NZTA B10 Notes: 2023

Notes to the Specification for Hi-Lab Pavement Design, Production and Construction

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Scope

NZTA B10 specification describes the materials quality and construction methodology for a new heavy duty pavement construction technique, referred to as **Hi**gh strength **L**ow fines **A**ggregate **B**ase (Hi-Lab). The pavement structure consists of a very densely packed and interlocked, mainly single sized large aggregate skeleton, combined with a low cement and fines void filler. The small percentage of cemented finer particles specific to the particle size distribution ensures optimal void fill is achieved without causing separation of the interlocked large aggregate particles. This enables direct load transfer to take place between the large, interlocked particles.

The heavy-duty pavement is modelled on the original Macadam pavement philosophy with specific reference to cement-bound Macadam. Hi-Lab pavements have a very specific aggregate particle size distribution consisting of good quality crushed angular stone combined with low cement and fines content which allows the layer to act as a “solid body”, thereby enabling direct load transfer between larger stone particles.

Performance testing of in-situ core and beam cut test samples shows the strength characteristics achieved are like lean mix concrete and roller compacted concrete (RCC).

Advances in modern day construction equipment and increased focus on productivity resulted in the demise of the original labour-intensive macadam process. Therefore, the challenge was to mechanise the cement-bound macadam concept. This was achieved through the innovative use of modern construction equipment. Three percent (3%) cement by dry weight is added to produce a paste to improve the workability of the product during the mixing and compaction processes.

Design Methodology

General

The design specification is based on a Layered Elastic Mechanistic design approach. The design is based on two failure criteria:

(a) Phase 1: pre-cracked cement-bound phase, the horizontal tensile stress under the Hi-Lab layers is limited to mitigate fatigue cracking; and

(b) Phase 2: post-cracked phase, the vertical compressive strain at the top of the subgrade is limited to prevent permanent deformation within the subgrade.

For new builds the maximum horizontal stress under the Hi-Lab layers must be less than the fatigue threshold value. This is like the pavement design approach presented by Brown on lean-concrete base layers (Brown, 1979). Hence, the horizontal tensile stress under the Hi-Lab layers will be limited to a failure threshold fatigue value to prevent fatigue cracking over the design life. Consequently, for a new build the intent is for the pavement to function below the threshold fatigue value. In theory the design can be defined as perpetual and, therefore, the post cracked Phase 2 may not eventuate.

Horizontal Tensile Stress Criteria

Falling Weight Deflectometer (FWD) survey data is used to back-calculate typical stiffness ranges from completed Hi-Lab construction. The layered elastic back-calculation analysis shows the 10th percentile values range between 3,500MPa to 10,000MPa with median values of 12,000MPa. Experience shows the back-calculated stiffness/modulus obtained from FWD for rigid layers seems to under report.

Williams (1972) presents a relationship between unconfined compression strength and flexural strength, which is used to calculate the elastic modulus for lean mix concrete. The same equation is used to calculate elastic modulus for Hi-Lab:

$$E = 7{,}125(f_{flex}) + 20{,}500\text{MPa} \qquad (1)$$

Where f_{flex} = flexural strength (MPa) and E = elastic modulus (MPa)

Similarly, the flexural strength (f) has been estimated from cube compression strength by using:

$$f_{flex} = 0.1\ f_u \qquad (2)$$

Where f_u = unconfined compression strength (MPa)

Williams indicated equation (2) to be the lower-bound value and is appropriate for design (Williams, 1972). Using the above equations and assigning the lower value of 10MPa (Hi-Lab40) and 15MPa (Hi-Lab65) obtained from in-situ cube compression test samples then the resulting elastic modulus is in the order of 30,000MPa.

The tensile strains were also measured in the laboratory under four-point flexural beam loading for multiple Hi-Lab in-situ cut beam samples to estimate elastic modulus. The tensile strains were measured with two foil strain gauges. The foil gauges were 110mm in length and two gauges were placed on each side of the beam along the centre, as close as possible to the bottom of the beam. The averaged measured strain values from the two foil gauges were reported. Equation (3) was used to calculate the stress:

$$\text{Stress (kPa)} = pl/wd^2 \qquad (3)$$

Where:

p = load (kN),

l = beam length (m),

w = beam width (m) and

d = beam depth (m)

The measured strain values from the foil gauges and stress from equation (3) were used to calculate elastic modulus. The lower elastic modulus values calculated from the actual measured strain values under four-point beam testing were similar to the 30,000MPa calculated above in equation (1). Hence, the measured laboratory strain values provide strong support to the equations proposed by Williams in the paper by Brown (Brown, 1979).

The maximum horizontal tensile stress is calculated at the bottom of the Hi-Lab layers by assigning layered elastic properties (isotropic Ev = Eh = 30,000MPa and Poisson's Ratio = 0.2) to the layers. Layered Elastic (LE) or Finite Element (FE) analysis can be used to model the Hi-Lab layers, the supporting pavement and subgrade layers.

The maximum horizontal stress under the Hi-Lab layer using layered elastic analysis must be less than 30% of the beam stress at break. Therefore, the maximum allowable horizontal tensile stress should be less than 420kPa (30% of 1400kPa) based on in-situ field beam test samples with a stress at break equal or greater than 1400kPa. The same principles can be applied for any layered elastic mechanistic design criteria used by other international road agencies.

