



Testing Certificate Number: 0743.01

September 30, 2015

Mark Semm  
The Clubs of Cordillera Ranch  
808 Highway 46 East  
Boerne, TX 78006

Mr. Semm:

The Southwest Limestone Gravel was subjected to the standard gravel testing procedure used to determine acceptable materials for golf course construction. The results were compared to the *USGA Recommendations for a Method of Putting Green Construction* (2004).

The TXSS Bunker White 1830 was evaluated for use according to the procedures defined in an article by Dr. K. W. Brown & Mr. J. C. Thomas (Golf Course Management, Vol. 54, July 1986). Although no official guidelines have been established on the requirements for a bunker sand, some guidelines have been formulated as a result of research by Dr. K. W. Brown and J. C. Thomas. Reference of these guidelines is found in James Beard's book, *Turf Management for Golf Courses*, Burgess Publishing Company.

## Gravel Recommendations

### Selection of Gravel For USGA 2-Layer System of Construction:

The USGA criteria are based on engineering principles which rely on the largest 15% of the sand particles "bridging" with the smallest 15% of the gravel particles. Smaller voids are produced, and they prevent migration of sand particles into the gravel yet maintain adequate permeability. The  $D_{85(sand)}$  is defined as the particle diameter below which 85% of the sand particles (by weight) are smaller. The  $D_{15(gravel)}$  is defined as the particle diameter below which 15% of the gravel particles (by weight) are smaller.

For bridging to occur, the  $D_{15(gravel)}$  must be less than or equal to eight times the  $D_{85(sand)}$ .

To maintain adequate permeability across the sand/gravel interface, the  $D_{15(gravel)}$  shall be greater than or equal to five times the  $D_{15(sand)}$ .

Furthermore, any gravel selected shall have 100% passing a 1/2" (12 mm) sieve and not more than 10% passing a No. 10 (2 mm) sieve, including not more than 5% passing a No. 18 (1 mm) sieve.

# Bunker Sand Recommendations

## 1. Particle Size Analysis and Sand Distribution -

- a.  $\leq 3\%$  gravel
- b.  $\leq 15\%$  very coarse sand
- c.  $\geq 65\%$  total coarse and medium sand
- d.  $\leq 25\%$  total medium-fine, fine and very fine sand
- e.  $\leq 3\%$  total silt and clay

## 2. Fried Egg Lie Development -

Greater than $2.4 \text{ kg/cm}^2$	Very Low Tendency To Bury The Ball
2.2 to $2.4 \text{ kg/cm}^2$	Slight Tendency To Bury The Ball
1.8 to $2.2 \text{ kg/cm}^2$	Moderate Tendency To Bury the Ball
Less than $1.8 \text{ kg/cm}^2$	High Tendency To Bury The Ball

## 3. Crusting and Set Up -

No crusting or set up desired after saturated and dried.

## 4. Sand Color and Shape -

Light color of moist sand preferred, measured by the Munsell Color Chart.  
Angular shape with a low degree of sphericity preferred.

## 5. Saturated Hydraulic Conductivity (Infiltration Rate) -

$\geq 20$  inches per hour with a functioning under drainage system

# Discussion of Results

The results of the tests performed on the Southwest Limestone Gravel and TXSS Bunker White 1830 samples proposed for use in bunker construction at the Clubs of Cordillera Ranch are summarized in the enclosed tables. The gravel was checked for compatibility in the 2-layer system of construction with the bunker sand. The results of the quality control samples run simultaneously with these samples indicate the data are accurate.

As requested, the results of the ASTM C-88 Sulfate Soundness Test on the Southwest Limestone Gravel will be reported separately once the testing is completed.

### Southwest Limestone Gravel

Upon visual inspection, the Southwest Limestone Gravel appeared to be a crushed limestone product.

The Southwest Limestone Gravel was free of particles greater than 12.5 mm in size. The gravel contained 2.0% of the particles in the 9.5-12.5 mm range, 58.5% in the 6.3-9.5 mm range, 36.8% in the 4.0-6.3 mm range and 2.1% in the 2.0-4.0 mm range. The gravel contained an acceptable total of 0.6% of the particles in the less than 2.0 mm ranges which is within the

recommended maximum of 10%. Based on these results, the Southwest Limestone Gravel does meet the USGA's particle size recommendations for use in the 2-layer system of construction.

