BACKGROUND TO THE THIRD EDITION OF THE BRITISH PORTS ASSOCIATION HEAVY DUTY PAVEMENT DESIGN MANUAL

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Summary

The Third Edition of the British Ports Association heavy duty pavement design manual has recently been published and for the first time, a radically new way of analysing pavements is incorporated in the design method. The original research upon which the First Edition[1] was based was undertaken in the 1970's and pavements were analysed by programmable calculator technology[12]. This meant that stresses and strains could be calculated accurately at only one or two special points in the proposed pavement structure. The Third Edition includes pavement design charts which are based upon finite element analysis.This has allowed design to be based upon the concept of Equivalent Single Load. Also, it has allowed the design of the whole pavement can be separated into design of the base and design of the foundation. In making this separation, no accuracy is lost and the design exercise has been greatly simplified such that only one Chart is now required for design. That Chart is included in this paper and may be used to proportion the base course of a heavy duty pavement. Table 6 in this paper can then be used to select the pavement foundation according to ground conditions. The resulting pavement should remain serviceable throughout its life. During the last 10 years, a good deal of experience has been gained in the use of Material Conversion Factors or Material Equivalence Factors so that they can now be used as a means of effectively swapping one material for another during the design process. This means that when a design has been produced using the Chart, the designer can generate alternative design solutions using different materials and so investigate a full range of solutions. Table 5 gives Material Conversion Factors for a full range of commonly used base materials. The new Edition differs from previous ones in that Material Conversion Factors were used previously only in overlay design. Overlay design has been deleted from the third Edition: it has been found to be less relevant than was expected to be the case when the First Edition was published in 1984. Difficulties associated with drainage and with changes in levels have meant that overlaying existing pavements has failed to become a cost effective solution to either rehabilitation or strengthening of existing pavements

Introduction

The background to the Third Edition of the British Ports Association/Interpave manual (henceforth referred to as the BPA manual) is explained in this paper. The BPA Manual uses a design procedure which is based upon the principle that pavements are designed to remain serviceable throughout the design life of the pavement. In terms of structural performance, serviceability failure in a heavy duty pavement usually occurs by either excessive vertical compressive strain in the subgrade or excessive horizontal strain in the base. For pavements with stabilised bases the tensile strain in the base is the active design constraint whereas subgrade compressive strain is the active design constraint for pavements with granular bases. Surface deformation in the order of 50 mm to 75 mm will normally exist at failure. The BPA Manual is particularly important to the development of concrete block paving because in many situations, concrete block paving proves to be the appropriate sufracing material in heavy duty paving.

Analysis Technique

In order to produce the new design Charts pavements have been analysed using the finite element method in which a model was developed to represent all components of the pavement. Elastic properties and Poisson's ratio values were chosen to describe the behaviour of each pavement component. Fatigue is taken into account by defining limiting stresses to which the pavement can be exposed for one load pass and then reducing those stresses to account for multiple load repetitions.

The new method of design divides the pavement into foundation and structure so that the base thickness can be proportioned to withstand the applied load regime and the foundation can be proportioned to develop adequate support to the upper layers taking into account ground conditions. The rationale behind this is that it was found during the research leading to the publication of the Third Edition of the BPA manual that present highway pavement design procedures include pavement foundation guidance which relates sub-base and capping specification to subgrade strength such that the subgrade is always stressed to a level commensurate with its strength. Essentially, recent developments in pavement design procedures have separated design into foundation design which is based upon subgrade strength and base design which is based upon loading regime.

Calibration of the Design Method

All design procedures based upon mechanistic analysis require proven criteria for levels of stress or strain which define limiting permissible values. Usually, these criteria are stresses or strains known to exist in successful designs produced by empirical design methods. By this means, the mechanistic model is effectively calibrated and designs produced by it have the same level of integrity as those produced by the design method used in the calibration exercise. In the BPA manual the limiting stresses upon which the design curves are based are determined as follows. A proven semi-empirical pavement design method has been used to assess the levels of stress at critical positions in the following manner. BS 7533[6] has been used to produce a number of design examples covering a wide range of pavement design situations which have then been analysed using the same linear elastic finite element model as is used to establish permissible stresses. The stresses which the finite element model has demonstrated to exist in pavements designed according to BS 7533 are used as the critical design stresses in pavement design. In other words, the design charts have been produced using the same finite element model which has been used to back-analyse a range of pavements produced by BS 7533. This means that the experience and methodology underpinning BS7533 has been extended in the manual to deal with all those pavements likely to be encountered in heavy duty pavement design situations. A benefit of this technique is that should the finite element model include inaccuracies, then those inaccuracies should largely cancel in that they will have been included in the BS7533 back-analysis calibration exercise in exactly the same way as they have been included in the design charts.

Fifteen pavements designed according to BS 7533 were analysed using the finite element model to determine stresses and strains at critical locations in each pavement. The pavement sections developed from BS7533 are shown in Table 1. Table 1 shows the design thicknesses adopted for each course when designed according to BS7533. All of the pavement structures presented in Table 1 were analysed using the finite element model in conjunction with a standard axle load of 8 tonnes.

Table 1: BS7533 pavement course thicknesses used in finite element analysis.

CBR	1%	2%	5%
Capping	600 mm	350 mm	Omit
Sub-base	150 mm	150 mm	150 mm
Millions of Standard Axles	**Base Thicknesses**		
0 to 1.5	100 mm	130 mm	130 mm
1.5 to 4	130 mm	130 mm	130 mm
4 to 8	165 mm	165 mm	165 mm
8 to 12	200 mm	200 mm	200 mm
12 to 25	230 mm	230 mm	230 mm

Preliminary analysis using the finite element program confirmed that the critical stresses occur at the underside and at the upper side of the base directly beneath the applied load. Values of stresses at these critical locations are shown in Tables 2 & 3. (In the first Edition of the British Ports Association Manual, compressive stress in the sub-base was also assessed, but in all practical cases, this has been found to be not critical).

