Deformation Characteristics of Base and Subbase Layers under Monotonic & Cyclic Loading

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ABSTRACT

Base and Subbase layers are considered as the platform for distributing the different applied stresses in flexible pavements. The two layers must provide sufficient strength to resist any excessive generated deformation to achieve this goal, proper compaction machinery is essential to reach the required degree of compaction.

The present paper investigates the influence of degree of compaction of the base and Subbase layers on the generated deformation under the action of both monotonic and cyclic loadings. Model tests were performed by compacting beds of base and Subbase layers to relative densities of 65%,77% and 88%, inside steel container of dimensions 1000mm*750mm*750mm. The final thicknesses of the base and Subbase layers were 150mm and 350mm respectively.

A circular model footing of diameter 175mm: equivalent to 24194 mm^2 tire contact area is placed on the base layer and subjected to a series of monotonic and cyclic loadings. The results of monotonic tests revealed an increase of 71% and 107% in the carrying capacity when the relative density increased from 65% to 77% and from 65% to 88% respectively.

The cyclic tests revealed a substantial increase in the number of cycles at any stress level as the relative density increases from 65% to 77% and from 65% to 88%.

خصائص التشوه لكل من طبقتي الاساس وما تحت الاساس تحت تاثير الحمل الساكن والمتكرر

الخلاصة

تعتبر كل من طبقتي الأساس وماتحت الأساس القاعدة المسؤولة عن توزيـع الاجهـادات المختلفـة المسلطة على مقطع التبليط المرن,وعليه فأن كـلا الطبقتين يجب ان تـوفرا مقاومـة كافيـة لمقاومـة اي هبوط متولد نتيجة للاحمال المسلطة.

يقدم البحث تحقيقا ودراسـة عـن تـأثير درجـة الحـدل (درجـة الـرص) لكـل مـن طبقتـي الأسـاس وماتحت الأساس على مقدار الهبوط المتولد تحت تأثير كل من الاحمال الساكنة والمتكررة.

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تـم حـدل طبقتـي الأسـاس وماتحـت الأسـاس بكثافـات نسـبية مختلفـة هـي : ٦٥%,٧٧% و ٨٨%
داخل حاوية حديدية ذات ابعاد (١٠٠٠ملم*٧٥٠ملم*٧٥٠ملم) على طبقتين بحيث يكون سمك طبقـة
الأساس ١٥٠ ملم وسمك طبقة ماتحت الأساس هو 350 ملم.

تم وضـع نمـوذج لاسـاس دائـري مصـنع مـن الحديـد بقطـر ١٧٥ملم علـى طبقـة الأسـاس المحـولة, ان
اختيـار قيمـة القطـر للاسـاس الـدائري هـو مقـارب للمسـاحة البالغـة ٢٤١٩٤ ملم مربـع المسـاوية لمسـاحة
تلامـس اطـار مركبـة قياسـية مع الطريق.

بينـت نتـائج فحـوص الاحمـال السـاكنة بـأن مقـدار الزيـادة فـي قابليـة التحمـل لنمـوذج الفحـص وصـلت
الـى ٧١% و١٠٧% عنـدما تـتم زيـادة الكثافـة النسـبية لكـل مـن الطبقتـين مـن ٦٥% الـى ٧٧% مـرة ومـن
٦٥% الـى ٨٨% مرة اخرى.

بينمـا اشـارت نتـائج فحـوص الاحمـال المتكـررة الـى زيـادة فـي قابليـة التحمـل مـن خـلال زيـادة عـدد
دورات التحميـل عنـد اي قيمـة للاجهـاد المسـلط علـى نمـاذج الفحـص عنـدما تـتم زيـادة الكثافـة النسـبية لكـل
مـن الطبقتـين مـن ٦٥% الـى ٧٧% ومـن٦٥% الـى ٨٨%.