The Southwest Limestone Gravel had an acceptable coefficient of uniformity of 1.9 which is within the recommended maximum of 3.0. This indicates the gravel has a narrow spread in particle sizes which is ideal.

### **Southwest Limestone Gravel / TXSS Bunker White 1830 - Compatibility**

To determine if the Southwest Limestone Gravel and TXSS Bunker White 1830 could be used in the 2-layer system of construction, the bridging and permeability factors were calculated and are shown in the enclosed compatibility table. The gravel and bunker sand combination had an acceptable bridging factor of 5.2 which is within the recommended maximum of 8.0. This indicates the sand will not migrate into the gravel. The gravel and bunker sand combination had an acceptable permeability factor of 13.5 which indicates the gravel can transmit the needed amount of water to the drains.

### **TXSS Bunker White 1830**

The particle size analysis of the TXSS Bunker White 1830 showed it to contain an acceptable total of 2.1-2.4% silt and clay which is within the recommended maximum of 3%. The sand was free of gravel which is ideal. The sand contained an acceptable 2.7-3.1% very coarse sand which is within the recommended maximum of 15%. The sand contained 68.2-69.3% coarse sand and 23.5-24.2% medium sand for an acceptable total of 92.4-92.8%. This total is above the recommended minimum of 65%. The sand contained an acceptable 2.0-2.5% of the particles in the total of the medium-fine, fine and very fine sand fractions which is within the recommended maximum of 25%. The sand had a severe reaction to acid which indicates the presence of a significant amount of carbonates. Based on these results, the TXSS Bunker White 1830 does meet the particle size recommendations for an ideal bunker sand.

The TXSS Bunker White 1830 scored 2.5 kg/cm<sup>2</sup> in the fried egg lie development test which indicates the sand will have a very low tendency to bury golf balls that land in the bunkers. A score of 2.4 kg/cm<sup>2</sup> or greater is recommended for an ideal bunker sand. The sand particles were sub-angular to angular in shape with a low to medium degree of sphericity. Angular sands with a low sphericity are preferred as they are more resistant to displacement by incoming golf balls. The sand was white and you will have to be the final judge as to the acceptability of this color. The sand had a very slight tendency to form a crust, but did not set-up which indicates the sand will require a minimum amount of maintenance to keep the bunkers in playable condition after rainfall or irrigation events.

The TXSS Bunker White 1830 had an acceptable saturated hydraulic conductivity (infiltration rate) of 130.7 inches per hour which is above the commonly accepted minimum of 20 inches per hour for a bunker sand. This infiltration rate will be sufficient to keep the bunkers adequately drained provided they are equipped with a functioning under drainage system. To maintain this saturated hydraulic conductivity, the sand should not be allowed to become contaminated with fines or other foreign material that may be blown or washed in from adjacent areas.

### **Summary**

The Southwest Limestone Gravel did meet the USGA's recommendations for use in the 2-layer system of construction. The gravel had an acceptable coefficient of uniformity indicating a narrow spread in particle sizes which is ideal. The gravel had acceptable bridging and permeability factors with the TXSS Bunker White 1830.

The TXSS Bunker White 1830 did meet the particle size recommendations for an ideal bunker sand. The sand had a very low tendency to bury golf balls that land in the bunkers. The sand will require a minimum amount of maintenance to keep the bunkers in playable condition after rainfall or irrigation events. The sand had an acceptable saturated hydraulic conductivity which will be sufficient to keep the bunkers adequately drained.

Assuming the ASTM C-88 Sulfate Soundness Test results on the Southwest Limestone Gravel are acceptable; the TXSS Bunker White 1830 is acceptable for use above the Southwest Limestone Gravel in the 2-layer system of construction and these materials should work well together in the Better Billy Bunker construction method.

If you have any questions concerning these recommendations or are in need of further assistance, please feel free to phone me directly at 979-575-5107. You may also send E-Mail to: <soiltest@thomasturf.com>. Thank you for using Thomas Turf Services, Inc.

