Experimental Assesment of Geosynthetic Stabilized Flexible Pavement Sections

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Abstract- *Unbound base layers deform under load and contribute to the accumulation of ruts. Therefore, this study was concerned with studying the effect of reinforcement on the behavior of unbound granular material that used inflexible pavement layers as a base course. Two main geothynthetic types were used in this study. These types were woven geo textile and geo grid. Two geo grid open-ing sizes were used (GR105and GR420). The experimental work was designed to evaluate plastic and elastic deformation and the modulus of elasticity of reinforced limestone base course. This experimental work carried out utilizing the static plate loading test in a test-model which simu- lated the subgrade and bas ecourse of the flexible pavement. The effect of base thickness, geogrid depth, modulus of elasticity of base course and geogrid edges fixationon the deformation characteristics were studied. Further more, the effect of loading time on the accumulated deformation was investigated. Moreover, the effect of reinforcement on base thickness saving(BCR) and de-formation reduction ratio (DRR) was studied. Agreat influence for reinforcement specially with geogrid (GR420) was observed in improving the deformation characteristics of base course.*

Keywords- Flexible Pavement, Geosynthetics, Deformation, Base Course

I. INTRODUCTION

Major pavement deteriorations, similar to those observed in some indian roads, especially in metro regions, resultbasicallyfrompermanentdeformationinbasecourseorsubgr adesoil.This deformation causes alligator ormap cracking, chuck holes, settlement and undulations.Inrecent years,geosyntheticshavebeen proposedand usedtoimprove theperformanceof pavedroadways.The majorfunctionsof geosyntheticmaterialsaresepara- tion,reinforcement, filtration, drainage andliquidbarrier. Inprovidingreinforcement, the geo syntheticmaterial structurallystrengthensthepavements ection bychanging theresponse ofthe pavementtoloading.Studiesto date have found thatincorporationofgeosyntheticsinflexible pavement provides a degree of performance im- provement. A few studies have triedtoquantify the benefits of geosyntheticreinforcement,but nofirm conclu- sionscanbe drawn due to differences of results.Thus,animportant need exists to quantify the benefitsderived from stabilizingflexible pavementswithgeosyntheticsandtheconditionsnecessaryforsucc essful geosynthetic stabilizationif anadequate cost comparisonis to be made.

Theimprovementinplasticsurface deformationbase course was investigated byLengand Gabr (2002)[5] usingtwotypesof geogrids(BX1andBX2).Highermodulus geogridBX2 provideda bettereffectinreducing theplasticsurfacede formation.Demerchantetal.(2002)[6] performedplateloadtestsusingadiameterplate (B) of305mmtostudytheeffect of the geogriddepth(u) onsubgrademodulus.Theresultsindicatethatthe subgrade modulus decreases as u/B increases.Moreover, themost recent work by Gabrand Hart (2000)[7]re- portedthat the elasticmodulusdecreasedwithincreasingdepthofthetop geogrid layer. Theresults oflaborato- ry and fieldtests performedby Mirafi Construction Products(2004) [8] indicatedthat geosynthetictypeaffected thepavement performance. Thebasecoursereduction(BCR)which expressedasa percentage savingsofthe unreinforcedbasethickness reachedto22%-33%with using geotextileas basereinforcementwhileBCR reachedto30%-50%usinggeogrid. HoeandWeng(2001)[9] produced that inclusionofgeotextilesatthe baselayer-subgradeinterface resultedinreductioninrut depth. Non-woven geotextilesshoweda betterrutim- provement.Gurung(2003)[10] indicatedthat the useof geosynthaticsincreased thetensilestrengthandtheten- sile strength of a pavement reinforced usinga geogrid washigher than using geotextile.

Ingranularmateriallayers,themechanism of rutdepth reduction through geo synthetic reinforcement may be explained the Lateralmovementsare prevented by aggregate confinement,leadingtoincreasein bulkstress,and aggregate layerstiffness,alongwithdecreaseinverticalstressontopofsubgra deandverticalcompressive strainreductioninlower halfof base andinthe subgrade. Overthe period of pavement construction,there are usuallytwo feasiblealternativesfor groundimprovement,namely,soil stabilization and geosynthetic reinforcement.Attimes,someofthecontractorsprefertouse geo synthetics to reinforce subgrade[11]-[15]. An experi- mental program was presentedinthisresearch,aimedtostudytheeffect of using geosynthetic reinforcement on the deformation characteristics of granular materialthat usedasa basecourse. Apavementmodelcontaininga basecourse layerabovea subgradesoilwaspreparedtosimulatethefieldcondition.