Subgrade Vertical Strain Criteria

The subgrade strain criteria as described in the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design (Austroads, 2017) is used to predict permanent deformation within the subgrade. In the case of the subgrade strain criterion, the stiffness of the Hi-Lab layers is assigned a very conservative value of 500MPa (anisotropic, no sub-layering, Poisson's Ratio = 0.35) for a secondary cracked phase in the Mechanistic Empirical model to calculate the vertical compressive strain at the top of the subgrade layer.

For pavement design beyond Australasia, other international vertical compressive strain criteria to assess subgrade deformation, specific to those countries can also be used (e.g. Shell 85% and South African (10mm and 20mm rut depth) subgrade strain).

Construction Criteria

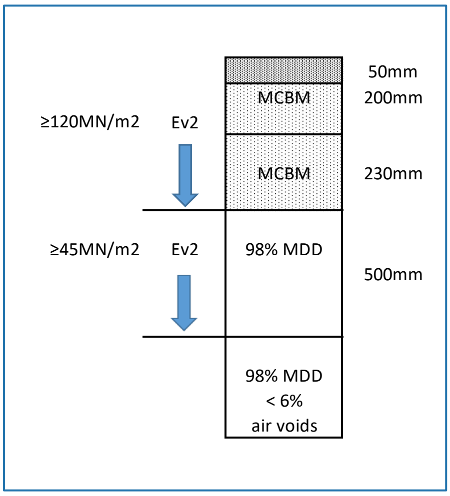
Unless otherwise specified, Hi-Lab layer thickness will normally be as follows:

(a) HiLab 65 will be constructed with a finished layer thickness between 200mm – 250mm.
(b) HiLab 40 will be constructed with a finished layer thickness between 150mm – 200mm.

Achieving the pavement design assumptions during construction and especially the influence from supporting lower pavement layers will hugely impact the performance of the Hi-Lab layer which is universal for most pavement systems. Hence, the importance to validate design assumptions during construction becomes paramount as experience shows designers tend to overestimate the stiffness/modulus (CBR) assigned to lower pavement layers within layered elastic pavement design models. This is especially the case for new construction as the pavement design assumptions are in general based on initial and insufficient geotechnical investigations of natural ground conditions prior to earthworks. The variability within the natural ground conditions makes this more challenging.

Pavement designers should give careful consideration to the risk of post-construction settlement when Hi-Lab is to be constructed over new earthworks and subgrade improvement layers. Settlement of supporting layers can cause cracking of the Hi-Lab pavement and subsequent loss of waterproofing integrity of the surfacing layers.

The design follows the European (German and French) approach whereby a bearing strength (MN/m²) is specified for the lower supporting pavement layers. The diagram below shows an example catalogue design for the Mechanised Cement Bound Macadam (MCBM) like the German design approach (Guidelines to the Standardisation of Surfaces for Road Traffic Areas). The specified minimum criteria for bearing capacity have been validated as appropriate for Hi-Lab design based on field testing during construction of multiple motorway projects.



The following construction performance criteria are hence specified for the supporting pavement layers under the Hi-Lab:

(c) The design shall specify the bearing strength (MN/m²) of the lower supporting pavement layers to meet the construction compaction requirements below. The specified minimum criteria for bearing capacity have been validated as appropriate for Hi-Lab design based on field testing during construction of multiple new built projects. The methods of ASTM D1195 or D1196, or alternative equivalents may be used to determine the supporting layer strength.

(d) Continuous Compaction Control (CCC) criteria is specified for compaction to ensure full mat monitoring and compliance reporting. The CCC roller output is a dynamic response and is reported as an Evib value. The roller Evib response must be calibrated with the bearing plate Ev2 measurements for the specific soil or material type. The output from various manufacturers of CCC rollers may differ as some use a unitless output value. Irrespectively, the CCC roller output and Ev2 must be calibrated. The light weight deflectometer (LWD) can also be calibrated and used as an alternative to Benkelman Beam deflections.

(e) The compaction density for the lower layers must be at least 81% of aggregate Solid Density. The nuclear gauge in direct transmission is used for reporting in-situ density.

(f) Benkelman Beam deflections and/or Falling Weight Deflectometer (FWD) at 10m spacing staggered between wheel paths for all lanes is specified. The criteria for Benkelman Beam deflections shall be <1.5mm (95th %) and maximum ≤1.8mm. Using the FWD as compliance, the Benkelman Beam deflection criteria can be reduced by 10% to 15%.

References

(c) Brown S.F. Design of pavements with lean-concrete bases. Publication of the paper sponsored by Committee on Flexible Pavement Design, University of Nottingham, Nottingham, England, 1979.

(d) Williams R.I.T., Properties of cement stabilised materials. Journal of the Institute of Highway Engineers, Vol. 14, No.2, 1972, pp.5-19.

(e) Road and Transportation Research Association, Work Group Infrastructure Management, Guidelines for the Standardisation of Surfaces of Road Traffic Areas, 2012 Edition (RStO 12).