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EXECUTIVE SUMMARY
The Washington Suburban Sanitary Commission (WSSC) has used Prestressed Concrete Cylinder Pipe (PCCP) since it was introduced, and has installed 145 miles of large diameter PCCP transmission mains.

The Problem: Failure in the structural integrity of large transmission mains poses a substantial risk to public safety; such a failure results in an initial explosive force of between 20 and 200 tons pounds* of dynamite and the release of pressurized water with an initial velocity of 90 miles per hour. The potential hazards associated with large diameter PCCP structural failure are shown in the Engineering Report section of this document.

WSSC has experienced several of these pipe failures, including:
- Clagget Farm 96-inch PCCP - March 1996
- Allentown Road 42-inch PCCP – September 2001
- Palatine Drive 60-inch PCCP – December 2003
- River Road 66-inch PCCP - December 2008
- Capital Heights 54-inch PCCP – January 2011

Evolving Solutions: WSSC pioneered the installation, operation, and maintenance of PCCP, including the analysis of its failure mechanisms and risk management strategies like the use of state-of-the-art monitoring, inspection and repair technologies. WSSC is confident that its current PCCP monitoring, inspection and repair program is as or more effective than any other utility’s management program in the United States.

In the 1980s, WSSC initiated a Condition Assessment Program, including a safety analysis score (SAS) for large diameter transmission mains that considered pipe diameter and year of construction, pipe material used and manufacturing process, and proximity to buildings or structures (a higher score means greater risk). These factors are important considerations in assessing the potential hazard posed to buildings or people in proximity to these pipelines. Over time, WSSC’s approach to managing these pipelines has evolved as our monitoring, inspection and repair programs have become much more robust, e.g. “Smart Ball” acoustic leak detection, internal acoustic fiber optic “AFO” cables to monitor wire breakage, and carbon fiber wrap repairs. However, robust inspection and maintenance programs and state-of-the-art technologies do not eliminate the risk of structural failure of these large PCCP transmission mains, and WSSC developed the proposed Amendment to the Design Manual as an additional safeguard.

Using Public Policy to Address the Continuing Risks: Development activities adjacent to large diameter PCCP transmission mains increase the risk factor for those pipelines. A 2008 engineering analysis highlighted the challenge of the significant increase in the number of high density projects near large transmission mains. Moving these pipelines or replacing them in their current locations using different materials are not practical options. There are policy options, however, that provide a substantial opportunity to further reduce the risk associated with a potentially catastrophic structural failure. While WSSC can do nothing to rectify the proximity of existing development, there is both an obligation and an opportunity to reduce known risks to public safety by working with developers to use siting, design and other engineering elements early in
the design phase of future development projects to better manage the potential risks associated with encroachment on the PCCP pipelines.

**Basis of the Proposed 80-Foot Setback Design Manual Amendment:** WSSC staff investigated a strategy to provide greater transparency, clarity and better coordination with the development community on future development projects along the PCCP transmission lines in an effort to enhance public safety. WSSC’s Pipeline Design Manual currently includes language that development within 200 feet of these pipelines may require special consideration. WSSC determined that:

- The 200-foot language currently in the Pipeline Design Manual provides inadequate guidance to developers and to WSSC project plan reviewers;
- The Design Manual Amendment should provide a very specific guideline that would be relatively easy for all to interpret and utilize;
- The Design Manual Amendment should provide substantial flexibility to the developer in the design and engineering of a structure to meet an appropriate standard if a project encroaches on a PCCP transmission main;
- The Amendment should account for the fact that each development is unique (for example, the size and configuration of a parcel, its soil conditions, design and uses of each structure and the size and location of the adjacent pipe).

In order to address these objectives, WSSC prepared an Engineering Report which examined large diameter PCCP pipe failures at WSSC and elsewhere and concentrated on three areas:

1. The size of the hole created by the initial explosive break and washout from a pipeline break (averages 30 to 50 feet from the center line of a break)
2. The debris thrown by the explosive release of energy when the pipe catastrophically fails (30 to 210 feet), and
3. The amount and velocity of the water flowing from the broken pipeline (up to 90 miles per hour releasing tremendous volumes of water).

Each of these factors poses meaningful risk, but if the intent is to improve the likelihood that a structure will survive a catastrophic failure of these large PCCP pipelines, the building should not be in the vicinity of the hole created by the failing pipeline, and it is possible that building foundations outside of the hole may still be too close to it (the ground supporting the foundation could fail due to the load from the structure resulting in the structure still being claimed by the hole.) This is the primary factor (of the three) that led to the 80-foot setback proposal. WSSC provided flexibility in the application of the standard by allowing a project developer and their professional engineer to make a determination that balances their project objectives, e.g. proximity to PCCP pipe and other objectives like building location and placement, building design/structural elements, hardscape design, parking structures, and the pipe location, condition and operating factors.

WSSC also analyzed the force of the water jet striking the structure, using the varying pipeline pressures that WSSC transmission mains operate under to estimate how the force drops off with distance from a failed pipe. The Force Analysis also supported the choice of an 80-foot setback.
Design Manual Amendment Permits Construction Within 80 Feet: Based on this analysis, WSSC chose an 80 foot setback distance, but it is critically important to note that WSSC is not forcing all new structures to remain outside the setback. As currently written, the proposed revision to the Pipeline Design Manual will continue to require structures to remain outside the WSSC right of way, but structures may be built within the setback distance. Should a structure be placed within the setback area, the developer is obligated to ensure that the structure is designed and built to survive a potential failure of the large PCCP transmission main with consideration of the four factors discussed above.

Clarifying Existing Regulations to Address Risks to Future Development Projects: The Pipeline Design Manual Amendment is a policy/rulemaking initiative resulting from multiple strategies that have evolved over a long period of time. As WSSC continues to seek solutions that optimize outcomes for the community we serve, the public safety focus of this initiative is paramount. WSSC has also, however, worked to ensure that it follows an objective, transparent, inclusive and measured approach, hallmarks of good policy development, in developing this regulatory proposal.

- WSSC experienced several instances of catastrophic failure involving large diameter PCCP transmission mains within its distribution system.
- There has been direct observation of events within WSSC’s distribution system that resulted in serious property damage and the attendant and demonstrable risk to human health and safety. This experience extends to other utilities that have installed PCCP pipelines, as well.
- WSSC has relied on expert internal staff and outside resources to refine our understanding and define the parameters of the problem.
- WSSC worked over several years to develop assessment tools, management and operations practices, monitoring and inspection technologies, as well as leading edge maintenance and repair technologies. These efforts are intended to ensure we take progressive steps required to reduce the risk of damage to physical infrastructure from a catastrophic failure of large diameter PCCP that poses a public safety hazard.
- WSSC promulgated a policy position (regulation noting special considerations within 200 feet of these pipelines) to address the emerging understanding of the risks posed by large diameter PCCP pipe when there is a loss of structural integrity.
- WSSC’s experience with this previously promulgated regulation (the “special considerations” language) demonstrates that the policy has been inadequate, providing insufficient guidance to private and public project developers as well as to WSSC development project reviewers.
- WSSC completed an engineering analysis (inclusive of case evaluation of PCCP pipeline failures). Based on careful consideration of its findings, WSSC developed a practical proposal addressing new development projects adjacent to large diameter PCCP transmission mains.
• WSSC is responsible for this infrastructure, but has also shared information and encouraged other agencies with appropriate and cross-cutting regulatory authority to assist in this effort, but with no adequate response to date.

• The proposed regulation is based on an industry consensus and WSSC’s experience indicating there is risk of catastrophic PCCP pipe failure.

The proposed regulation follows progressive and methodical improvements in best management practices and new and emerging technologies to address the issue and thereby reduce risks to public safety by other means.

WSSC recognizes that development and redevelopment in Prince George’s and Montgomery counties is critically important. This agency has a critical role in working with the private sector and with other agencies to not simply facilitate, but to support economic growth and development. Therefore, in advance of the formal public notice that will solicit additional public comment, WSSC has reached out to stakeholders in both the public and private sectors to seek specific guidance and advice to improve the proposal as amended. We have taken that guidance very seriously, and took very significant steps to address the concrete problems that stakeholders identified. As a result the amendment is a much improved proposal that provides clarity and flexibility while achieving a better outcome for developments planned adjacent to large diameter PCCP transmission mains.

*Note: Correction of tons to pounds April 18, 2013*
Background and Analysis Summary

Prestressed Concrete Cylinder Pipelines are Portland cement concrete composite pipelines that utilize prestressed carbon steel wires to achieve necessary tensile strength. A view is shown below. Problems develop if enough of the carbon steel wires fail as the pipeline segment will then fail. Should the composite structure become compromised and allow aggressive corrosive tendencies to occur then the pipeline can fail much earlier than the pipeline would otherwise be expected to fail.

The WSSC has a long history with Prestressed Concrete Cylinder Pipe, beginning to utilize it almost since its inception as a viable product in the market place. Engineering staff at WSSC have pioneered the inspection and maintenance of this type of pipeline ever since identifying the potential failure mechanisms associated with this type of pipe. WSSC has always been at the forefront of the effort to manage the risk associated with this pipe, utilizing the cutting edge of available technologies to manage that risk. As the pipelines age WSSC continues to manage that risk with state-of-the-art technology. But as development continues to move closer and closer to existing transmission mains it has become apparent that perhaps another layer of risk mitigation for future development is in order.

INSTALLATION HISTORY

Prestressed Concrete Cylinder Pipe, or PCCP, has been manufactured since 1943. Its history with the Washington Suburban Sanitary Commission (WSSC) is almost as long as the first line constructed for WSSC occurred in 1945 (Contract Number 143-W). This 42-inch diameter pipeline remains in service today originating at the Patuxent Water Filtration Plant and crossing under I-95 heading toward south-central Prince George’s County.
For approximately 35 years, from 1945 to 1976, WSSC constructed 350 miles of PCCP water mains with diameters ranging from 16 to 96 inches. During this era, for pipelines that were 36 inches and larger in diameter, WSSC typically bid contracts allowing either PCCP or steel pipelines as determined by the contractor. The awarded contracts predominantly used PCCP and WSSC now owns 145 miles of large-diameter PCCP (36-inch and larger diameter).

