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1. Introduction

Kent Engineering (KE) is a forensic engineering firm with over 30 years of experience in product testing, design, manufacturing processes and quality control. KE has assisted in developing and implementing multiple patented products and materials used in the construction industry. We were hired by Atlantic Water Gardens to perform a compression test on a set of Eco-Blox water matrix blocks, as well as offer insights into physical property analysis and improvements. The primary objective to testing was to determine if the product would be able to withstand loading in accordance with ASSHTA HS-20 loading conditions. The testing was done in a manner to test the unconstrained condition of a single matrix block, which would be the worst loading case possible. The average dimensions of the Eco-Blox, when fully assembled, are 17.6” x 26.9” x 16.0”.

The matrix design is comprised of multiple 1.5” squares with diagonal supports, which is known as one of the strongest designs for load support and is used in bridge, home, and general construction designs. To test the compressive strength, a load was applied to the top of the matrix block, which is the 16” x 26.9” side. The compressive force was applied to 3 individual blocks until failure occurred and the data was recorded, then analyzed and calculated to define the strength of the blocks.

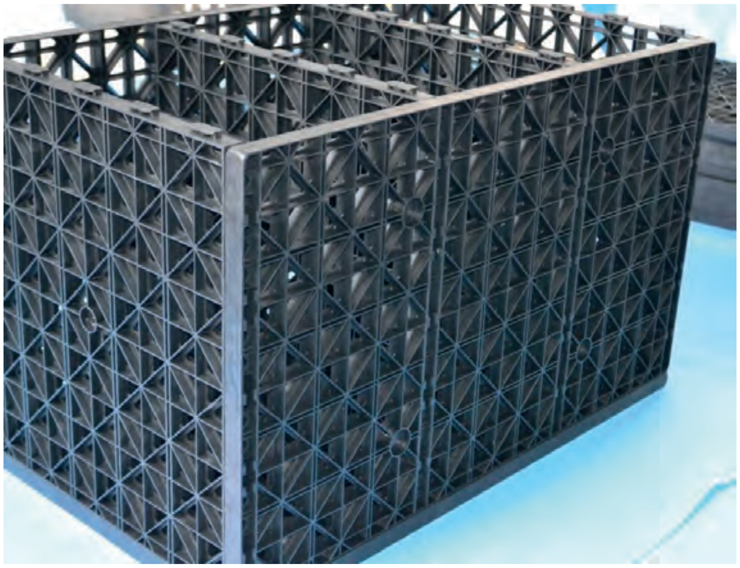

Figure 1: Atlantic Water Gardens Eco-Blox assembly without lid.

2. Testing Setup

To evenly distribute the loading across the top of the Eco-Blox, a steel plate measuring 27" x16" x 0.75" was placed between the press and the test piece. The steel plate connected to the press cylinder measures 12" x 16" x 1" and is used to distribute the load. The test machine utilized was a Satec 600WHVL with a 600,000 lb capacity. The cross head was a Satec WHVL600 with a range of 0.050in/min to 1.000 in/min. The cross head speed and the load cell were both calibrated on May 6, 2014 and the calibration certificate is attached for reference.

The loading was applied by the top platen movement and controlled by lowering at a rate of 0.050" per minute, which was adopted from the ASTM D695-10, which is the standard test method for compressive properties of ridged plastics. A computer readout was given and the raw data of load, displacement, and time was supplied for reference as well. Pictures and video were taken during the testing to show the process and results.

Figure 2: Test machine with steel plate on the test block.

3. Testing Process

For each of the three Eco-Blox tested, the following procedure applies; Initially, the Eco-Blox was assembled according to the instructions provided. The block was measured for overall dimensions and photo documented in the “prior test” condition. Each matrix block was labeled 6530A, 6530B, and 6530C for test 1, 2, and 3 respectively. The block was placed on the lower platen of the test machine and centered with the top of the block as noted from the assembly instructions. Next, the steel plate was placed on top of the block and centered. Then, the top platen and press plate were lowered to contact with the steel plate. A preload of 120 lbs was applied. Once the machine was zeroed the test was initiated with steady state displacement, increasing the load.