The experimental program included many variables suchas base course thickness, moisture contents, position of the geogridlayerandthe geogrid openingsize.

II. METHODOLOGY

An experimental program was carried out toinvestigate thein fluence of geo thyntheticas reinforcementforthe granular base layerofa flexible pavement constructed on silty subgrade.Plateloading test was performedas a controltesttoevaluatethe deformation characteristicsand bearingcapacity ofreinforced and unreinforced base course.

2.1.SubgradeandBaseMaterial

Asilty soil was usedassubgrade.Crushed limestone was usedasa base course. The grainsize distributionsas wellasthegradinglimitsaccordingtoAASHTOspecificationsfors ubgradesoilandbasecourseareillustrated inFigure 1and Figure2 .Thesesoilsweretestedagainst Atterberglimitsandmaximum dry density.Thephys- ical andmechanical properties for subgradeand base course arepresented inTable1andTable2.

2.2.GeothyntheticMaterial

Twopolyethylene geogrids(GR105andGR420) with different opining sizeasshown inFigure 3were usedin thisstudy.Thegeogridsthicknesswas1.6mm,therhombopeningar easwere105and420mm2 respectively. AsshowninFigure3,the woven geotextileusedinthis study waslocallymanufacturedas 45tapes/10cm.Ta- ble3showsthetensilestrength,themaximum elongationandthemodulus ofelasticityforboth geogridsand geotextile.

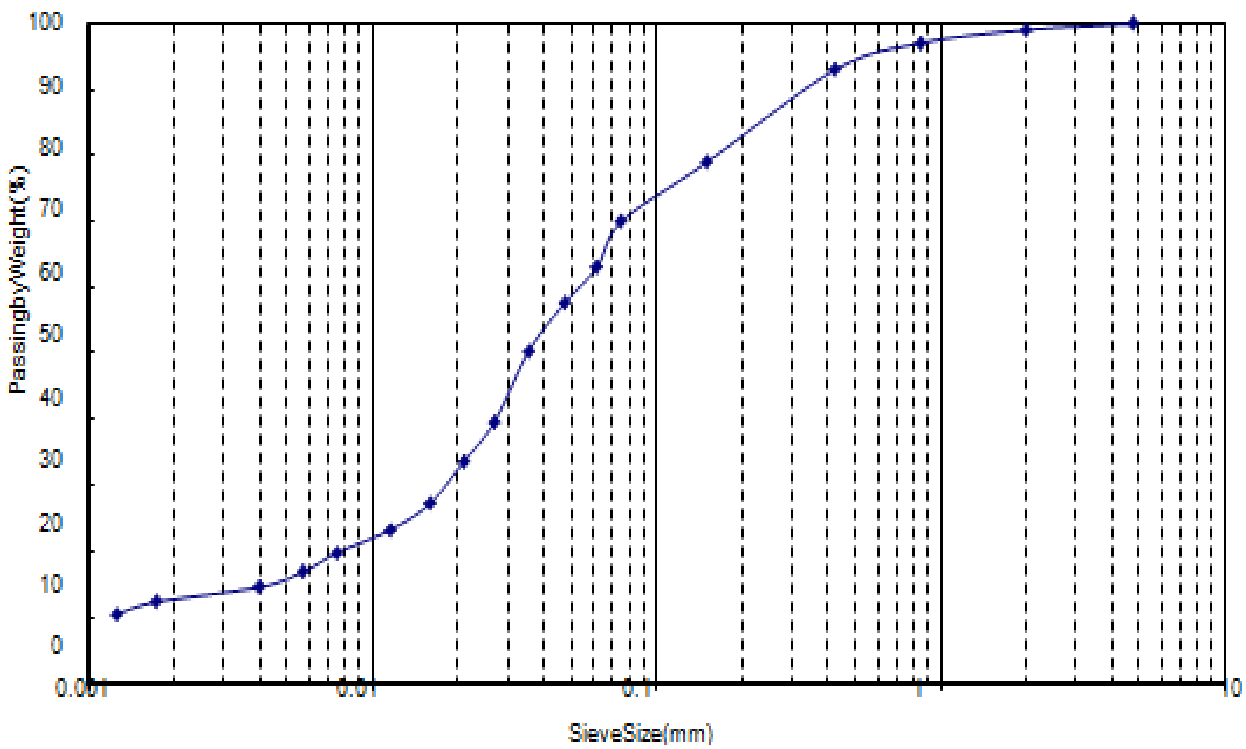

Figure 1. Grain sized is tribution fors ubgrade soil.