<table>
<thead>
<tr>
<th>Diameter</th>
<th>16-30”</th>
<th>36”</th>
<th>42”</th>
<th>48”</th>
<th>54”</th>
<th>60”</th>
<th>66”</th>
<th>72”</th>
<th>96”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mileage</td>
<td>205</td>
<td>37.6</td>
<td>30.3</td>
<td>18.2</td>
<td>8.7</td>
<td>21.9</td>
<td>12.8</td>
<td>4.5</td>
<td>11</td>
</tr>
</tbody>
</table>

PCCP SUSCEPTIBLE TO CORROSION

The composite design of the steel and concrete pipe makes it susceptible to corrosion should the steel elements become exposed to corrosive environments. The steel component that gives the pipe its strength is a high carbon steel wire, one of the strongest steels made. The very high-strength wire is protected from corrosion by a coating of cement mortar. However, some strength classes of the steel wire can suffer a failure mechanism known as hydrogen embrittlement, which can result in sudden breaks in the wire (this occurs when the wire is subject to corrosion and the wire adsorsbs hydrogen generated by the corrosion process). The hydrogen embrittlement failure of wire and the subsequent failure of pipes became prevalent around the nation. A reason for the pipe failures caused by hydrogen embrittled wire was the fact that in the 1970’s the manufacturers of PCCP began to include what came to be known as “Class IV”, a higher strength wire. While stronger, this newly extruded wire turned out to be very susceptible to hydrogen embbrittlement and by 1985 this problem was very well documented. Ultimately there were a series of class-action lawsuits against the manufacturers and designers that concluded with a settlement for the plaintiffs (including WSSC) in 1994.

WSSC INITIATES AN INSPECTION PROGRAM

Beginning in 1968 and through the 1970’s water utilities, primarily in the southeast began experiencing PCCP failures. WSSC began experiencing PCCP failures in 1970 through the 1980’s, and in 1979 began to create what became the WSSC PCCP Inspection Program; its first internal large diameter pipeline inspection was conducted in 1981 on a 72-inch line that had failed the year before.

TECHNOLOGY AND INSPECTION HISTORY

The first inspections were internal and utilized manned teams conducting visual inspections and soundings by striking on the pipes with hammers. Sighting of large circumferential and longitudinal cracks indicate distress while soundings identify ‘hollow sounds’ or areas of delamination in the concrete indicating likely separation of the prestressed wires and the concrete they are embedded within.

As early adopters of PCCP, WSSC staff has been integrally involved with PCCP inspection and the development of inspection technologies:
In 1987 WSSC staff, along with Openaka Corporation and Corrpro Company, surveyed PCCP using pipe to soil electro potential surveying in an attempt to determine if wire corrosion could be determined from above ground.

In 1988, working with Entech Engineering, Incorporated, WSSC used infrared technology and surface penetrating radar on failed PCCP in storage. WSSC also contracted with metallurgical and materials consultants and hired a metallurgical materials engineer from the oil and gas industry to investigate failed PCCP and to investigate methods for PCCP condition assessment.

In 1989 WSSC began looking at radar, pulse echo, acoustic emissions and seismic pulse echo as techniques to move beyond the simple visual and sounding approach utilized in the inspection program at that time. Working with Gould, Lewis and Proctor (currently Lewis Engineering) staff work resulted in what became the ASTM and AWWA PCCP standards for prestressing wires. These investigations and standards were the basis for the wire manufacturing industry modifying its wire production methods.

In 1990, WSSC was the first to perform electromagnetic inspection of a PCCP line adapting equipment used in the oil and gas industry. 1990 was also the year when WSSC validated the viability of acoustic monitoring and remote field electromagnetic technologies for PCCP condition assessment. Also beginning in 1990 and throughout the rest of the 1990’s WSSC worked with the Weston Geophysical Corporation to develop and to build a prototype of sonic/ultrasonic pulse echo (seismic pulse echo) technology, enhancing the sounding technique utilized from the beginning of the program. WSSC was a joint holder of the resulting patent of this technology for PCCP. Use of this sonic/ultrasonic technology was incorporated into WSSC’s inspection activities and became a significant part of the inspection and condition assessment program in 1995.

During the 1990’s WSSC shared its work on acoustic monitoring with the United States Army Corps of Engineers in their support of the Bureau of Land Reclamation. The work led to the formation of Pipe Technologies, Incorporated later sold to Pressure Pipe Inspection Company (PPIC). PPIC was formed in 1994 from remote field electromagnetic work WSSC shared with Dr. Atherton at Queens University at Kingston (Canada) in 1992. In 1995 WSSC introduced acoustic and electromagnetic assessment methods to Sound Print Company, which went on to become Pure Technologies. WSSC first used electromagnetic testing as part of the inspection program in 2002 and used Pure’s Hydrophone arrays to listen to a 42-inch PCCP along Norbeck Road.

In 2007 the use of permanently installed fiber optic cabling for acoustic monitoring of PCCP wire-break activity began and then in 2008 “Smart Ball” acoustical leak detection was added to the inspection process. That year was also the first use of internal carbon fiber reinforcement as a repair method for pipe segments that could not be placed back into service post inspection but which were deemed repairable (if not repairable, pipe segments are replaced). In 2010 WSSC piloted internal robotic inspection of a 42-inch line using electromagnetic and camera visual inspection.
CURRENT INSPECTION AND PCCP REPAIR PROCESS

The current inspection process follows a six-year plan updated annually that utilizes a frequency intended to inspect the 77 miles of 48-inch and larger diameter pipelines approximately every six years. Those 77 miles of pipe will have been inspected by the close of FY 13. Beginning in FY 13 the additional 68 miles of 36 and 42-inch diameter lines will begin robotic inspections. Also beginning in FY 14 the inspection process begins will be repeated for the 77 miles of 48-inch and larger pipelines.

The inspection process begins with internal coordination with operating elements in order to confirm that operations and maintenance activities can support the intended plan. The inspection itself begins with utilizing the “Smart Ball” to locate any leaks within the pipeline to be inspected that would otherwise not be discernable to the inspectors. The “Smart Ball” identifies leaks and their location so that crews can locate them and ensure repairs are completed before the pipeline is put back into service.

The pipeline is then dewatered and manned teams enter the pipeline to conduct the inspection. Steps include pipe section numbering, visual inspection and sounding as well as sonic/ultrasonic inspections that are very similar to inspections conducted since the inception of the program. However, since 2002 electromagnetic field testing is also done. Results of all the testing are analyzed to establish a baseline number of broken wires for each pipe segment. Finite element analysis techniques are utilized to estimate the yield and ultimate strength limits in terms of the number of broken wires for each individual design classes of PCCP segments within a pipeline. Segments that are found to be in a critical state are repaired or replaced while the pipeline is out of service. Before putting the pipeline back into service a permanent acoustic fiber optic (AFO) cable and data acquisition computers are placed (if not already there) for use in monitoring wire break activity once the pipe is put back into service. Once these steps are done the pipeline is put back into service. It costs WSSC about $150,000 per mile to inspect its PCCP infrastructure. Approximately 1 to 2% of the pipe segments inspected using these three methods are found to need some form of rehabilitation. On average, WSSC has replaced 2 pipe segments (each 16 feet long) per mile and repaired 3 pipe segments per mile with carbon fiber. The cost of replacing a pipe segment is $80,000 and repairing using carbon fiber is $70,000 at an average cost per mile (for replaced/repaired segments) of $375,000.

For the smaller 36 and 42-inch diameter pipelines robotic inspections will be used. The differences for inspections are primarily two-fold. First, WSSC will reduce the operating pressure in the pipeline but will not fully dewater the pipeline. This means that the inspection will use robotics rather than relying on human entry into the pipe. With robots, the visual inspection will use high-definition cameras and the electromagnetic inspection will be done from a towed package of instruments. The second difference will be that the sonic/ultrasonic sounding will not be done. The cost of robotic inspections will be $80,000 per mile.

FIBER OPTIC MONITORING

As noted above, permanent AFO cables are placed in the pipelines as the last step in the current inspection process before putting the pipeline back into service. At the conclusion of the FY 11 program year, over 50 miles of 48-inch and larger diameter pipelines have been inspected, rehabilitated and have AFO monitoring systems installed. By the conclusion of FY 13 all 77 miles of 48-inch and larger diameter pipelines will have AFO monitoring systems.
AFO monitoring systems allow WSSC (through its consultants’ computerized system and data analysis) to monitor wire break activity in PCCP pipelines that are in service. When a wire breaks a sound is created and the resulting mechanical sound wave propagates away from the break. This mechanical wave interacts with the electromagnetic light wave that is moving through the fiber optic cable. This interaction is “sensed and filtered” by the data acquisition computer system and a corresponding signal utilizing GPS locates the origin of the wire break. The computer assigns a wire break to a specific pipe section number and a notification is made to consultant analysts and WSSC staff. Since each segment has a baseline already established, keeping track of the status of the wire break activity becomes a book keeping exercise and allows the analysts and WSSC staff to decide what, if any, mitigating steps are to be taken and when to act as a pipe segment approaches its yield and ultimate strength limits.

The system has been tested and has proven to be a viable warning system. Perhaps the most widely known example occurred in late June 2010. The AFO system warned of a cascade of wire break activity that concerned the WSSC staff. This led to the decision to modify the PCCP Inspection Program schedule then underway and take the 96-inch pipeline with the wire break activity out of service under emergency conditions. When the sixteen-foot pipeline section was removed over the 4th of July Holiday, the visual signs of incipient failure were obvious. The AFO system worked. While the cost of this occurrence was relatively high at about $500,000, when compared to the costs associated with having to react to the 66-inch River Road break over Christmas 2008 it was a relative bargain. River Road cost $1.7million for repairs alone, lost millions of gallons of water and put people in serious jeopardy. WSSC’s decision to take the pipeline out of service saved at least an estimated $1.2million in repair costs and addressed a potentially imminent and very serious risk to public safety.

The incident above is widely known but it is not the only pipeline where AFO has proven itself. The Inspection Program is one where reaction to day-to-day activities may force changes to planned inspection activities. Operational requests for an investigation of a sinkhole necessitated changes in the FY 12 program. There was a 96-inch PCCP in the vicinity of the sinkhole (though not leaking and not the cause of the sinkhole) and exploratory excavations necessitated dewatering the pipeline (for safety reasons). Coincidentally, this same pipeline had been experiencing some increasing wire break activity some distance away from the sinkhole investigation. Because the pipeline was already out of service for the sinkhole investigation, the annual inspection plan was adjusted to take advantage of the unplanned work and the pipeline dewatering was enlarged to cover the segment with the wire break activity. The investigation concluded that the pipe segment with increasing wire break activity was in a state of incipient failure and needed replacement. This was done prior to the pipeline being put back into service at the conclusion of the sinkhole investigation. Thus another potentially dangerous pipe segment identified by AFO was safely dealt with.

The cost to supply and install an AFO monitoring system in a typical six-mile length of PCCP is about $764,000 or approximately $128,000 per mile (AFO cabling at $12.12 per foot and one monitoring computer at $380,000). Annual AFO monitoring costs per mile are approximately $13,000.