4. Test Results

From zero to 10,000 lbs, the system showed no change in structural integrity. When the load reached approximately 10,000 lbs, the sides bowed slightly toward the outside and on the back and side panels. As the load neared 14,000 lbs of force, sounds of cracking or popping were heard. At this load, significant bowing of the end pieces were observed. After failure occurred, it was clearly observed where the de-bonding or cracking was located. These locations were at the tabs. The test was performed until failure/fracture of the vertical end pieces. The data was recorded and the test repeated for the remaining blocks.

The test results showed good consistency between the three test blocks and showed an average loading capacity of approximately 15,500 lbs and strength of 36.2 lbs/in^2 (psi) at failure. Table 1 shows the results of the three compression tests. The stress was calculated using the dimensions of the cross section being compressed. This assumes that the load and stress is distributed evenly across the area being tested. Various graphs and photos are attached as an appendix and all the data, photos, and video are available on a DVD or other method of your choice.

Table 1: Results of the compression tests of the three Eco-Blox

Test data from Eco-Blox Compression testing					
Test #	**1**	**2**	**3**	**Average**	**Range**
Specimen Label	6530A	6530B	6530C	N/A	N/A
Maximum Load (lbs)	14740.54	16015.79	15736.77	**15497.7**	1275.244
Maximum Displacement (in)	0.366036	0.406011	0.388592	**0.38688**	0.039974
Maximum Stress (psi)	34.40233	37.38621	36.75796	**36.18216**	2.983882
Length (in)	26.83	26.875	26.875	26.86	0.045
Width (in)	15.97	15.94	15.93	15.94667	0.04
Height (in)	17.562	17.562	17.562	17.562	0
Area (sq in)	428.4751	428.3875	428.1188	428.3271	0.35635

5. Conclusion

After compression testing of three of the Atlantic Water Gardens Eco-Blox in a worst case loading condition, it has been found that they are able to hold an average of 36.2 pounds per square inch (psi). When these blocks are used in the field, they will likely be stacked, and/or placed side to side with backfill, so the sides will be able to resist buckling and hold higher loads. In order to meet the requirements for ASSHTA HS-20 loading conditions the matrix blocks need to hold the loads of an axle from a tractor trailer, which equates to approximately 32,000 lbs per axle. Using the below conditions for HS-20 loading, KE calculated a minimum safety factor of 1.87, at a depth of 18 inches, under the most extreme conditions, as seen in Table 2. KE also calculated using less extreme conditions and included the results in Tables 3 and 4 below. It is clear from the results of the results in Tables 2-4, that the assumptions and input values into the equations make a large difference in the factor of safety. These blocks have factor of safety above 2.0 for every condition and depth calculated except the one condition using the most extreme angle and a depth of 18 inches.

6. Calculations

To calculate the loads needed, Kent Engineering used liberal estimations, to calculate the worst case loading conditions that will be seen in the field. As seen in figures 3-5 below the angle of repose can drastically change the applied load area and with a larger angle of repose, such as a

63.4 degree angle, depicted in figure 5, the load does not get distributed as wide as with a shallower angle, such as a 45 degree angle, depicted in figure 4. The distribution of the load across a wider area decreases the load that each block will support, therefore reducing the stress on each block. The highest slope that KE used was based on a 1:2 slope ratio, which means for every unit in width, there are two units of depth. In addition to the angle of repose, the weight of the road base material that is between the surface and the buried matrix blocks can vary between 100 lbs per cubic foot and140 lbs per cubic foot. KE used the maximum angle of repose of 63.4° (1:2 ratio) and used a weight of 130 pounds per cubic foot of road base material. In

Table 2: Shown below are the calculations of HS-20 loading conditions with most difficult assumed conditions of 1:2 slope (26.6° angle from the vertical) and 130lbs per cubic foot.

