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September 28, 2009

SCS&T No. 0911070
Report No. 1

Mr. Brendan Sheppard
Tensar International Corporation
5883 Glenridge Drive, Suite 200
Atlanta, Georgia 30328

Subject: REINFORCED PAVEMENT SECTION STUDY
CARROLL CANYON ROAD
SAN DIEGO, CALIFORNIA

Dear Mr. Sheppard:

INTRODUCTION

In accordance with a request from Mr. Lars Nelson of Tensar International Corporation, Southern California Soil and Testing, Inc. prepared this report to transmit the findings of the reinforced pavement section study SCS&T performed at the subject site. The purpose of the study was to document the benefit, if any, of Tensar's TX-160 and TX-170 reinforcing grids in the design of flexible pavement sections. The TX-160 and TX-170 are TriAX geogrids with triangular structure. The TriAx grids have an increased rib thickness as compared to the traditional geogrids with square apertures. It is suggested the triangular structure along with the increased rib thickness provides a better junction efficiency.

SITE DESCRIPTION

The subject project consists of widening Carroll Canyon Road from Camino Ruiz approximately 2,300 feet west to the western terminus of Carroll Canyon Road. The widening improvements will consist of adding 2 eastbound lanes, construction of a raised median, curb and gutter, sidewalks and retaining walls. Carroll Canyon Road is bounded by an ascending slope and retaining walls along the southern perimeter and a commercial building park along the northern perimeter. Traffic loads at this time are considered moderate to light. However, we understand that Carroll Canyon Road will eventually extend westward, connecting to Camino Santa Fe.

SUBGRADE CONDITIONS

The road alignment is underlain by fill and formational material commonly identified as the Lindavista Formation. The fill is comprised of medium dense to dense clayey sand with gravel and clayey gravels that ranges from nil to about 10 feet in thickness. The Lindavista Formation typically consists of very dense clayey sandstone with cobble conglomerate. These materials have moderate to good pavement support characteristics. The R-Values measured at the project range from 26 to 34. A summary of the subgrade material observed at each test location is presented in Table 1.

Table 1

Test Location	USCS Classification	R-Value	In-Place Dry Density (lbs/ft^3)	Relative Compaction (%)
Station 15+25	Well-Graded Gravel with Clay and Sand	29	123.7	96.1
Station 19+00	Well-T Graded Gravel with Clay and Sand	26	122.9	91.7
Station 30+00	Clayey Gravel with Sand	34	124.4	96.2

PAVEMENT SECTIONS

The un-reinforced pavement section along Carroll Canyon Road was designed in accordance the City of San Diego and California Department of Transportation methods. The design was based on an assumed R-Value of 25 and a Traffic Index (TI) of 11. The reinforced sections were designed in accordance the recommendations of Tensar® Corporation. A summary of the flexible pavement sections constructed along the new eastbound lanes of Carroll Canyon Road is presented in Table 2.

Table 2

Carroll Canyon Road Station	Reinforcement Type	Asphalt Concrete Thickness (inches)	Class 2 Aggregate Base Thickness (inches)
Un-Reinforced Section Station 15+00 to 15+25	N/A	5	22
Reinforced Section Station 15+50 to 22+00	TX-160	5	16
Reinforced Section Station 22+00 to 38+00	TX-170	5	14

LABORATORY TESTING

Laboratory tests were performed to evaluate selected engineering properties of the subgrade materials. The following tests were performed:

- Grain Size Analyses
- Atterberg Limits
- Maximum Density and Optimum Moisture Content
- R-Value Test

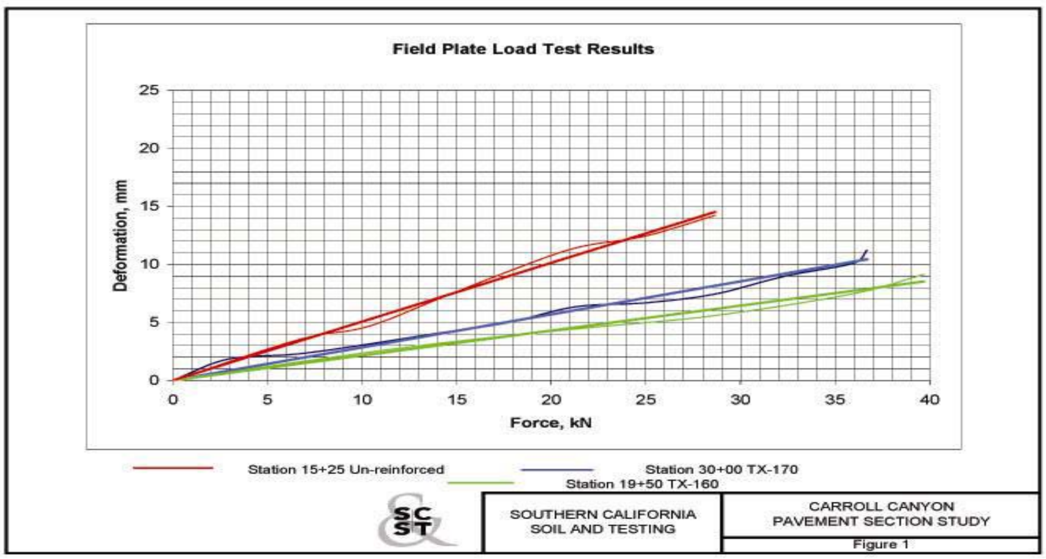
The test results and brief descriptions of the test procedures are contained in Appendix I.