While the AFO system works well, it does not preclude a pipe break and the setback proposal is intended to add an additional layer of safety to supplement these current measures.
COMPLETE PCCP PIPELINE REPLACEMENT IS NOT A REALISTIC OPTION

Many have asked whether a PCCP replacement program would make sense because these pipelines have the potential to be so problematic. Indeed it is an option that WSSC staff has studied. The conclusion is that this approach is not feasible or warranted at this time.

For the pipelines that are largest in diameter there is no available open space to build relief pipelines that could minimize downtime to only that necessary to make the tie-ins to the existing system. Thus new pipelines would have to be in the same location as the existing lines or built at high cost as tunnels deep underground. Whether slip lining with steel, which has the added problem of sacrificing hydraulic capacity, or same-trench replacement, the overall problem of having the pipelines out of service for a long period of time would have a major adverse impact on the water transmission system.

There is a limit to the redundancy that the WSSC system includes and it is not feasible for pipelines to be out for extended periods of time for replacement while also taking others out of service to inspect them, and others to support other needs like development tie-ins. WSSC staff estimates that it will take a year to replace two-thirds of a mile of pipeline. For the 145 miles of 36-inch and larger diameter pipelines this means a combined down time of 218 years (115 years just for the 77 miles of 48-inch and larger).

Another issue is the significant cost associated with such a program to replace these PCCP pipelines. The current construction cost (only) estimate to replace all 350 miles of PCCP is $2.9 billion and $2 billion of this is for the 36-inch and larger diameter pipelines.

As WSSC inspects its PCCP assets each year, the typical number of segments in need of repair or replacement rarely exceeds 2% of the number inspected. This means a program designed to begin just replacing pipelines would be, on balance, replacing 98% of pipe segments with significant useful life remaining in them. In other words out of the $2 billion needed to replace the 36-inch and larger diameter pipelines, $1.96 billion of it would be dollars spent to replace pipes with remaining useful life.

The current program, with the inclusion of the proposed Amendment to the Design Manual, maximizes the useful life of this portion of our critical infrastructure, maintains adequate access to critically important water transmission pipelines, and manages the demonstrated public safety risk that is associated with PCCP.

SERIOUS CONCERN ABOUT ENCROACHMENT

WSSC is confident that the current PCCP monitoring, inspection and repair program is as or more effective a management program as exists at any other utility in the United States. The WSSC staff has been, and remains, second to none in its knowledge of the risks associated with PCCP and the appropriate operational practices and technologies available to manage risk.

WSSC acknowledges and accepts the fact that the potentially catastrophic failure of a large diameter PCCP is a serious and genuine risk. In many instances, construction of these transmission mains preceded development. As the 20th century closed WSSC staff began to review the impact of the close encroachment of new properties to WSSC’s large diameter PCCP water mains as developers sought to maximize the value of their investments. Close proximity of structures to existing water mains has always been factored into determining WSSC’s
inspection priorities. While WSSC can do nothing to rectify the proximity of existing development, there is both an obligation and an opportunity to reduce known risks to public safety by working with developers to use siting, design and other engineering elements early in the design phase of future development projects to better manage the potential risks associated with encroachment on the PCCP pipelines.

Work analyzing PCCP failures has been ongoing since the first failures in the 1970’s and the 1980’s. The first step, based upon the known “debris throw” of over 200 feet that is associated with a large PCCP failure, led WSSC to insert the current language in its Pipeline Design Manual stating that development within 200 feet of these pipelines may need special consideration. WSSC staff investigated a strategy to provide greater transparency, clarity and better coordination with the development community on future development projects along the PCCP transmission lines in an effort to enhance public safety.

ANALYSIS THAT LED TO THE 80-FOOT SETBACK RECOMMENDATION

The language currently in the Pipeline Design Manual has proven inadequate as development has been allowed up to the edge of WSSC pipeline rights-of-way, and in some cases into the rights-of-way. Absent additional direction or guidance from WSSC or other regulatory bodies that directly regulate development activity in the Sanitary District, the 200-foot language also does not provide WSSC staff with sufficient guidance in their review of development projects as they pertain to PCCP pipelines. Thus WSSC staff concluded that it was necessary to take additional action to help ensure that new structures (buildings) survive a PCCP failure. Safety of a building’s inhabitants is the primary motivator for this action. The intention for changing the Design Manual was to develop a very specific guideline that would be relatively easy for all to interpret and utilize and would provide substantial flexibility to the developer in the design and engineering of a structure that encroaches on a PCCP line.

Such a standard should recognize that each development opportunity/project is unique (for example, the size and configuration of a parcel, its soil conditions, facility design and uses of each structure, and the working pressure, size and depth of adjacent pipe). But any attempt to provide a guideline or family of guidelines tailored to address all the potentially countless variables of any given project would prove unmanageable for all concerned.

In order to address these objectives, analysis of large diameter PCCP and cast iron pipe failures at WSSC, as well as other locations, concentrated on three areas. Results of that analysis are summarized in a March 25, 2011 Engineering Report, and include the results of staff effort begun in 2007 and concluded in 2008. The three areas covered by the analysis include:

- The size of the hole created by a pipeline break
- The distance debris is thrown by the explosive release of energy when pipe catastrophically fails, and
- The amount/velocity of the water flowing from the broken pipeline.

The biggest risk in terms of the sheer amount of potential damage lies with the flowing water. Of the three factors, this is the one that depending upon the topography and proximity may result in the most serious damage. It is also one that depending upon the terrain, establishing a setback basically may do little to mitigate. With the right terrain and other circumstances even
having a very large setback could do little. Imagine a situation where a pipeline bursts at the top of a long hill and all the water is channeled down the hill. A setback of a very long distance will do little to protect the structure if that structure is in the path of the water at the bottom of the hill. On the other hand, the topography may be such that a setback may be enough to provide an increased benefit and may provide the additional room necessary to greatly alleviate risk.

Debris throw is another factor that was investigated. Debris throw was measured anywhere between 30 and 210 feet from the point of failure. Since the pipes fail basically at a point on the pipeline the associated danger zone is more limited than from the water flow. Additionally, this factor is only relevant for the very short duration occurring right as the pipe fails. The kinetic energy of any debris throw lessens the further from the throw one goes but that energy is going to be different for each circumstance. So a setback will decrease the risk as furthering the distance will lessen the energy but trying to choose a simple guideline to cover this range proved difficult and ultimately was not a large factor used to make the final selection of the setback distance.

The last area investigated was the size of the hole created by the failure. There was a consistent range of 35 to 50-foot diameter holes regardless of the size of the pipe. Clearly if one intends to have a structure survive a catastrophic failure of a PCCP line the structure should not be in the vicinity of the hole created by the failing pipeline. When one looks at the potential building foundations that might be involved, it is possible for structures to be outside of the hole but still too close to it – the ground supporting the foundation may fail (due to the load from the structure) and the structure could still be claimed by the hole. Another situation noted is that if the soil is not very cohesive then the soil itself may fall into the hole and again may result in a structure at risk. This is the primary factor (of the three) that led to the 80-foot setback Pipeline Design Manual amendment proposal. Since the foundation and the soil types will be unique to each situation, the desire to have a clear guideline led WSSC to use 80 feet as that guideline. Note that the March 25, 2011 Setback Recommendations Report is enclosed as a reference for the reader.

After the determination was made regarding the setback distance based on the size of the hole, a fourth factor was analyzed. The fourth factor dealt with the force of the water jet striking the structure. That analysis attempted to use the varying pipeline pressures that WSSC transmission mains operate under to estimate how the force drops off with distance from a failed pipe. That analysis supported the decision to impose an 80-foot setback. Note that this analysis entitled, “Treatise on Water Jet Force and Kinetic Energy” is also enclosed as a reference for the reader.

While WSSC chose 80 feet as its setback distance, it is important to note that WSSC is not forcing all structures to remain outside the setback. As currently written, the intended provision for the Pipeline Design Manual will require structures to remain outside its right of way but structures may be built within the setback distance. Should a structure be placed within the setback then the developer is obligated to ensure that the structure is designed and built to survive the failure of a PCCP in close proximity, with respect to and in consideration of the four factors discussed above.

EARLY STAKEHOLDER INVOLVEMENT

Concerns regarding the encroachment of development and what to do about it were shared with WSSC senior management via a series of briefings in 2007 (when the study was directed)
and culminating in a briefing to the Interim General Manager on March 6, 2008. At that meeting the decision to brief the Commissioners was made. At the March 19, 2008 Commission meeting the Commissioners provided direction to approach Maryland National Capital Park and Planning Commission (MNCPPC) for assistance in moving the issue forward.

The briefing to MNCPPC occurred on April 16, 2008 with WSSC’s expectation that WSSC and MNCPPC would address the issue in concert. That expectation was not realized and the issue lay dormant. Periodic discussions with the Maryland National Capital Building Industry Association (MNCBIA) did continue culminating in a November 10, 2008 meeting where MNCBIA comments led to the concept allowing structures to sit within the setback zone if designed to take into account the potential for the water-line failure. When the 48-inch Derwood line failed in the summer of 2008 and then the 66-inch River Road failure occurred, the program received attention resulting in more emphasis being placed on the inspection program along with a commensurate increase in resources for the program – one of the recommendations from the earlier study.

PIPELINE DESIGN MANUAL AMENDMENT – 2010 TO 2012

The issue reemerged with the arrival of the current General Manager. Development was continuing and the 200-foot consideration was of no meaningful effect. The current General Manager received a briefing on the topic and decided to move forward on the setback issue to address a continuing Agency concern about public safety. The initial proposed language for the Pipeline Design Manual utilizing the 80-foot setback was briefed to the WSSC Commissioners on December 15, 2010. The briefing to the Commissioners included the intention to utilize the language with reviews of ongoing development plans. That practice continues today.

Following another briefing to the Commissioners on February 16, 2011, WSSC staff met with a stakeholder group on February 24, 2011 whose membership consisted of staff from both Prince George’s and Montgomery Counties as well as from MNCPPC. The primary outcome of this first meeting was the cancellation of an already scheduled Public Hearing on March 1, 2011. Also on February 24, 2011 WSSC staff attended a MNCPPC meeting in Silver Spring. Both meetings on February provided input that served notice that the WSSC intention to establish setback requirements, even with the potential for mitigation through properly engineered solutions, was not well received.

Meetings with the stakeholder group continued on March 18, April 8 and October 25, 2011, as well as on February 8, 2012. At each meeting WSSC received comments consistent with the concerns which had been raised earlier, but WSSC received no specific recommendations for language to modify the proposed Pipeline Design Manual amendment. WSSC staff failed to discern any movement from stakeholders who continued to express consistent concerns regarding the “foundation” for justifying further action by WSSC on this issue.