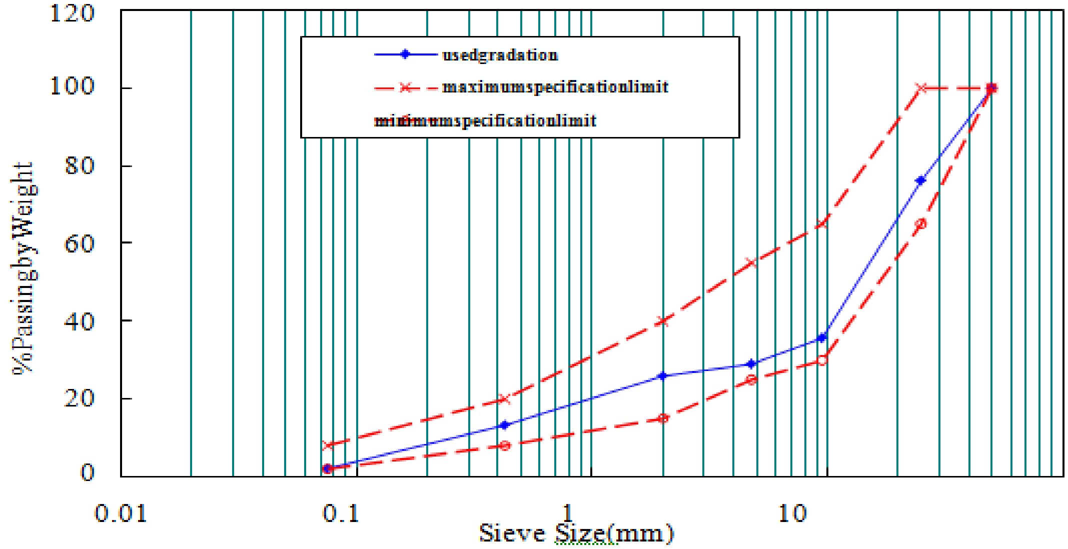

Figure 2. Grainsizedistributionforbase course.

Figure 3. Geosynthetics used instudy.

Table1. Physical properties of subgrades oil and base course.

Test	Subgrade soil	Base course
Natural moisture content,%	7.0	1.30
Liquid Limit,%	54.0	19.0
Plastic Limit,%	40.0	13.6
Specific Gravity, gm/cm³	2.68	2.65
Loose density, gm/cm³	1.33	1.70
Maximum dry density, gm/cm³	1.665	2.12
Optimum moisture content,%	16.0	7.13
AASHTO classification group	A-7-5	A-2-4
Unified classification group	MH	GP

Table2. Mechanical properties of subgrade soil and base course.

Test	Subgrade soil	Base course
Cohesion(N/mm²)	0.067	0.055
Internal friction(o)	19	23
CBR (%)	8.8	97.0
Unconfined comp. strength(N/mm²)	0.165	-
Modulus of elasticity(N/mm²)	4.88	45.0

Table3. Properties of geo grid and geotextile.

Geo synthetic Type	Geo grid Type		Geo textile
	GR10	GR420	
Tensile strength (kN/m)	5.70	1.65	1.71
Elongationat Max. Load(%)	50	40	34
Modulus of Elasticity(N/mm^2)	62.63	22.9	34.9

2.3. TheTest-ModelDescription

Thetest-modeconsistedofasquareironbox0.5m wide by 0.5m longand0.5m depth. This boxdividedinto twohalvescontainingtwolayers,0.25m depthsubgrade, and limestone basecoursewith10,15and25cm depths. The geo syntheticlayerwas place dat theinterface betweensubgradeand base course and at different depths inside thebase layer.

2.4. Preparation of Tests

Initially,thesubgradesoilwaspreparedbyaddingoptimummoisturecontentandcompactedinfivelayers.

Then, the geo synthetic was incorporated intheaggregateat aspecifiedlocation.Afterthat,the base course ma- terial wasprepared by adding theoptimum moisturecontent (8%).Finally,the basecourse materialwascom- pactedin layerstoobtainthicknessof10,15and25cm.At25cm base thickness for reinforcedandunrein- forced sections, four moisture contents were used (OMC−2%, OMC, OMC+1.5%, OMC+3%).