Table 2: Maximum principle stresses (tensile) at the underside of the base course in those BS7533 pavements back-analysed in the calibration exercise (N/mm^2)

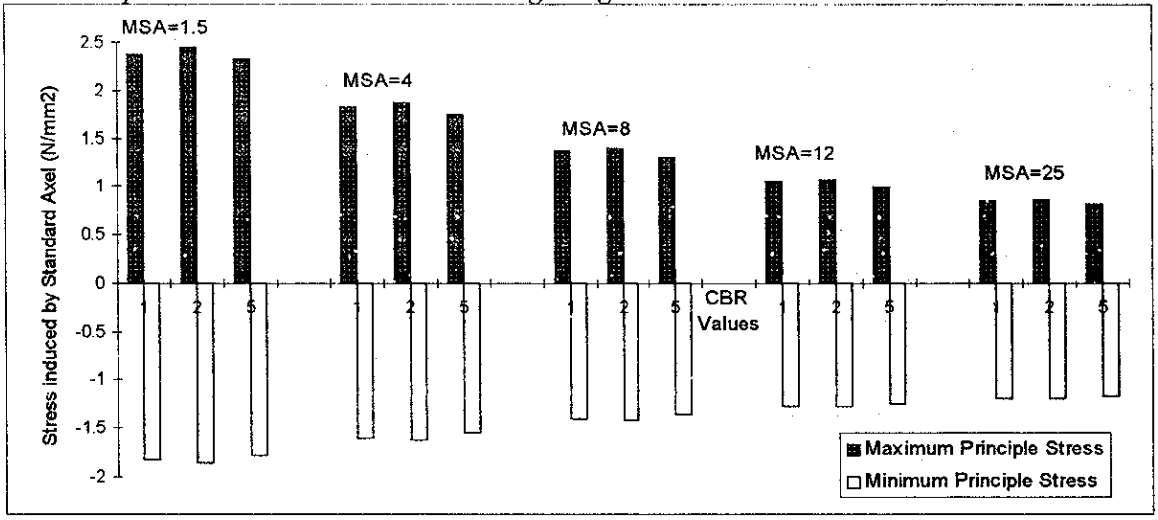
MSA/CBR	1%	2%	5%
0 to 1.5	2.38	2.452	2.323
1.5 to 4	1.817	1.866	1.749
4 to 8	1.363	1.394	1.300
8 to 12	1.049	1.069	0.9959
12 to 25	0.8539	0.8678	0.8098

Table 3 Minimum principle stresses (compressive) at the underside of the base course in those BS7533 pavements back-analysed in the calibration exercise (N/mm^2)

MSA/CBR	1%	2%	5%
0 to 1.5	-1.829	-1.856	-1.772
1.5 to 4	-1.602	-1.621	-1.547
4 to 8	-1.363	-1.412	-1.359
8 to 12	-1.269	-1.274	-1.239
12 to 25	-1.191	-1.193	-1.169

The values in Tables 2 & 3 are shown graphically in Figure 1.

Figure 1: Relationship between permissible stresses and number of passes of a standard axle. The values above the axis represent tension and are the limiting design stresses.



From Figure 1 it can be seen that the stresses induced in the base of the pavement are very similar for each subgrade CBR value and that they diminish with increasing levels of traffic. Figure 1 enables design stresses to be selected for all pavement types. Figure 1 indicates that the value of the maximum compressive stress varies little with an increase in the number of load repetitions and is of less importance in design since in general materials used to construct the base of a heavy duty pavement are stronger in compression than they are in tension, often by an order of magnitude. A small stress range in compression is to be expected owing to the equilibrium of vertical forces through the pavement from the point of load application down to other areas. In conclusion the tensile stress at the underside of the base is the limiting stress for design purposes in all practical pavements. Table 4 shows average values of the three stresses existing in pavements designed over subgrades with CBR's of 1%, 2% and 5% for each of the five fatigue levels (1.5 MSA to 25 MSA) used in the analysis.

Table 4: Average tensile stresses to be used as design stresses (N/mm^2)

MSA/CBR	**1%**	**2%**	**5%**	**Average**
0 to 1.5	2.38	2.452	2.323	2.4
1.5 to 4	1.817	1.866	1.749	1.8
4 to 8	1.363	1.394	1.300	1.4
8 to 12	1.049	1.069	0.9959	1.0
12 to 25	0.8539	0.8678	0.8098	0.8

Having used the finite element model to calculate the stresses shown in Table 4 which exist in pavements designed according to BS7533, it is possible to analyse a range of typical pavements in order to establish the loads which generate similar stress values for a given number of load passes. This exercise has been carried out to produce the curves in the design charts

Details of finite element model used to calibrate the design method

The finite element model used in developing the BPA design charts and in the calibration exercise comprised an axi-symmetric idealisation in which a cylindrical layered system of diameter 7m and depth 2.5m was modelled by 70 rectangular elements each having a node at each corner and midway along each side. Each model perimeter node was restrained horizontally and each node at the lowest level was restrained both horizontally and vertically. A single point load was applied at the uppermost node at the centre of the model. In order to simulate the effect of a circular patch load accurately, an extra very stiff axi-symmetric element, of radius equal to the radius of the load patch was generated above the cylinder. The load patch radius was determined by assuming the load to be applied as a pressure of 0.8N/mm^2. The model was graded such that smaller elements were concentrated near the point of load application where stress variation was steep and larger ones were generated at greater depth and radius. The Lusas finite element package licensed to the Civil Engineering Department at Newcastle University, UK, was used to generate the model.

The finite element model has been used to produce diagrams showing contours of stress in pavement bases designed according to the BPA design chart. Three bases are shown, corresponding with CBR values of 3% and 30%. For each a C10 concrete base has been designed to accommodate 1,000,000 repetitions of an equivalent wheel load of either100kN or 500kN. The Figures show that pavements designed using the BPA charts incorporating C10 concrete as the base develop tensile stresses of up to 1.4N/mm^2. This figure should be compared with the value of 1.6N/mm^2 which Figure 2 suggests should be the maximum permissible. Two diagrams are included to demonstrate the influence of surface stiffness on tensile stress values in the base. The BPA Manual is based upon the principal that large variations in surface stiffness have little effect on the performance of the base. Table 5 shows the four values of surface stiffness which have been compared together with the maximum resulting tensile stresses in the base. Each of the four surface stiffnesses applies to a pavement designed to withstand a load of 300kN over subgrade with a CBR of 3%. Table 5 shows that a change in surface stiffness from 1000N/mm^2 to 8000N/mm^2 leads to a change of only 4% in tensile stress. Most authorities consider that concrete block paving has a stiffness of between 1000N/mm^2 and 5000N/mm^2 which would lead to a variation in stress values in the base of less than 2%. This suggests that any enhancement in structural performance which might be engineeried into types of pavers is of little or no consequence in heavy duty paving.

