Date: June 7, 2016 (Revised June 16, 2016)
To: Office
From: Lysandra Lincoln
Re: EE Memo 4 – Diverted Flow in Drainage Net from Foundation Construction Wills Wharf, Baltimore, MD
File: 12582A-111

This memorandum summarizes the analysis of impedance to flow and changes in flow direction within the drainage net resulting from construction of foundations for the Wills Wharf development.

Exhibits

Calculation Set 1 Percent Obstruction to Flow within Drainage Net
Calculation Set 2 Assessment of Infiltration to Drainage Net
Table 1 Concrete Retaining Wall Pile Caps

Sketch SK-1 Location plan showing extents of parking lot with pavement surface cover
Sketch SK-2 Location plan showing surface runoff drainage net
Sketch SK-3 Drainage net above existing geomembrane
Sketch SK-4 Drainage net flowing towards concrete retaining wall pile caps
Sketch SK-5 Hydraulic gradient in Area A2

Available Information
1. Drawing DDP F1.10 – Boring Location Plan
2. Drawing DDP F1.20 – Sheet Pile Barrier Wall Plan, dated April 29, 2016
4. Drawing DDP F1.50 – Foundation Details and Sections, dated April 29, 2016

References
Multimedia Cap

The Corrective Measures Implementation Report (CMI Report) by Black and Veatch details the construction and layering of the multimedia cap (MMC). The MMC includes a synthetic drainage net on the geomembrane. The MMC was constructed such that water that infiltrates the soil cover will flow away from the center of the cap through the drainage net and will not pond on the membrane. A contour of the surface of the geomembrane layer is presented in Ref. 1. The water flowing through the drainage net is discharged into the embankment along the waterside perimeter, and is collected in a toe drain that runs parallel to the Wills Street extension. The toe drain, which is outboard of the soil-bentonite barrier, conveys water to the embankment where it is allowed to permeate into the porous embankment fill. Since construction of the MMC the site has been largely unused, except for temporary parking. It is presumed that settlement has not created a negative slope of the drainage net and ponding does not occur.

Concrete Retaining Wall Foundations

The Wills Wharf development includes the extension of Wills Street. Wills Street will descend from the existing Plaza Garage at El. +28 south towards the water to El. +12, terminating just north of the promenade being constructed as part of the Project.

Wills Street will be constructed with pile supported concrete retaining walls running north-south and east-west. The north-south retaining wall will run for approximately 315 linear feet (lf) to the south (i.e., towards the water). The east-west retaining wall will run approximately the width of Wills Street. The Wills Wharf Office building wall will retain the street fill on the east side of Wills Street. The southern end of Wills Street will terminate with a vehicular turnaround before it approaches the pedestrian promenade and the harbor.

The piles supporting the concrete retaining wall will pass through the existing geomembrane. Each pile penetration will be sealed using a mechanical boot with stainless steel clamp and gasket system. Pile caps are designed to remain above the surrounding geomembrane. A geomembrane dam will be placed around each pile cap to isolate drainage net water from the pile cap excavation. This dam will be left in place after pile cap construction is completed.

Obstruction to Drainage Net Below Development Structures Analysis

Pile cap construction will isolate the pile cap and piles from the drainage net using a geomembrane dam at the perimeter of each excavation. Drainage net capacity to carry water between these flow obstructions is reviewed in this section. This analysis was performed on pile foundations known as of April 29, 2016.

Area 1 to the west of the Wills Street extension is covered by asphalt pavement and does not allow surface infiltration. Precipitation and water flowing over the ground surface will flow downslope as surface runoff to the existing infiltration trench at the southern waterside perimeter. Sketches SK-1 and SK-2 show the extents of this area and the drainage flow net for water at the ground surface.

Water that does permeate through the pavement surface cover will follow the contours of the existing geomembrane, as shown in Sketch SK-3. The majority of the drainage net will flow south to the existing infiltration trench. The drainage net flows east towards the existing perimeter toe drain along a 95 ft long
segment of Wills Street, where five of the concrete retaining wall pile cap foundation dams will obstruct the drainage net.