While receiving no recommendations for specific language changes, the stakeholder meetings resulted in substantial modifications by WSSC to address concerns raised by the staff members of the stakeholder group:

- A concern regarding the impact of the setback on redevelopment plans within the Counties led WSSC to modify its proposed amendment to fully exclude redevelopment projects,
A concern regarding the impact of the setback on in-fill development led WSSC to modify its proposed amendment to fully exclude in-fill development for 40-acre parcels (or smaller), and

A Concern raised that the proposed language did not sufficiently address the option to build within the 80-foot setback since WSSC had to approve the mitigation leading WSSC staff to amend its proposal to ensure that the developer’s professional engineer will certify the mitigation necessary for the structure to sit within the 80-foot setback.

WSSC staff seriously considered these concerns resulting in a substantive reevaluation and modification to the proposed amendment.

One other result from the staff stakeholder meetings was the result of discussion surrounding the actual size of the setback and how it was determined. A question arose as to whether it was the correct distance in terms of any objective way of measurement. The question was the basis for work that led to looking at the force water jet from a failed pipe striking a building (the force decreases the further the structure is away from the break). Analysis of this force was completed and indicated that the 80-foot setback was an appropriate distance to use when considering the force of the water jet and it was the basis for the fourth factor cited above.

WSSC staff members have also met with representatives of the development community. Their comments have not been positive. This is not surprising; although WSSC believes that this provision will mitigate risks of a pipe failure to new building structures and to public safety, which is a benefit to all stakeholders, it may also result in additional near-term costs (neither the setback nor its engineering mitigation in lieu of the setback are likely to have zero cost).

Meetings with individual developers as a consequence of WSSC plan reviews are also ongoing. To date, no developer has concluded that the 80-foot setback provision in its entirety will prevent implementation of the developer’s project.

DESIGN MANUAL LANGUAGE

The text portraying the provision for the Pipeline Design Manual as it is currently written is enclosed as a reference for the reader.
Setback Recommendations Report

Case Study Review of Failures of 36-inch Diameter and Greater Pre-Stressed Concrete Cylinder Pipe and Cast Iron Pipe

Prepared by:

WASHINGTON SUBURBAN SANITARY COMMISSION
LAUREL, MARYLAND

March 25, 2011
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ARTICLE I.  INTRODUCTION

Section 1.01  PREFACE

This report examines ten case studies of 36-inch diameter and greater water transmission main failures which were constructed of rigid pipe materials including Pre-stressed Concrete Cylinder Pipe (PCCP) and Cast Iron Pipe (CIP) to determine an appropriate setback distance for these major transmissions mains from new development, specifically, proposed buildings and dwellings. The information for the case studies in this report are in part from first hand investigations performed following the failure of Washington Suburban Sanitary Commission (WSSC) pipelines as well as information obtained through research of significant pipe failures from other utilities.

In recent years, an increasing amount of new development is occurring on sites in the WSSC service area containing large diameter water transmission mains which are contained with a WSSC dedicated right of way. The current setback for pipelines 12-inch diameter and greater is 25 feet from the outside diameter of the pipe to a building or dwelling. WSSC right of way widths for 36-inch to 42-inch pipe is 40 feet, for 48-inch to 66-inch pipe is 60 feet and for the largest diameter of 72-inch and greater the right of way width is 75 feet. These parameters were developed primarily to allow for future maintenance of the pipelines. Currently a 96-inch diameter water main centered in a 75 foot right of way would require the maximum setback of 33.5 feet. A review of the case studies will make it clear that the current setback is not adequate to protect buildings and dwellings in the event of a catastrophic pipe failure.

An engineering review of water pipeline failures and the consequential damage does not appear to have been performed by the water utility industry agencies such as AWWA, EPA, WRF, etc. Accordingly, this report was prepared to examine various factors such as pipe diameter, operating pressure, surface cover material and others to examine the consequences of failure of large diameter water mains. The concept of an acceptable setback from a building or dwelling will be determined based on actual cases, as well as by performing analytical calculations of the theoretical debris throw and diameter of the crater resulting from a pipe failure. The degree of risk reduction and damage in the
event of a failure as result of a greater setback will vary based on site conditions because some events, including flooding, may not be mitigated by setbacks.

**Section 1.02 PURPOSE**

Many of WSSC’s transmission mains have been in service for nearly fifty years. Approximately 80% of the mains 36-inch thru 96-inch are made of PCCP and CIP. WSSC has 163 miles combined of PCCP and CIP 36-inch thru 96-inch which includes 18 miles of CIP and 145 miles of PCCP as shown in Table 1.0. Due to the rigid and brittle inherent nature of these pipe materials, they can fail with little or no warning. As pipes of any material type age, the risk of failure increases. Any water main break is problematic, but a large diameter transmission main failure can be catastrophic, particularly if it is a rigid pipe that fails practically instantaneously without a leak or other warning. Such failures release very large quantities of water, soil, rocks and often pieces of pavement and other debris as they quickly erode their earth cover.

**TABLE 1.0 WSSC Large Diameter PCCP and CIP Water Mains**

<table>
<thead>
<tr>
<th>Pipeline Diameter</th>
<th>PCCP (miles)</th>
<th>CIP (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36-inch</td>
<td>37.6</td>
<td>5.4</td>
</tr>
<tr>
<td>42-inch</td>
<td>30.3</td>
<td>9.9</td>
</tr>
<tr>
<td>48-inch</td>
<td>18.2</td>
<td>2.7</td>
</tr>
<tr>
<td>54-inch</td>
<td>8.7</td>
<td>none</td>
</tr>
<tr>
<td>60-inch</td>
<td>21.9</td>
<td>none</td>
</tr>
<tr>
<td>66-inch</td>
<td>12.8</td>
<td>none</td>
</tr>
<tr>
<td>72-inch</td>
<td>4.5</td>
<td>none</td>
</tr>
<tr>
<td>96-inch</td>
<td>11</td>
<td>none</td>
</tr>
<tr>
<td>Total</td>
<td>145</td>
<td>18</td>
</tr>
</tbody>
</table>

According to a 2007 AWWA Research Foundation presentation at the AWWA Annual Convention in Toronto, Canada, each pipe section in a large diameter PCCP pressurized water main
contains stored energy equal to between 20 and 200 lbs of dynamite. The initial explosive force is immense, and very large amounts of highly pressurized water are released with an initial velocity approaching 100 miles per hour after the water breaks through the ground cover. As the distance from the break increases, the intensity and velocity of the emitted water jet decreases and spreads as shown in the picture below. In addition to the danger to the public and property damage posed by the actual break and flooding, there is a significant impact to the water distribution system and customers, which can disrupt water service to large portions of the service area for days at a time.

In order to mitigate the effects of a 36-inch and greater PCCP and CIP pipeline failure, an additional separation beyond the existing right of way limits and 25 foot building separation requirements specified by the current WSSC Pipeline Design Manual is required between proposed 36-inch and larger mains and proposed buildings and dwellings. Additional separation between new development and water transmission mains are expected to lower the potential property damage risk to buildings and dwellings, lower the potential safety risks to the public and lower the property density.
adjacent to WSSC transmission mains. This will also lower the cost of maintenance and future replacement.

ARTICLE II. EVALUATION OF PCCP AND CIP PIPE FAILURES

Section 2.01 TEN CASE STUDIES

Following are ten representative PCCP failures used to discern associated characteristics useful to promulgate a revision to the setback distance in the WSSC Pipeline Design Manual. For each there is a summary of the pipe diameter, measured or estimated debris throw, measured or estimated crater size, the existence of pavement (or not), the soil classification and the working pressure of the pipe. Where available, actual measured or known parameters were used where noted; when these were unavailable, industry accepted or estimated parameters were used.

**CASE 1: WSSC 96-inch PCCP, Clagget Farm Property, Montgomery County, MD**

On the morning of March 12, 1996 at approximately 8:00 a.m., a 96-inch PCCP water main failed on Clagget Farm in Montgomery County near Berger Terrace. Figure 1.a. shows the condition of the break approximately one hour after the initial report was received. Before the valve could be closed, over 70 million gallons of water were released in approximately 4 hours, which is nearly the daily production total of the WSSC Patuxent Water Filtration Plant. The main was substantially shutdown with the help of portable electric valve operators at approximately noon that day.
Figure 1.a. WSSC 96-inch PCCP failure on Clagget Farm property, approx. one hour after report received. Initial debris throw has ended and water is forming a crater and causing flooding.

Fortunately, the pipe failure did not create any damage to buildings or dwellings since the event occurred on farm land. The pipeline was without a pavement cover under 5 to 6 feet of earth cover consisting of silty clay and sandy soil with some rocks which were transported approximately 200 to 250 feet away.
Figure 1.b. WSSC 96-inch PCCP pipe failure site during dewatering of trench.

Figure 1.c. WSSC 96-inch PCCP pipe failure site following trench dewatering.

**Case 1 Parameters:**
- Pipe Diameter: 96-inch PCCP
- Measured Debris Throw Distance: 90 feet
- Measured Crater Diameter: 50 feet
- Pavement: None
- Soil Type: SC/SP (USC)
- Working Pressure (per Manufacturer Specs): 115 psi

**CASE 2:** 72-inch PCCP, Broening Highway and Dunhaven Road, Dundalk, Maryland

On the afternoon of September 18, 2009, a 72-inch PCCP water main failed near Broening Highway and Dunhaven Road in Baltimore County which flooded more than 100 homes in Logan Village, Watersedge and Turner Station washing away part of a road, flooding cars and trapping some residents in their homes. Water at the height of flooding was chest deep in some places. Figures 2.a. and 2.b. show the severe flooding and Figure 2.c. shows the resulting crater.
Figure 2.a. Flooding from 72-inch PCCP failure in Dundalk, Baltimore, MD.

Figure 2.b. Aerial View - Flooding from 72-inch PCCP failure in Dundalk, Baltimore, MD.
The Dundalk pipe failure is an example of the more severe flooding which is possible with large diameter water main failures. In this case, the pipe failed at a higher elevation and the flooded homes were in a low lying area with poor drainage. The crater caused by the failure was somewhat limited by the presence of asphalt cover.

**Case 2 Parameters:**

- Pipe Diameter: 72-inch PCCP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 40 feet
- Pavement: Asphalt
- Soil Type: Assumed SC (USC)
- Working Pressure: 110 psi (assumed)
CASE 3: 66-inch PCCP, Interstate 25, Denver, Colorado

On the afternoon of February 7, 2008, a 66-inch PCCP water main failed on Interstate 25 near the 58th Avenue exit ramp in north Denver. The break caused a sinkhole 40 feet wide by 16 feet deep, shutting down all northbound lanes of the highway. State Police saw water bubbling out of the roadway and closed off the lanes before the collapse of the road. The very thick highway pavement provided an early warning sign and restrained the size of the hole and intensity of the failure event.