Stiffness of Surface (N/mm^2)	**Maximum tensile stress in Base (N/mm^2)**
1000	1.18
2000	1.16
4000	1.15
8000	1.13

Table 5. Effect of change in surface stiffness on tensile stress in base

The final diagrams comprise vertical stress contour diagrams which show how a pavement designed to withstand a load of 300kN spreads the applied pressure of 0.8N/mm^2 into the underlying subgrade. The diagrams apply to subgrade CBRs of 3% and 5% respectively and they demonstrate how a greater thickness of sub-base plus capping leads to lower levels of compressive stress in the subgrade in the case of lower strength subgrades. The 3% CBR subgrade attains a vertical stress of $12kN/m^2$ and the 5% CBR subgrade attains a vertical stress of $13.5kN/m^2$. The vertical stress contours run near to horizontal in the stiff base and near to vertical in the more flexible sub-base, capping and subgrade. This confirms the load dissipating effect of a cement stabilised base.

Paving Materials

The material properties used in the analysis upon which the design charts are based are presented in Table 6. The design charts allow designs to be developed for pavements including a base comprising C10 concrete with an assumed flexural strength of $2N/mm^2$(CBM3). It is assumed that the surface comprises 80mm thick concrete pavers bedded in 30mm thickness sand. Experience has shown that alternative pavement surfacing materials have little influence on overall pavement performance. In the finite element analysis, the surface has been modelled as a homogeneous 110mm thick layer of material having an elastic modulus of $4000N/mm^2$ and a Poisson's Ratio of 0.15. This has been found to equate closely with the properties of both concrete block paving and bituminous bound surfacing materials. In the case of concrete block paving, 80mm thick rectangular units laid to a herringbone pattern have been found to exhibit a high level of stability and strength. Other types of paving units and other laying patterns may also be satisfactory but care should be exercised when deviating from the proven rectangular units laid to a herringbone pattern. In some situations, consideration should be given to a paver joint stabilisation material in order to ensure that the requisite surfacing properties are maintained

Once a pavement section has been developed using C10 concrete, it can be "exchanged" for one incorporating base material of either greater of lesser flexural strength with the base thickness being adjusted accordingly using the factors in Table 9.

Table 6: Pavement material properties used in producing design charts

Layer	Elastic Modulus, E (N/mm^2)	Poisson's Ratio
Surfacing (pavers)	4,000	0.15
Base (C10 Concrete)	35,000	0.15
Sub-base	300	0.20
Capping	150	0.25
Subgrade	10 x CBR	0.25

Surface - Pavers or Asphalt

Structure - Base

Foundation - Sub-base and Capping

Formation - Subgrade

Figure 2: Pavement Components

Load Assessment

The loading regime to be used with the design Chart is rationalised to a single equivalent load describing the actual regime. When the design process is started there is usually no unique load value which characterises the operational situation. Consequently it is necessary to gather information known about the loading environment in order to derive the equivalent single load to be used with the design chart. Firstly information regarding the types of loads that can be expected is given with factors that should be considered. This is followed by a rational method of deriving the single equivalent pavement load required for use with the design chart through proximity and dynamic factors. The value of the design wheel load depends upon the range of container weights being handled. Design should be based upon the Critical Load which is defined as the load whose value and number of repetitions leads to the most pavement damage. Relatively few repetitions of a high load value may inflict less damage than a higher number of lesser load values. The entire load regime should be expressed as a number of passes of the critical load. Experience in the use of the previous Editions of the BPA manual indicates that when the containers being handled comprise 100% 40ft containers, the critical load is commonly 22000kg and when 20ft containers are being handled, the critical load is 20,000kg. In general, mixes of 40ft/20ft containers have a critical container weight of 21,000kg. The contact area of a tyre of handling plant is assumed to be circular with a contact pressure equal to that of the tyre pressure. Some larger items of plant may be fitted with tyres for operating over soft ground. When such tyres travel over a paved area the contact area is not circular and the contact stress under the tread bars is greater than the tyre pressure. Although this affects the stresses in the surfacing material, stress concentrations are dissipated substantially at lower levels of the pavement. Some terminal trailers are fitted with solid rubber tyres. The contact stress depends upon the trailer load but a value of $1.7N/mm^2$ is typical and the higher pressure is dispersed satisfactorily through the pavement. The effects of dynamic loading induced by cornering, accelerating, braking and surface unevenness are taken into account by the factor f_d. Where a section of a pavement is subjected to dynamic effects the wheel loads are multiplied by the factors given in Table 7.

Table 7: Table of dynamic load factors

Condition	Plant Type	f_d
Braking	Front Lift Truck	1.3
	Straddle Carrier	1.5
	Side Lift Truck	1.2
	Tractor and Trailer	1.1
Cornering	Front Lift Truck	1.4
	Straddle Carrier	1.6
	Side Lift Truck	1.3
	Tractor and Trailer	1.3
Acceleration	Front Lift Truck	1.1
	Straddle Carrier	1.1
	Side Lift Truck	1.1
	Tractor and Trailer	1.1
Uneven Surface	Front Lift Truck	1.2
	Straddle Carrier	1.2
	Side Lift Truck	1.2
	Tractor and Trailer	1.2

Note: Where two or three of these conditions apply simultaneously, f_d should take into account multiple dynamic effects.

