SUSTAINABLE MUNICIPAL INFRASTRUCTURE PLANNING, MAINTENANCE, REPAIR, AND REPLACEMENT IN KARST SINKHOLE PRONE AREAS

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THE PROBLEM – AGING UTILITIES
THE PROBLEM – KARST GEOLOGY

Feature A is a sinkhole with a sagging residuum which has been exposed by a highway cut. When a small sink or unconfined depression is present at the surface it may collect enough runoff for a pond or perched water table to be formed. Horizontal bedding planes, formed by sediments infilling the sinkhole, become inclined with time. This is primarily because the residuum settles with continued solution of materials at depth. (Bretz, 1946, described a variety of infilled solution cavities in ancient weathering profiles which were exposed in quarries in Illinois.) The slope stability problem develops when a relatively steep bocock cut encounters the soil filling the sinkhole and the overly steep slope collapse.

Feature B, the collapse sinkhole, seldom causes a stability problem. Although the collapsed rock may be weaker than the surrounding rock, the nature of the material is apparent when the excavation begins. However, the collapsed debris may become mixed with clayey residual soil and a larger slope failure could develop.

Feature C is an incipient sinkhole in which the lower portion is filled with soft clay. This feature is likely to lead to a more serious slope failure than the others because the low strength of the soft clay may not be determined until the slide develops.
THE PROBLEM – URBAN LAND

UNDEVELOPED SUBURBAN AREA

CARTWAY

DEVELOPED URBAN AREA

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Figure 9. The bathtub model. A. Water infiltrates through the soil. B. As soil enters the drain, a void is left behind. C. Over time, the soil moves into the void and the void “migrates” toward the surface. D. Support is removed and collapse occurs. E. If enough water is supplied, an open connection to the drain results.
THE PROBLEM - KARST BEDROCK

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PROBLEM BACKGROUND

- Migration of surface water from deteriorating pavements, sidewalks, and curbs into residual soils can result in slow subsurface erosion of soil into the underlying bedrock resulting in subsidence.
Subsidence of soil supporting utilities can in turn result in leaks or even main breaks that can result in significant subsurface erosion and the formation of a sinkhole.
Allentown water main break
( Donna Fisher/The Morning Call / December 30, 2011 )

Officials gather as the sinkhole at 10th and Gordon Streets undergoes excavation. Old trolley tracks are evident at right.
RESULTING PROPERTY DAMAGE

Allentown water main break
(Donna Fisher/The Morning Call / December 29, 2011)
A new sign marks the home at 401 N. 10th Street as unfit for habitation in the wake of a water main break in the street’s 300 block Thursday morning.

Homes in the 300 block of N. 10th Street are affected by the sinkhole at 10th and Gordon Streets in Allentown.
Failure of underground utilities in sinkhole prone karst areas can result in major property damage and even loss of life.
MAJOR SINKHOLE – MAIN BREAKS

- VERA CRUZ RD SINKHOLE – SAUCON VALLEY
- MACUNGIE SINKHOLE – MACUNGIE PA
- LIBERTY & REFWAL STREET MAIN BREAK-SINKHOLE
- CORPORATE PLAZA COLLAPSE & DEMOLITION
- PENN STREET MAIN BREAK-SINKHOLE
- NORTH 5TH STREET MAIN BREAK – GAS EXPLOSION
- LEHIGH VALLEY COLLEGE MAIN BREAK-SINKHOLE
VERA CRUZ ROAD - SAUCON VALLEY

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HISTORY OF DESTRUCTION

April 2, 1988: About 100 homes in center city Allentown are evacuated when a 105-year-old water main breaks between Gordon and Liberty streets, creating a hole 6 feet deep and 40 feet in diameter in front of St. Andrew United Church of Christ.

Feb. 17, 1988: The Church of God of Prophecy, 817 Liberty St., collapses after a water main break; gas main in the area was capped after odors emanated from the street.

Aug. 29, 1990: An Allentown woman is killed and seven others injured when a gas explosion levels one house at 423 N. 5th St. and partially topples an adjacent residence.

Aug. 8, 1978: Two firefighters are killed and another injured while investigating gas that seeped into a home at 1127 Oak St.