Figure 3.a. 66-inch PCCP Failure, Denver, Colorado, Interstate 25.

Figure 3.b. 16 foot deep excavation to repair the failed Denver 66-inch PCCP.
Case 3 Parameters:

- Pipe Diameter: 66-inch PCCP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 40 feet
- Pavement: Very Thick Asphalt
- Soil Type: Assumed SC/SM (USC)
- Working Pressure: 110 psi (assumed)

CASE 4: WSSC 66-inch PCCP, River Rd, Bethesda, Maryland

On the morning of December 23, 2008 at approximately 7:30 a.m., a 66-inch PCCP water main failed on River Road in Bethesda, Maryland. The unique site conditions limited potential damage to property in the immediate vicinity of the break. Damage to the nearest residential property was prevented as the property was at a significantly higher ground elevation above the pipeline and away from pipeline right of way (Figure 4.b.) This PCCP pipeline was also constructed in a trench that was blasted through rock which limited the crater size and the area washed out was also limited by an embankment, see Figure 4.b. and 4.c. The site configuration created a fast flowing river by the release of water from the pipeline down River Road with as much as 150,000 gallons per minute flowing down the steep incline, stranding motorists in their cars who were rescued by fire truck, helicopter and a tethered boat as shown partially in Figure 4.a. There were no injuries in the incident which resulted in severe erosion on either side of River Road and the water drained into Cabin John Branch stream at the bottom of the incline.
Figure 4.a. Conditions along River Road after WSSC 66-inch PCCP failure during water discharge.

Figure 4.b. WSSC 66-inch River Road failure, trench condition after shutdown and before dewatering.
Figure 4.c. WSSC 66-inch River Road failure, dewatered trench, rock under River Road restrained the size of the crater and prevented road from washing out.

**Case 4 Parameters:**

- Pipe Diameter: 66-inch PCCP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 30 feet
- Pavement: None
- Soil Type: Rock/GW (UCS)
- Working Pressure: 118.6 psi

**CASE 5:** WSSC 60-inch PCCP, Palatine Drive and Piney Meetinghouse Road, Maryland.

On December 1, 2003, a WSSC 60-inch PCCP water main near Palatine Drive and Piney Meetinghouse Road failed. The break caused a crater 35 foot wide and debris was found to have been thrown approximately 115 feet away. The area was outside of the limit of pavement and the pipeline was parallel to a 36-inch PCCP. The 36-inch was not damaged because it was on the opposite side of the failure from the 60-inch; as can be seen from the picture, the area washed out was on the same side of the pipeline as the hole in the pipe.
Figure 5.a. Crater created from WSSC 60-inch PCCP failure at Palatine Drive and Piney Meetinghouse Rd. Montgomery County, MD.

Figure 5.b. Soil content from WSSC 60-inch PCCP failure at Palatine Drive and Piney Meetinghouse Road.
Figure 5.c. WSSC 60-inch PCCP failure at Palatine Drive and Piney Meetinghouse Rd. Distance comparison showing the size of the crater and the distance of the debris throw.
Figure 5.d. WSSC 60-inch PCCP failure at Palatine Drive and Piney Meetinghouse Rd.

Case 5 Parameters:

- Pipe Diameter: 60-inch PCCP
- Measured Debris Throw Distance: 115 feet
- Measured Crater Diameter: 35 feet
- Pavement: None
- Soil Type: GC/GM (UCS)
- Working Pressure: 127.0 psi

CASE 6: WSSC 54-inch PCCP, E. Hampton Rd, Capital Heights, Maryland

On the early morning of January 24, 2011, at approximately 4:00 a.m., a 54-inch PCCP water main failed at E. Hampton Roads, Capital Heights, Maryland. The water main break caused the closure of the inner loop of the Capital Beltway in Prince George County due to flooding and freezing conditions, snarling morning traffic. The pipe ruptured Monday morning between Ritchie Marlboro Road and Route 214 and closed all southbound lanes of Interstate-95 for several hours. There was significant damage to the adjacent office park building, with chunks of asphalt strewn across the parking lot, the glass front of the building shattered, the building flooded and three cars filled with water and overturned.
Figure 6.a. WSSC 54-inch PCCP failure in Capitol Heights. Distance to the building shown.

Figure 6.b. WSSC 54-inch PCCP failure at East Hampton Rd. in Capitol Heights; crater size.

Figure 6.c. WSSC 54-inch PCCP failure at East Hampton Rd. in Capitol Heights; building view.
Case 6 Parameters:

- Pipe Diameter: 54-inch PCCP
- Measured Debris Throw Distance: 80 feet
- Measured Crater Diameter: 35 feet
- Pavement: Asphalt Parking Lot
- Soil Type: SC (UCS)
- Working Pressure: 125.0 psi (per Manufacturer Specs)

CASE 7: 48-inch CIP, Manhattan, New York at 5th Avenue and 19th Street

On January 2, 1998, early Friday morning about 5:00 a.m., a 48-inch CIP ruptured at 5th Avenue and 19th Street in New York City. The water main break caused a 35 foot wide sinkhole collapsing a portion of 5th Avenue and flooding numerous businesses and apartments; no one was hurt during the incident.
Figures 7.a. and 7.b. 48-inch Cast Iron Pipe (CIP) failure in Manhattan, New York at 5th Avenue and 19th Street.
Case 7 Parameters:

- Pipe Diameter: 48-inch CIP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 35 feet
- Pavement: Asphalt Roadway
- Soil Type: Unknown
- Working Pressure: 110 psi (assumed)

**CASE 8: WSSC 42-inch PCCP, Allentown Rd, Prince George’s County**

On September 15, 2001, at approximately 2 a.m., a 42-inch PCCP water main ruptured on Allentown Road, in Camp Springs, Maryland. The water main break caused a 30 foot wide and 10 feet deep sinkhole with debris throw up to to 60 feet away and collapsing a portion of the asphalt and concrete roadway in Allentown Road; no one was hurt during the incident.

*Figure 8.a. WSSC 42-inch PCCP failure at Allentown Road in Public Road R/W*
Figure 8.b. WSSC 42-inch PCCP failure at Allentown Road; very sandy soil under the paving.

Case 8 Parameters:

- Pipe Diameter: 42-inch PCCP
- Measured Debris Throw Distance: 60 feet
- Measured Crater Diameter: 30 feet
- Pavement: Asphalt and Concrete
- Soil Type: SW/SP (USC)
- Working Pressure: 110 psi (per Manufacturer Specs)

Case 9: 42-inch PCCP, Fort Lauderdale, Florida

On June 21, 2003, a 42-inch PCCP water main ruptured in Fort Lauderdale, Florida. The water main break caused a 25 foot wide sinkhole collapsing a portion of the roadway. Sandy soil was found
below the asphalt paving and the existing pavement minimized the effect of the PCCP burst and size of the hole.

![Figure 9.a. 42-inch PCCP failure in Fort Lauderdale in public right of way under the paving.](image)

**Case 9 Parameters:**
- Pipe Diameter: 42-inch PCCP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 25 feet
- Pavement: Asphalt Roadway
- Soil Type: SW/SP (USC)
- Working Pressure: 110 psi (assumed)
CASE 10: 36-inch PCCP, West Montrose Avenue, Chicago, Illinois

Overnight at approximately 1:30 a.m. on February 22, 2008, a 36-inch PCCP failed at W. Montrose Avenue in Chicago, Illinois collapsing a major portion of the street. Trees, street lights, parked cars and parking meters along with sections of the concrete sidewalk and asphalt and concrete roadway all collapsed into the crater.

Water rushed down Honroe Street at depths reaching 4 feet until the main was finally shutdown near 7 a.m. The initial crater is estimated at 24 feet and the resulting excavation from the repair was approximately 50 feet by 50 feet and 15 feet deep. Existing pavement minimized the throw of debris and the effect of the pipe burst however, the water undermined the rigid concrete and asphalt roadway.

Figure 10.a. 36-inch water main failure in West Montrose Avenue, Chicago in the public right of way under the paving.
Figure 10.b. 36-inch water main failure in West Montrose Avenue, Chicago following dewatering.

Figure 10.c. Crews begin repairing the ruptured 36-inch main in W. Montrose Ave.
Case 10 Parameters:

- Pipe Diameter: 36-inch PCCP
- Measured Debris Throw Distance: Unknown
- Estimated Crater Diameter: 24 feet
- Pavement: Asphalt/Concrete Roadway
- Soil Type: SC (USC)
- Working Pressure: 110 psi (assumed)

Section 2.02 FACTORS EFFECTING CONSEQUENCES OF FAILURE

There are many factors that will ultimately contribute to the nature of a failure of a rigid PCCP and CIP pipe and the extent of damage and consequences of that failure. They include factors such as pipe diameter, internal pressure, pipe bury depth, soil type, soil surface cover such as grass or pavement, ground topography, length of time before shutdown, distance from failure to surrounding structures, population density, time of day, season of the year, etc. These many factors present the challenges in determining or predicting the ultimate outcome as result of a catastrophic large diameter pipeline failure. The one common predictable denominator effecting the consequence of failure is distance of a building/dwelling from the failure site at the time of rupture.

1) STAGES IN A PCCP AND CIP PIPELINE FAILURE

There are three stages of a PCCP and CIP rigid pipe failure that cause damage:

**Stage One** The sudden burst of the energy from the failed pipe causes the initial opening up of the ground cover, and as the water quickly erodes the cover it generates a throw of debris such as pipe pieces, soil, rocks and pavement fragments (if present) along a trajectory that are carried a distance by the high pressure water jet. Structural damage from the thrown materials and the resulting impulse of the water jet against the structure.

**Stage Two** Continued structural damage, potentially both from the water jet and any subsequent flooding from the continuous flow of water, and scouring of the surrounding ground in the direction of the water exiting the hole in the pipe creating a crater.
Stage Three  Consequential surrounding damage caused by the failure event above may produce:

(a) Third party failures such as gas main explosions, biohazards, electrical faults and shocks in affected properties;
(b) Structural damage and collapse of adjacent buildings and structures, settlement and foundation failures caused by erosion due to the continuous flow of water;
(c) Flooding of buildings/dwellings and properties in the path of water flow and icing of roads.

2) WSSC RIGHT-OF-WAY LIMITS AND BUILDING SETBACK LINE

A schematic of a typical large diameter pipeline right of way and the building/dwelling setback line is depicted in Figure 2.a. Section 2.03 will summarize an analysis of the ten case studies presented and compare the observed and theoretical crater size and debris throw distances to the right of way widths and minimum building setback specified in the WSSC Pipeline Design Manual.

