Full-Scale Field Live Load Testing of a Buried ACO StormBrixx® SD Structure

Executive Summary by Issam Khoury and Teruhisa Masada, April 2020

Abstract: An underground three (3) level structure consisting of eight (8) StormBrixx blocks on each level was constructed in dry, silty sand and covered with 22 in (0.56 m) soil cover and a 2 in (0.05 m) asphalt pad. The structure was instrumented with wire potentiometers and earth pressure cells to measure response of the installation under static and dynamic loads provided by a 30 ton (267 kN) truck load. The maximum vertical soil pressure on the structure under dead and live combined was recorded as 16 psi (110.32 KPa) at the top plate of the structure. The maximum lateral was recorded as 6.50 psi (44.82 KPa) on the side wall at middle row. Maximum deflection from the live load recorded by the wire potentiometers was 48 mil (1.2 mm) or less. 60%-85% of the deflection was immediately recovered in elastic rebound once the load was removed. The deflections the structure experienced under live load applications were less than 0.06%. This is far below a total allowable deflection limit of 5.0% set for buried polypropylene drainage structures in the 2017 AASHTO LRFD Bridge Specifications. During the repeated heavy static load applications, the structure regained most of the load-induced deformations through elastic rebound upon unloading and thus accumulated minuscule permanent deformations. Overall, the StormBrixx SD structure proved to be rigid, with elastic properties, stable, and strong.

ACO StormBrixx SD

Objective

Measure the structural responses of a StormBrixx SD installation under static and dynamic live loads applied by a loaded heavy truck (32 tons).

The StormBrixx Installation

For the load testing, a 14 ft (4.3 m) square area of undisturbed ground next to the ACO Casa Grande, AZ, building was excavated to a depth of about 11 ft (3.5 m). The in-situ soil appeared to be dry, brown, silty sand. The soil at the bottom of the hole was compacted, and a 6 in (0.15 m) layer of pea gravel was placed to form a flat bed for the structure. A nonwoven geotextile sheet was spread over the excavated area. StormBrixx SD blocks were laid on the bottom of the area to form the first of three levels, with each level consisting of eight (8) StormBrixx blocks with the arrangement of blocks in the next level staggered to avoid continuous vertical joints (potential shear planes), see Figure 1. The fully assembled stormwater retention structure was a cube with length on each side of 98 in (2.49 m). Figure 2 shows the completed three layer structure, which was then wrapped with the geotextile sheet before backfilling with an additional 8 in (0.20 m) layer of compacted in-situ soil. The installation was topped with a 6 in (0.15 m) thick base coarse layer and a 4 in (0.10 m) thick asphalt concrete layer to bring the installation flush with the surrounding ground surface. The AC pavement

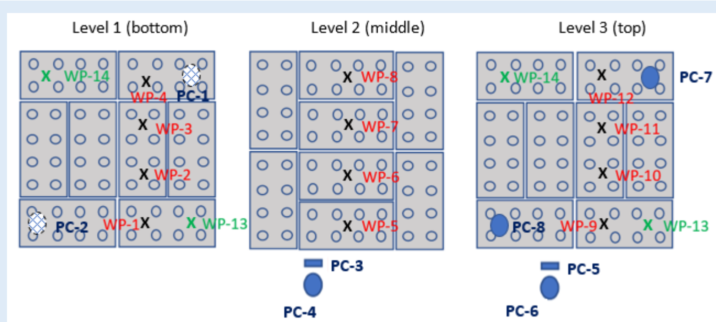

Figure 1. Layout of eight (8) StormBrixx SD blocks in each level of the installation. Locations of wire potentiometers are indicated by black X's labeled WP-1 through WP-12 and green X's labeled WP-13 and WP-14 for those strung between Layers 1 and 3. Pressure cells are indicated by hatched blue-white circles for PC-1 and PC-2 in bedding under Level 1 measuring vertical soil pressure, by solid blue circles PC-4 and PC-6 through PC-8 for cells measuring vertical soil pressure, and by blue rectangles PC-3 and PC-5 measuring lateral soil pressure. Pressure cells PC-7 and PC-8 lie in the soil above Level 3.