INTRODUCTION

Flexible pavements generally based onprepared base &subgrade layers which are the roadbed soils or borrow materials compacted to a specific density. Subbase and base layers represent the combination and manipulation of soils thatare capable of supporting traffic in all weather conditions.For these reasons Subbaseand base layers must possess sufficient shearing strength to withstand traffic loadings under different environmental conditions without excessive deformation.

A Subbase course constructed and compacted on the top of the prepared roadbed, where compaction process resulting densification and reduction in porosity, associated with changes to the soil structure and (usually) an increase in strength and a reduction in hydraulic conductivity.(Corps of Engineer,ETL).(2003).

Stresses beneath tires and tracks of vehicles have been measured by many researchers, both in laboratory soil bins and in the field (Al-Qadi.I.L and Appea A.K. (2003)). Stresses at the tire-soil contact generally range from about 50 kPa (under track and wide or dual tires) to 300 kPa or more (narrow tires with heavy vehicles. (Al-UTBI A.I.K. (2011)).

The compaction process led to effective utilization of local materials in order to increase strength properties of the soil and decreases the construction cost. The desired level of compaction is best achieved by matching the soil type with its proper compaction method. Other factors must be considered as well, such as compaction spaces and job condition**s.**

EXPERIMENTAL WORK
Materials used
Subbase & Base Materials

The subbase& base are brought from Al-Nibaee quarry, north of Baghdad, commonly used in flexible pavement construction. Grain size analysis was performed on subbase& base specimens in accordance with (BS 1377:1975, Test 7 (B)). The grain size distribution curves are shown in Figures (1&2). The subbase& base are classified as (GW) according to Unified Soil Classification System (USCS).

	Gravel	Sand	Silt & Clay
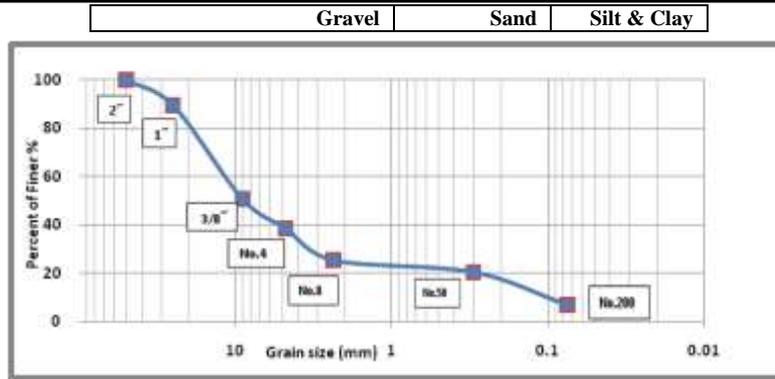
Figure (1)Subbase Soil Material.

	Gravel	Sand	Silt & Clay
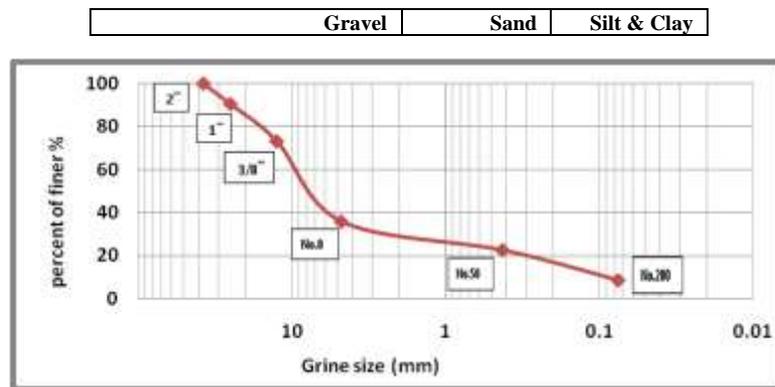
Figure(2)Base Soil Material.

The other physical and chemical properties of the Subbase& base used are shown in Table (1).

Table (1)Physical and Chemical Properties of Subbase& Base Used.

