On the expected changes in the resilient modulus of a compacted soil and their implications for pavement design

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ABSTRACT
In this work, the author presents some experimental results to illustrate the expected change on resilient modulus of a compacted soil, due to evolution of their water content and saturation degree, by the drying and wetting processes being part of the interaction of the pavement structure with environment. A discussion is presented on the selection of a resilient modulus value for pavement design.

RESUMEN
En este trabajo se presentan una serie de resultados experimentales que ilustran los cambios que el módulo de resiliencia de un suelo compactado puede experimentar, cuando sufre cambios en sus contenidos de agua y grado de saturación, por efecto de los procesos de secado y humedecimiento a los que está sujeto el pavimento de una carretera en su interacción con el medio ambiente. Se discute la problemática asociada a la selección del módulo de resiliencia adecuado para fines de diseño de pavimentos.

1 INTRODUCTION

The stress-strain analyses for a pavement structural section are commonly performed by using the Burmister Theory for stratified elastic media. The elastic moduli used for this purpose are obtained by means of laboratory triaxial cyclic load tests that in the case of compacted soils and granular materials are called Resilient Modulus, Mr.

The assessment and selection of this modulus for design is determinant to appraise the structural contribution of the compacted soils in the long term pavement behavior, as a structural unity.

A deficient behavior of compacted soil layers contribute to the occurrence of surface permanent deformations and cracking, affecting the quality of the service state and increasing the conservation and operation costs. This situation is not desirable for any kind of road, but particularly not for expressways and main axis roads of our network.

Nevertheless, our experience had demonstrated without any doubt that the initial compacted soil properties can change by the interaction between the road and the environment. In effect, the climatic variations in terms of rain and evaporation, and the interaction with the subsoil water induce changes of potential in various points of the compacted soil layer, inducing changes in the water content and saturation degree, affecting the mechanical properties of the material as the resilient modulus.

This article has the intention to clarify this situation through the presentation of several laboratory research results in which we have measured the resilient modulus in compacted soil samples, after performing controlled changes in their water content and saturation degree. We discuss the possible implications of results on the pavement design practice.

2 TESTING PROCEDURE

The soil used for this experimental study was high plasticity silt, classified as MH according with SUCS. The liquid limit and the plasticity index where of 57 and 26% respectively. For the compactation process, the optimal value for water content was 33.42% and volumetric dry weight of 12.88 kN/m^3, accordingly with the Proctor Standard Test.

A large number of specimen samples where compacted for this optimum Proctor conditions and then submitted to moistening or drying controlled processes. The drying process was at open air in laboratory conditions. The moistening process was by slow water sprinkling at haze point and then setting the sample at rest for 8 days, protected by an auto sealing plastic film and at constant temperature. This procedure allows us to get adequate homogeneous water content. This moistening and drying process were applied to several samples with durations of 5 and 10 days.

At the end of the moistening or drying process, the resilient modulus test where performed with every specimen. The results are shown here after and they are the average of three measurements in all the cases.

3 TEST RESULTS

3.1 In optimal compactation conditions

Resilient Modulus values Mr obtained with the specimens in optimal compactation conditions, without any drying or moistening process, are shown in figure 1. It is important to say that in this testing procedure, every specimen is subjected to 16 consecutive series of 100 repetitions of a certain cyclic deviatoric stress and a constant confinement stress. The confinement stress levels were of 14, 28, 41 and 55 kPa. The corresponding deviatoric stresses were of 25, 43, 62 and 88 kPa. At the end of each 100 repetitions series, the Resilient Modulus is obtained as the quotient between the applied deviator stress and the recovered elastic strain.

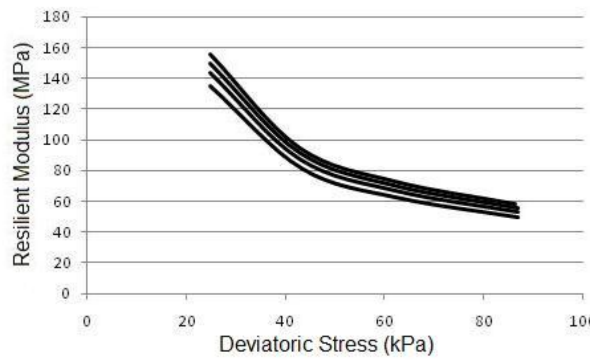

Figure 1. Resilient Modulus for optimal conditions:
$w = 33.42\%$, $\gamma_d = 12.88$ kN/m^3 and $S_r = 84\%$