Static loads from corner casting feet apply very high stresses to the pavement. If the pavement is designed to carry repetitive wheel loads, it will usually be able to carry the associated static loads without structural failure. However the surface must be designed to withstand high contact stresses and loads. In the previous Editions of the BPA manual, some users found that pavements could not be designed to withstand the effect of containers stacked more than three high. In the new edition, container storage areas are dealt with specially. Containers are usually stacked in rows or blocks, usually no more than three high, with a maximum of five high. Corner castings measure 178mm x 162mm and they project 12.5mm below the underside of the container. Table 8 gives the maximum loads and stresses for most stacking arrangements. Since it is unlikely that all containers in a stack will be fully laden the maximum gross weights will be reduced by the amounts shown. The values shown in Table 8 can be used directly in the design chart.

Table 8: Pavement loads from stacking containers

Stacking Height	**Reduction in Gross Weight**	**Contact Stress (N/mm^2)**	**Load on Pavement (kN) for each stacking arrangement**		
			Singly	**Rows**	**Blocks**
1	0	2.59	76.2	152.4	304.8
2	10%	4.67	137.2	274.3	548.6
3	20%	6.23	182.9	365.8	731.5
4	30%	7.27	213.4	426.7	853.4
5	40%	7.78	228.6	457.2	914.4

The active design constraint is horizontal tensile strain at the bottom of the base course. If one wheel only is considered, the maximum horizontal tensile strain occurs under the centre of the wheel and reduces with distance from the wheel. If two wheels are sufficiently close together, the strain under each wheel is increased by a certain amount owing to the other wheel. Wheel loads are modified by the appropriate proximity factor from Table 9. These factors are obtained as follows. If the wheel proximity were not considered, the relevant stresses would be the radial tensile stress directly beneath the loaded wheel. If there is a second wheel nearby, it generates tangential stress directly below the first wheel. This tangential stress is added to the radial stress contributed by the primary wheel. The proximity factor is the ratio of the sum of these stresses to the radial tensile stress resulting from the primary wheel. The following equations are used to calculate the stress:

$$\sigma_R = \frac{W}{2\pi}\left[\ \frac{3r^2 z}{\alpha^{5/2}} - \frac{1-2\nu}{\alpha + z.\alpha^{1/2}}\ \right]$$

$$\sigma_T = \frac{W}{2\pi}\left[1-2\nu\right].\left[\ \frac{z}{\alpha^{3/2}} - \frac{1}{\alpha + z.\alpha^{1/2}}\ \right]$$

Where: σ_R = radial stress

σ_T = tangential stress

W = load

r = horizontal distance between wheels

z = depth to position of stress calculations

v = Poisson's ratio

$a = r^2 + z^2$

When more than two wheels are in close proximity, the radial stress beneath the critical wheel may have to be increased to account for two or more tangential stress contributions. Table 9 shows that the proximity factor depends on the wheel spacing and the Effective Depth to the bottom of the pavement base. The Effective Depth can be approximated from the following formula and represents the depth from the pavement surface to the underside of the base should the base have been constructed from subgrade material.

$$Effective\ Depth = 300.\sqrt[3]{\frac{35000}{CBR \text{ x } 10}}$$ Where CBR = California Bearing Ratio of the subgrade.

As an example, consider a front lift truck with three wheels at each end of the front axle. The critical location is beneath the centre wheel. Suppose a pavement were designed on ground with a CBR of 7% and the wheel lateral centres were 600 mm. From the formula, the approximate Effective Depth of the bottom of the pavement base is:

$$Effective\ Depth = 300.\sqrt[3]{\frac{35000}{7\ x\ 10}} = 2381\text{mm}$$

By linear interpolation from Table 4 the proximity factor is 1.86. This should be applied twice for the central wheel. This means that the effective single load scaled up by 0.86: twice i.e. 1 + 0.86 + 0.86 = 2.72. Note that this is approximately 10% less than 3 so that this type of wheel arrangement effectively reduces pavement load by 10%. For wheels bolted side by side, the entire load transmitted to the pavement through one end of the axle can be considered to represent the wheel load. An investigation of the actual equivalent wheel load indicates that the actual equivalent wheel load is approximately 1.97 times one wheel load when there are two wheels bolted together at an axle end.

Different Base Materials

The design chart has been constructed with reference to C10 concrete with a flexural strength of 2N/mm^2. The thickness of C10 produced by the design chart may be exchanged for an equivalent amount of an alternative material of greater or lesser strength using Material Conversion Factors set out in Table 10 and the rationale for this technique of exchanging one material for another is described below. It should be recognised that experience in the use of Material Conversion Factors indicates that within a limited range, they can prove to be an efficient means of expanding one design solution into many alternatives, each of similar structural capability. The relationship between relative base thicknesses and allowable stresses is:

$$d_{new} = d_{stand} \text{ x } (\sigma_{stand}/\sigma_{new})^{1/2}$$

Table 9: Wheel proximity factors

Wheel Spacing (mm)	Proximity factor for effective depth to base of:		
	1000 mm	2000 mm	3000 mm
300	1.82	1.95	1.98
600	1.47	1.82	1.91
900	1.19	1.65	1.82
1200	1.02	1.47	1.71
1800	1.00	1.19	1.47
2400	1.00	1.02	1.27
3600	1.00	1.00	1.02
4800	1.00	1.00	1.00

Where: d_{new} = the revised base thickness for alternative material

d_{stand} = the design thickness specified for C10 concrete

σ_{stand} = flexural stress for C10 lean concrete (2 N/mm^2)

σ_{new} = flexural strength of alternative material

Table 10: Different base materials with flexural strengths and conversion factors

Pavement Layer	**Flexural Strength N/mm^2**	**Conversion Factor from C10 lean Concrete**
(i) Plain C30 concrete	4.0	0.70
(ii) 20 kg/m^3 steel fibre C30 concrete	4.8	0.65
(iii) 30 kg/m^3 steel fibre C30 concrete	6.4	0.55
(iv) 40 kg/m^3 steel fibre C30 concrete	7.6	0.50
(v) Plain C40 concrete	4.8	0.65
(vi) 20 kg/m^3 steel fibre C40 concrete	5.6	0.60
(vii) 30 kg/m^3 steel fibre C40 concrete	7.6	0.50
(viii) 40 kg/m^3 steel fibre C40 concrete	9.0	0.45
(ix) Wet lean concrete 4	3.6	0.75
(x) Wet lean concrete 3	3.0	0.80
(xi) Wet lean concrete 2	2.0	1.00
(xii) Wet lean concrete 1	1.4	1.20
(xiii) Cement Bound Material Category 1 (CBM1)	0.8	1.60
(xiv) Cement Bound Material Category 2 (CBM2)	1.4	1.20
(xv) Cement Bound Material Category 3 (CBM3)	2.0	1.00
(xvi) Cement Bound Material Category 4 (CBM4)	3.0	0.80
(xvii) Crushed rock of CBR >80%	-	3.00

The flexural strength values in Table 10 are based upon reported test results. Where local data is available, it can be used instead and the Conversion Factors altered accordingly

Design Table and Charts

Table 11 shows sub-base and capping thicknesses for different CBR subgrades. The pavement design Chart is shown as Figure 2.