Test	Index Property	Subbase	Base	Test Method
1	Total unit weight kN/m^3	22.6	22.3	BS 1377
2	Max.dry unit weight	21.3	21	BS 1377
3	Min.dry unit weight	14.6	14.89	BS 1377
4	C.B.R (at Total unit	45%	58%	ASTM D 1883
5	Optimum Moisture	6.5%	6%	BS 1377
6	Liquid Limit%(LL)	NL	NL	AASHTO T 89
7	Plasticity Index%(PI)	NP	NP	AASHTO T 90
8	SO3 Content%	1.48*	2*	BS 1377 test No. 9
9	Total Dissolved Salt	2.58*	3.5*	Earth Manual of U.S.
10	Gypsum Content%	0.76*	0.74*	AASHTO T 19
11	Organic Matter%	0.06*	0.06*	Test No. 8 of BS 1377

*Tested in laboratories of State Company of Geological Survey and Mining. According toIraqi General Specification   for Roads and Bridges, (2001-2003).

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Preparation of Model Test
Preparation of Subbase and Base Granular Layers
   A sufficient amount of subbase and base soils were placed in an oven for a period of 3 days for complete drying. The soils were mixed with water corresponding to optimum water contents of 6.5% and 6% for subbase and base respectively. After through the soils were prepared and compacted inside a steel container of dimensions (1000mm*750mm*750mm). The final compacted thicknesses of the layers are 350mm and 150mm for subbase and base respectively. After this stage the layers were ready for testing.
 Testing Setup
   The setup used was designed and manufactured by *Rahil.F.H (2007)*, as shown in plate No.1, capable of applying both of monotonic and repeating loading, monitoring of the tests wascarried out directly through a PLC unit, (programmable logic controller unit).

Plate No.(1)Setup Testing.

Model Test
   The circular footing was placed on the surface of the compacted base layer, and the whole assembly was then placed in position in the middle of the setup. Monotonic loads were applied incrementally through a hydraulic jack at displacement rate of 0.03mm/sec, and the generated settlement of the footing was recorded by rotary encoder shaft. The process continued up to failure.
   In case of repeated loading, stress increments representing a ratio of the stress at failure were applied in a repeated form and the generated settlement of the footing were recording with the number of cycles directly similar to the monotonic test.

RESULTS AND DISCUSSIONS
Presentation and Discussion of Model Test Results under Monotonic Loading.
Model Tests on Subbase & Base Granular Layers Only
   This series consists of three model tests performed on layers of subbase& base compacted at relative densities 88%, 77% and 65%. Figure (3)represents the relationship between the applied vertical stress (q) and the settlement ratio (S/B) – where B = Dia. or Width of footing- of the three model tests. The mode of failure for the model prepared at the lowest relative density 65% characterized in shape as that of local shear failure type. As the relative density was increased to the highest value of 88%, the mode change toward a general shear failure type exhibiting some heaving outside the border of the footing. The model test performed at R.D=77% demonstrate a mode of failure intermediate between local and general shear failure. The ultimate

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bearing capacity being 266.51kPa, 457.55 kPa and 551.89 kPa at settlement ratio S/B=10% for the subbase and base with relative densities 65%, 77% and 88% respectively, the increase in applied stress at failure is about 71% when the R.D is increased from 65% to 77% and reaches to 107% when the R.D is increased to 88%.
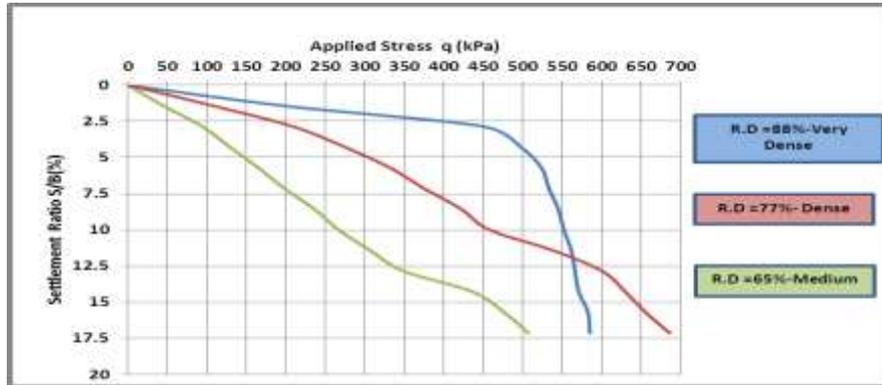
**Figure(3)Monotonic Tests at Different Relative
Densities for Granular Layers.**

