Some Aspects of Pavement Design on Cohesive and Non-cohesive Subgrades

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ABSTRACT: Pavement thickness design is based on subgrade California Bearing Ratio (CBR) tests. CBR for cohesive soils is determined based on laboratory tests on remolded samples compacted to a specified density and moisture ratio. CBR measured in the laboratory for cohesive soils may not be representative of the performance in the field due to several factors including the surcharge weight, percentage of oversize materials discarded and the moisture content. For non-cohesive soils, most designers prefer to assess CBR based on insitu testing, such as Dynamic Cone Penetration Tests (DCP), Plate load test, Light Weight Falling Deflectometer (LFWD) tests etc. Where insitu tests are carried out on an unconfined surface, the interpreted CBR is always less than that under confined conditions. For heavy duty pavements such confinement could be as much as 1m depth of overburden over subgrade. Design of pavement based on unconfined test results could be expensive and unnecessary. The paper discusses some test results from a heavy duty pavement.

1 INTRODUCTION

1.1 *Pavement thickness design based on subgrade strength*

Pavement thickness design for highway traffic loads as well as for industrial pavements subjected to heavy axle loads such as from fork lifts and front end loaders are based on the assessment of strength of the subgrade soils. The subgrade is natural soil or man-made fill above which pavement layers; subbase, basecourse and wearing course are placed. Traditionally the pavement thickness design requires the designer to assess the traffic load by way of Equivalent Standard Axle (ESA) repetitions and the subgrade strength based on California Bearing Ratio (CBR) or the Resilient Modulus (RM) , which is subgrade modulus when subjected to repeated loads of small duration similar to load generated by traffic.

Mechanistic pavement thickness design is mostly based on design charts which provide the total pavement cover required depending upon the subgrade CBR and the design ESA.

In the past 30 years or so computer programs have been developed to assess the subgrade compressive strain when subjected to traffic loads and failure criteria have been developed to relate the number of repetitions for a given strain before subgrade deformation makes the pavement unserviceable. For example in Australia, the computer program CIRCLY is mostly used which requires as inputs the traffic load (ESA), subgrade modulus and moduli of various pavement layers to determine the pavement thickness.

1.2 *Test Methods*

The most common test employed to assess subgrade strength is the CBR test on remolded samples collected from the proposed subgrade soils. The sample is usually moisture conditioned to be close to its Optimum Moisture Content for Standard Compaction (some jurisdictions used Modified Compaction) and compacted in a 150mm diameter mould to a specified density (usually within 2% of the maximum density for the given compaction effort). The sample is soaked for 4 to 10+days with a surcharge placed on top. The sample is taken out of water, allowed to drain and penetrated with a 50mm diameter plunger. The load penetration curve is plotted and the load corresponding to 2.5mm and 5.0mm penetrations a percentage of standard loads for each penetration is calculated. The higher ratio from the two values is taken as the CBR value. In order to aid in evaluation of results, additional parameters such as moisture content and percentage swell are also measured.

Laboratory soaked CBR on remolded specimens are sometimes compared with “in-situ” CBR obtained from Dynamic Cone Penetration (DCP) Tests. In this test a cone tip is penetrated with blow from a 9kg hammer falling over 510mm drop and the penetration for each blow is measured. In situ CBR in Australia is estimated based on the results published Austroads (2012).

The stiffness of formed subgrade is also evaluated with Falling Weight Deflectometer where a plate is dropped from a known distance and the deflection bowl is measured from a series of probes along a straight line. A similar system is used in

Benkelman Beam test where a beam is placed between the tyres of a truck loaded to a standard axle weight and the deflection of the ground is measured as the truck moves. In both cases computer programs based on beam deflection on a layered system based on elastic theory is used to evaluate subgrade stiffness either as CBR or Modulus.

Insitu CBR tests where the CBR equipment is used directly in the field is also used for estimating subgrade CBR.

Field Plate Load tests are carried out to assess the modulus of subgrade reaction. The term modulus of subgrade reaction is "polluted "as initially Terzaghi used it to express the load on a 305mm diameter plate to produce 25mm deflection. For highway engineering applications the coefficient of subgrade reaction is commonly defined as the ratio of the load to deflection caused by 69kPa pressure on a 750mm diameter plate.

Light Weight Falling Deflectometer (LWFD) has been used in recent times to assess subgrade stiffness instead of large diameter static plate load tests as a method which is simple and quick to implement. The evaluation is based on the deflection caused by the falling weight and the velocity of penetration. The results are based on proprietary evaluation methods.

With the more widespread use of Mechanistic Pavement Thickness design using computer software based on elastic theory, the need to measure the input parameters directly from testing rather than correlation with CBR, coefficient of subgrade reaction or plate load modulus became necessary. Repeated Load Triaxial Testing has been carried out for more important projects. However due to the complex nature of sample preparation and testing and costs (and time) such tests are not used for routine highway projects.