Sincerely,

James C. Thomas, C.P.Ag.  
Pres., Thomas Turf Services, Inc.

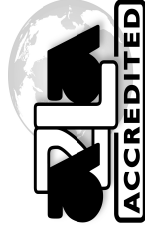
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Enclosure: Tables (5)

File: 99156, G9686 - Bunker

**Thomas Turf Services, Inc.**  
**Soil Analysis & Turf Management**

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**Testing Certificate Number: 0743.01**  
**Geotechnical Putting Green Materials**

The Clubs of Cordillera Ranch Mark Semm 808 Highway 46 East Boerne, TX 78006 Toll Free: 830-336-3710 Cell: 210-889-5226 Fax: 830-336-3720 E-mail: msemm@cordilleraranch.com	Facility: The Clubs of Cordillera Ranch Account No.: 99156 Lab ID: G9686 Date Rec'd: 9-Sep-15 Test Date: 10-Sep-15 Report Date: 30-Sep-15
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**Gravel Distribution Report - ASTM Test Method C136-01**

Diameter U.S. Sieve	>12.5 mm 1/2 inch	9.5 - 12.5 mm 3/8 inch	6.3 - 9.5 mm 1/4 inch	4.0 - 6.3 mm No. 5	2.0 - 4.0 mm No. 10	1.0 - 2.0 mm No. 18	<1.0 mm <No. 18
Units	0						< 10**
2004 USGA Recommendations*							
Sample ID							
Southwest Limestone Gravel	0.0	2.0	58.5	36.8	2.1	0.1	0.5

\* For use in the 2-layer system  
 \*\*<10 % passing 2 mm including <5 % passing 1 mm

Reviewed by: \_\_\_\_\_  
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**Gravel / Rootzone - Compatibility Report\***

	<b>D<sub>15</sub></b>		<b>D<sub>85</sub></b>		<b>D<sub>90</sub></b>	Coefficient of Uniformity	Bridging Factor	Permeability Factor
	Gravel	Sand	Sand					
2004 USGA Recommendations						D 90g/D 15 sand ≤3	D15g/D85 sand ≤8	D15g/D15 sand ≥5
Sample ID								
Southwest Limestone Gravel	4.67				8.98	1.9		
TXSS Bunker White 1830		0.35	0.90				5.2	13.5

\* Based on test data from ASTM Methods F1632 and C136-01

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**Particle Size Analysis Report - ASTM F1632 - Method A**

	Textural Analysis					Particle Size Distribution						
	Sand	Silt	Clay	Gravel		Very Coarse	Coarse	Medium	Med-Fine	Fine	Very Fine	
	.05 - 2.0	.002 to .05	<.002	>2.00		1.0-2.0	0.50-1.0	0.25-0.50	0.15-0.25	0.10-0.15	< .10	
	%	%	%	%	%	%	35	60	100	140	< 140	
Bunker Recommendation (%)	94 - 100	3 Max		3 Max		15 Max	65 Minimum			25 Maximum		
Sample ID												
TXSS Bunker White 1830	97.6	1.7	0.7	0.0		2.7	68.2	24.2	1.2	0.4		0.9
Duplicate	97.9	1.8	0.3	0.0		3.1	69.3	23.5	1.2	0.3		0.5

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**Bunker Sand Analysis Report**

Brown & Thomas, Golf Course Management Vol. 54:64-70, July 1986  
 \*Thomas Turf Services Procedure For Acid Reaction

Sample ID	Fried Egg		Color	Crusting	Set-up	Sphericity / Angularity	Acid Reaction*
	Lie Development	kg/cm2					
TXSS Bunker White 1830	2.5		2.5Y 8/1 White	Very Slight	None	Low To Medium / Sub-angular To Angular	Severe

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### Physical Measurements Report ASTM Test Method F1815\*

Units	Saturated Hydraulic Conductivity
	in / hr
<b>Recommended Range</b>	<b>&gt;20</b>
TXSS Bunker White 1830	130.7

Core Samples Compacted Using 21 Drops of a 2.22 kg. Hammer = 14.7 ft. lbs. per sq. inch

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