT	LT	LT	LT	LT	LT	LT	LT	OHV	LT	LT	OHV
900	100	50	No	P	P	No	P	P	No	P	P	No	P	P
900	100	75	C	C	C	C	C	LT	C	C	LT	C	C	LT
900	100	100	LT	LT	LT	LT	LT	LT	LT	LT	OHV	LT	LT	OHV
900	100	125	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV
900	125	50	No	P	P	No	P	P	No	P	P	No	P	P
900	125	75	P	C	C	C	C	C	C	C	C	C	C	C
900	125	100	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	OHV
900	125	125	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV	OHV	OHV	OHV
900	150	50	No	No	P	No	No	P	No	No	P	No	No	P

Table 4. Design Table for Concrete Plank Pavers

900	150	75	P	C	C	P	C	C	C	C	C	C	C	C
900	150	100	C	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
900	150	125	LT	LT	OHV	LT	OHV	OHV	LT	OHV	OHV	LT	OHV	OHV
1200	75	50	No	No	No	No	No	No	No	No	No	No	No	No
1200	75	75	No	P	P	P	P	C	P	P	C	P	P	C
1200	75	100	P	C	C	P	C	C	C	C	C	C	C	LT
1200	75	125	C	C	LT	C	C	LT	C	LT	LT	C	LT	LT
1200	100	50	No	No	P	No	No	P	No	No	P	No	No	P
1200	100	75	P	P	C	P	C	C	P	C	C	P	C	C
1200	100	100	C	C	LT	C	LT	LT	C	LT	LT	C	LT	LT
1200	100	125	LT	LT	LT	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV
1200	125	50	No	No	P	No	No	P	No	P	P	No	P	P
1200	125	75	P	C	C	C	C	C	C	C	C	C	C	C
1200	125	100	C	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT	LT
1200	125	125	LT	LT	OHV	LT	LT	OHV	LT	LT	OHV	LT	OHV	OHV
1200	150	50	No	No	P	No	No	P	No	No	P	No	No	P
1200	150	75	P	C	C	P	C	C	P	C	C	C	C	C
1200	150	100	C	LT	LT	C	LT	LT	C	LT	LT	C	LT	LT
1200	150	125	LT	LT	LT	LT	LT	LT	LT	LT	OHV	LT	LT	OHV

P = Pedestrian, C = Passenger Cars, LT = Light Trucks, OHV = Occasional Heavy Vehicles

Table 5. Design Table for Tile Pavers

Length (mm)	Width (mm)	Thickness (mm)	Tile Pavers Suitability for Use in Granular Base											
			Subgrade Modulus (MPa)											
			35			50			60			80		
			Flexural Strength (MPa)											
			4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2	4.5	4.8	5.2
200	100	20	No	No	No	No	No	No	No	No	No	No	No	No
200	100	30	No	No	P	No	No	P	No	No	P	No	No	P
200	100	40	P	P	C	P	P	C	P	P	C	P	C	C

P = Pedestrian, C = Passenger Cars, LT = Light Trucks, OHV = Occasional Heavy Vehicles

CONCLUSIONS

The results of this study provide a logical and defendable approach to the structural design of pedestrian and roadway designs surfaced with large element paving slabs and tiles. While the approach taken is considered to be conservative, the validity of the designs would benefit through validation based on field observation or accelerated load testing.

REFERENCES

AASHTO 1993. “AASHTO Guide for the Design of Pavement Structures”, American Association of State Highway and Transportation Officials, Washington D.C., 1993.

Al-Qadi, I.L., Elseifi, M., and Yoo, P.J., “Pavement damage due to different tires and vehicle configurations“, Michelin Americas Research and Development Corporation, Greenville, South Carolina, 2004.

Blab, R., Kluger-Eigl, W., and Füssel, J. 2012. “Accelerated pavement testing on slab and block pavements using the MLS10 Mobile Load Simulator”, Faculty of Civil Engineering, Vienna University of technology, Vienna, Austria, M. Arraigada, EMPA Duebendorf, Duebendorf, Switzerland.

British Standards Institute Technical Committee B/507, 2014. “Pavements Constructed with Clay, Natural Stone or Concrete Pavers, Draft British Standard, BS 7533-101:2014.

Bull, J.W., and Al-Khalid, H., 1989. “An Analytical Solution to the Design of Footway Paving Flags”, Department of Civil Engineering, University of Newcastle Upon Tyne, England.

Shackel, B., and Pearson, A., 2000. “The Design of Concrete Flag Pavements”. Jipea World Congress, 2000.

Transpavé, 2015. “Transpavé Technical Guide”, 2015. Transpavé Inc., Saint-Eustache, Québec, Canada.