Surface Flood-induced Groundwater Seepage Modeling for Coastal Flood Hazard Areas

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Bin Wang, Chad Cox, Cassandra Wetzel and Dan Stapleton
OUTLINE

• Background
• Analysis
• Results
• Takeaways
• Properties flooded during Sandy 2012
• Damage assessment and recovery completed
• Improvements for resiliency against future risks
• Load calculation using the Design Flood Elevation (DFE)
Effective September 5, 2007
BACKGROUND

Preliminary
December 5, 2013
**BACKGROUND**

**Hurricane Sandy 2012**

**Observed Water Levels at The Battery**

- Max water level = 11.3 ft
- Max storm surge = 9.4 ft

**Duration over 10 ft = 2 hours**
Mean Sea Level Trend
8518750 The Battery, New York

The mean sea level trend is 2.84 millimeters/year with a 95% confidence interval of +/- 0.09 mm/yr based on monthly mean sea level data from 1856 to 2015 which is equivalent to a change of 0.93 feet in 100 years.
Estimated Relative Sea Level Change Projections From 2016 To 2116 -
Gauge: 8518750, The Battery, NY (2.77 mm/yr)

USACE SLR Scenarios

- +0.9' in 100 years
- +2.2' in 100 years
- +6.4' in 100 years

Scenarios assigned with equal probabilities
For flood resilience studies, issues if assuming hydrostatic conditions:

- Insufficient structural capacities
- Costly upgrades
- Feasibility and/or constructability
Numerical Transient Seepage Modeling:

- 2-dimensional finite element model
- Stage hydrographs with design flood elevations (DFE)
  - \( \text{DFE} = \text{BFE} + 1' \text{ Freeboard} + 3' \text{ SLR} \)
- Various improvement options
- Refined results

\[ H(t) \]

Sea level

\[ \text{GWL} \]
Groundwater flow analysis

SEEP/W analyzes groundwater flow within porous materials. Its formulation enables analyses ranging from simple saturated steady-state problems to sophisticated saturated/unsaturated time-dependent problems.

SEEP/W can be applied to the analysis and design of geotechnical, civil, hydrogeological, and mining engineering projects.
Finite Element Model – Existing Conditions

Boundary and Initial Conditions

Example Building Cross Section (DFE El.15')

Fixed Head Boundary

GWL

Elevation (ft, NAVD88)

Distance (ft)

Name: Fill
Hyd. Conductivity: 0.0003 ft/sec

Name: Sand
Hyd. Conductivity: 0.0003 ft/sec

Name: Silty Sand & Sandy Silt
Hyd. Conductivity: 3e-005 ft/sec
BASE RUN

Finite Element Model – Transient Stage

Hydraulic Boundary Function (stage hydrograph)

Example Building Cross Section (DFE Bl.16")

Potential Seepage face

Free Boundary

Name: Fill
Hyd. Conductivity: 0.0003 ft/sec

Name: Sand
Hyd. Conductivity: 0.0003 ft/sec

Name: Silty Sand/Sandy Silt
Hyd. Conductivity: 3e-005 ft/sec

No Flow

Fixed Head Boundary

Distance (ft)
Flood Hydrograph (ft, NAVD88)

Stage Hydrograph

2 hr

12 hr
Input Hydrograph

- Flood Hydrograph (ft, NAVD88)
- Hour
- DFE (El. 15' for SLR=3')
- Water Level Observed during Hurricane Sandy 2012
BASE RESULTS

Steady State - Initial Conditions

Example Building Cross Section (DFE E1.15°)

- Phreatic Surface
- Fixed Head Boundary
- (assumed conservative GWL)
- Fixed Head Boundary

Elevation (ft, NAVD88)

Distance (ft)
Transient Stage @ Hour 7

**Pres. = 780 psf or 12 ft vs. Hydrostatic 16 ft**

**Uplift = 590 psf or 9 ft vs. Hydrostatic 15 ft**
IMPROVEMENT #1

Finite Element Model – 10-ft Impervious Cover
TRANSIENT STAGE @ HOUR 7

Uplift = 540 psf or 8 ft vs. Hydrostatic 15 ft

Pres. = 710 psf or 11 ft vs. Hydrostatic 16 ft
Finite Element Model – 20-ft Impervious Cover

Example Building Cross Section (DFE El.16')

Impervious

Name: Fill
Hyd. Conductivity: 0.0003 ft/sec

Name: Sand
Hyd. Conductivity: 0.0003 ft/sec

Name: Silty Sand/Sandy Silt
Hyd. Conductivity: 3e-005 ft/sec

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Transient Stage @ Hour 7

**Pres. = 520 psf or 8 ft vs. Hydrostatic 16 ft**

**Uplift = 410 psf or 6 ft vs. Hydrostatic 15 ft**
IMPROVEMENT #3

Finite Element Model – 6-ft Cutoff
Transient Stage @ Hour 7

Uplift = 500 psf or 6 ft vs. Hydrostatic 15 ft

Example Building Cross Section (DFE El. 15')

No pressure on wall

Distance (ft)

Elevation (ft, NAVD88)
SUMMARY

Normalized Maximum Pressure

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Wall</th>
<th>Uplift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrostatic</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Transient (Base)</td>
<td>0.75</td>
<td>0.60</td>
</tr>
<tr>
<td>Impvmt #1 (10' W)</td>
<td>0.50</td>
<td>0.40</td>
</tr>
<tr>
<td>Impvmt #2 (20' W)</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Impvmt #3 (6' D)</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

± 25% ± 40% ± 50%
SUMMARY

For improvement #2

$$F_{\text{w/ seepage}} = \frac{F_{\text{hydrostatic force w/o seepage}}}{\pm 25\%}$$

- Hydrostatic w/o Seepage
  - Base (No Impvmt)
  - Impvmt 1 (10-ft)
  - Impvmt 2 (20-ft)
TAKEAWAYS

• Flooding impacts the below-grade portion of structures;
• Transient vs steady state;
• Infiltration and flow path;
• Site-specific parameters
• Effective for resiliency improvement studies
THANK YOU

Bin Wang, P.E., CFM  
Technical Specialist  
Norwood, MA  
781-278-5809  
Bin.Wang@gza.com

Chad Cox, P.E.  
Principal  
Norwood, MA  
781-278-5787  
Chad.Cox@gza.com

Cassandra Wetzel, P.E.  
Associate Principal  
New York, New York  
212-594-8140  
Cassandra.Wetzel@gza.com

Daniel Stapleton, P.E.  
Senior Principal  
Norwood, MA  
781-278-5743  
Daniel.Stapleton@gza.com