2.5.Applied Vertical Pressure

In this study, a contact pressure of 0.5N/mm2(70 Ib/in2) on asphalt surface layer was considered.BISAR-Linear elastic program was used to calculate the vertical stressatthesurface of basecourseconsidering5.0cm asphalt wearingcourseand5.0cmasphaltbindercoarse.Theresultsindicatedthatverticalstressdecreasedto0.35 N/mm2onthetop of the base course.

2.6.Plate Loading Test

Aninitial static pressureof0.0875 N/mm2wasapplied on thesteel plate by usingtheloading head,the deflec- tionwasallowedtoreachamaximum (waitingtimeabout20min.). As shown in Figure 4,the deflection was measured at theplatecenter aswellasatthe otherpointsacrossthetest-modelcenter line.Then,thepressure increasedto 0.35 N/mm2in 0.0875 N/mm2increments.The elasticmodulus could be calculatedas follows:

$$E=\frac{1.38p\cdot a}{w} \quad (1)$$

where:

E: modulus of elasticity (Mpa);

p: uniformappliedpressure (Mpa);

a: radius ofcircular plate (mm);

w: deflectioncorrespondingtothethirdload ontherigid plate (mm).

III. ANALYSIS OF EXPERIMENTAL RESULTS

The plateloadingtestresultforunreinforced10cm base course is shown in Figure 5.Staticloadtestisapplied and released three times on the base course material. Initially,itcanbenoticedthat,thecumulativedeformation of the first loadcycle underthe plateincreasedrapidly withincreasingthe vertical pressure onthe plate.When thetotal loadreleasedandthematerial took asufficient timetorebound, one part of vertical deflectionwasre- turnandthe residual part was remained.Thereturned divisionrepresents theelastic deformation,whilethe re- maineddivisionsymbolizesthe plasticdeformation.The rateofaccumulateddeformation becameslightlyinthe secondandthirdloadcycle because ofthe basematerial hasalready deformedandcompactedinthe first load cycle.

Figure 4. Plat loadingtest at 25 cm basethickness.

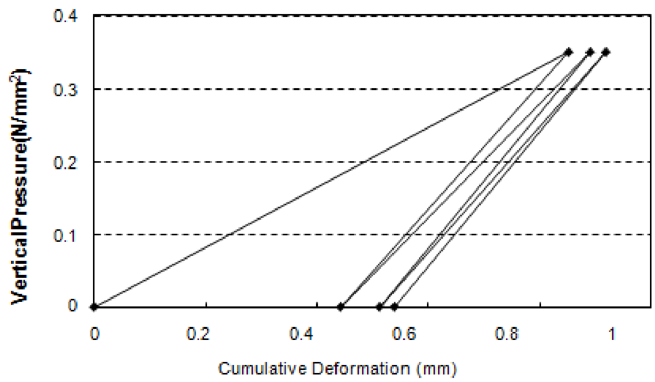

Figure 5. Cyclic loading test forum reinforced section.

Themajorobjectivesofthisresearchwerestudyingtheinfluence ofreinforcement,moisturecontents ofbase courseand geogridfixation onelasticand plastic deformation. Moreover, th eeffect of basethickness, geogrid positionandloadingtime on the deformation character is tics wereinvestigated.Foreach basecourse thickness, reinforced sections(RS) and unreinforced sections (URS) wereperformed.

3.1.Effect of Reinforcement on Modulus of Elasticity

The amount of total deformation and the modulusof elasticity (E) values foreachreinforcementcaseareshown inTables4-6 foreach basethickness(h).Thereinforcement depth(Dr) wasinvestigated.Moreover, therein- forcement benefitratio(RBR)wasobtainedasthereductionratiointotaldefor mationbetweenthereinforced and unreinforcedsections.

From Table4,itcould be noticed that all sectionsreinforcedwithGR105 gavea high negativeRBR values. Basedonthis result,the geogrid(GR420) waschosenas reinforcementforthe other basecoursethickness. Moreover, usinggeotextilealone hadn'tanyo bvious effecton reduction ofdeformation.Thefixedbottom rein- forced section (BRS) provided highermodulusofelasticity; higher benefit ratioand lower plastic deformation than the middle reinforced section (MRS).For25cmbasecoursetheoptimalreinforcementdepthratio within the base course which provided lower plastic deformation wasobtainedat(Dr/h= 0.4to 0.6).Thedoublerein- forcedsectionDRS(bottomfixedlayerandmiddleunfixedlayer)achievedthelowestplasticdeformationand the highest benefit ratio.