HS-20 Loading Calculation and Capacity of Eco-Blox

	Cover Base Depth (inches/feet)										
Variable	**18/1.5**	**24/2**	**36/3**	**48/4**	**60/5**	**72/6**	**84/7**	**96/8**	**108/9**	**120/10**	**144/12**
Axle Load (lbs)	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Tire Load (lbs)	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Tire Contact Area (10" x 20" = 200 sq in)	200	200	200	200	200	200	200	200	200	200	200
Area of Applied Load at 63.4° Angle of Repose (sq in)	1,064	1,496	2,576	3,944	5,600	7,544	9,776	12,296	15,104	18,200	25,256
Area of Applied Load at 63.4°Angle of Repose (sq ft)	7.39	10.39	17.89	27.39	38.89	52.39	67.89	85.39	104.89	126.39	175.39
Static Wheel Load Applied to Eco-Blok	15.04	10.70	6.21	4.06	2.86	2.12	1.64	1.30	1.06	0.88	0.63
Dynamic Loading Safety factor of 1.2	18.05	12.83	7.45	4.87	3.43	2.55	1.96	1.56	1.27	1.05	0.76
Cover Base Pressure at 130 lbs/cf (psi)	1.35	1.81	2.71	3.61	0.35	5.42	6.32	7.22	8.13	9.03	10.83
Total Load Applied to Eco-Blox (psi)	**19.40**	**14.64**	**10.16**	**8.48**	**3.78**	**7.96**	**8.28**	**8.78**	**9.40**	**10.08**	**11.59**
Capacity of Eco-Blox Unit (psi)	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20
Safety Factor	**1.87**	**2.47**	**3.56**	**4.27**	**9.59**	**4.55**	**4.37**	**4.12**	**3.85**	**3.59**	**3.12**

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Table 3: Shown below are the calculations of HS-20 loading conditions with less extreme field condition of a slightly less steep angle of 30° and keeping 130lbs per cubic foot.

HS-20 Loading Calculation and Capacity of Eco-Blox

	Cover Base Depth (inches/feet)										
Variable	**18/1.5**	**24/2**	**36/3**	**48/4**	**60/5**	**72/6**	**84/7**	**96/8**	**108/9**	**120/10**	**144/12**
Axle Load (lbs)	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Tire Load (lbs)	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Tire Contact Area (10" x 20" = 200 sq in)	200	200	200	200	200	200	200	200	200	200	200
Area of Applied Load at 60° Angle of Repose (sq in)	1,262	1,810	3,197	4,971	7,132	9,681	12,618	15,942	19,653	23,753	33,114
Area of Applied Load at 60°Angle of Repose (sq ft)	8.77	12.57	22.20	34.52	49.53	67.23	87.62	110.71	136.48	164.95	229.96
Static Wheel Load Applied to Eco-Blok	12.67	8.84	5.01	3.22	2.24	1.65	1.27	1.00	0.81	0.67	0.48
Dynamic Loading Safety factor of 1.2	15.21	10.61	6.01	3.86	2.69	1.98	1.52	1.20	0.98	0.81	0.58
Cover Base Pressure at 130 lbs/cf (psi)	1.35	1.81	2.71	3.61	0.35	5.42	6.32	7.22	8.13	9.03	10.83
Total Load Applied to Eco-Blox (psi)	**16.56**	**12.41**	**8.71**	**7.47**	**3.04**	**7.40**	**7.84**	**8.43**	**9.10**	**9.84**	**11.41**
Capacity of Eco-Blox Unit (psi)	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20
Safety Factor	**2.19**	**2.92**	**4.15**	**4.84**	**11.91**	**4.89**	**4.62**	**4.30**	**3.98**	**3.68**	**3.17**

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Table 4: Shown below are the calculations of HS-20 loading conditions with conditions of a 1:1 slope (angle of 45°) and keeping 130lbs per cubic foot.