surface extended beyond the perimeter of the excavated area and had dimensions of 20 ft (6.1 m) by 20 ft (6.1 m). Figure 3 is a scaled engineering drawing showing a side view of the assembled structure and installation, along with dimensions in inches of the various components. Taking the top of the pea gravel bedding as zero (0), the elevations of the various layers are as follows: Compacted soil, -6 in (-0.15 m); bottom of Layer 1, 0 in (0 m); top of Layer 1 and bottom of Layer 2, 36 in (0.91 m); top of Layer 2 and bottom of Layer 3, 72 in (1.83 m); top of Layer 3 and entire structure, 108 in (2.74 m); top of backfill over structure, 126 in (3.20 m); top of asphalt base course, 130 in (3.30 m); top of asphalt surface/ground level 132 in (3.35 m).

Figure 2. Three layer StormBrixx SD test structure assembled.

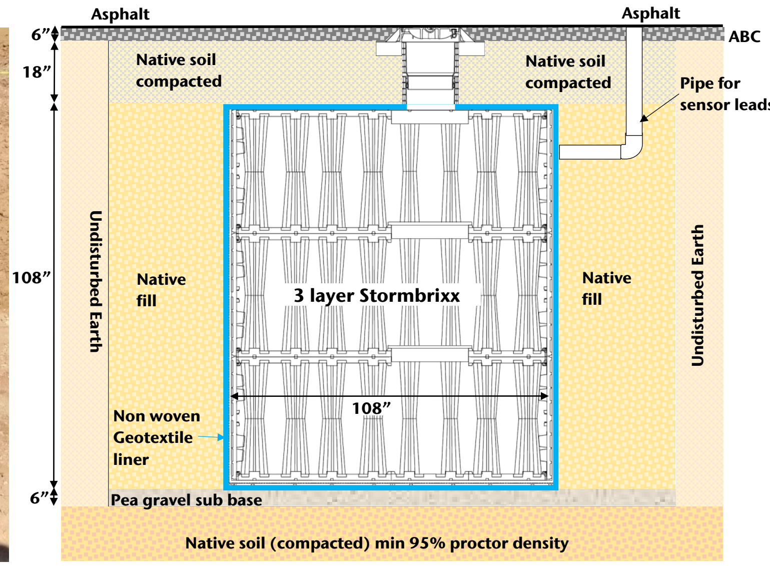

Figure 3. Side view drawing of the StormBrixx SD test structure as installed.

Instrumentation of the StormBrixx SD Structure

While assembling the subsurface drainage structure, it was instrumented with sensors. A total of fourteen linear potentiometers were installed inside the assembled structure to record vertical displacements (or compressions). The diagram in Figure 1 shows the position of the wire potentiometers, shown as large black **X'**s labeled WP-1 through WP-14. Wire Potentiometers WP-1 through WP-4 and WP-9 through WP-12 were directly under the wheel path of the loaded truck during the live load tests, while WP-5 through WP-8 on Level 2 were along the center of the structure, slightly offset to avoid placing sensors on the gaps between StormBrixx units. Groups of three (3) sensors were aligned vertically under the wheel path of the load truck, with the offset on Level 2: (WP-1, WP-5, and WP-9), (WP-2, WP-6, and WP-10), (WP-3, WP-7, and WP-11), and (WP-4, WP-8, and WP-12). Wire potentiometers WP-13 and WP-14 were mounted to the bottom of Level 1 and had their wires extended all the way up to the top of Level 3 to measure total compression of the assembled structure. A total of eight (8) vibrating-wire soil pressure cells were placed beneath, around, and on top of the buried structure to record pressures that develop in soils adjacent to the structure, as shown in Figure 1. Each pressure cell had a thin 9 in (229 mm) diameter circular plate as a pressure sensing element. These soil pressure cells were all installed within a sand lens to minimize the bridging effect and record soil pressure as a function of depth. Some of them were oriented horizontally to measure vertical pressures, while others were oriented vertically to measure lateral pressures. The sensors were numbered PC-1 through PC-8.