3.2.PlasticandElasticDeformation

From the plate loading testresultsafterthethirdloadingcycle,elasticandplasticdeformationcould becalcu- lated.Figure6correlates betweendeformation anddistancealongmodelcenterlineforunreinforced10cm base course.

Forallstudiedbasethicknessofunreinforcedsections,the plasticdeformationwasfoundtobegreaterthan the elastic deformationunderthe platecenter.However,withincreasingthe distance from theplatecenter,the elasticdeformation becamegreaterthan plasticdeformation.Forreinforcedsections,it could beconcludedthat for base thicknessless than 25cm,the plastic deformation became greater than elastic deformation atallpoints. For basethickness of25cm,theplastic deformation became greaterthantheelastic deformationatall pointsat lower geogrid depth(Dr\hlessthan orequal to 0.2)however,at higher geogrid depth(Dr\hmorethan 0.2),the plastic deformation became greaterthan theelastic deformation undertheplate center only.

3.3. Effect of Loading Time on Accumulated Deformation

The effect of loading time up to 48 hoursontheaccumulateddeformationunderastaticloadwas performed for the URS andreinforced section (fixedBRSfor 10cmbasecourseandDRSfor15and25cmbasecourse).A great influence forreinforcement wasobservedwherethe accumulated deformationcurves forreinforcedsec- tions were asemiconstant orincreasedslightlywithincreasingtheloadingtimeespeciallyatth eend ofthetest period.Summaryofthe deformation progress underthe platecenterandatdistances of10and20cm for10cm base coursearerepresented in Figure7.

Table 4. Effectofreinforcement for10cm Base.

Geo grid Type	Reinforcement Case	Total Deformation (mm)	E(N/mm²)	Benefit Ratio (%) (RBR)
None	Unreinforced section	0.92	42	
Geo textile	1-Bottomunfixedgeotextile	0.91	42.46	1.08
GR105	1-Compositereinforcement 2-Bottomunfixedgeogrid 3-Middleunfixedgeogrid	1.94 2.04 1.52	19.9 18.94 25.42	−110.8 −121.7 −65.2
GR420	1-Bottomunfixedgeogrid 2-Bottomfixedgeogrid 3-Middleunfixedgeogrid	0.88 0.85 0.96	43.9 45.46 40.25	4.34 7.6 −4.3

Table5. Effect of Reinforcement for15cm Base

Geo grid Type	Reinforcement Case	Total Deformation (mm)	E(N/mm²)	Benefit Ratio(%)
None	Unreinforced Section(URS)	0.85	45.45	
Geo textile	1-BottomUnfixedGeotextile	0.89	43.41	-4.7
GR420	1-BottomUnfixedGeogrid	0.82	47.12	3.53
	2-BottomFixedGeogrid	0.74	52.21	12.94
	3-CompositeReinforcement	0.812	47.58	4.47
	4-MiddleUnfixedGeogrid	0.792	48.21	6.82
	5-MiddleFixedGeogrid	0.785	49.22	7.65
	6-TwoLayersReinforcemend	0.67	57.67	21.18

Table 6. Effect of reinforcement for 25cm base

Geo grid Type	Reinforcement Case	Total Deformation (mm)	E(N/mm²)	Benefit Ratio(%)
None	Unreinforced Section(URS)	0.81	47.7	
GR420	1-Dr/h=0.2	1.28	30.19	-58
	2-Dr/h=0.4	0.755	51.18	6.79
	3-Dr/h=0.6	0.765	50.5	5.55
	4-Dr/h=0.8	0.85	45.46	-4.94
	5-BottomUnfixedGeogrid(Dr/h=1)	0.79	48.9	2.47
	6-BottomFixedGeogrid(Dr/h= 1)	0.69	56	14.8
	7-Twogeogridlayers(Dr/h=1 and0.4)	0.678	57	16.3

3.4.Effect of Base Thickness on Elastic Modulus

Three basecoursethickness10,15and25cm andadditional unreinforcedthicknessof40cm were used.As showninthepreviousresultsandinFigure8,itcouldbeindicatedthattheplasticdeformationdecreasedand themodulus ofelasticityof basecourseincreasedasthe basecoursethicknessincreased.Onthe other hand,the fixed bottomreinforcement section performed betterthanit for unfixedRSat all studied basethickness.