IN-PLACE STRENGTH EVALUATION

Plate Load Test

Plate load tests were performed at Station 15+25, 19+50 and 30+00 along the eastbound lanes of Carroll Canyon Road. The test consisted of placing a 5-inch diameter, ½-inch thick steel plate on the surface of the compacted aggregate base. A load was then placed on the plate using a 25-ton hydraulic ram. Deformations of the plate were recorded using dial gauges accurate to the nearest 0.001 inch. A Unimog® drill rig was used to supply the reaction force against the hydraulic ram. The results of these tests are presented on Figure 1.

Plate Load Test Results Showing Deformation vs Load for the Control and Two Reinforced Sections



The results in Figure 1 can be used to calculate the effective modulus of the aggregate base layer for all three sections. The gradient of the load-deformation curves for each section represents the aggregate layer stiffness. These have been calculated and the results are shown in Table 3. In general, the reinforced sections performed better than the un-reinforced section in the plate load tests, as shown by the improvement factor in Table 3. The TX-160 reinforcing grid showed significant improvement. In our opinion, this is most likely the result of the variability in pavement material, subgrade material and construction methods. An increase in the number of test points would most likely rectify this anomaly.

Table 3
Measured Stiffness of the Aggregate Base
Using Plate Load Test Data

Analysis to Calculate Measured Aggregate Layer Stiffnesses (Using Figure 1)					
		Equation	**Un-Reinforced**	**TX160**	**TX170**
A	**Change in Deformation (mm)**		10	5	5
B	**Layer Thickness (mm)**		559	406	356
C	**Strain (%)**	(A ÷ B)	1.8	1.2	1.4
D	**Change in Load (kN)**		20	23	18
E	**Convert Load to Stress (MPa)**	D/Plate Area	1.557	1.837	1.387
	Layer Stiffness Modulus (MPa)	E/C	87	153	99
	Improvement Factor		**1**	**1.7**	**1.1**

Dynamic Cone Penetrometer Testing

A summary of the DCP test results is shown in Table 2. Based on the results of a DCP test, a CBR value was assigned to the material tested using empirical data from previous studies. The DCP test results show that the TX170 section provides the strongest aggregate base section, followed by the TX160 section. In both cases, the reinforced aggregate base sections are stronger than the un-reinforced control section.

Table 4
DCP Test Results

Name	**Aggregate Base* CBR***	**Aggregate Base Improvement Factor**	**Subgrade CBR***	**Subgrade R-Value**
TX170	100*	1.4	100*	34
TX160	91	1.2	100*	26
Control Un-Reinforced	74	1	100*	29

*** Determined in accordance with procedures presented in the Kessler DCP User's Manual. Note100 is the maximum value allowed.**

DISCUSSION OF FIELD TEST RESULTS

The field tests demonstrated that the thinner reinforced sections performed as well as or better than the thicker un-reinforced section in the field tests performed for this study. A summary of the measured improvement factors is shown in Table 5 below.

Table 5
Improvement Factors for
TX160 and TX170 Reinforcing Grids

Field Tests	TX160	TX170
DCP	1.2	1.4
Plate Load Test	1.7	1.1
Average	1.5	1.3

Based on the test results, it is our opinion that the empirically based pavement section design methods are conservative.

In accordance with the Corp of Engineers' sub layering equation that considers layer stiffness, layer thickness and subgrade modulii, the aggregate base layer could be reduced to about 12 inches. This is the minimum thickness of the aggregate base allowed to be used in accordance with Tensar® guidelines for placing reinforcing grids.

Reinforced Pavement Section Design

At this time, a modified AASHTO design method for reinforced pavement sections exists. This method is capable of determining the required aggregate thickness for a given asphalt thickness, and the required asphalt thickness for a given aggregate base thickness. This is accomplished by providing an increase in the structural layer coefficient of the aggregate base. Additionally, Tensar® has developed empirically based pavement section design methods based on laboratory and field tests. Using the data obtained by Tensar®, a modified California Department of Transportation pavement section design method can be used to determine a reinforced pavement section design. One of the following can be assumed in order to model the aggregate base being reinforced with geogrid:

- A lower Traffic Index
- A higher R-Value for the subgrade material
- An increased gravel factor for the aggregate base section

The following table shows an example of the reinforced pavement section design for the subject project using a modified California Department of Transportation pavement section design procedure.