Figure 2.a. Schematic of a pipeline right of way with building setback – note that for most large diameter pipelines the ROW actually extends beyond the setback line
3) **FAILURE SITE CONDITION FACTORS**

The extent of damage caused by a pipe failure depends upon many factors and site conditions which affect the energy released in the beginning of Stage One; velocity, the amount of the thrown debris and the rate of the water flow in Stage Two are the results of that energy release. The force associated with that energy release is the working pressure of the pipe. Specific site conditions and pipeline design will affect the scale of the damages caused by pipe failures and topography will play a large role in possible flooding and dissipation of the water released.

(a) **Pipe Size**

i) Debris throw distance (Stage One) is independent of pipe size but depends on operating (working) pressure in the pipe and site conditions;

ii) The larger the pipe size, the greater the potential damage caused in Stage Two due to water quantity discharged and flooding.

(b) **Pipe Material**

PCCP and CIP are rigid or “brittle pipe materials” and can fail suddenly, without warning, releasing significant amount of initial energy. The progress and extent of the damage caused by the failure is dependant on a number of pipe properties and operating conditions. Steel and ductile iron pipe differ because they are flexible materials that tend to first corrode and leak extensively prior to failure which will likely be detected before rupture.

(c) **Pipe Depth**

i) The greater the depth of the failed pipeline, the greater the crater size created by the water, but debris throw distance is reduced due to the energy dissipation, the clear angle of trajectory from the crater;

ii) Shallow pipe depths cause a greater distance of the debris throw of pipe pieces, rock debris, soil and pavement fragments due to less energy dissipation and less obstructed trajectory angle.
(d) **Working Pressure**

i) The higher the working pressure in the pipe, the greater the damage due to greater initial energy release and the faster water velocity and scouring of the crater;

ii) Higher working pressure results in further distance for the debris thrown from the ground and washed along the ground surface.

(e) **Soil Properties**

i) The type of soils covering and surrounding the pipeline contribute to the degree of the damage;

ii) Coarse soil containing a large amount of rocks, gravel and buried construction debris add more material for the debris throw, conversely, fine sandy, silty and clayey soils contain smaller particles which result in less debris throw;

iii) The density of soil contents determines the speed and character of the crater excavation and the trajectory range of debris, for example, loose sand and gravel will be quickly scoured and thrown, whereas, compacted clay would be slower to scour.

(f) **Ground Cover**

Existing pavement or road surface mitigates the initial Stage One energy, the degree of the damage and causes a smaller crater. Hard cover such as thick concrete slows progression of failure, provides a short warning, and minimizes the debris throw. This same hard cover can also cause unseen sink holes under road surface before the road collapses.

(g) **Location of Break (Hole) in Pipe**

Most PCCP pipe failures occur at the 4 and 8 o’clock positions around the pipe. The location around the pipe determines the hole size and geometry (as do soil type and site geometry) and direction of the initial blast and debris throw. The hole location also influences the trajectory
and distance of the debris throw. CIP failures are either a circumferential split or a longitudinal split. The longitudinal split in CIP is the most severe and damaging.

(h) **Local Topography**

i) An elevated pipe location will increase the debris throw distance to the adjacent areas situated at a lower elevation within Stage One.

ii) During Stage Two, a pipeline located at a higher elevation has a potential for greater property damage due to the path of water flow. A pipe on the top of a hill has a potential for great property damage for any low lying areas located below.

iii) As a contrast, buildings/dwellings located at elevations higher than the ground surface at the break location are at a much lower risk for flooding.

(i) **Urban Areas**

Consequences of failure are greater in developed urban areas. Exposure time may be very short for the debris throw and the crater size will be somewhat reduced due to mostly paved surfaces. But soils with rock debris and presence of the pavement fragments will increase personal injury risk within Stage One. Structural property damage may be less in Stage One than that caused by the water flood within Stage Two. Water flow from failed pipe causes the most damage and in terms of quantity, poses the highest injury and drowning risk to the public. The sudden water flood event following a pipeline break is almost impossible to mitigate.

(j) **Property Use**

The presence of electric, gas, chemicals and biohazards near the failure site will increase consequential damage within Stage Three.

(k) **Building/Dwelling Setback**

The closer the buildings/dwellings are to the failed pipeline, the greater the Stage One, Stage Two and Stage Three property damage and public risk. The foundation type and depth, and
structural framing materials (wood, sidings, concrete blocks) becomes significant to mitigate damages due to the close range.

(I) **Shutdown Time**

The longer the time to shutdown the water main following a failure, the greater the Stage Two consequences of the event caused by the continuous water flow.

Section 2.03 **ANALYTICAL EVALUATION OF CASE STUDY FAILURES**

This section will compare the consequences of failure, namely the crater size and debris throw distance from the ten case study failures presented in Section 2.01, with an analytical calculation of the theoretical crater size and debris throw in order to determine an average of the same to determine a minimum setback distance for water transmission mains 36-inch and greater. The case study samples contain a good data set representing pipe sizes across the range between 36-inch through 96-inch and include both PCCP and CIP. A summary of the parameters used in the analysis are shown in Table 2.1 below. Where available, actual measured or known parameters were used where noted; when these were unavailable, industry accepted or estimated parameters were used.

The analytic calculations were performed based on the methods presented in Appendix I. The results of the analysis are shown for comparison in Table 2.2 below. An average of the measured or estimated values as well as calculated theoretical values for all test cases were also computed for both the debris throw and the crater size and are shown in the table. The collective results of the observed and theoretical provide a debris throw ranging from 60 to 115 feet and average distance of 93 feet and a crater size ranging from 24 to 50 feet with an average of 34 feet.

There are two reasons why an average debris throw distance less than 96 feet is expected. The calculated theoretical debris throw is based on the optimum angle of 45 degrees; meaning the hole in the pipe would need to be at either the 10 o’clock or 2 o’clock position. Most PCCP pipes fail at the 8 o’clock or 4 o’clock position; therefore, the actual trajectory angle would normally be less than the 45 degrees that would create the maximum throw distance. Secondly, the pipe depth is at an elevation
lower than the ground surface so the path or trajectory of the debris throw shown in Figure 2.b. is truncating the trajectory short of its maximum. So the factors that will lessen the values calculated for the debris throw include the depth of cover above the pipe, the location of the break and the associated angle of the water jet and the pressure in the pipe. Using physics to determine the equations of motion (as done in Appendix I) will result in equations that can be used to get a sense of the shortened distance. There is no horizontal acceleration so once knowing the appropriate time, \((t)\), the resulting debris throw would be:

\[ S_x = V_p \cos \Theta (t) \]

To calculate the appropriate time \((t)\) one would use:

\[ S_y = V_p \sin \Theta (t) - \frac{((g) t^2)}{2} \]

where: \(g = \text{gravitational constant} \ (32.2 \text{ ft/sec}^2)\)

Example:

Using \(\Theta = 45^\circ, V_p = 54 \text{ feet/sec} \ (110 \text{ psi})\) and a cover depth of 6 feet with the break at 2 o’clock, we calculate \(t = 0.23 \text{ sec}\) to clear the crater and \(2.14 \text{ sec}\) to strike the earth.

Using \(t = 2.14 \text{ sec}\) yields a debris throw of 82 feet which is 10 feet less than the 92 feet cited in Appendix I as the maximum debris throw at 110 psi pipe pressure \((C_o = 0.7)\).

---

**Figure 2.b. Schematic of Debris Throw Distance for a large diameter pipeline failure**
TABLE 2.1. TEN CASE STUDIES - PARAMETERS USED FOR ANALYSIS

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Location</th>
<th>Pipe (in)</th>
<th>Working Pressure (psi)</th>
<th>Measured Debris Throw (ft)</th>
<th>Estimated Crater Size (ft)</th>
<th>Pavement</th>
<th>Soil (USC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clagget Farm, MD*</td>
<td>96 PCCP</td>
<td>115.0</td>
<td>90</td>
<td>50**</td>
<td>None</td>
<td>SC/SP</td>
</tr>
<tr>
<td>2</td>
<td>Dundalk, Balt., MD</td>
<td>72 PCCP</td>
<td>110.0</td>
<td>NA</td>
<td>40</td>
<td>Asphalt</td>
<td>SC</td>
</tr>
<tr>
<td>3</td>
<td>Denver, CO</td>
<td>66 PCCP</td>
<td>110.0</td>
<td>NA</td>
<td>40</td>
<td>Asphalt</td>
<td>SC/SM</td>
</tr>
<tr>
<td>4</td>
<td>River Rd., MD*</td>
<td>66 PCCP</td>
<td>118.6</td>
<td>NA</td>
<td>30</td>
<td>None</td>
<td>Rock GW</td>
</tr>
<tr>
<td>5</td>
<td>Palantine Dr., MD*</td>
<td>60 PCCP</td>
<td>127.0</td>
<td>115</td>
<td>35**</td>
<td>None</td>
<td>GC/GM</td>
</tr>
<tr>
<td>6</td>
<td>Capital Hghts., MD*</td>
<td>54 PCCP</td>
<td>125.0</td>
<td>80</td>
<td>35**</td>
<td>Asphalt (part)</td>
<td>SC</td>
</tr>
<tr>
<td>7</td>
<td>5th Ave NYC</td>
<td>48 CIP</td>
<td>110.0</td>
<td>NA</td>
<td>35</td>
<td>Asphalt</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Allentown Rd., MD*</td>
<td>42 PCCP</td>
<td>110.0</td>
<td>60</td>
<td>30**</td>
<td>Asphalt</td>
<td>SW/SP</td>
</tr>
<tr>
<td>9</td>
<td>Ft. Lauderdale FL</td>
<td>42 PCCP</td>
<td>110.0</td>
<td>NA</td>
<td>25</td>
<td>Asphalt</td>
<td>SW/SP</td>
</tr>
<tr>
<td>10</td>
<td>Chicago, IL</td>
<td>36 PCCP</td>
<td>110.0</td>
<td>NA</td>
<td>24</td>
<td>Asphalt</td>
<td>SC</td>
</tr>
</tbody>
</table>

* WSSC Pipeline
** Measured Crater
- NA – Not Available
- (USC) – Unified Soil Classification
### TABLE 2.2 RESULTS OF CASE STUDY ANALYSIS