Live Load Test Procedure

A fully loaded water truck, see Figure 4, was used to apply heavy loads to the buried StormBrixx SD structure. The truck had a single front axle with single tires and a tandem rear axle with two pairs of tires [with a 6 ft (1. 8 m) space between the tandem axles]. The gross total weight of the loaded truck was measured at 30 tons (60,000 lb or 267 kN) on a scale, distributed as 6 tons (12,000 lb or 53 kN) on the front axle and 24 tons (48,000 lb or 214 kN) on the rear axle. This means that the weight from each side of the rear axle was about 12 tons (24,000 lb or 107 kN). The applied load exceeded H-20 loading. A total of 23 load tests were conducted. Tests 1-10 and 21-23 were static load tests, where the truck was parked so that the center of the rear tandem axle

Figure 4. Loaded truck with the center of the passenger side rear tandem axle positioned where the white lines met on the asphalt pad, with a small offset.

on the passenger side was positioned at the center point close to the manhole cover, at the intersection of the white reference lines shown in Figure 4.

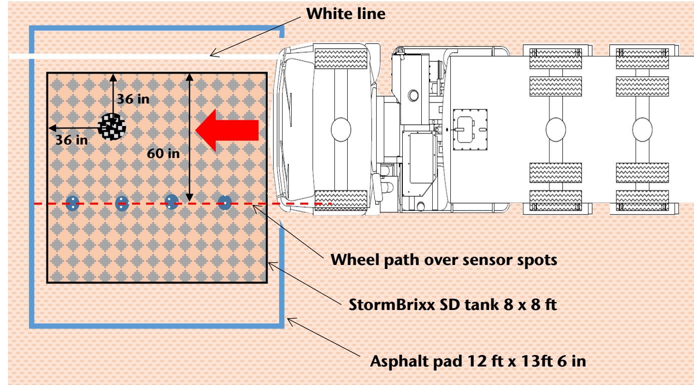

Figure 5. Diagram of static live load tests

Figure 5 is a drawing showing the dimensions of the test area and the load positions. Tests 11-20 were dynamic load tests, where the center of the truck's passenger side tire moved slowly along the painted white line. Figure 6 shows the readings produced by one of the pressure cells over the entire experiment, with each vertical jump corresponding to the start and end of one of the tests. A similar graph for a wire potentiometer is shown in Figure 7.
The minimum, maximum, and mean pressure increases recorded by each pressure cell under static loads, except pressure cells PC-1 and PC-2, are given in Table 1. PC-1 and PC-2 are embedded in the bedding layer beneath the assembled structure and furthest from the surface, and measure negligible pressure under live loads, between 0.1 psi (0.7 kPa) and -0.5 psi (-3.5 kPa). Pressure cells PC-7 and PC-8 had the largest pressures as they were closest to the surface at a depth of about 15 in (380 mm). During the dynamic load applications, the pressure cells responded but did not provide as much detail as during the static load applications.

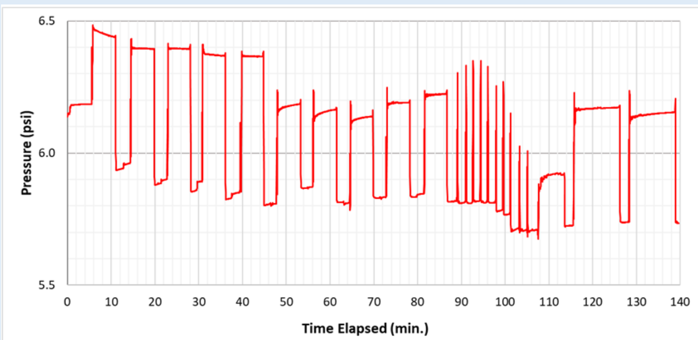

Figure 6. Pressure readings from pressure cell PC-3 (1 psi = 6.89 kPa).