Table 6
Reinforced Pavement Section Design Example

Pavement Section	AC Thickness (inches)	AB Thickness (inches)	TI	R-Value	AB Gravel Factor	GE Required	GE Actual
Un-Reinforced (Original Design Section)	5	22	11	25	1.1	2.64	2.73
TriAx Geogrid Design TI Decrease	5	12	8	25	1.1	1.93	1.94
TriAx Geogrid Design R-Value Increase	5	12	11	49	1.1	1.80	1.81
AB Gravel Factor Increase	5	12	11	25	1.93	2.64	2.64

Cost Analysis

A cost savings can be realized when using reinforced pavement sections compared to un-reinforced sections. This is the result of using less aggregate base and minimizing the required excavation to achieve the planned subgrade elevation. A summary of the cost analysis performed for the subject project is shown below.

Table 7
Cost Analysis Summary

Pavement Section	AC Thickness (inches)	AB Thickness (inches)	CTB Thickness (inches)	Unit Cost ($/SY)
Un-Reinforced Flexible Section	5	22	n/a	$48.50
Rigid Section (CTB)	5	n/a	17	$53.25
TX160 Geogrid Reinforced Section	5	16	n/a	$46.25
TX170 Geogrid Reinforced Section	5	14	n/a	$44.25
TriAx Geogrid Post-Construction Section	5	12	n/a	$42.17

* A summary of the cost analysis is presented in Appendix II.

Comparing Sections:
Cement Treated Base vs. Geogrid (Mechanical Reinforcement)

The main advantage of using an aggregate base reinforced with geogrid as compared to plant mixed cement treated base is cost. Aggregate base typically costs less than cement treated base and an additional cost savings can also be realized with faster construction methods. Depending on the project specifications, cement treated base may be limited to placing 3,000 tons per day. There is no limit to amount of aggregate base that can be placed in one day. An additional benefit of aggregate base over cement treated base is that it is less susceptible to shrinkage cracks that can be reflected in the overlying asphalt concrete.

CONCLUSIONS

The reinforced sections performed as good or better than the un-reinforced section. The Tensar® triaxial reinforcing grids appear to have increased the effective support modulus of the aggregate base. This is most likely the result of a transfer of loads from unbound aggregate to the reinforcing grid through the Mechanical Interlocking Process (MIP). The MIP is where aggregate penetrates the openings in the reinforcing grid and become locked in-place. This process adds shear strength to the aggregate base and increases the stiffness characteristics of the aggregate base.

The field test results indicate that the pavement test section designs are conservative. Based on the measured improvement factors and the analyses performed using the Army Corp of Engineers' sub layering equation, the reinforced aggregate base pavement section thicknesses could be reduced by about 3 inches.

Additionally, it is our opinion that accelerated pavement testing (APT) studies should be performed in compliance with National Cooperative Highway Research Program (NCHRP) Report 512 and Synthesis 325 to determine a better relationship between the gravel factor of un-reinforced and reinforced aggregate base for flexible pavement section design using the California Department Transportation Method. The purpose of APT research is to provide long term performance data to determine how a TriAx geogrid improves the performance of the aggregate base. The APT testing shall be conducted on paved structures, evaluated with standard highway moving wheel loads, comparing thinner geogrid reinforced sections to thicker unreinforced (control) sections, and results shall be evaluated by a Professional Engineer. Assuming the results of the APT testing show a similar benefit of using geogrid to this field data, it is our opinion that that the geogrid reinforced pavement sections should be implemented by the City.

This opportunity to be of professional service is sincerely appreciated.

Respectfully Submitted,
SOUTHERN CALIFORNIA SOIL & TESTING, INC.