City church collapses into sinkhole
Area still unstable; residents evacuated

Gas explosion kills woman, levels Allentown row homes
Seven others were injured; one critical
City church collapses into sinkhole

Area still unstable; residents evacuated

At 6:20 p.m., in what looks like a sinkhole, a large portion of the church collapsed into the street.

Assistant Fire Chief Tony and other firefighters were reportedly called to the scene.

The church, located at 123 Liberty St, collapsed into the street, leaving a large hole.

Residents were evacuated from the area, and the church was deemed unstable.

Church collapses after main breaks, street caves in

Continued from Page B1

Fire Chief Ernest E. Tuttle, who was working on the remaining part of the structure, was reportedly injured.

He said, "I'm afraid the building is going to collapse and the main broke through the wall." He added, "But we're very fortunate at this time there are no injuries.

Tuttle said he was grateful there was no gas explosion, but the building's chances remained intact.

He credited the combined efforts of city employees and volunteers for the handling of the situation.

"I would like to commend our firemen, the city police, the fire department, and the inspection bureau for their cooperation at the scene," he said.

Art Kline, a volunteer for the Red Cross Disaster Service, said five volunteers would work through the night if necessary.

As of last night, some of the people evacuated from their homes needed Red Cross assistance.

"We are doing our best to assist those who need it," Kline said.

Around 30 fire police volunteers assisted at the scene, said Fire Chief Cap Jim Redline.

A second fire was brought in last night and several more were brought in as a precaution.

An estimated 400 residents were evacuated from their homes, and the church was deemed unstable.

John Johnson, who lives two doors down from the church, said he noticed a large crack in the church's foundation.

"I saw the crack forming about an hour ago," Johnson said.

"I noticed it was getting wider and wider, and then the building started to move," he said.

Johnson said he and his family were evacuated from their home and were now staying with friends.

A spokesperson for the church said they would be working on the church's foundation.

They said, "We will be doing some work on the church's foundation, and we will be working with the city to make sure it is safe."
CORPORATE PLAZA – 1994

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Sinkhole damages Allentown homes

Eleven buildings were evacuated. Officials say two may have to be demolished.

By KIRK BELDON JACKSON
Off The Morning Call

A sinkhole on N. Penn St. in Allentown is cracked after a sinkhole opened up early Tuesday. Residents were evacuated in Allentown, PA Section AWWA 64th Annual Conference – Lancaster, PA
Gas explosion kills woman, levels Allentown row homes

Seven others were injured; one 'critical'

An Allentown firefighter hoses down the remains of two homes destroyed in an early morning explosion and fire that killed one person and injured at least seven. The homes are at 423 and 421 N. 5th St.
NORTH 5TH STREET - ALLENTOWN

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POSTULATED MAINBREAK CAUSE

1. HARD/SOFT PAVEMENT SUBGRADE SUPPORT RESULTS IN CRACKING OF CONCRETE PAVEMENT
2. SURFACE WATER BEGINS TO MIGRATE OVER TIME INTO CRACKS SOFTENING RESIDUAL SOILS
3. SLIGHT SUBSIDENCE OCCURS IN SOLUTION ZONES
4. SUBSIDENCE AT LEAD JOINT AT CURB BOX/CorP RESULTS IN LEAK/BREAK OF WATER SERVICES OVER THE PAST 35 YEARS WHICH FURTHER DESTABILIZE SUPPORTING SOILS IN PINNACLED ROCK AREAS
5. WATER SERVICE LEAK OCCURS AT 427 ON 1/28/90 MIGRATING WATER FOLLOWS SIDEWALK/CorB
6. RELEASED WATER ENTERS BEDROCK SOLUTION ZONE RESULTING IN SUBSIDENCE OF SUPPORTING SOILS FOR 425 & 423 GAS/WATER LATERALS
7. FURTHER LEAKS OCCUR IN 423 LATERALS ON 8/29 RESULTING IN A MAJOR LEAK OF GAS AND WATER
8. GAS EXPLOSION OCCURS BREAKING LATERALS/MAIN
9. ONCE WATER MAIN BREAKS, SUBSURFACE EROSION OF SUPPORTING SOILS OCCURS BY ENTRY OF RELEASED WATER INTO UNDERLYING SOIL AND ROCK VOIDS
10. SANITARY MAIN SUBSIDES/GAS MAIN IS BROKEN
11. SUBSURFACE EROSION CONTINUES UNTIL MAIN IS SHUT OFF RESULTING IN MAJOR GROUND LOSS AND SUBSIDENCE
NORTH 5TH STREET - ALLENTOWN