HS-20 Loading Calculation and Capacity of Eco-Blox

	Cover Base Depth (inches/feet)										
Variable	**18/1.5**	**24/2**	**36/3**	**48/4**	**60/5**	**72/6**	**84/7**	**96/8**	**108/9**	**120/10**	**144/12**
Axle Load (lbs)	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000	32,000
Tire Load (lbs)	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000	16,000
Tire Contact Area (10" x 20" = 200 sq in)	200	200	200	200	200	200	200	200	200	200	200
Area of Applied Load 45°Angle of Repose (sq in)	2,576	3,944	7,544	12,296	18,200	25,256	33,464	42,824	53,336	65,000	91,784
Area of Applied Load 45°Angle of Repose (sq ft)	17.89	27.39	52.39	85.39	126.39	175.39	232.39	297.39	370.39	451.39	637.39
Static Wheel Load Applied to Eco-Blok	6.21	4.06	2.12	1.30	0.88	0.63	0.48	0.37	0.30	0.25	0.17
Dynamic Loading Safety factor of 1.2	7.45	4.87	2.55	1.56	1.05	0.76	0.57	0.45	0.36	0.30	0.21
Cover Base Pressure at 130 lbs/cf (psi)	1.35	1.81	2.71	3.61	4.51	5.42	6.32	7.22	8.13	9.03	10.83
Total Load Applied to Eco-Blox (psi)	**8.81**	**6.67**	**5.25**	**5.17**	**5.57**	**6.18**	**6.89**	**7.67**	**8.48**	**9.32**	**11.04**
Capacity of Eco-Blox Unit (psi)	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20	36.20
Safety Factor	**4.11**	**5.42**	**6.89**	**7.00**	**6.50**	**5.86**	**5.25**	**4.72**	**4.27**	**3.88**	**3.28**

7. Appendix A: Diagrams and Testing Results

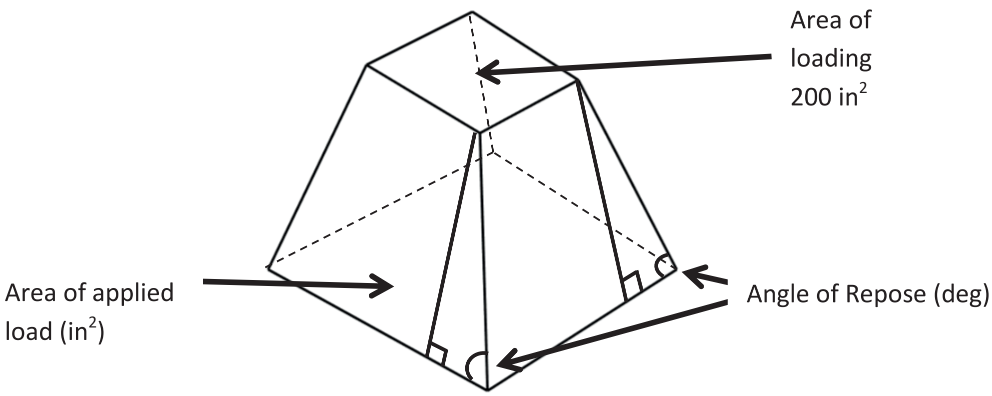

Figure 3: An example of how the angle of repose and depth expand and increase the loading area in all four directions.

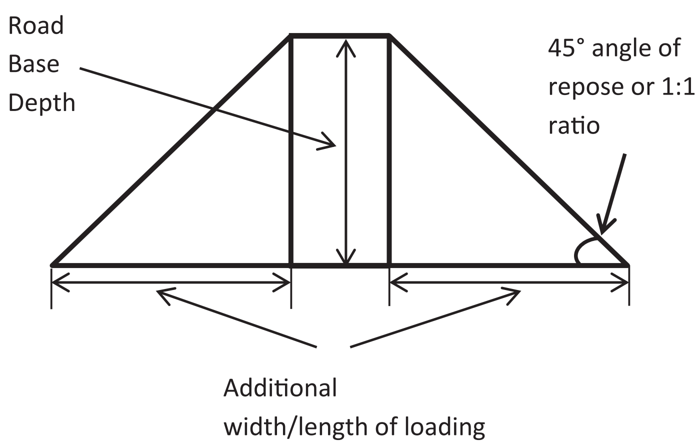

Figure 4: An example of how the angle of repose affects the amount of increased area. Angle is not to scale.