Garrett B. Fountain, GE 2752
Principal Engineer

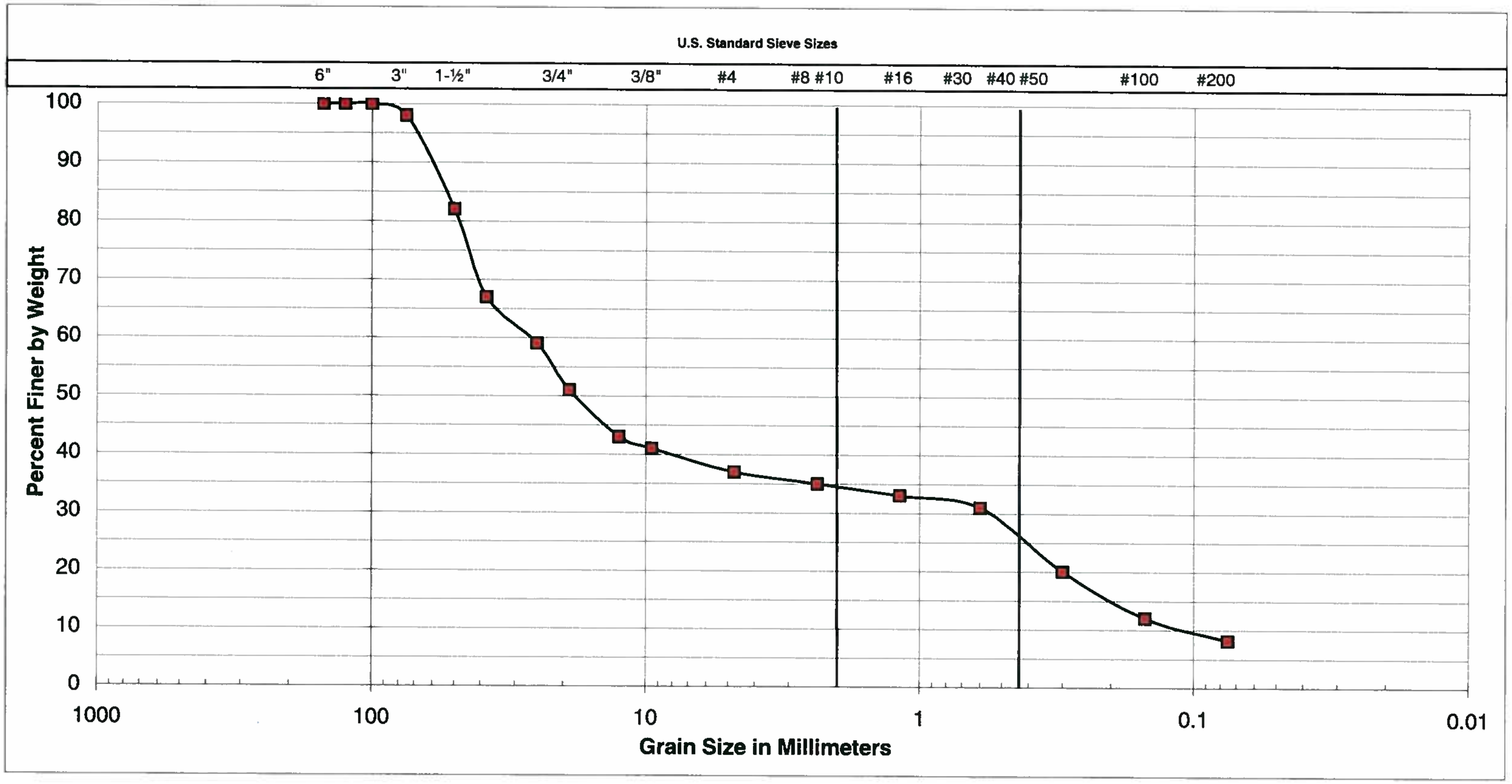
GBF:aw

(6) Addressee

REFERENCES

1. Kessler DCP, Dynamic Cone Penetromter User's Manual, May 2003.
2. "Geosynthetic Reinforcement of the Aggregate Base Course of Flexible Pavement Structures, AASHTO Designation: PP 46-01 (2003)".
3. "Design Method for Geogrid-Reinforced Unpaved Roads. I. Development of Design Method", J.P. Giroud, M. ASCE and Jie Han, M.ASCE, Journal of Geotechnical and Geoenvironmental Engineering, August 2004.
4. "Design Method for Geogrid-Reinforced Unpaved" Roads. II. Development of Design Method", J.P. Giroud, M. ASCE and Jie Han, M.ASCE, Journal of Geotechnical and Geoenvironmental Engineering, August 2004.
5. "Unified Facilities Criteria, Pavement Design For Airfields, UFC 3-260-02, Appendix J", June 30, 2001.