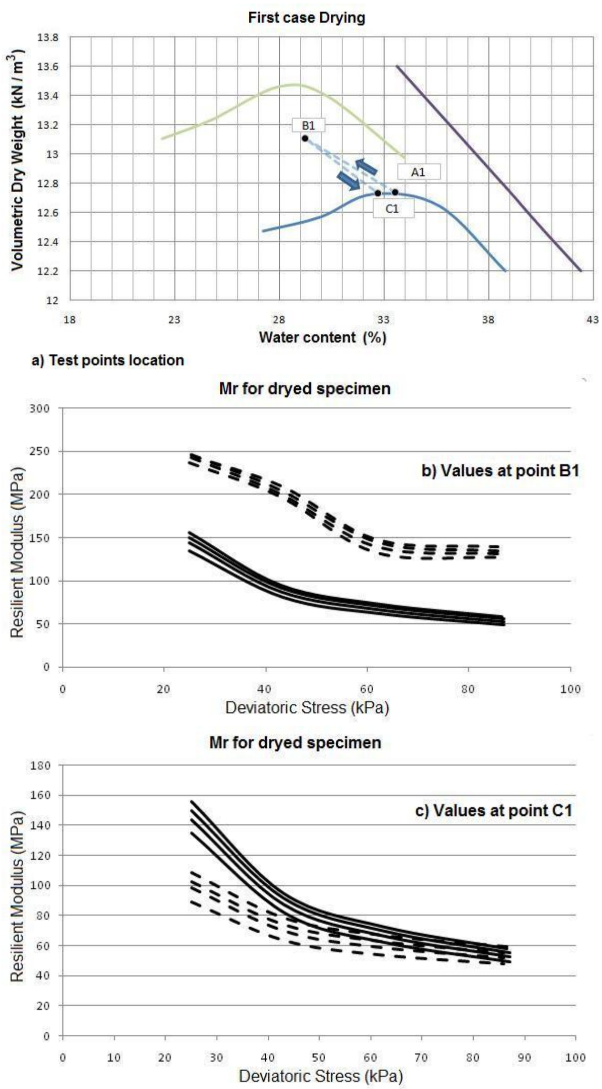

Figure 2. Mr values for the first case dried-moistened trajectory (discontinuous lines)

The observed behavior is typical for a compacted fine soil, in which it is shown a strong dependence on the deviatoric stress level and small effect on the confinement one that hardly allows seeing differences between the four curves of figure 1. For pavement design purposes, the appropriate modulus is chosen from these curves as a function of the expected stress state. If the case requires, it is possible to model the complete curve for the non-linear stress-strain analyses.

The curves shown in figure 1 represent the initial construction conditions of the compacted soil. So it is against these values that we compare the results obtained from the drying and or moistening processes and will appear as solid lines in the next figures.

3.2 In dried and then moistened conditions

The Mr results for two specimen, the first one taken from the optimal compactation condition (A1 point) to a dry