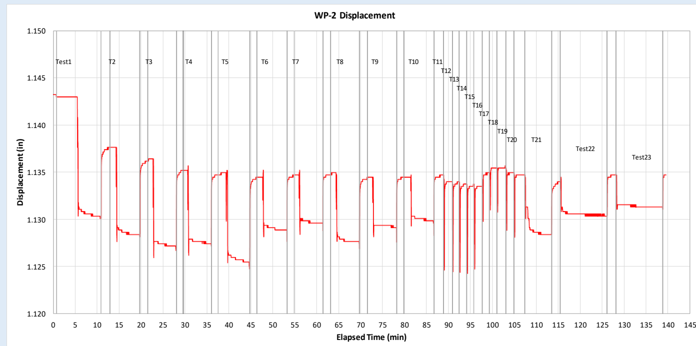

Figure 7. Vertical displacements recorded by wire potentiometer WP-2 (1 in = 25.4 mm).

Figure 8 illustrates a typical response pattern exhibited by wire potentiometers, where compression from the live load is followed by an elastic rebound as the load is removed.

Sensor	Minimum pressure (psi)	Minimum pressure (kPa)	Maximum pressure (psi)	Maximum pressure (kPa)
PC-1	-0.50	-3.45	0.10	0.69
PC-2	-0.50	-3.45	0.00	0.00
PC-3	5.70	39.30	6.50	44.82
PC-4	2.70	18.62	4.00	27.58
PC-5	1.00	6.89	1.90	13.10
PC-6	2.70	18.62	5.00	34.47
PC-7	1.00	6.89	16.00	110.32
PC-8	1.00	6.89	9.00	62.05

Table 1. Minimum, maximum, and mean pressure increases under static load recorded by each pressure cell.

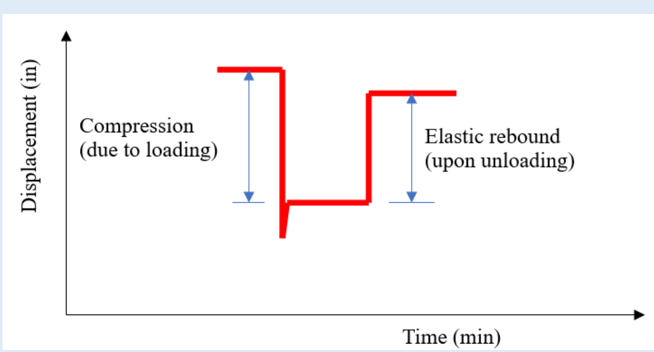

Figure 8. Typical response pattern of a wire potentiometer.

	Permanent compression		Vertical compression						Elastic rebound					
			Minimum		Maximum		Mean		Minimum		Maximum		Mean	
Sensor	(mil)	(mm)	(mil)	(mm)	(mil)	(mm)	(mil)	(mm)	(mil)	(mm)	(mil)	(mm)	(mil)	(mm)
WP-1	12.0	0.30	2.3	0.058	5.0	0.127	3.4	0.085	2.2	0.056	3.5	0.089	2.7	0.069
WP-2	7.0	0.18	3.2	0.081	12.6	0.320	6.9	0.175	3.4	0.086	8.9	0.226	6.2	0.158
WP-3	3.0	0.08	3.4	0.086	10.9	0.277	4.9	0.124	2.9	0.074	7.8	0.198	4.3	0.109
WP-4	25.0	0.63	1.5	0.038	10.3	0.261	5.3	0.135	1.3	0.033	6.2	0.157	3.4	0.086
WP-5	14.0	0.36	2.7	0.069	6.0	0.152	4.4	0.113	2.6	0.066	3.8	0.096	3.2	0.081
WP-6	3.0	0.08	2.2	0.056	8.0	0.203	4.7	0.118	2.1	0.053	5.8	0.147	3.8	0.098
WP-7	4.0	0.10	2.9	0.074	10.0	0.254	4.9	0.125	2.7	0.069	6.4	0.162	3.9	0.100
WP-8	18.0	0.46	2.9	0.074	10.8	0.274	6.3	0.159	2.4	0.061	4.9	0.124	3.7	0.093
WP-9	17.0	0.43	1.6	0.041	16.5	0.419	6.8	0.173	1.8	0.046	10.0	0.254	4.6	0.116
WP-10	0.0	0.00	1.3	0.033	12.3	0.312	6.2	0.156	2.0	0.051	8.7	0.221	4.9	0.125
WP-11	4.0	0.10	1.3	0.033	21.0	0.533	4.6	0.116	1.7	0.043	13.0	0.330	3.6	0.092
WP-12	17.0	0.43	4.4	0.112	21.7	0.551	10.2	0.260	3.0	0.076	13.3	0.338	6.3	0.160
WP-13	15.0	0.38	1.9	0.048	5.1	0.129	3.1	0.077	1.2	0.030	2.5	0.063	1.9	0.048
WP-14	48.0	1.22	10.0	0.254	31.1	0.789	17.5	0.445	-	-	-	-	-	-