Impedance to flow within the drainage net was quantified by computing the percentage of drainage net removed and not replaced. Sketch SK-4 divides the drainage area into three zones:

- \(A_1\) – Area below proposed Wills Street extension. Surface water will be captured by storm drains and carried offsite.
- \(A_2\) – Area to the west of the Wills Street extension where groundwater may flow east and be forced around the pile cap obstructions.
- \(A_3\) – Area to the west of Wills Street extension where groundwater will flow to the south and will not encounter any obstructions.

The percent of the \(A_2\) drainage net area reduction after pile cap construction is 6.7%. However, \(A_2\) only accounts for 20% of the total drainage net area (\(A_1 + A_2 + A_3\)).

Water infiltration to the drainage net in area \(A_2\) was calculated for the design rainfall event (100-year storm). This infiltration flow volume is equal to 0.01425 ft\(^3\)/sec and accounts for the demand on drainage net flow to the concrete retaining wall interface on the west side of the Wills Street extension. The drainage net flow capacity was calculated using the hydraulic conductivity of the drainage net, hydraulic gradient across area \(A_2\), and the cross-sectional area of the drainage net at the retaining wall interface. Before the pile cap construction, the flow capacity is equal to 0.0406 ft\(^3\)/sec. After the pile cap construction, the flow capacity is reduced to 0.0305 ft\(^3\)/sec. The factor of safety against potential head build up above the geomembrane is calculated as the drainage net flow capacity / infiltration to the drainage net. Before pile cap construction, the factor of safety is \(FS_I = 2.85\). With the pile cap obstructions, the factor of safety is reduced to \(FS_F = 2.14\), a 25% reduction in the factor of safety.

**Summary**

The obstruction to the drainage net due to pile cap blockage occurs only at Area \(A_2\). The 6.7% reduction in \(A_2\) drainage net area results in a 25% reduction in drainage flow capacity. This reduction is acceptable, as the capacity of the drainage net with obstructions is sufficient to manage water infiltration during the design rainfall event without head build up. Infiltration to Area \(A_1\) is prevented by surface drainage improvements, reducing water volume in drainage net downstream of Area \(A_2\); this should increase the rate of flow towards the toe drain for water from Area \(A_2\) entering Area \(A_1\). Water in Area \(A_3\) will continue to flow south to the existing toe drains and independently discharges to the embankment without flowing through pile obstructions.

By: ____________________________

Lysandra Lincoln
SUBJECT: OBSTRUCTIONS TO FLOW WITHIN DRAINAGE NET

PURPOSE: ASSESS THE TOTAL AREA OF OBSTRUCTED FLOW IN DRAINAGE NET FROM PILE CAP CONSTRUCTION.

ASSUMPTIONS:
1. DRAINAGE NET IS REMOVED WITHOUT REPLACEMENT AT PILE CAPS FOR CONCRETE RETAINING WALL, AS SHOWN ON SK-3 AND SK-4.

CALCULATIONS:

AREA OF DRAINAGE NET WITH POTENTIAL TO FLOW EAST AROUND PILE CAPS
\[ A_2 = (65 \text{ ft})(1600 \text{ ft}) \]
\[ = 10,400 \text{ ft}^2 \]

AREA OF PILE CAP OBSTRUCTIONS (SEE TABLE 1)
\[ A_3 \]
\[ = 696 \text{ ft}^2 \]

PERCENT OF \( A_2 \) DRAINAGE NET REDUCTION
\[ = \left( \frac{10400 - 696}{10400} \right) = 0.933 \]

OR \( 6.7\% \) REDUCTION

PERCENT OF TOTAL DRAINAGE NET AREA REDUCED
\[ = \left( 6.7\% \right) \frac{A_2}{A_1 + A_2 + A_3} \]
\[ = \left( 6.7\% \right) \frac{10400}{53125} \]
\[ = 1.3\% \] REDUCTION IN TOTAL DRAINAGE NET AREA
SUBJECT: ASSESSMENT OF INFILTRATION TO DRAINAGE NET

PURPOSE: COMPARE THE DESIGN FLOW CAPACITY WITHIN THE IMPEDED DRAINAGE LAYER TO THE EXPECTED FLOW BASED ON SITE CONDITIONS AND INFILTRATION FROM THE DESIGN RAINFALL EVENT.