APPENDIX I



Cobbles	Gravel		Sand			Silt or Clay
	Coarse	Fine	Coarse	Medium	Fine	

SAMPLE LOCATION
Station 15+25

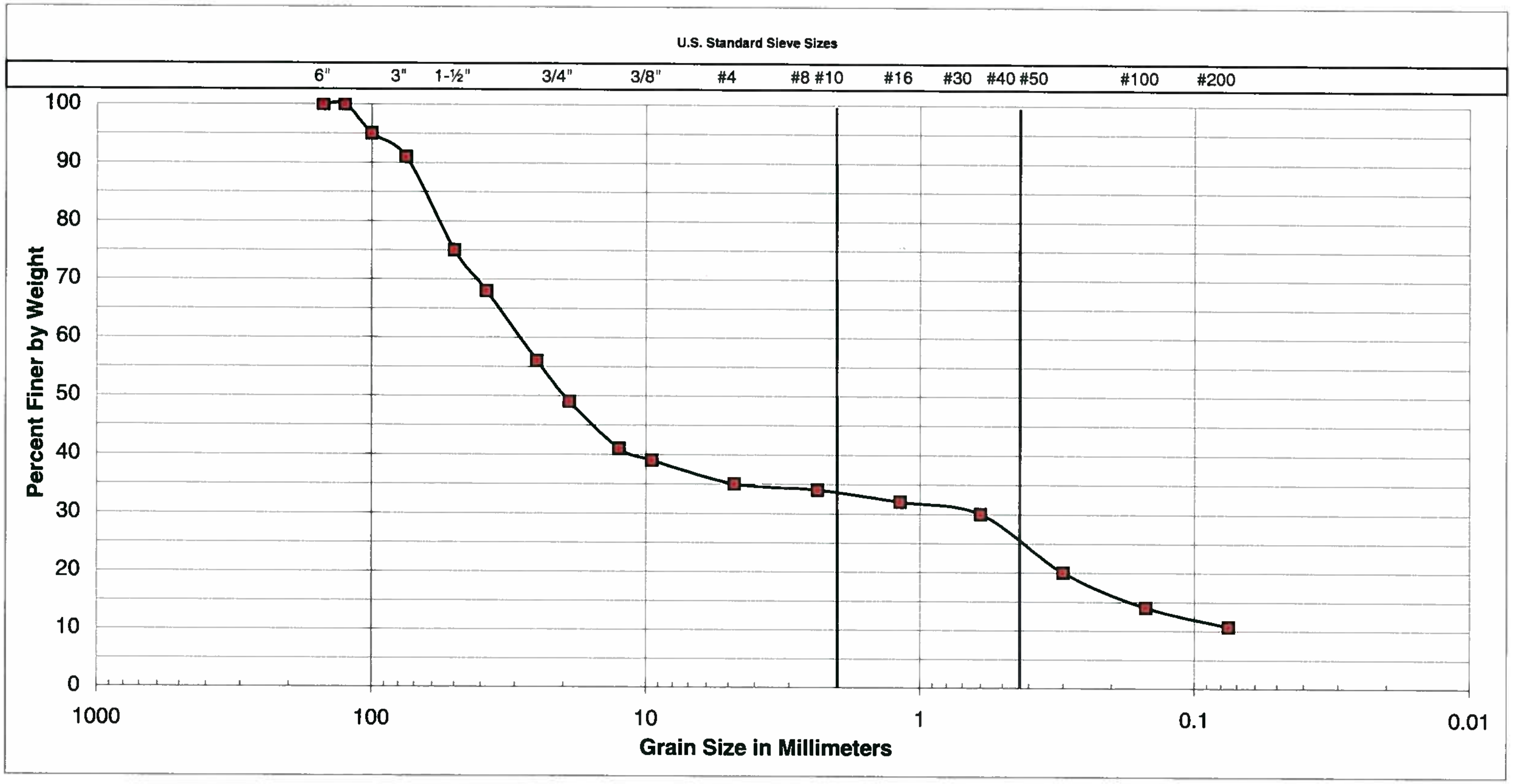
UNIFIED SOIL CLASSIFICATION:	GW
DESCRIPTION	Well Graded Gravel with Clay and Sand

ATTERBERG LIMITS	
LIQUID LIMIT	35
PLASTIC LIMIT	22
PLASTICITY INDEX	13

SOUTHERN CALIFORNIA SOIL & TESTING, INC.