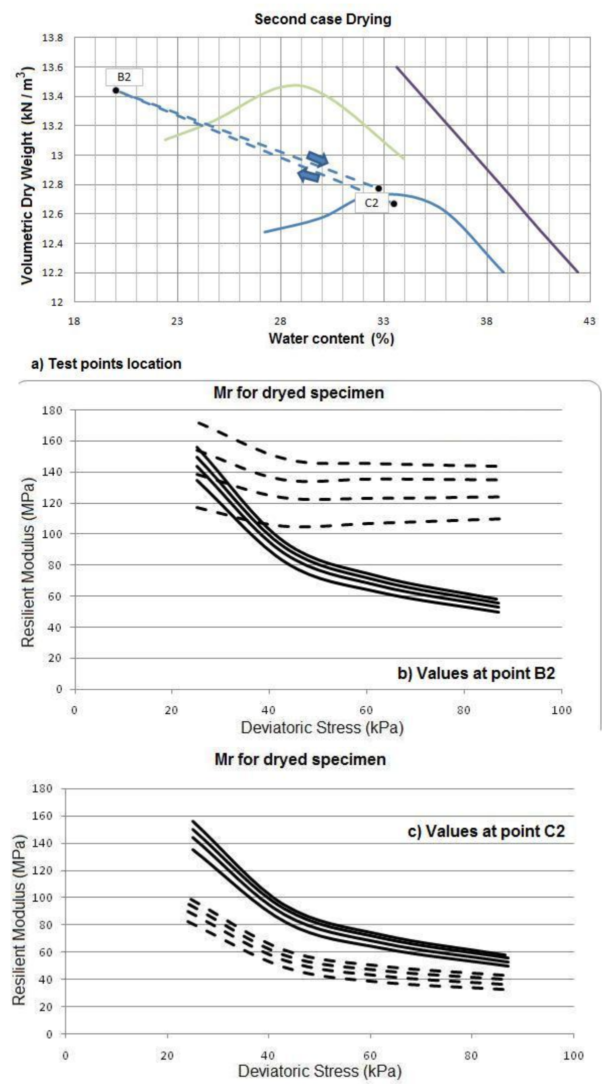

Figure 3. Mr values for the second case dried-moistened trajectory (discontinuous line)

condition (B1 point), and the second one subjected to the same drying process but then taken back to the optimal condition by moistening (C1 point), are shown as a discontinuous line in figure 2.

In the case of B1 specimen, the water content was reduced to 29.2% and the degree of saturation S_r to 78.9%. The resilient moduli values obtained in this condition shows a significant increment for all the deviatoric stresses values and the confinement stress effect continues to be small (Fig. 2b).

In the case of C1 specimen it can be shown that even when the water content comes back to the optimal compactation conditions, the consecutive drying then moistening process is not reversible. In fact, the resilient moduli are lower than the original ones particularly for lower deviatoric stresses values (Fig. 2c).

If the drying process is more intense, as shown in figure 3 for point B2, where the water content was reduced to 20% and the degree of saturation *Sr* to 56.9%, the Mr behavior curves change noticeably.

As it can be seen, the influence of the deviatoric stress diminishes and on the contrary the confinement stress becomes significant (Fig. 3b), as it is common for granular soils.

This is like the drying causes the formation of internal clots in soil structure that modify partially their grading. When water content comes back to the optimal conditions (point C2) we can see that the effect on the resilient moduli are also not reversible (Fig. 3c), and the Mr values are lower than the reference ones.

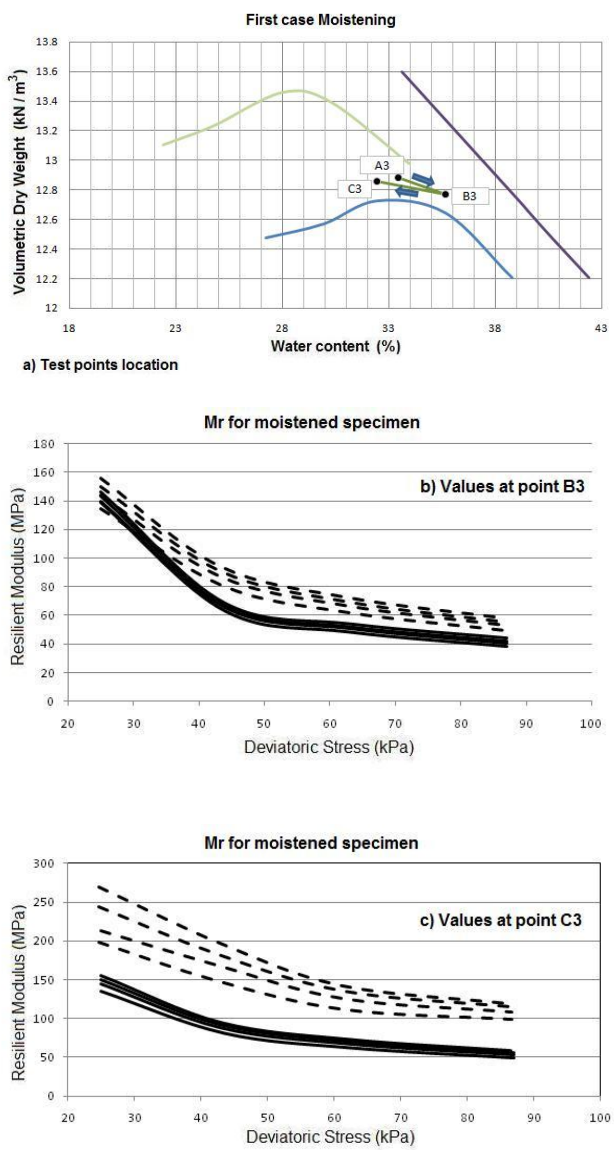

Figure 4. Mr values for the first case moistened-dried trajectory (discontinuous lines)