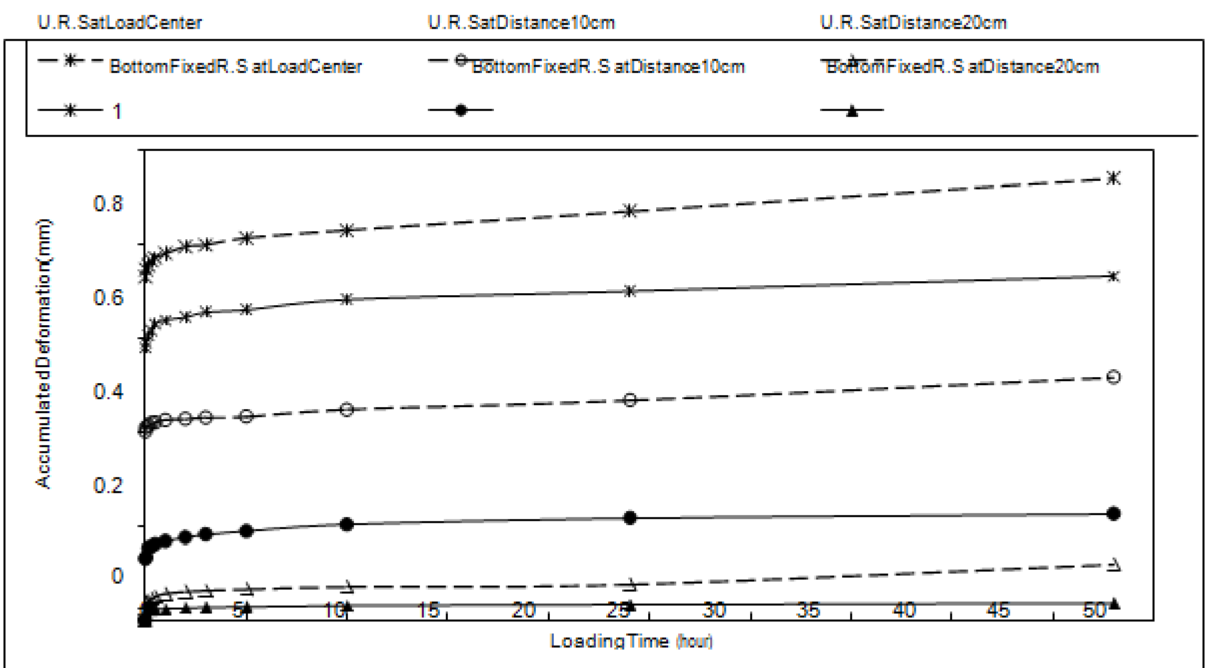

Figure 7. Effectofloadingtime 10cm base section.

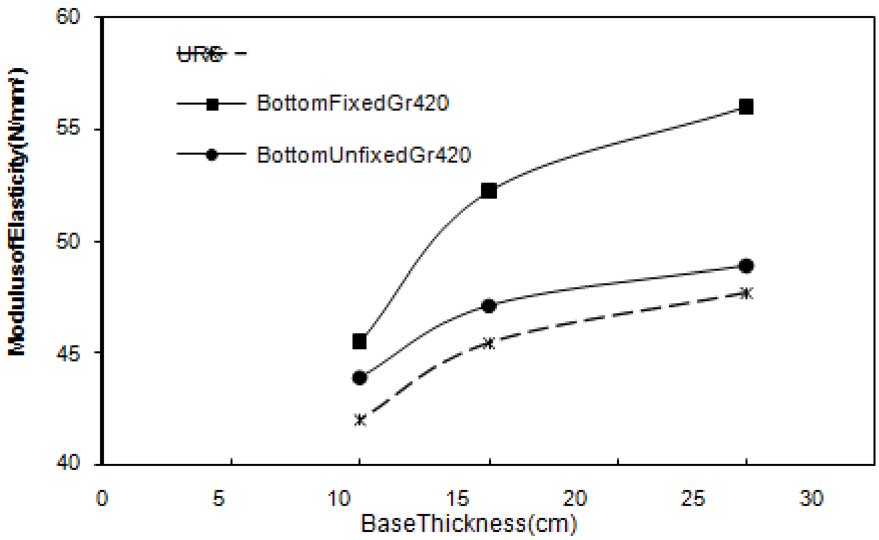

Figure 8. Effectofbase thickness on the modulus of elasticity

3.5. Effect of Moisture Content for 25cm Base Sections

FromTable 7 and Figure9it could be observedthat withincreasingmoisture content,the reinforcement benefit ratios(RBR) decreased.The highest modulus ofelasticity(E)obtainedat OMC wheretheimprovement de- creased with increasingmoisturecontents.AsshowninFigure10,the ratioofplastic deformationtothetotal accumulateddeformation(PDR)for reinforced sectionwaslowerthanitfor unreinforcedsection forallmois- ture contents especially above OMC.