CARROLL CANYON ROAD PAVEMENT SECTION STUDY

By	GBF	Date	9/28/09
Job Number	0911070	Figure	I-1



Cobbles	Gravel		Sand			Silt or Clay
	Coarse	Fine	Coarse	Medium	Fine	

SAMPLE LOCATION
19+00

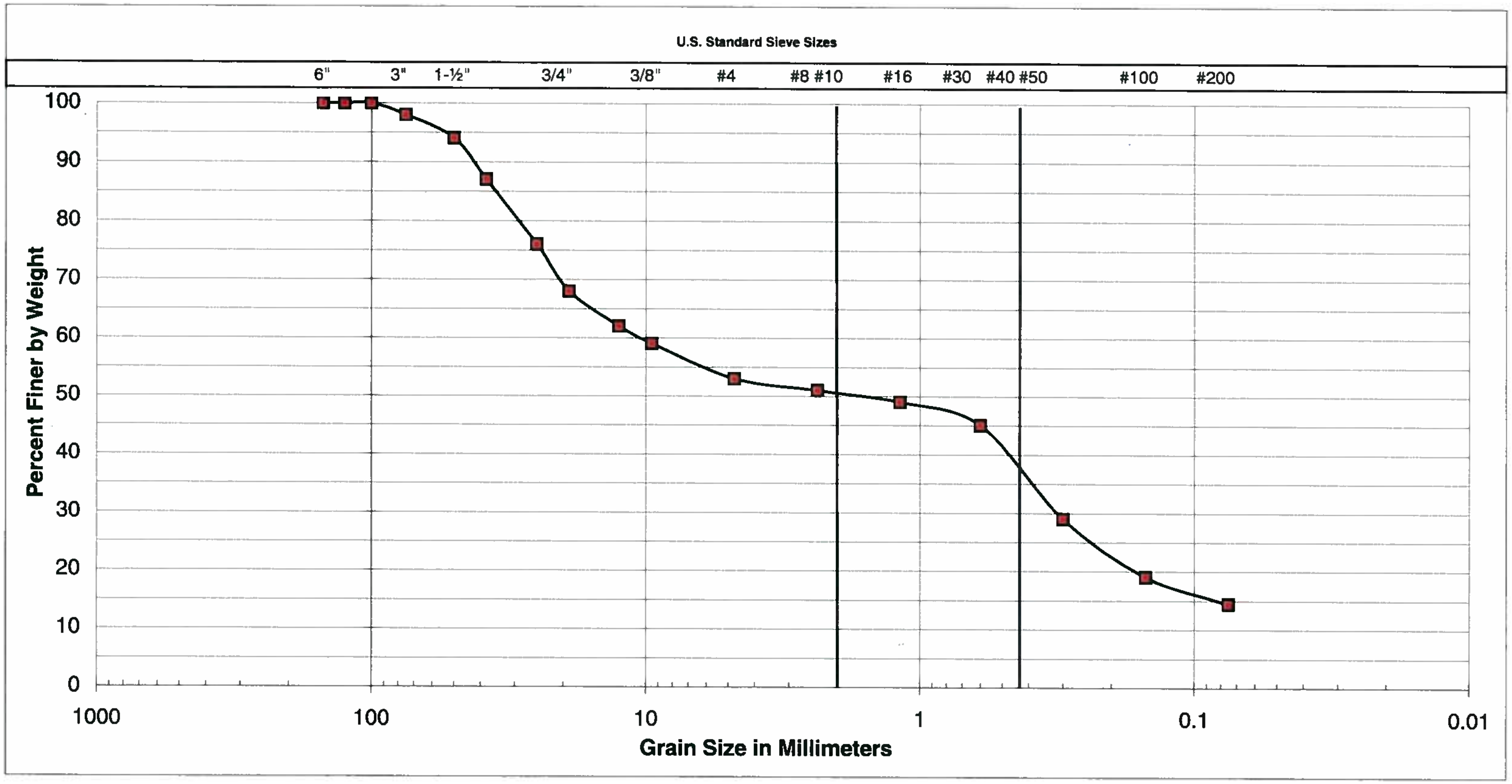
UNIFIED SOIL CLASSIFICATION:	GW
DESCRIPTION	Well Graded Gravel with Clay and Sand

ATTERBERG LIMITS	
LIQUID LIMIT	36
PLASTIC LIMIT	20
PLASTICITY INDEX	16

SOUTHERN CALIFORNIA SOIL & TESTING, INC.

CARROLL CANYON ROAD PAVEMENT SECTION STUDY

By	GBF	Date	9/28/09
Job Number	0911070	Figure	I-2



Cobbles	Gravel		Sand			Silt or Clay
	Coarse	Fine	Coarse	Medium	Fine	

SAMPLE LOCATION
30+00

UNIFIED SOIL CLASSIFICATION:	GC
DESCRIPTION	CLAYEY GRAVEL with SAND

ATTERBERG LIMITS	
LIQUID LIMIT	36
PLASTIC LIMIT	20
PLASTICITY INDEX	16

SOUTHERN CALIFORNIA SOIL & TESTING, INC.