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Location</th>
<th>Pipe Design</th>
<th>Working Pressure&lt;sup&gt;(1)&lt;/sup&gt;</th>
<th>Debris Throw&lt;sup&gt;(5)&lt;/sup&gt;</th>
<th>Crater Size&lt;sup&gt;(5)&lt;/sup&gt;</th>
<th>Soil Data</th>
<th>Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>in</td>
<td>psi / ft</td>
<td>feet</td>
<td>estimated</td>
<td>calculated</td>
<td>estimated</td>
</tr>
<tr>
<td>1</td>
<td>Clagget Farm, MD</td>
<td>96</td>
<td>PCCP</td>
<td>115.0**</td>
<td>90.0</td>
<td>50</td>
<td>SC/ SP</td>
</tr>
<tr>
<td>2</td>
<td>Dundalk, Balt., MD</td>
<td>72</td>
<td>PCCP</td>
<td>110.0*</td>
<td>N/A</td>
<td>40</td>
<td>SC</td>
</tr>
<tr>
<td>3</td>
<td>Denver, CO</td>
<td>66</td>
<td>PCCP</td>
<td>110.0*</td>
<td>N/A</td>
<td>40</td>
<td>SC/ SM</td>
</tr>
<tr>
<td>4</td>
<td>River Rd, MD</td>
<td>66</td>
<td>PCCP</td>
<td>118.6</td>
<td>N/A</td>
<td>30</td>
<td>Rock GW</td>
</tr>
<tr>
<td>5</td>
<td>Palantine Dr., MD</td>
<td>60</td>
<td>PCCP</td>
<td>127.0</td>
<td>115.0</td>
<td>35</td>
<td>GC/ GM</td>
</tr>
<tr>
<td>6</td>
<td>Capital Hghts, MD</td>
<td>54</td>
<td>PCCP</td>
<td>125.0**</td>
<td>80.0</td>
<td>35</td>
<td>SC</td>
</tr>
<tr>
<td>7</td>
<td>5th Ave NYC</td>
<td>48</td>
<td>CIP</td>
<td>110.0*</td>
<td>N/A</td>
<td>35</td>
<td>N/A</td>
</tr>
<tr>
<td>8</td>
<td>Allentown Rd, MD</td>
<td>42</td>
<td>PCCP</td>
<td>110.0**</td>
<td>60.0</td>
<td>30</td>
<td>SW/ SP</td>
</tr>
<tr>
<td>9</td>
<td>Ft. Lauderdale, FL</td>
<td>42</td>
<td>PCCP</td>
<td>110.0*</td>
<td>N/A</td>
<td>25</td>
<td>SW/ SP</td>
</tr>
<tr>
<td>10</td>
<td>Chicago, IL</td>
<td>36</td>
<td>PCCP</td>
<td>110.0*</td>
<td>N/A</td>
<td>24</td>
<td>SC</td>
</tr>
</tbody>
</table>

**Notes:**

1. Working pressures indicated thus XXX.X* are assumed.
2. Working pressures indicated thus XXX.X** are per Manufacturer Specs average
3. Orifice Coefficient used for calculations in this table - Co = 0.7
4. Specific gravity of rocks used for calculations in the table Sp = 2.7
5. Calculated Throw Distance and Crater Size are given without pavement
6. N/A - Not available
7. Calculated Throw Distance and Crater Size are given without pavement
8. United Soil Classification (USC) soil group information is estimated
9. Angle of internal friction is estimated
ARTICLE III. EXISTING GUIDELINES AND CONDITIONS

Section 3.01 WSSC RIGHT-OF-WAYS AND SETBACK GUIDELINES

WSSC current guidelines for right of way widths and setbacks or clearances between buildings/dwellings and pipelines are set forth in the WSSC Pipeline Design Manual. The minimum right of way widths are specified to allow adequate space for construction of the pipeline (along with any temporary construction strips) and to allow for the mobility of equipment and personnel for future maintenance. The right of way widths for water pipelines are specified in Part Three, Section 2.b. in Table 20 of the Design Manual, are also included in Appendix II and summarized in Table 3.1 below.

<table>
<thead>
<tr>
<th>Pipeline Diameter</th>
<th>Width of Right of Way</th>
</tr>
</thead>
<tbody>
<tr>
<td>36-inch to 42-inch</td>
<td>40 feet</td>
</tr>
<tr>
<td>48-inch to 66-inch</td>
<td>60 feet</td>
</tr>
<tr>
<td>72-inch and larger</td>
<td>75 feet</td>
</tr>
</tbody>
</table>

The Pipeline Design Manual also includes additional guidelines for new development proposed in close proximity to existing right of ways for large diameter PCCP pipelines in Part Three, Section 2.b.1). This section states:

“1) The existing widths of right of ways shown/provided for existing large diameter pipelines (30-inch and larger) may be inadequate from both public safety and operation and maintenance perspectives. The most serious risks are posed in situations where occupied spaces are built within short distances of large diameter Pre-Stressed Concrete Cylinder Pipe (PCCP). PCCP fail catastrophically and result in serious public safety concerns. For any new development proposed within two hundred (200) feet of these pipelines, special considerations and modifications may be imposed.”
The minimum building/dwelling setbacks are set to allow for adequate clearance for equipment to access the pipeline and to allow for excavation of the pipeline without damage to building foundations. The Pipeline Design Manual guidelines for building/dwelling clearances from large diameter water/sewer pipelines are contained in Part Three, Section 3.c.2).b) and Appendix II which states:

“b) For pipelines larger than 12-inches in diameter, the minimum separation from a building or dwelling is to be determined based on the following factors: maintain a minimum horizontal separation of 25 feet and consider the potential property damage and physical injury during construction, maintenance and failure of the pipeline in assessing whether a greater separation is warranted. Select the separation so that the existing or proposed foundation of the building or dwelling will not be damaged during construction, maintenance or failure of the pipeline.”

As indicated above for both determining right of way widths and dwelling/building setbacks, WSSC promotes design guidelines for new development to take into consideration as part of the design, an appropriate setback distance from existing large diameter water mains in the interest of protecting property and public safety in the event of a catastrophic pipeline failure. However, it has been the experience of WSSC engineering and project management staff that it is difficult or impossible to implement these guidelines during the design review process and all too often, new development prevails and buildings or dwellings are built at or very near, the WSSC right of way line. Therefore, a change in the current Pipeline Design Manual guidelines is necessary to further mitigate the consequences of a large diameter PCCP or CIP pipeline failure.

Section 3.02   EXAMPLES OF INADEQUATE SETBACKS

When many of WSSC’s large diameter water mains were originally constructed, they were often built across open land areas within right of ways suitable for pipeline access and maintenance. As development sprawls and expands, the once rural areas become more urban and closed in on the water transmission main right of ways. When WSSC does not own the land adjacent to the right of
way, development often is built very near or directly abutting the right of way. This often places new buildings, homes and other development at higher risk of the consequences that could result from a major pipeline failure. Figure 3.1 below, illustrates an example of a large open tract of land with the proposed development superimposed. The once undeveloped pipeline right of way becomes the location for high density development with dwellings and buildings often having their foundations and basements built at or near the right of way line. Figure 3.2 depicts the close proximity of the proposed dwellings/buildings to the pipeline with the pipeline right of way being highlighted in pink.

![Figure 3.1 Proposed Development with High Density/Occupancy surrounding 36/60-inch PCCP R/W](image1)

![Figure 3.2 Proposed Buildings/Dwellings on 36/60-inch PCCP R/W line (highlighted), the yellow/green lines are 10 foot interval lines beyond the 50 foot r/w shown in pink.](image2)
Section 3.03 WSSC PCCP ASSET MANAGEMENT STRATEGY

The WSSC manages its inventory of large diameter PCCP pipelines with an asset management strategy designed to maintain safe and continuous operation of the mains and realize the practical useful life of the pipelines to assure value to the ratepayers. WSSC owns a total of 350 miles of PCCP water mains including 77 miles that are 48-inch and greater and 68 miles that are 36-inch through 42-inch totaling 145 miles that are 36-inch and greater. The WSSC approach to managing these critical assets to mitigate pipeline failures includes proactive routine inspections and repairs followed by continuous monitoring of mains 48-inch and larger. By the end of 2011, WSSC will have 54.5 of the 77 miles of mains 48-inch and larger equipped with continuous monitoring, with the remaining 22.5 miles planned to be completed by 2013.

There are a number of reasons why WSSC cannot simply replace the PCCP pipelines. For the vast majority of the mains, there is no available space to build replacement mains within or adjacent to the existing right of way due to development. This means that most replacements will have to be placed along the same alignment as the existing lines, which requires the existing pipeline to be taken out of service and removed for replacement. As the primary supply mains, there is not adequate redundancy to allow the long term shutdown for replacement. The construction time is estimated at two-thirds of a mile per year. For the 77 miles of 48-inch and larger that would equate to over 115 years (total) to replace these mains but more importantly, our system will experience 115 years that these pipelines will be out of service. Routine PCCP inspections identify an average of 2% or less of the total number of individual pipe sections in a pipeline as requiring repair or replacement. This means that approximately 98% of the existing segments at the time of inspection need no repair or replacement and have significant remaining useful life and do not require replacement at this time. This low percentage of deteriorated pipe sections warrants the use of an asset management strategy versus total replacement.
Under the WSSC PCCP Inspection and Condition Assessment Program, routine cyclic internal inspections are performed on a 5 to 7 year interval for mains 48-inch and larger on a prioritized basis using state of the art techniques for leak detection, condition assessment, repairs or replacements and long term monitoring. Advanced acoustical fiber optic (AFO) technology is used to monitor acoustical reinforcing wire breaks at an early stage so that pro-active remedial action can be taken. State of the art techniques are used for leak detection, condition assessment and repairs to establish a baseline pipeline condition, and then the long term AFO monitoring is installed and maintained on a continuous basis. These methods include:

- Internal acoustical leak detection;
- Internal visual inspection and sounding of concrete pipe core;
- Internal electromagnetic survey to detect broken pre-stressing wires (Figure 3.1);
- Internal sonic/ultrasonic non-destructive testing to detect anomalies (Figure 3.2);
- Permanent acoustic fiber optic monitoring to listen for wire breaks (Figure 3.3);
- Internal carbon fiber repair or replacement of individual pipe sections (Figure 3.4).

*Figure 3.1. Electromagnetic survey of PCCP to detect broken wires*
Figure 3.2. Sonic/ultrasonic survey of PCCP to detect anomalies

Figure 3.3. Acoustical Fiber Optic (AFO) PCCP monitoring equipment
An example of the benefits of this asset management strategy was revealed on June 29, 2010. A series of multiple acoustical events was recorded and reported from the WSSC AFO monitoring system on a 96-inch PCCP in the 8000 block of Tuckerman Lane, in Montgomery County. WSSC took immediate decisive action based on the information provided by the monitoring system and shutdown the main removing it from service to begin an investigation and repairs on the main. The pipe was found to be in a significant deteriorated condition requiring immediate replacement. The condition of the section of 96-inch pipe that was removed is shown in Figure 3.4; this pipe section was located in a residential area approximately 50 feet from the nearest dwelling.
Section 3.04 WHAT ARE OTHER WATER UTILITIES DOING?