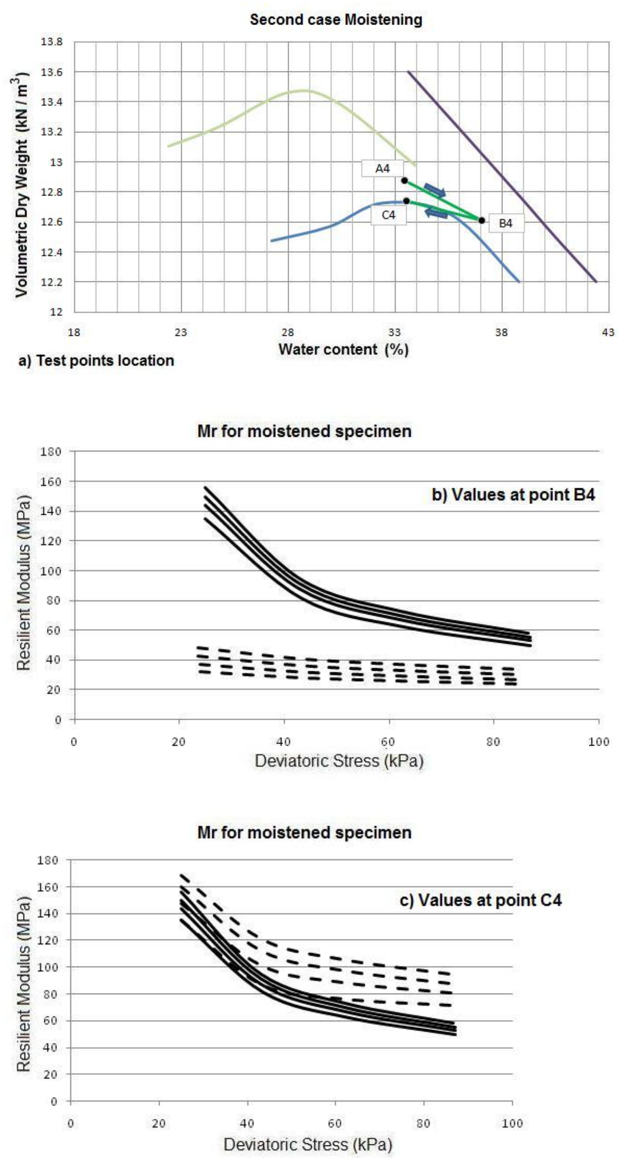

Figure 5. Mr values for the second case moistened-dried trajectory (discontinuous lines)

3.3 In moistened and then dried conditions

The values of Mr for a specimen B3 taken from the optimal conditions to the wet branch of the compactation curve are shown in figure 4b. For this case, the water content was increased up to a value of 35.7% and the degree of saturation S_r up to 91.4%.

A second case for the moistening trajectory was achieved with specimen B4, with the results shown in figure 5b. In this case the achieved values of water content and degree of saturation were w = 37.0% and S_r = 92.4%.

Although the water content and degree of saturation for specimens B3 (Fig. 4a) and B4 (Fig. 5a) are very similar, the soil behavior in terms of resilient moduli is very different as we can see comparing these figures. In the case of specimen B4 there is a clear reduction in Mr values by effect of moistening.

For the case of specimens C3 and C4, dried in order to take them to optimal conditions, the resilient moduli values returns to values higher than the reference ones (Figs. 4c and 5c).

In view of the variations of the resilient modulus for a compacted soil, the pavement design engineer needs to choose the values which he thinks are more adequate. Although in this research a particular fine soil was used; it is well known that such reported behavior is characteristic of natural soils, including granular ones. The implications of such a result are discussed as follows.

4 IMPLICATIONS FOR PAVEMENT DESIGN

In the current the pavement design practice, the admissible charge repetitions with the maximum stresses and strains for certain points of the structural section are associated. For the case of fatigue cracking, we take for instance, the maximum unitary tension strain ϵ_t at the inferior fiber of the asphaltic carpet and to estimate the bottom layers permanent deformation, the maximum unitary compression strain ϵ_c at the superior part of the sub-grade. The calculation of these strains considers an elastic behaviour of materials (Figure 6).