CARROLL CANYON ROAD PAVEMENT SECTION STUDY

By	GBF	Date	9/28/09
Job Number	0911070	Figure	I-3

APPENDIX II

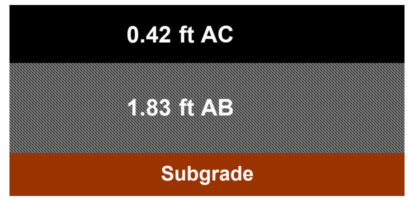
Carroll Canyon Road, City of San Diego: Pavement Design Calculations Cost Analysis

MATERIAL COST (IN-PLACE)	$/Ton	$/CY	($/inch*SY)	($/SY)
Asphalt Concrete	$90.00	$176.18	$4.89	n/a
CTB	n/a	$50.00	$1.39	n/a
Class 2 AB	$15.00	$26.93	$0.75	n/a
Excavation	n/a	$10.00	$0.28	n/a
TriAx Geogrid	n/a	n/a	n/a	$4.00

*Pacific Building Group Bid Tabs, 2009

UNREINFORCED DESIGN	
Traffic Index	11
Subgrade R-value	25

Unreinforced Pavement Profile

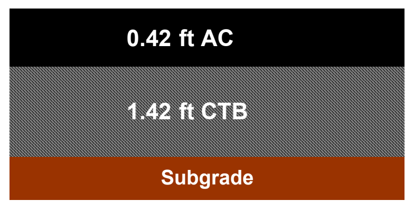


Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.64	2.73	0.42	5.0
Class 2 AB	78	1.1			1.83	22.0
Total:					2.25	27.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$16.46
Excavation	$0.28	$7.50
	Total:	**$48.43**

CEMENT TREATED BASE DESIGN	
Traffic Index	11
Subgrade R-value	25

CTB Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.64	2.70	0.42	5.0
CTB	78	1.4			1.42	17.0
Total:					1.83	22.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
CTB	$1.39	$23.61
Excavation	$0.28	$6.11
	Total:	**$54.19**

Carroll Canyon Road, City of San Diego: Pavement Design Calculations Cost Analysis

Reducing the Traffic Index Design Method:

TX170 GEOGRID DESIGN	
TX170 Geogrid Reinforced T.I.[1]	8.6
Subgrade R-value	25

Geogrid Pavement Profile

Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.93	2.06	2.09	0.42	5.0
Class 2 AB	78	1.1			1.17	14.0
Total:					1.58	19.0

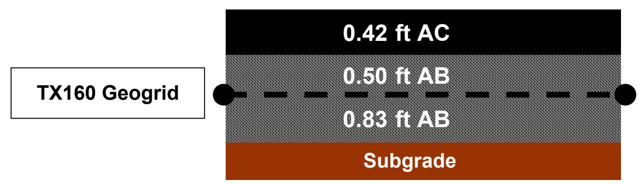
Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$10.47
Excavation	$0.28	$5.28
Geogrid	N/A	$4.00
	Total:	**$44.22**

Notes:

1. TriAx geogrid increases the stiffness of the section (Such that a conventional TI = 11 is equivalent to a reinforced geogrid TI = 8.6

TX160 GEOGRID DESIGN	
TX170 Geogrid Reinforced T.I.[1]	9.0
Subgrade R-value	25

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.89	2.16	2.25	0.42	5.0
Class 2 AB	78	1.1			1.33	16.0
Total:					1.75	21.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$11.97
Excavation	$0.28	$5.83
Geogrid	N/A	$4.00
	Total:	**$46.27**

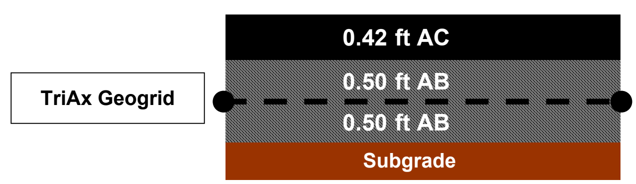
Notes:

1. TX160 geogrid increases the stiffness of the section (Such that a conventional TI = 11 is equivalent to a reinforced geogrid TI = 9.1

Post - Construction Performance:

TriAx GEOGRID DESIGN	
TriAx Geogrid Reinforced T.I.[1]	8.0
Subgrade R-value	25

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	2.00	1.92	1.94	0.42	5.0
Class 2 AB	78	1.1			1.00	12.0
Total:					1.42	17.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$8.98
Excavation	$0.28	$4.72
Geogrid	N/A	$4.00
	Total:	**$42.17**

Notes:

1. TriAx geogrid increases the stiffness of the section (Such that a conventional TI = 11 is equivalent to a reinforced geogrid TI = 8.0

Carroll Canyon Road, City of San Diego: Pavement Design Calculations Cost Analysis

Increasing the Gravel Factor Design Method:

TX170 GEOGRID DESIGN	
T.I.	11.0
Subgrade R-value	25

Geogrid Pavement Profile

Pavement Layer	R-value	Gravel Factor[1]	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.64	2.64	0.42	5.0
Class 2 AB	78	1.65			1.17	14.0
Total:					1.58	19.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$10.47
Excavation	$0.28	$5.28
Geogrid	N/A	$4.00
	Total:	**$44.22**

Notes:

1. TX170 geogrid increases the stiffness of the section (Such that the AB Gravel Factor increases from 1.1 to 1.65)

TX160 GEOGRID DESIGN	
T.I.	11.0
Subgrade R-value	25

Geogrid Pavement Profile

Pavement Layer	R-value	Gravel Factor[1]	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.64	2.71	0.42	5.0
Class 2 AB	78	1.5			1.33	16.0
Total:					1.75	21.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$11.97
Excavation	$0.28	$5.83
Geogrid	N/A	$4.00
	Total:	**$46.27**

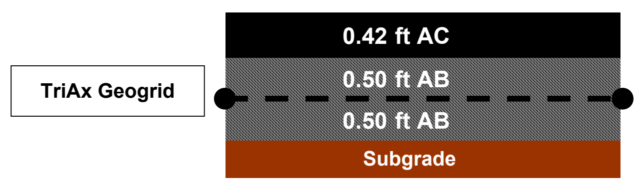
Notes:

1. TX160 geogrid increases the stiffness of the section (Such that a Gravel Factor of 1.1 is increased to a Gravel Factor of 1.5)

Post - Construction Performance:

TriAx GEOGRID DESIGN	
T.I.	11.0
Subgrade R-value	25

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor[1]	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.64	2.64	0.42	5.0
Class 2 AB	78	1.93			1.00	12.0
Total:					1.42	17.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$8.98
Excavation	$0.28	$4.72
Geogrid	N/A	$4.00
	Total:	**$42.17**

Notes:

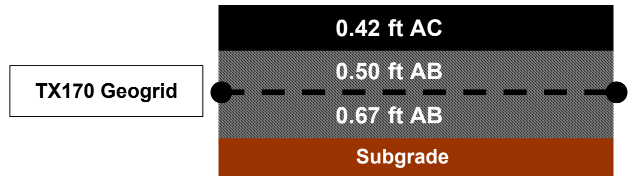
1. TriAx geogrid increases the stiffness of the section (Such that a Gravel Factor of 1.1 is increased to a Gravel Factor of 1.93)

Carroll Canyon Road, City of San Diego: Pavement Design Calculations Cost Analysis

Increasing the R-value Design Method:

TX170 GEOGRID DESIGN	
T.I.	11.0
Geogrid Reinforced R-value[1]	44

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	1.97	2.00	0.42	5.0
Class 2 AB	78	1.1			1.17	14.0
Total:					1.58	19.0

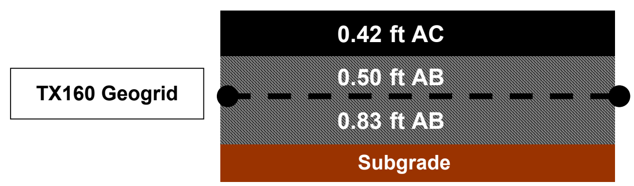
Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$10.47
Excavation	$0.28	$5.28
Geogrid	N/A	$4.00
	Total:	**$44.22**

Notes:

1. TX170 geogrid increases the stiffness of the section (Such that the R-value is increased from 25 to 44)

TX160 GEOGRID DESIGN	
T.I.	11.0
Geogrid Reinforced R-value[1]	39

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	2.15	2.18	0.42	5.0
Class 2 AB	78	1.1			1.33	16.0
Total:					1.75	21.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$11.97
Excavation	$0.28	$5.83
Geogrid	N/A	$4.00
	Total:	**$46.27**

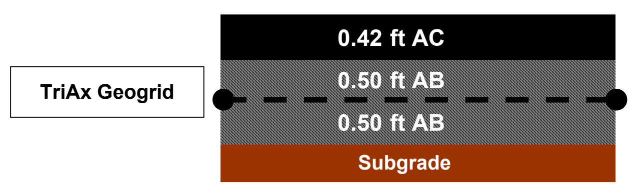
Notes:

1. TX160 geogrid increases the stiffness of the section (Such that the R-value is increased from 25 to 39)

Post - Construction Performance:

TriAx GEOGRID DESIGN	
T.I.	11.0
Geogrid Reinforced R-value[1]	49

Geogrid Pavement Profile



Pavement Layer	R-value	Gravel Factor	Required GE (ft)	Actual GE (ft)	Required Thickness (ft)	Required Thickness (in.)
Asphalt Concrete	N/A	1.71	1.80	1.81	0.42	5.0
Class 2 AB	78	1.1			1.00	12.0
Total:					1.42	17.0

Pavement Layer	Cost ($/inch*SY)	Cost ($/SY)
AC	$4.89	$24.47
AB	$0.75	$8.98
Excavation	$0.28	$4.72
Geogrid	N/A	$4.00
	Total:	**$42.17**

Notes:

1. TriAx geogrid increases the stiffness of the section (Such that the R-value is increased from 25 to 49)