Figure (4)Represents the bearing improvement ratio (B.I.R) ($q_f^{88\%}/q_f^{65\%}$) and ($q_f^{77\%}/q_f^{65\%}$) defined as the applied stress at failure of the highest value of relative density to the next lowest value plotted against settlement ratio. The Figure demonstrates that the relative density of subbaseand base model has a major contribution in providing the resistance to failure and ultimately. The overall strength of pavement section experience some sort of improvement.

The Figure demonstrate the development of maximum B.I.R at deformation ratio S/B=2.5%. Followed by a sudden drop as S/B exceeds 2.5%. This behavior indicates that maximum improvements can be achieved at working loads rather than ultimate or close to failure loads.
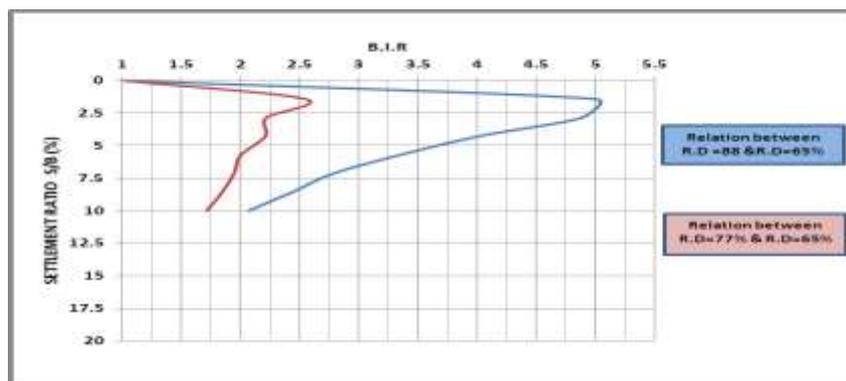
**Figure(4)Relations of B.I.R vs Settlement Ratio for
Subbase & Base Layers at Different Relative Densities.**

Presentation and Discussion of Model Test Results under Repeated Loading.

Repeated loading tests were performed by applying a specific stress usually selected as a ratio of stress at failure determined from the monotonic model tests; say 0.2 q_u, 0.4 q_u, 0.6 q_u and 0.8 q_u.

The definition of failure is considered as the number of cycles required to generate a settlement of 10% of the footing width (diameter in this research) at any applied stress increments, or the test continues till 10^4 cycles, who ever occurred first. Rahil F.H. (2007).

Model Tests of Untreated Granular Layers.

This series consists of twelve model tests performed on granular layers (Subbase and Base) identical to the model tests of the monotonic loading. The series is divided into 3 groups according to the relative density:

Granular soils (Subbase & Base) with R.D =88%.
Granular soils (Subbase & Base) with R.D =77%.
Granular soils (Subbase & Base) with R.D =65%.

A. Settlement Ratio versus Number of Stress Cycles.

Figures (5 to 7) demonstrate the relationship between the settlement ratio S/B where B=D (D= diameter =175mm), and the logarithmic of the number of stress cycles under the different applied stresses 0.2 q_u, 0.4 q_u, 0.6 q_u and 0.8 q_u. for model tests prepared at R.D= 88%, 77%, and 65%.