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Pavement cracking was an early indicator of subsurface erosion and subsidence

The increasing number of water service leak-break frequency was a secondary warning

The presence of suspected solution weathering zones identified where a failure could occur
PAVEMENT CRACKING INDICATORS

PA Section AWWA 64th Annual Conference – Lancaster, PA
SANITARY LIMESTONE BEDROCK PROFILE

PA Section AWWA 64th Annual Conference – Lancaster, PA
UTILITY-LEAK BREAK INDICATORS
# Utility Leak-Break Data

## Table 1. Leak-Break Chronology

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Date</th>
<th>Component</th>
<th>Cumulative Leak-Breaks</th>
</tr>
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<tbody>
<tr>
<td>1956</td>
<td>416</td>
<td>6/28/56</td>
<td>Corp</td>
<td>1</td>
</tr>
<tr>
<td>1957</td>
<td>414</td>
<td>7/16/57</td>
<td>Corp, pipe</td>
<td>2</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Street Reconstructed</td>
<td></td>
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<tr>
<td>1965</td>
<td>412</td>
<td>9/17/65</td>
<td>Curb Box</td>
<td>3</td>
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<tr>
<td>1970</td>
<td>445</td>
<td>3/04/70</td>
<td>Corp</td>
<td>4</td>
</tr>
<tr>
<td>1971</td>
<td>429</td>
<td>10/13/70</td>
<td>Curb Box, pipe</td>
<td>5</td>
</tr>
<tr>
<td>1973</td>
<td>427</td>
<td>5/04/73</td>
<td>Corp</td>
<td>6</td>
</tr>
<tr>
<td>1976</td>
<td>425</td>
<td>2/09/76</td>
<td>Curb Box</td>
<td>7</td>
</tr>
<tr>
<td>1980</td>
<td>435</td>
<td>5/28/80</td>
<td>Corp</td>
<td>9</td>
</tr>
<tr>
<td>1982</td>
<td>407</td>
<td>4/05/82</td>
<td>Corp</td>
<td>10</td>
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<td>1984</td>
<td>442</td>
<td>9/26/84</td>
<td>Corp</td>
<td>11</td>
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<tr>
<td>1988</td>
<td>421</td>
<td>8/18/88</td>
<td>Valve</td>
<td>12</td>
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<tr>
<td>1989</td>
<td>415</td>
<td>11/15/88</td>
<td>Curb Box</td>
<td>13</td>
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<td>1990</td>
<td>427</td>
<td>11/30/88</td>
<td>Corp</td>
<td>14</td>
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<tr>
<td>1990</td>
<td>423</td>
<td>2/14/89</td>
<td>Corp</td>
<td>15</td>
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<td></td>
<td></td>
<td>Summary</td>
<td>Corp Joint</td>
<td>16</td>
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<td>15</td>
<td>Solution Zones – 170lf</td>
<td>9</td>
<td>Curb Box</td>
<td>1</td>
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<tr>
<td>7</td>
<td>Shallow Rock – 330 lf</td>
<td>4</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>Total</td>
<td>13</td>
<td>Main-Valve</td>
<td>2</td>
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</table>