Table 11. Sub-base and capping thicknesses for carious subgrade CBR values

CBR of Subgrade	**Capping Thickness (mm)**	**Sub-base Thickness (mm)**
1%	600	150
2%	350	150
3%	250	150
5%-7%	Not required	225
10%-30%	Not required	150

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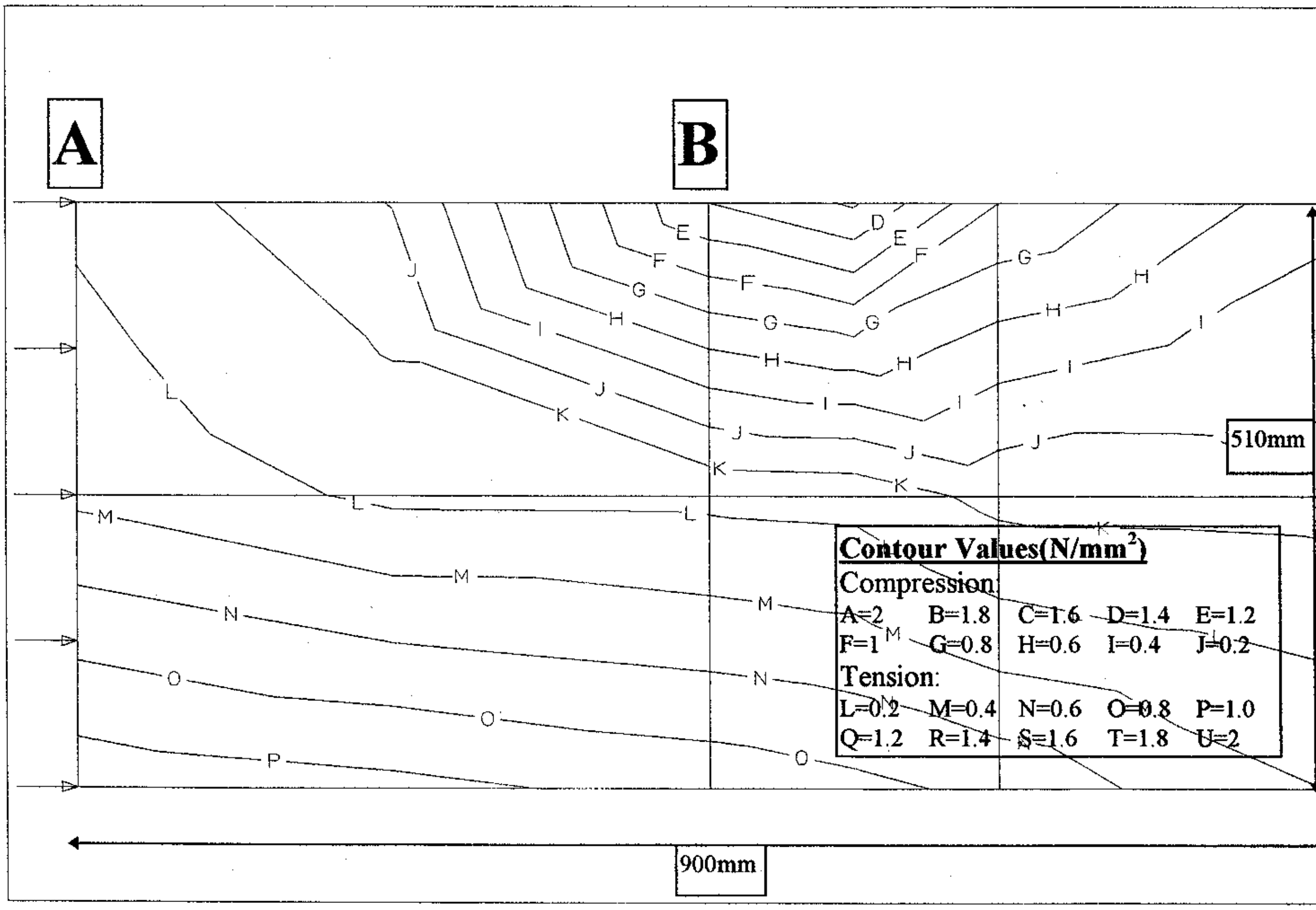
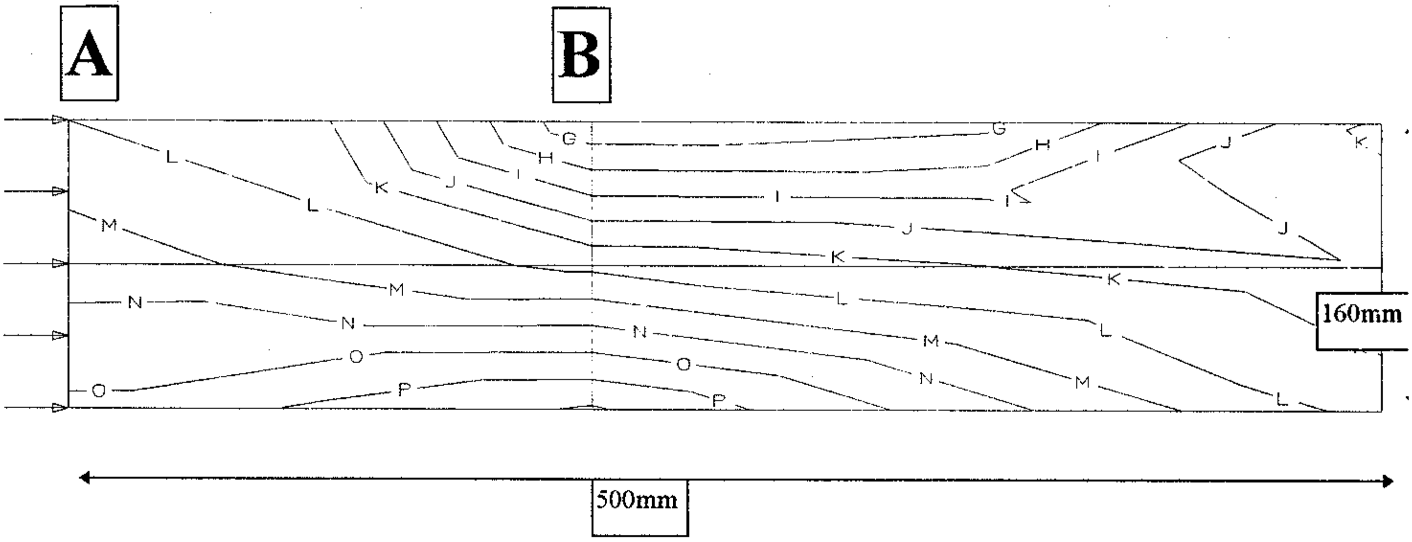
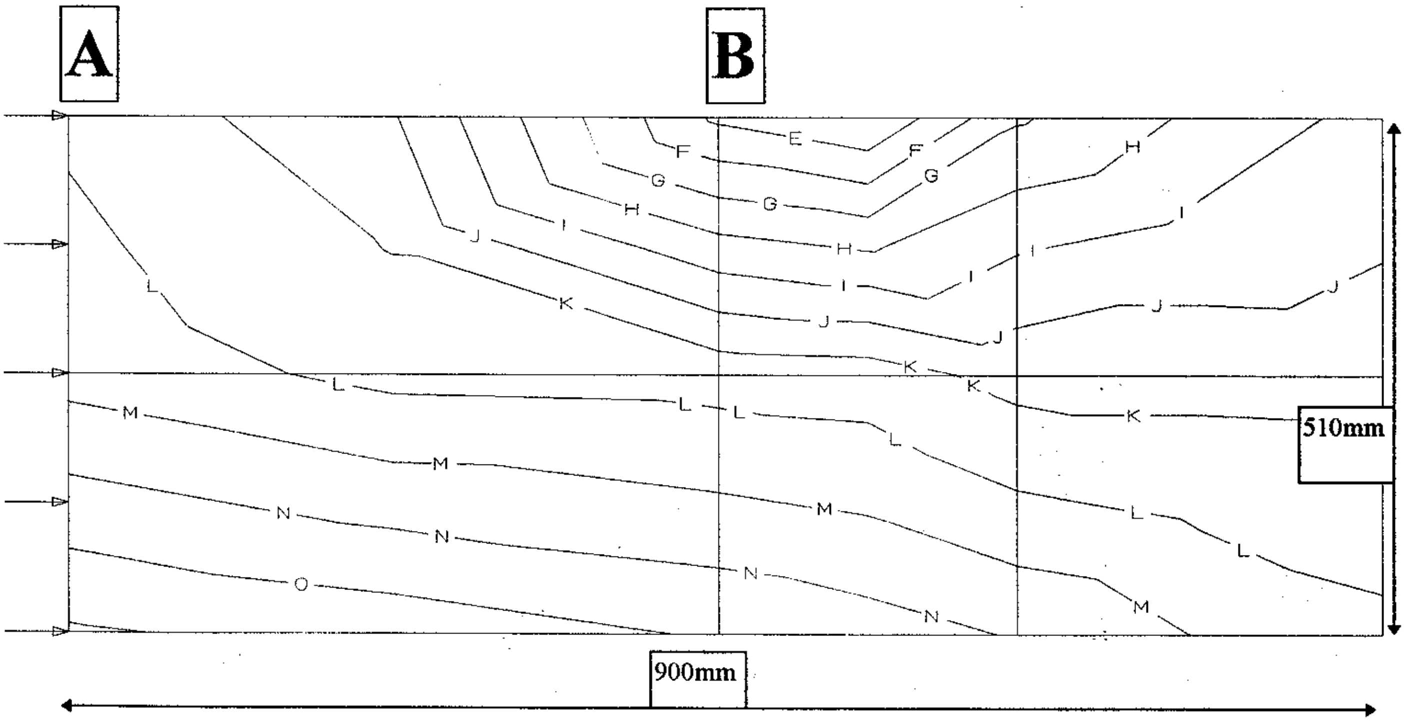