Generally the rate of generation of settlement increases with increasing number of cycles and increasing applied stress (especially at 0.6 and 0.8q_u). All repeated tests are based on failure stress q_u values obtained from the monotonic tests, of the untreated granular model tests as indicated below:

q_u = 551.89 kPa, at R.D = 88%.
q_u = 457.55 kPa, at R.D = 77%.
q_u = 266.51 kPa, at R.D = 65%.

The three figures show the importance of controlling the compaction process of the subbase and base layer in the field. The model tests performed at R.D = 88% exhibited stiffer behavior demonstrated by the small values of settlement ratios even at extreme values of applied stress and number of cycles, 10^4 cycles. On the contrary, the model tests performed at R.D = 65% exhibited higher settlement ratio after the first cycle even at lower stress ratio, 0.2q_u.

All model tests show a family of linear lines having approximately the same gradient starting from the deformation after the first cycle till the end of the test. The influence of the stress ratio on the generated settlement after the first cycle becomes more significant at higher values and levels.

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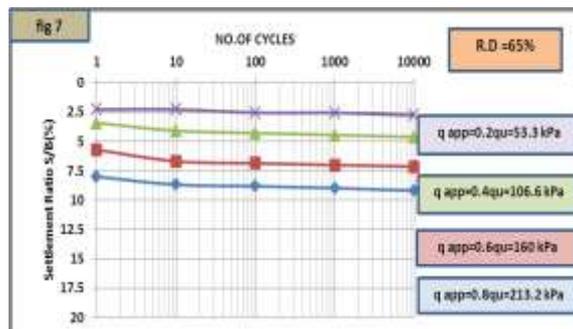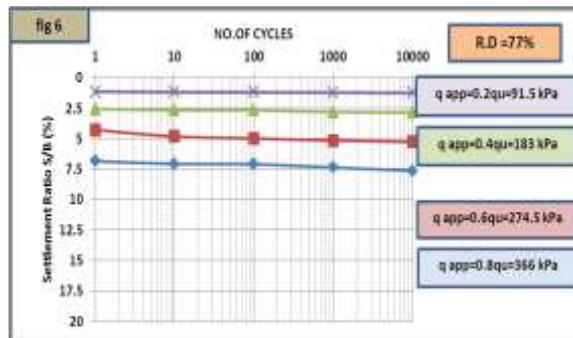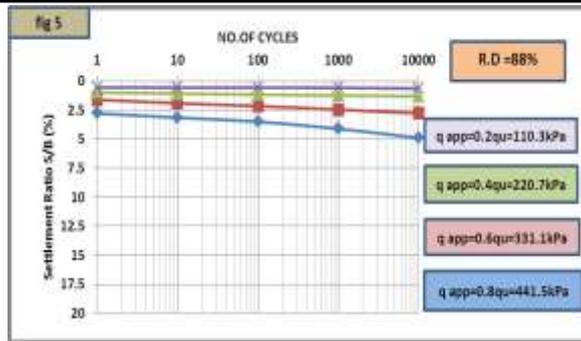
**Figures (5.To7) Relations between No. of Stress Cycles & Settlement
Ratio for the Granular Layers at Multi Relative Densities.**
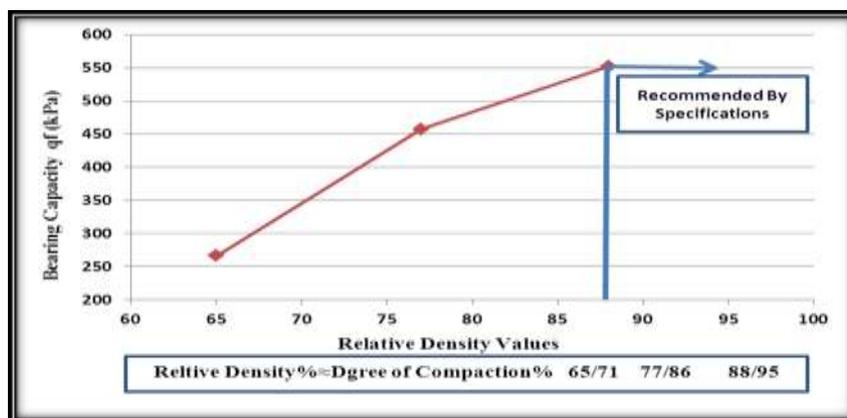
**Figure(8) Relation between Relative Density & Bearing Capacity
Stresses Values at Failure (q$_f$).**