ASSUMPTIONS:
1. DESIGN RAINFALL EVENT = 100-YR STORM:
   TOTAL PRECIPITATION OVER 24 HRS DURING 100-YR STORM = \( P = \frac{7.1 \text{ in}}{24 \text{ hr}} = 0.592 \text{ ft/hr} \)

2. DRAINAGE NET PROPERTIES:
   THICKNESS \( t = 0.25 \text{ in} \)
   TRANSMISSIVITY \( T = 2.8 \times 10^3 \text{ m}^2/\text{sec} = 0.0305 \text{ ft}^2/\text{sec} \)
   (*ASSUMING GRADIENT OF 0.1 AND CONFINING PRESSURE OF 2,000 PSF)

3. SOURCES OF WATER:
   WATER INFILTRATES THROUGH COVER SOIL IN AREA Z AND IS CARRIED BY DRAINAGE NET TO THE WILLS ST. RETAINING WALL.

CALCULATIONS:
- DRAINAGE AREA \( A_z = 10400 \text{ ft}^2 \)
- RAINFALL INTENSITY \( I = 0.592 \text{ ft/hr} \)
- RUNOFF COEFFICIENT \( C = 0.80 \) (80% of rainfall will be carried away by surface runoff)

- VOLUME OF WATER INFILTRATING INTO DRAINAGE NET:
  \[ W_i = (1-0.8)(10400 \text{ ft}^2)(0.592 \text{ ft/hr})(24 \text{ hrs}) = 1231.4 \text{ ft}^3/\text{24 hrs} = 0.04125 \text{ ft}^3/\text{sec} \]

(INITIAL) DRAINAGE NET FLOW CAPACITY:
\[ Q = K \times t \times A \] where \( K = \text{HYDRAULIC CONDUCTIVITY} = \frac{\text{TRANSMISSIVITY}}{\text{THICKNESS}} = 1.464 \text{ ft/sec} \)
\[ R = \text{GRADIENT} = 0.014 \]
(SEE SKETCH SK-5)
SUBJECT: INfiltration to Drainage Net (CONT.)

\[ A_i = \text{Flow Cross Sectional Area (Before Pile Cap Constr.)} = (95 \text{ ft}) (0.25 \text{ in}) \]

\[ A_i = 1.98 \text{ ft}^2 \]

\[ Q_i = (1.416 \text{ ft}^3/\text{sec})(0.014)(1.98 \text{ ft}^2) \]

\[ Q_i = 0.0406 \text{ ft}^3/\text{sec} \]

(Final) Drainage Net Flow Capacity:

\[ A_f = (95 - 3(3.5 \text{ ft}) - 2(6.5 \text{ ft})) \times (0.25 \text{ in}) \]

\[ A_f = 1.49 \text{ ft}^2 \]

\[ Q_f = (1.416 \text{ ft}^3/\text{sec})(0.014)(1.49 \text{ ft}^2) \]

\[ Q_f = 0.0305 \text{ ft}^3/\text{sec} \]

Factor of Safety

Before Pile Cap Construction:

\[ F_{SI} = \frac{\text{Drainage Net Flow Capacity}}{\text{Infiltration to Drainage Net}} = \frac{Q_f}{Q_i} = \frac{0.0305}{0.0406} = 0.07425 \]

\[ F_{SI} = 2.85 \checkmark \]

After Pile Cap Construction:

\[ F_{SF} = \frac{Q_f}{Q_i} = \frac{0.0305}{0.0406} = 0.07425 \]

\[ F_{SF} = 2.14 \checkmark \]
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<th>Pile Cap</th>
<th>Number of Piles</th>
<th>Excavation Subgrade Elevation</th>
<th>Excavation Subgrade Below MMC</th>
<th>Pile Cap Edge to Drainage Dam, B (ft)</th>
<th>Length of Pile Cap (ft)</th>
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*Pile caps that cause obstructions to flow

Total: 2,555

Total Area of pile cap obstructions: 696

Pile Caps dimensions

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Hydraulic Gradient:

\[ i = \frac{\Delta h}{\Delta L} = \frac{2 \text{ ft}}{144 \text{ ft}} = 0.014 \]