Table 2. Summary of permanent compression, vertical compression, and elastic rebound measurements recorded by wire potentiometers during static load tests.

Table 2. left, summarizes the vertical compression measurements of the blocks recorded by the wire potentiometers during the static load tests. During the dynamic load applications, the wire potentiometers responded but did not provide as much detail as during the static load applications. When calculating the average displacement values, any reading close to zero (0) was excluded. The elastic rebound measurements represent the amount of the vertical compression that was recovered when the load was removed, typically 60% to 85%. Figure 9 shows the rutting observed in the AC pavement during the live load testing program.

Further Analysis and Concluding Remarks

The StormBrixx SD short-term vertical and lateral compressive strength values are listed as 50.8 psi (350 kPa) and 10.2 psi (70 kPa) - refer to ACO Stormbrixx Catalog, December 2019. During the test program, the largest vertical and lateral pressures recorded were about 16.0 psi (110.32 kPa) and 6.50 psi (44.32 kPa), respectively. These peak pressure values each constituted a small fraction of the pressure required to cause a structural failure of the assembled StormBrixx® SD structure. This is also supported by the relatively small deformation readings recorded by all the wire potentiometers throughout the static loading program. Also, the modular construction of the structure allowed the vertical pressure applied at the ground surface to spread over an increasingly larger area from one level to the next. This led to the two pressure cells (PC-7 and PC-8) installed in the bedding layer picking up very small readings from the static loads.

Figure 9. Rutting observed on wheel path of the asphalt surface during load testing.

StormBrixx SD is an open-structure cellular block made of a polypropylene material. The assembled structure had a full height of 108 in (2.74 m), or 36 in (0.91 m) for each layer. During the live load test, the maximum compression recorded at any level was about 20 mil (0.02 in or 0.51 mm) and the maximum compression of the assembled structure remained under 40 mil (0.04 inches or 1.01 mm). These indicate that the level of deflection induced by the loaded truck was no more than 0.06%, well below the allowable deflection limit of 5.0% set for buried polypropylene drainage structures in C12.12.2.2 of Section 12 (buried structures and tunnel liners) of the 2017 AASHTO LRFD Bridge Specifications. The structure assembled from StormBrixx® SD is highly porous yet stable, rigid, elastic, and strong. During the repeated heavy static load applications, the structure regained most of the load-induced deformations upon unloading and thus accumulated negligible permanent deformations.

StormBrixx products are made of polypropylene, with an elastic modulus of about 145 ksi (1.0 GPa) at normal room temperature. Each column element has a total height of 18 in (457 mm) and diameter ranging linearly from 8.5 in (216 mm) at the base to 5.75 in (146 mm) at the tip. If the wall thickness is assumed to be close to 0.2 in (5.1 mm), the column wall cross-sectional area would vary linearly from 5.22 in^2 (3,368 mm^2) at the base to 3.52 in^2 (2,271 mm^2) at the tip. Also, assume that each column will take 25% [due to the spreading effect through the 24 in (609.6 mm) cover] of a 3,000 lb (13.3 kN) load. 24,000 lb (107 kN) total load is divided by eight (8) columns. The maximum compression of the column element is then calculated to be 19 mil (0.48 mm), this compares well to the actual displacements recorded by the wire potentiometers in the current project. Many factors including the loading time, the temperature of the StormBrixx components in the ground, the position and contact area of the tires, and the stiffness of the AC surface layer can influence the actual displacements.