3.6.Effect of Moisture Content on Plastic & Elastic Deformation

Figure11illustrates the effect of reinforcement on elastic and plastic deformationforOMC.Forallmoisture contents,theplasticdeformationwas foundtobe greaterthanelastic deformationunderthe platecenter.How- ever,withincreasingthe distancefrom the platecenter,theelasticdeformationbecamegreaterthanplastic de- formationat6%and 8%moisturecontent.Whileat 9.5% and11%,the plastic deformation became higherthan elastic deformationat allpoints.

Table7. Effect of moisture content on reinforcement benefit ratio.

Moisturecontent(%)	6		8(OMC)		9.5		11	
Sectioncondition	URS	RS	URS	RS	URS	RS	URS	RS
RBR(%)	---	23.5	---	16.3	---	12.5	---	6.75

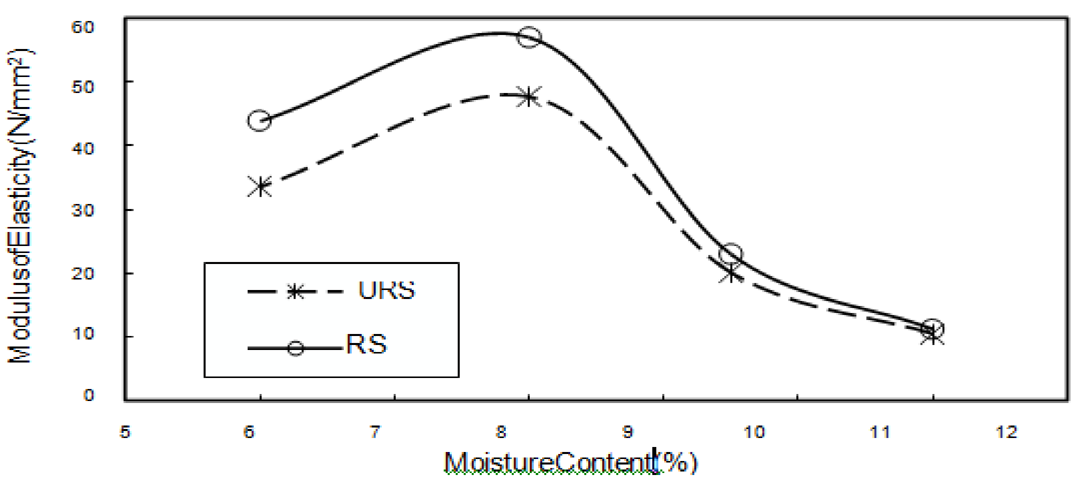

Figure 9. Effect of moisture content on modulus of elasticity.

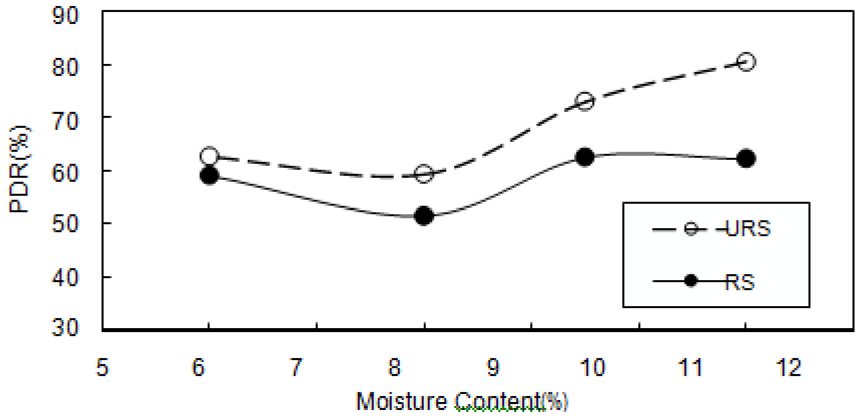

Figure 10. Effect of moisture content on plastic deformation ratio.