Fiche technique / Technical sheet

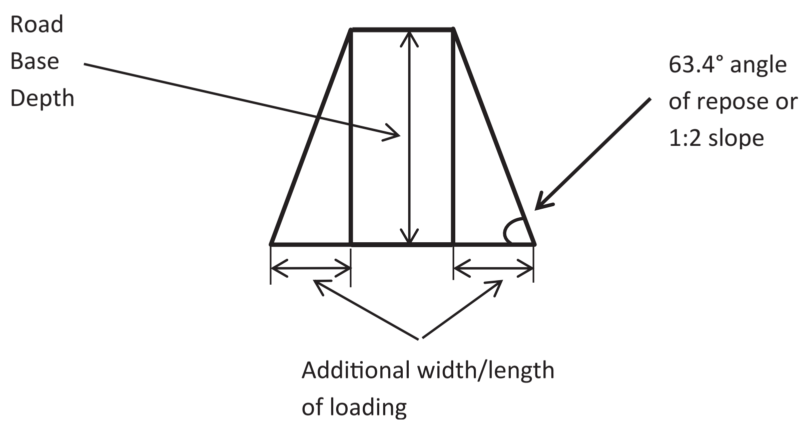

Figure 5: An example of how the angle of repose affects the amount of increased area. Angle is not to scale.

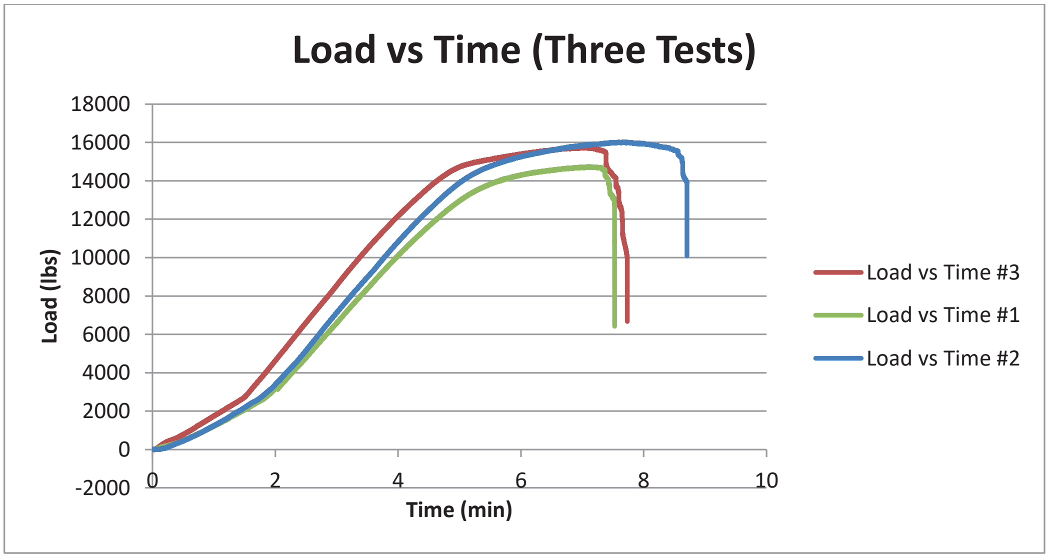

Figure 6: Load vs Time graph showing the consistency of the three test matrix blocks.