Stress contours in base of pavement designed to withstand an Equivalent Wheel Load of 500kN over soil of CBR 3%. The load is applied as a stress of 0.8N/mm^2 over a circular patch of radius AB 3

Stress contours in base of pavement designed to withstand an Equivalent Wheel Load of 100kN over soil of CBR 30%. The load is applied as a stress of 0.8N/mm^2 over a circular patch of radius AB

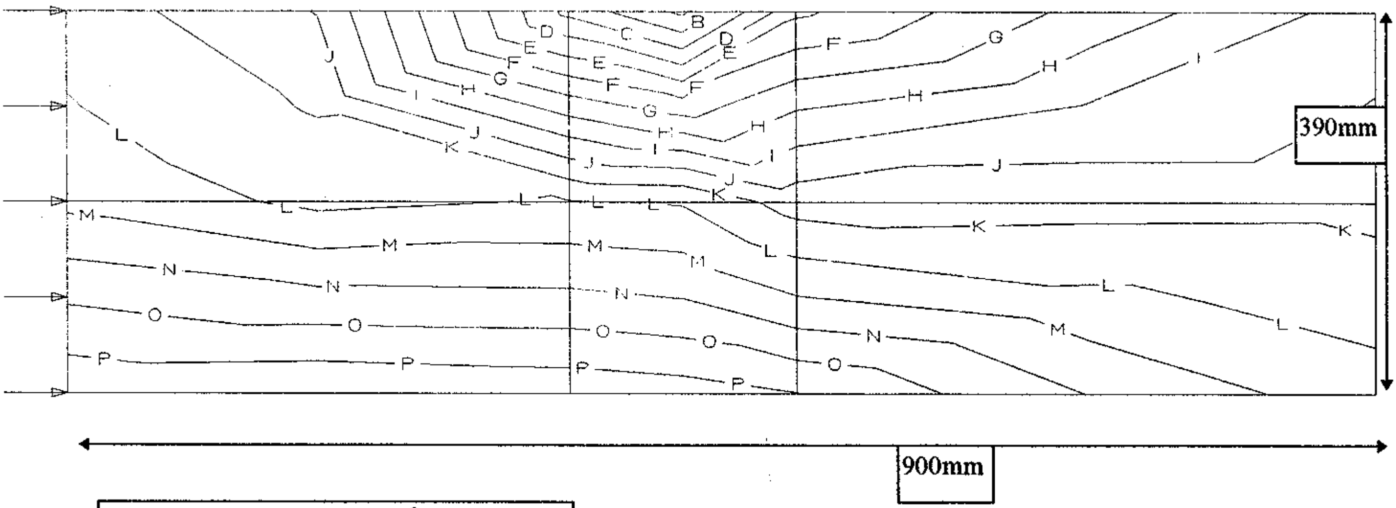




Stress contours in base of pavement designed to withstand an Equivalent Wheel Load of 500kN over soil of CBR 30%. The load is applied as a stress of 0.8N/mm^2 over a circular patch of radius AB

Effect of Surface Material on Stresses in Base

The contours represent horizontal stresses in the base for a pavement designed to withstand 300kN on a 3% CBR subgrade. In this case, the Elastic Modulus of the surfacing material is 1000N/mm^2. This is one of four diagrams illustrating the change in stress patterns in the base as the Elastic Modulus of the surfacing material is changed.



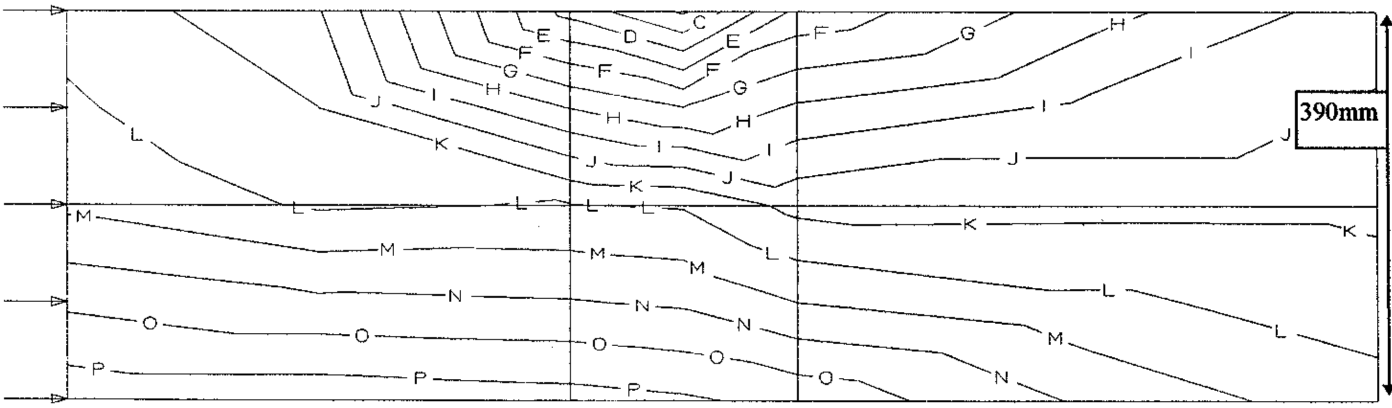
Contour Values(N/mm^2)

Compression:

A=2 B=1.8 C=1.6 D=1.4 E=1.2
F=1 G=0.8 H=0.6 I=0.4 J=0.2

Tension:

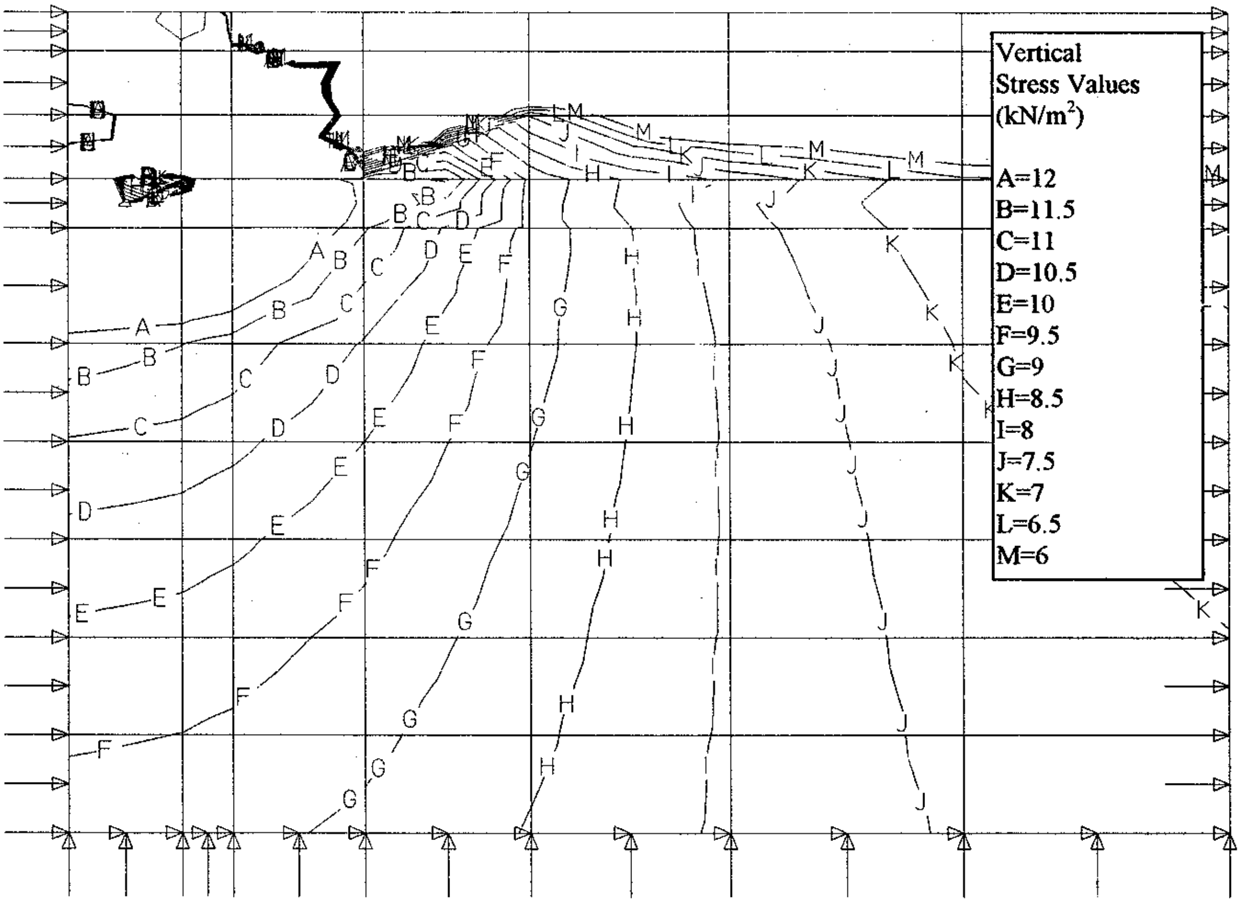
L=0.2 M=0.4 N=0.6 O=0.8 P=1.0
Q=1.2 R=1.4 S=1.6 T=1.8 U=2