1.3 *Limitations of test procedures*

The Laboratory Soaked CBR test has been viewed as a test which has poor reproducibility (Rallings 2014). In addition, accuracy of the determination of optimum moisture content, incomplete moisture conditioning, the remolding moisture content, the number of days soaked, the surcharge weight and the skill of the operator in remolding the sample for testing all affects the accuracy of the results. The sample is prepared from material passing 19mm sieve and the oversize fraction is removed which may be a major drawback in subgrade formed by weathered rock where a large percentage of oversize materials could be present.

All in-situ test procedures measure the stiffness of the subgrade at the field moisture content at the time of testing. The variation of strength characteristics with moisture variation is not well understood and the subgrades would be subjected to variable moisture contents depending upon the environmental conditions and drainage characteristics.

2.0 CLAY SUBGRADES

2.1 *The site*

The writer has been engaged in the geotechnical investigation for a large residential subdivision in the North West Growth Sector in Sydney where in the last 10 years or so more than 6,000 house sites have been constructed. The subdivision is located in an area underlain by Claystone and Siltstone (locally termed Shale) with inter-bedded fine grained Sandstone. An incised creek flows along the centre of the site and most of the eastern part of the site has a west facing slope of about 2^o-5^o. The western part comprises a ridge running north south and the east of the ridge slopes down to the creek.
The depth of soil cover ranged from less than 0.5m over the ridge and up to 3m over the slopes closer to the creek

2.2 *Subgrade testing*

Subgrade testing comprised remoulded soaked CBR tests on samples collected from the proposed centerline of the road alignment prior to preliminary boxing. Based on CBR test results an interim pavement thickness has been provided on which subgrades would be boxed out. Further subgrade CBR tests were carried out after preliminary boxing to confirm the pavement thickness design. Where the subgrade CBR of second batch of testing is significantly less than the design CBR, subgrade replacement has been carried out.

2.3 *Selection of design CBR*

A sample of about 50 tests was analyzed to demonstrate the difficulties in selecting a design subgrade CBR (Refer Fig. 1). The results indicate high variability of CBR results. It may be noted that for a small precinct of the subdivision the number of CBR tests carried out range from 4 to 6 usually at a rate of 1 test per about 100m length of road. Therefore the design has to be based on limited testing.

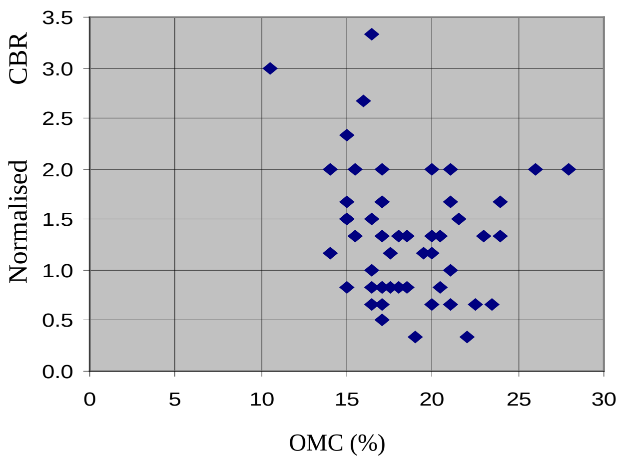

Fig 1. Normalised CBR VS OMC

The results indicate that CBR values ranged from 1.0% to 10% when compacted close to Standard Optimum Moisture Content (SOMC) to 100% Standard Compaction. Samples were tested after soaking for 4 days with a surcharge of 9kg equivalent to about 250mm thickness of pavement above the subgrade. A review of results shows the Maximum Dry Density for Standard Compaction (SMDD) ranged from 1.44t/m3 to 2.01t/m3 and SOMC ranged from 10.5% to 28.0%. Based on the review of test results for the project under consideration and other results from previous projects with similar soil conditions, some preliminary generalizations have been made. For example a sample with MDD less than 1.5t/m3 and SOMC more than 22% is unlikely to form a competent subgrade and test results in excess of CBR 2% has been viewed with caution. Samples where SOMC is less than 18% and the MDD more than 1.70t/m3 were expected to yield a CBR value of at least 3%. Where the results obtained were contrary to the above expectations CBR results were assessed against the factors discussed in Section 1.3 above. In addition, the depth of anticipated pavement was factored in evaluation of results. Experimental investigations carried by the author (not published) indicates that the increase of surcharge load from 9kg to 18kg increase the CBR of mostly clay soils by more than 50% when the CBR value is less than 3% under 9kg surcharge.

Based on the results discussed above, a CBR value of 3% has been used for the design of most roads, with some sections of the roads requiring subgrade replacement due to high plasticity clay with CBR less than 2% or subgrade was deflecting when subjected to proof roll testing. Pavement thickness used ranged from about 400mm to 600mm for traffic loads ranging from 10,000ESA to 1,000,000 ESA.