Figure (8) represents the relationship between different relative density values and the bearing stresses at failure limit with the representation of the relation between the relative density and degree of compaction; Figure refers to the importance of compaction effort with its contributing in carrying capacity increasing by gradual increasing in stress levels connecting with relative density increasing.

B. Factor of Safety versus Number of Stress Cycles for Untreated Granular Layers at Different Relative Densities.

To investigate the margin of safety achieved after specific number of cycles at different stress levels. The term factor of safety could be defined as the ratio of the stress at failure of the monotonic test to a stress that generates a specific settlement ratio after a specific number of cycles from the corresponding repeated test.

The factor of safety as defined above is an indication of the margin of safety that can be provided under different stress conditions. Model tests performed at high relative density, R.D =88%, exhibited higher safety values at lower stress levels as compared to factor of safety at higher stress level, as shown in Figures (9 to 11) .

The influence of R.D on factor of safety gradually decreases when comparing the three Figures at higher stress values, the factor of safety narrows down andranged between 4 to 1 or close to 1 after 10000 cycles. There is a clear drop down in factor of safety with increasing applied stress ratio after any specific number of cycles.
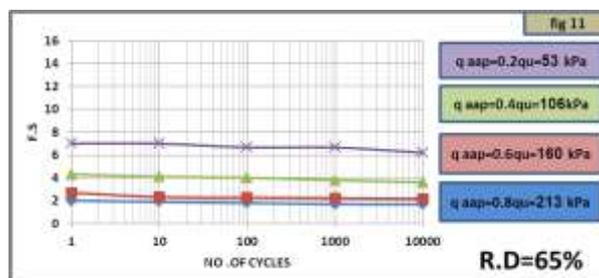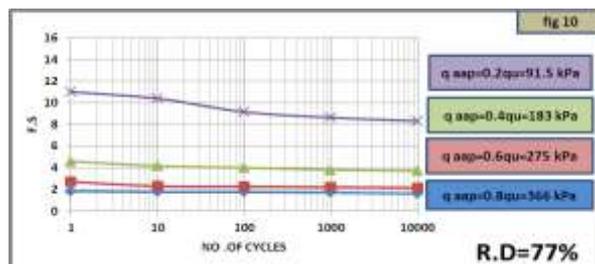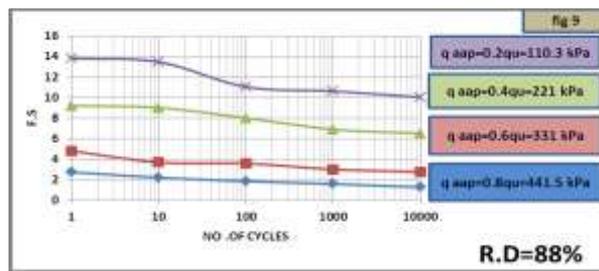
Figures (9) to 11 Variations between Factor of Safetyvs No.of Stress Cycles for Untreated Granular Layers at Multi Relative Densities.

CONCLUSIONS

The following points are drawn from the model tests performed within the limitations of test results:

1. The model test at R.D = 88% exhibited a general shear mode of failure with failure stress of 551.89 kPa,while the model test at R.D = 65% exhibited a mode of failure close to the local pattern and revealed a failure stress of 266.5 kPa.

2. Based on 1 above increasing the relative density from 65% to 88% provided an increase of 107% of the ultimate bearing capacity indicating the importance of controlling the compaction process in the field.

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