Such a consideration is valid for pavements because the stress levels generated by the vehicular charges vehicles are very low regarding the pavement shear stress resistance.

Nevertheless, the elastic moduli used must be obtained from cycled charge tests. The test procedures to obtain the dynamic moduli for asphaltic mixtures, elastic moduli for stabilized soils, and resilient moduli for compacted soils and granular materials are all normalized.

The structural contribution of all pavement constitutive layers is the key to achieve the desired pavement performance level for any road. For the bottom layers sub-base, sub-grade or capping layers, the compacted soil behavior is extremely important. In fact, in Mexico it is usual to have to rebuild a road in service when failures associated with material's misbehavior of these layers occurs.

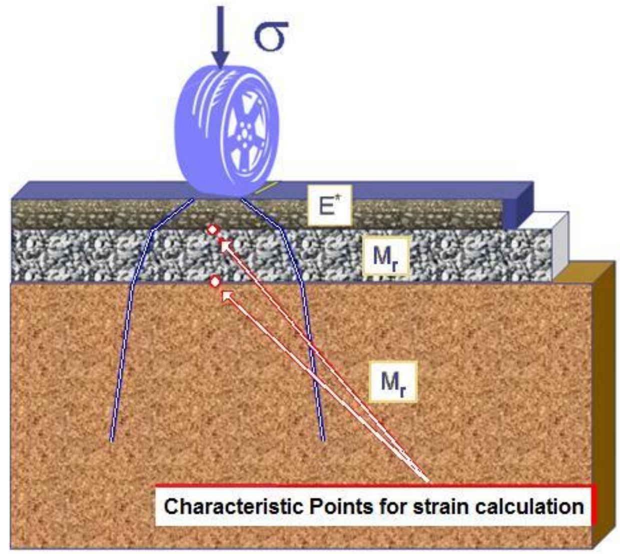

Figure 6. Stress-strain analyze model for a pavement structural section

This is the reason why the resilient modulus properties are considered so relevant.

It is also important that the structure of all the new built or rebuilt roads keep an adequate and sustained good behavior for a long time, which requires that the constituent material properties do not degrade with time. This is of course, a demanding challenge due to the changing number and loads from vehicular transit as well as the environmental condition changes all along a road.

Regarding the resilient modulus for compacted soils we can set several paradigms to engage the problem for design.

The first one, the more conservative, is to take the most unfavorable resilient modulus value. In this way we choose a low value that better represents the worst situation we shall have for a given road. In this case, the Mr is transformed in a simple calculation parameter that can be correlated with resistance indexes as the California Bearing Ratio (CBR). This is the case of design methods as the one proposed by the present AASHTO Guide developed in the USA during the 60's and widely used in Mexico and Latin America.

A more daring paradigm is to try to predict the water content and degree of saturation future evolution in the compacted soil layers, for say 20 years, in order to change the resilient modulus accordingly. This requires the knowledge of: detailed climatic data, very well defined soil properties, advanced numerical models, and excellent prediction of the number and loading from the transit vehicles. This case has the advantage of appraising the compacted soil behavior and their constitutive equations, promoting the use of new laboratory equipment as well as more sophisticated calculation methods. This is the case of the new AASHTO Guide, based on so called mechanistic methods, substituting the standing Guide in the short term.

Another intermediate paradigm is to calculate the stresses and strains taking into account the material properties and their probability distribution functions, which are also functions of the climatic conditions and of the transit vehicles loading. This could be a more effective posture. The French design methodologies embrace this philosophy.

There is a more practical paradigm, consisting in accepting that a natural compacted soil will always be subjected to changes in it's properties as illustrated in this article. If the design engineer wants to keep the properties of materials unchanged, with time, then he will never achieve his goal correctly by using natural soils. To do this, it is necessary to use chemical agents such as cement, lime or others. This is a common practice in many countries, like Spain, for pavement design for roads with whatever vehicle transit level. This way, with a good design of the asphaltic layers with high performance materials and the adequate use of stabilized soils for the lower layers, we'll have a long lasting resistant structure, with minimal maintenance needs, avoiding unwanted rebuilding and lowering the highways and main roads national net operational costs.

For Mexico the responsible authorities must decide which of these paradigms is the more convenient for the country, but in author's opinion, the best pavement design practice is found in a combination of the last two mentioned.

5 ACKNOWLEDGEMENT

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