In some instances where the subgrade CBR was less than 2% and the traffic loads were more than 500,000ESA, the subgrade was stabilized with lime to about 300mm depth and the design was based on CBR 5%.

3.0 SAND SUBGRADES

Sand subgrades offer special problems in construction as well as in subgrade evaluation. When subjected to laboratory CBR tests, clean uniform sand such as marine sand would record CBR values in the range 5% to 20% with an average of about 10%. Sand compacted with a smooth vibrating roller can achieve Density Index ranging from 80% to more than 100% based on laboratory test procedures. Dry Density ratio based on Standard Compaction can be in the range 100% to 105%. The Elastic Modulus measured based on plate load test results for these soils typically range from about 25MPa to 40MPa. Most workers take the elastic modulus as equal to resilient modulus and for use in conventional pavement thickness design charts the elastic modulus is converted to CBR based on a simple correlation such as resilient modulus in MPa to be ten times CBR (Austroads2012).

For cohesionless soils, in spite of laboratory CBR returning values of 5% to 20% when compacted to density that can be achieved in the field, most designers would opt to undertake field verification tests. DCP tests carried out in Sand would always produce very low penetration resistance in the upper 300mm to 600mm layer as expected. Experience indicates the average penetration rate for compacted marine sand in the top 300mm depth to be about 100mm/blow to 150mm/blow. In the case of design of shallow footings on sand most engineers would use a correction factor to compensate for the overburden pressure and would conclude sand to be dense or very dense. However in estimation of CBR value from penetration resistance, there is no precedence for applying a correction factor and the in-situ CBR is estimated as less than 2% using a correlation such as Austroads (2012). Plate load tests, Falling Weight Deflectomer and LWFD tests, if carried out on sand subgrade would yield Elastic Modulus values in the range 25MPa to 40MPa, slightly better than that obtained by DCP tests. However based on laboratory test results, the designers expect resilient modulus of 100MPa or more assuming Austroads correlation.

This apparent low subgrade CBR would make pavements to be much thicker than it needed to be and there have been attempts to undertake subgrade replacement and cement stabilization to overcome these technical issues.

FWD tests carried out on sand gave modulus values in excess of 150MPa for depths below 600mm.

The issues that need to be solved in this include: 1). should a conversion factor be applied for overburden pressure in converting penetration resistance to CBR using standard charts? 2) Whether the charts for conversion of DCP resistance to CBR derived for mostly cohesive soils still applicable to sand? 3) Can the modulus calculated from plate load tests and similar using elastic layer theory be taken as Resilient Modulus? 4) Should we adopt estimation of Resilient Modulus based on soil properties and stress condition as advocated by some road authorities (George 2004)

Our recent experience indicated that modulus of sand when confined by at least 600mm of overburden would provide reasonable modulus values that would be expected in laboratory tests. DCP values at depths in excess of 600mm also produced interpreted CBR values of 15% or more. It would appear that for testing of cohesionless soil, the interpretations of modulus may be made on the results obtained for the anticipated depth of confinement rather than based on the results on unconfined layer.

Based on limited experience it is apparent that Elastic Modulus measured from static plate load tests (including FWD and LWFD) may need to be carried out under the anticipated stress conditions if the results are to be used in the pavement thickness design. In addition simple correlation of Resilient Modulus to CBR used by Austroads appears to be not reliable particularly for CBR values more than 7% (Austroads 2009).

Plate load tests carried out in cohesive soils such as ripped sandstone compacted to 100% standard compaction indicates elastic modulus values in the range 60MPa to 90MPa whereas CBR on such materials would be more than 15%. Most designers would not hesitate to use a Resilient Modulus of 100MPa or more in pavement design on compacted sandstone subgrade.

Due to the above uncertainties the author uses a CBR 7% for design of pavements for light trafficked roads on compacted sand and if using CIRCLY for design a Resilient Modulus of 50MPa is assumed. For good cohesive subgrades a maximum CBR value of 7% or Resilient Modulus of 70MPa is used.

4.0 CONCLUSIONS

There is a trend in pavement thickness design to use stress strain models to assess pavement thickness and Resilient Modulus for subgrade and hence pavement materials should be correctly evaluated. It appears that the current practice of estimating the Resilient Modulus from simple tests needs further refinement particularly for cohesionless soils. Further research is needed in this area. Until such time the evaluation of Resilient Modulus is formalized, the existing relations should be used only for CBR values in the range 3% to 7%. The subgrade modulus for cohesionless soils should be estimated based on tests carried out at stress levels anticipated in service.

ACKNOWLEDGEMENT

The author wishes to thank co-workers at Network Geotechnics Pty Ltd in Sydney in providing data from various projects that they have been working.

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