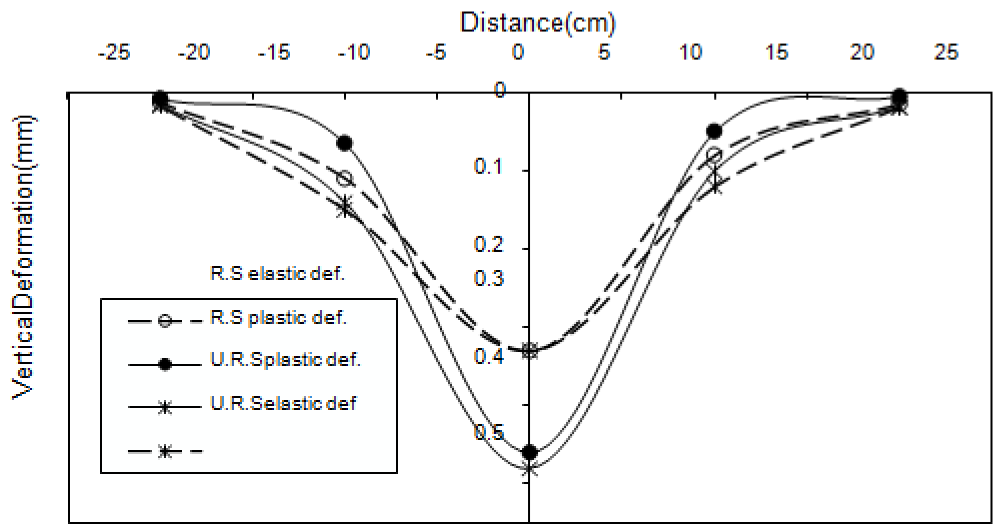

Figure 11. Plastic and elastic deformation at OMC of 8%.

3.7.EffectofReinforcementonBaseThicknessSaving

UsinggeogridGR420asreinforcement hadthe greatesteffect onthe reductionofbasethickness(BCR)andthe plasticdeformationreductionratio(DRR)wherethe base course thickness of 15cm could be reduced to 10cm (BCR=33%,DRR=14%)ifreinforcedwithfixedbottomgeogrid. Moreover,theunreinforcedsectionof25 cm basethicknesscould bereducedto15cm(BCR=40%)ifitisreinforcedwithfixedBRSor DRStoachieve DRR= 8.3%or21.7%respectively. Furthermore, the unreinforcedsectionof40cm basethicknesscouldbe re-ducedto15cm(BCR=62.5%,DRRof14.5%)ifitisreinforcedwith DRS,andcouldbereducedto25cm (BCR = 37.5%)if reinforced with fixed BRS or DRStoachieveDRRof5.7%or 12.7%respectively.

IV. CONCLUSIONS

1) The geogridGR420wastheoptimaltypetobe usedas reinforcementfor base course wherea greatreduc-tionofplastic deformationwasobtained.Moreover,Fixation ofthe geogridedges hadagreateffect onreduc- tion of accumulative plastic deformation ofbase course.

2) Thebottomreinforcedsection(BRS) was betterthan middlereinforcedsection (MRS).For25cm base coursethe optimalreinforcement depthratiowas obtainedat(Dr/h= 0.4to 0.6).By using geogridGR420the unreinforcedsectionof40cmcouldbereducedto15cm(BCR= 62.5%,DRRof14.5%)ifitwasreinforced with DRS.

3) Forreinforced basecourselessthan25cmthickness,the plasticdeformation becamegreaterthan elastic deformationatall points.The sameoccurredfor25cm thicknessatlower geogrid depth(Dr\hlessthan orequal to 0.2). Onanotherside,the accumulateddeformationcurves for reinforcedsections werea semiconstantwith increasingthe loading time up to 48 hoursespecially at theend ofthe testperiod.

4) Withincreasingmoisture content,the reinforcement benefit ratioRBR decreased.The ratio of plasticde-

formation(PDR)for reinforcedsection was lowerthanit for unreinforcedsectionforallmoisturecontentsespe- cially above OMC. Moreover,forallmoisture contents, the plasticdeformationwas greater than elastic defor- mation under the plate centeronly. Thesameoccurreda totherpointsfor9.5%and11%moisturecontent. While,the opposite occurred at 6% and 8%moisture content.

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