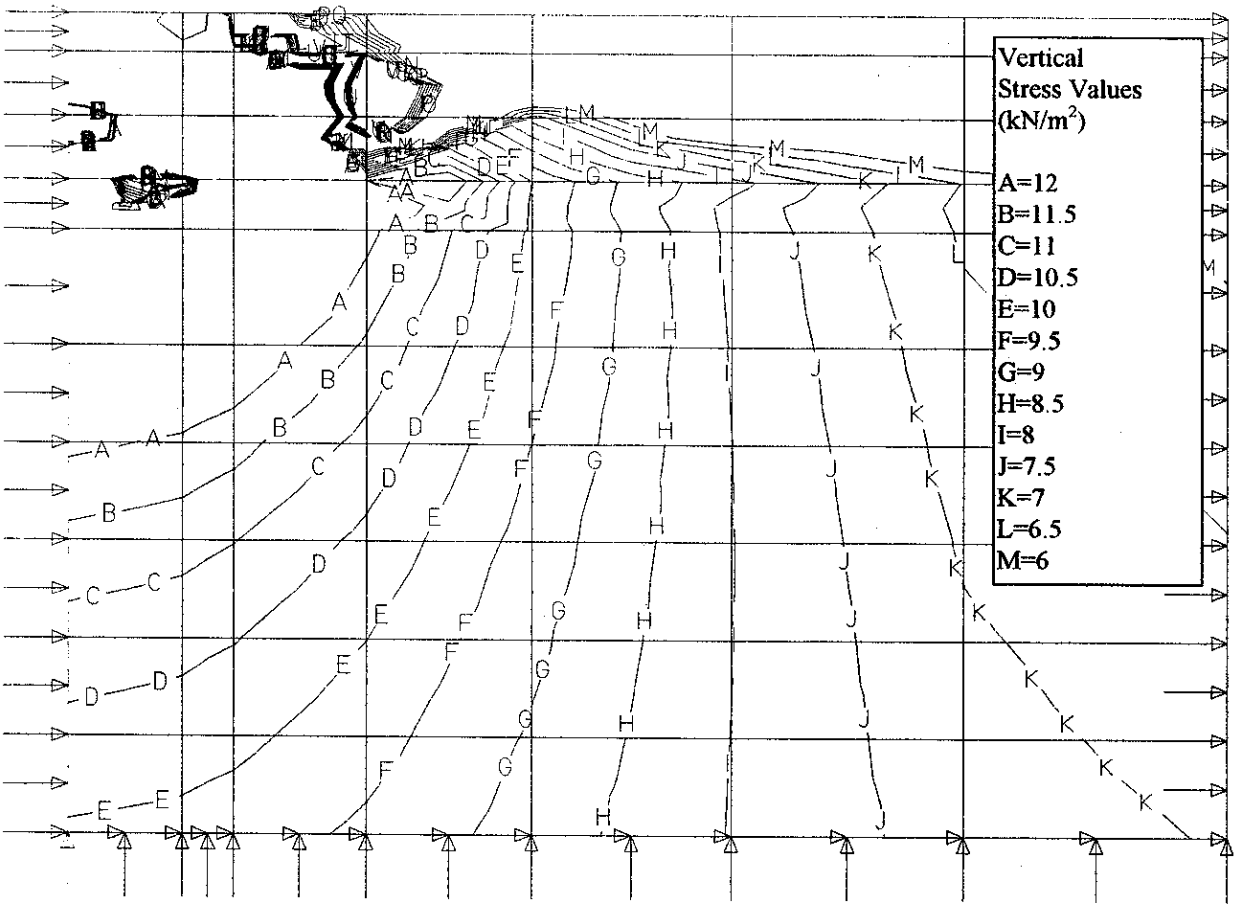
Effect of Surface Material on Stresses in Base

The contours represent horizontal stresses in the base for a pavement designed to withstand 300kN on a 3% CBR subgrade. In this case, the Elastic Modulus of the surfacing material is 8000N/mm^2. This is one of four diagrams illustrating the change in stress patterns in the base as the Elastic Modulus of the surfacing material is changed.

Pattern of Vertical Stress in pavement designed to withstand a load of 300kN over a subgrade of CBR 3%.



Pattern of Vertical Stress in pavement designed to withstand a load of 300kN over a subgrade of CBR 3%.



Pattern of Vertical Stress in pavement designed to withstand a load of 300kN over a subgrade of CBR 5%.