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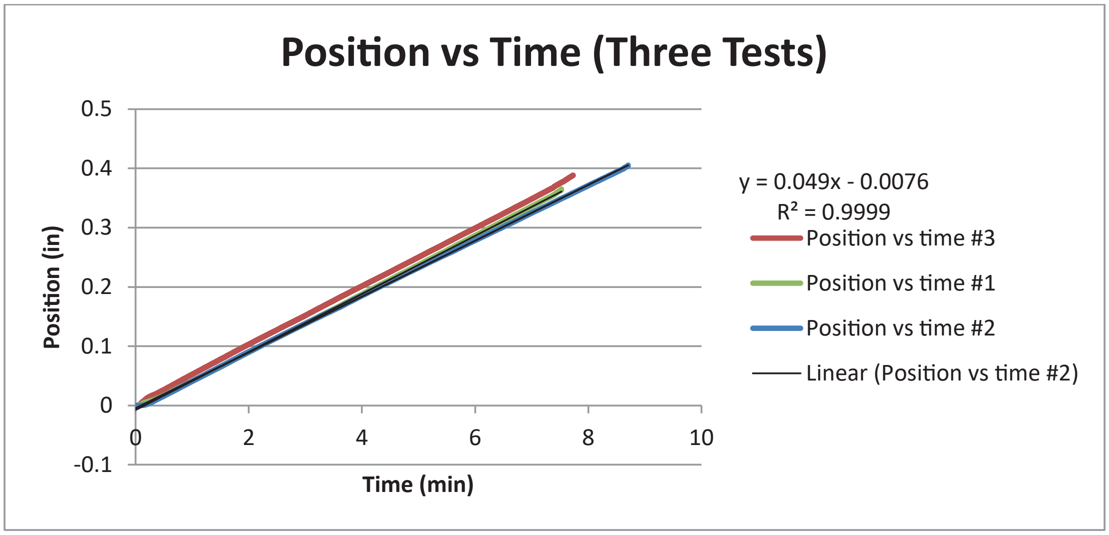

Figure 7: Position vs Time graph showing the consistency of the cross head speed across the three tests.

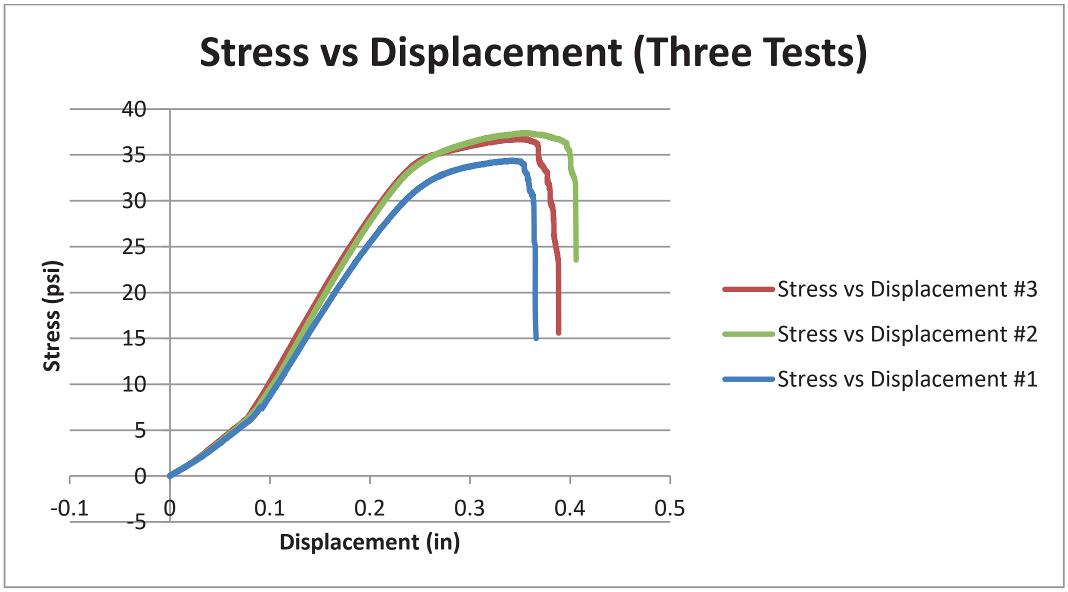

Figure 8: Stress vs Displacement graph showing the consistency of the three test matrix blocks.

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Figure 9: First test block failure from the back side

Broken tabs from the back and side plate bowing and buckling under the load

Broken back plate in the center, from buckling under the load