## Table 2. Leak-Break Analyses

<table>
<thead>
<tr>
<th>Item</th>
<th>Leak-Break Comparison</th>
<th>Analyses</th>
<th>Breaks Per Block Per YR</th>
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<tbody>
<tr>
<td>1.</td>
<td>Overall Break Rate</td>
<td>Services</td>
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<td></td>
<td>Total Per Block</td>
<td>20</td>
<td></td>
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<tr>
<td></td>
<td>Total Per Block Per YR</td>
<td>20/1/33</td>
<td>0.60</td>
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<tr>
<td></td>
<td>Total – Solution Zones</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Per Block</td>
<td>13/170/lf = 38 per blk</td>
<td>38* (4 Times)</td>
</tr>
<tr>
<td></td>
<td>Total Per Block Per YR</td>
<td>38/blk/33 =</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Total – Shallow Rock</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total per Block</td>
<td>6/330 If = 9 per blk</td>
<td>9*</td>
</tr>
<tr>
<td></td>
<td>Total Per Block Per YR</td>
<td>9/blk/33 =</td>
<td>0.3</td>
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<td>2.</td>
<td>Main-Valve Breaks</td>
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<tr>
<td></td>
<td>Total per Block</td>
<td>2/33 =</td>
<td>0.1</td>
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<tr>
<td>3.</td>
<td>Service Breaks</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corporations</td>
<td>13</td>
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</tr>
<tr>
<td></td>
<td>Curb Boxes</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Rate of Growth</td>
<td>Age of Pipe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1959 - 1969</td>
<td>80 yrs</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>1970 - 1979</td>
<td>90 yrs</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>1980 – 1989</td>
<td>100 yrs</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>1990 – 1999 (projected)</td>
<td>&gt; 100 yrs</td>
<td>4.0</td>
</tr>
<tr>
<td>5.</td>
<td>Estimated Useful Life</td>
<td>80 to 90 years</td>
<td>Increase 5 fold</td>
</tr>
<tr>
<td></td>
<td>100 Years</td>
<td>In Leak-Break</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rate after 90 yrs</td>
<td>Rate after 90 yrs</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: (*) Solution Zone
UTILITY FAILURE MODEL

LEAK-BREAK PER BLOCK

Urgent Action

Action Required

Monitor

Caution

Normal

ACTION LEVEL

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RECOMMENDED REMEDIAL ACTION

- Conduct a GPR Survey to confirm the location of solution weathered high risk areas
- Replace the water main in the high risk areas
GROUND PROBING RADAR SURVEY
GROUND PROBING RADAR SURVEY

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ABS - ALLENTOWN BUSINESS SCHOOL

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Migration of surface water from deteriorating pavements, sidewalks, and curbs into residual soils can result in slow subsurface erosion of soil into the underlying bedrock resulting in subsidence.

Subsidence of soil supporting utilities can cause utility leaks or even main breaks that can result in rapid subsurface erosion, significant ground loss, and the formation of a sinkhole.

Extreme Precipitation Events will greatly increase sinkhole risk, utility breaks & property damage.
HOW DO WE SOLVE THE PROBLEM

- Conduct a Comprehensive Inventory, Condition Assessment, Useful Life Determination

- Evaluate Life Cycle Costs & Replacement Fees

- Identify, Prioritize and Determine Costs for Critical Infrastructure Replacement Projects

- Establish a Long-Term Funding Source through Infrastructure Replacement Fees deposited into a Dedicated Reserve Account similar to that used by Condo Associations to Fund Infrastructure Repair, Reconstruction, and Replacement
Infrastructure Reserve Accounts would be used to obtain “zero” interest loans from Regional Federal Reserve Banks similar to the $8-Trillion made available to Wall Street Banks since 2008.

a) By Law the Federal Reserve is responsible for monetary policy which is to accomplish manageable inflation, full employment, and steady growth in the economy.

b) Investment of $3 to $4 Trillion in the Guarantee of Infrastructure Replacement Fee Account Loans would Lead to Increased Employment, Improvement of Local Economies, Increase in Tax and User Fee Revenues as well as Replacement of Critical Municipal Infrastructure that Sustains our Regional Economy and Quality of Life.
Qualification for Reserve Account Loans would come from the Submittal and Approval of Infrastructure Replacement Project Funding Requests by the Regional Municipal Planning (MPO) or Rural Planning Organization (RPO) which have been used for Federal Highway Transportation Infrastructure Funding Planning since 1962.

a. A Municipal Infrastructure Committee would be established for each MPO and RPO to review and approve infrastructure project requests and loans.

b. A Sustainability & Resilience Review would be conducted for each Infrastructure Replacement Project by Regional MPO or RPO Planning Organizations.

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MPOs are required to develop and maintain a Long Range Transportation Plan of at least 20 years and a Transportation Improvement Program that covers four years. MPOs are supported by Federal and State Planning Funds.

MPOs in Pennsylvania are (See Map 1)
1. Altoona
2. Centre Region
3. Delaware Valley
4. Erie
5. Harrisburg
6. Johnstown
7. Lackawanna/Luzerne
8. Lancaster
9. Lebanon
10. Lehigh Valley
11. Reading
12. Shenango Valley
13. Southwestern Pennsylvania
14. Williamsport
15. York

PA RPO's
Rural Planning Organizations
THANK YOU – ANY QUESTIONS?