A review was performed for water utilities that own and operate large diameter PCCP and CIP water mains located in Maryland as well other states to obtain information on their right of way requirements and buildings setbacks for large diameter water mains and any special requirements if PCCP or CIP was used. The results are shown in Table 3.2.

The review of the water utilities contacted revealed only two utilities requiring special considerations for large diameter water mains. Howard County, Maryland requires dwelling units to be located a minimum of 30 feet from transmission main easements. The County’s right of way width for this size of main is 30 feet, which would result in a minimum setback of 45 feet if the main is centered in the right of way. Phoenix Water requires a right of way width of 80 feet for transmission mains and a setback of 20 additional feet from the right of way line which would result in a minimum building setback of 60 feet if the main is centered in the right of way. If a building is less than 20 feet from the right of way line, a registered Arizona Professional Engineer is required to submit signed and sealed calculations which verify the integrity of structures adjacent to the water main under the condition of a main failure.
## TABLE 3.2 RESULTS OF UTILITY REVIEW

<table>
<thead>
<tr>
<th>Water Utility</th>
<th>Setback Requirement</th>
<th>Right of Way Widths</th>
<th>Special Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baltimore County DPW</td>
<td>None</td>
<td>Minimum Easement Widths: All pipe sizes: 15' minimum unless additional width is determined to be needed during design</td>
<td>None</td>
</tr>
<tr>
<td>Howard County DPW</td>
<td>Transmission mains: 30' setback between easement line and any proposed dwelling units.</td>
<td>Minimum Easement Widths: 16&quot; to 24&quot; - 25'  &gt; 30&quot; - 30'</td>
<td>None</td>
</tr>
<tr>
<td>Fairfax County</td>
<td>Minimum 20' setback from outside diameter of pipe to building.</td>
<td>Transmission mains: centered in 24' foot easement.</td>
<td>None</td>
</tr>
<tr>
<td>Dallas Water Utility</td>
<td>None</td>
<td>Minimum Easement Widths: 8&quot; to 12&quot; - 25' 16&quot; to 24&quot; - 50' 30&quot; to 66&quot; - 75' 72&quot; and Larger - 100'</td>
<td>None</td>
</tr>
<tr>
<td>Denver Water</td>
<td>None</td>
<td>Minimum Easement Widths: 16&quot; to 24&quot; - 34'  &gt; 30&quot; - 50'</td>
<td>None</td>
</tr>
<tr>
<td>Tucson Water</td>
<td>None</td>
<td>Design for available site conditions.</td>
<td>None</td>
</tr>
<tr>
<td>Phoenix Water</td>
<td>20' minimum from easement line - * See City of Phoenix Note.</td>
<td>Minimum Easement Widths: &lt; 16&quot; - 25' 16&quot; to 30&quot; - 50'  &gt; 30&quot; - 80'</td>
<td>* See City of Phoenix Note.</td>
</tr>
<tr>
<td>San Diego Water</td>
<td>None</td>
<td>Minimum Easement Widths: &lt; 20&quot; - 15' 20&quot; to 36&quot; - 20'  &gt; 36&quot; - 25'</td>
<td>None.</td>
</tr>
</tbody>
</table>

* City of Phoenix Note: "Regardless of the easement width, buildings shall have a sufficient setback from the easement boundary such that buildings, building foundations, or building slabs will not be undermined of damaged by a water main break. Proposed developments with buildings, building foundations, or building slabs proposed to be closer than 20' from an easement boundary shall be required to submit structural and soil calculations, signed and sealed by a registered Arizona Professional Engineer, which verify integrity of structures adjacent to the water main under the condition of a main failure."
ARTICLE IV.  SUMMARY OF FINDINGS

The evaluation of the pipe failure case studies demonstrated the scale of the consequences caused by large diameter pipeline failures and also presented the various factors in the site conditions, time of failure and pipeline design and operation that will influence the degree of resulting damage.

1. The crater size created by a failure will exceed the WSSC right of way widths in practically every case for mains 36-inch and larger if the pipe is centered in the right of way cases will cause structural damage to building and dwelling foundations located at or near the right of way line.

2. Debris throw will always significantly exceed the WSSC right of way width and may cause serious injury or property damage to those in its path. The amount of property damage from the debris throw is expected to be less than that by the resulting water flood.

3. Increasing the distance from the pipeline to the nearest structure reduces the risk to building occupants by providing more warning time to take avoidance action and more significantly, by reducing the initial energy of the failure that would cause property damage.

4. Direction of the water flow from the failed pipe is mostly controlled by the topography of the site as well as by which side of the pipe that the failure is on and may not by mitigated by a setback.
ARTICLE V. CONCLUSIONS

Based on the Summary of Findings derived from the evaluation of the ten case studies, and a review of the current guidelines in the WSSC Standard Design Manual, it can be concluded that:

1. In order to minimize property damage and personal risk for new development, the building or dwelling setback distance from the current 25 feet must be increased.
   
   a. Looking at the crater, it is important that the structure be safely beyond any resulting crater. Calculated and measured values (see Table 2.2) generally were an average of 35 feet with the worst case at 50 feet. The worst case example will occur when the soil conditions are favorable for erosion and there is no pavement surface involved. Any setback needs to be at least 50 feet plus a safe distance to ensure that intermediate earth between the crater and the structure will not fail, resulting in a secondary action damaging the structure.

   b. Looking at the debris throw, (see Table 2.2) and an average distance of 93 feet with a median and most frequent distance of 92 feet seemingly would yield a similar value as the requirement. However, the pipeline is below the ground surface and the angle of the water jet is unlikely to be the optimum, so the value portrayed is likely overly conservative. The example in Section 2.03, calculates a shortened distance for the debris throw considering the depth of the pipe of 10 feet. But rather than 82 or 83 feet, we decided that 80 feet would be a good representation of the average debris throw.

   c. A reasonable value that safely goes beyond the 50 foot crater requirement and meets the debris throw average is 80 feet.

2. In cases where the minimum setback cannot be provided, include a requirement that mitigative measures suitable to withstand the forces of the pipeline failure be provided to protect the building
or dwelling. Such measures shall be submitted to WSSC and supported by necessary calculations and drawings, signed and sealed by a Professional Engineer licensed in the State of Maryland.

3. Continue to implement the aggressive WSSC 5 Year PCCP Condition Assessment and Inspection Program Plan which will install continuous AFO monitoring in all PCCP pipelines for mains 48-inch and larger and initiate the routine inspection of 36-inch and 42-inch PCCP mains by the end of 2013. The inspection of the 68 miles of 36-inch and 42-inch PCCP mains will be included along with the cyclic inspection of mains 48-inch and larger to be completed in approximately ten years.
APPENDIX I. LARGE DIAMETER WATER MAIN SETBACK ANALYSIS

By David C. Shen, P.E. December 31, 2007

Approach 1:
To analyze the required set-back distance once assuming that the trajectory of a debris particle resulting from a pipe burst would follow the trajectory of the water jet.

Any debris particle with a mass \(m_p\), greater than the mass of air, \(m_a\) would be subject to the same gravitational deceleration as the water jet undergoes while traveling through the air, thus following the trajectory inscribed by a water jet through the air. Another assumption is that any debris particle of mass, \(m_p\), which is subject to motion in air as the water jet impinges on it, would travel through air. Any particles which are too heavy to be moved by the water jet would either remain in-place, or move without being thrown into the air.

The key to this approach is how to estimate the resulting motion or the velocity, of the debris particle as it is impinging upon by a water jet.

\[ \begin{align*}
  V_p & \quad \text{vertical component of velocity} \\
  V_{p \, \text{horiz}} & \quad \text{horizontal component of velocity} \\
  \Theta & \quad \text{angle of the vector}
\end{align*} \]

\[ \text{Fig. 1. Initial velocity of the debris particle} \]
Let: \( V_p \) = Initial velocity of debris particle at which the projectile motion is launched

\[ \Theta = \text{initial angle at which the particle trajectory travels through air, with respect to the ground surface, which is assumed to be horizontal.} \]

Let the vertical velocity component be \( V_{p\text{ vert}} \)

\[ V_{p\text{ vert}} = V_p \sin \Theta \] \hspace{2cm} \text{[Equation 1]} \]

Let the horizontal velocity component be \( V_{p\text{ horiz}} \)

\[ V_{p\text{ horiz}} = V_p \cos \Theta \] \hspace{2cm} \text{[Equation 2]} \]

Based on the theory of projectile motion of trajectory: the time, \( t \), where \( V_{p\text{ vert}} \) decelerates to zero is:

\[ t = \frac{V_{p\text{ vert}}}{g} \] \hspace{2cm} \text{[Equation 3]}

where: \( g = \text{gravitational constant (32.2 ft/sec}^2)\); \( V_{p\text{ vert}} = \text{initial vertical velocity of the projectile motion} \)

The vertical distance \( S_{\text{vert}} \) the particle attains in time \( (t) \) is:

\[ S_{\text{vert}}(t) = V_{p\text{ vert}}(t) - \frac{gt^2}{2}; \] \hspace{2cm} \text{[Equation 4]} \]

The horizontal velocity of the debris particle is \( V_{p\text{ horiz}} \) which is NOT subject to gravitational deceleration. Therefore, the total horizontal distance that the particle travels through air would eventually be assumed to be the farthest horizontal distance that a debris particle could travel as the result of a pipe burst. This is an important assumption.

Let the total horizontal distance be \( D_{p\text{ horiz}} \). Therefore, \( D_{p\text{ horiz}} = V_{p\text{ horiz}} (2t) \), where \( (2t) = \text{total time that a particle would travel through air} \). This assumes that the final resting place is the same elevation as the initial launch elevation. Therefore:

\[ D_{p\text{ horiz}} = V_p \cos \Theta (2t) \] \hspace{2cm} \text{[Equation 5]} \]

Where \( (t) \) is calculated by [Equation 3] above: \( D_{p\text{ horiz}} = \frac{(2V_p \cos \Theta V_{p\text{ vert}})}{g} \)

which equates to: \( D_{p\text{ horiz}} = \frac{(2V_p \cos \Theta V_p \sin \Theta)}{g} \)

Therefore:

\[ D_{p\text{ horiz}} = \frac{(2V_p^2 \cos \Theta \sin \Theta)}{g} \]

By differentiating the above equation with respect to angle \( \Theta \), it can be shown the farthest horizontal distance of \( D_{p\text{ horiz}} \) is obtained with \( \Theta = 45^\circ \)

\[ \text{Where:} \]

\[ \cos \Theta = \sin \Theta = (0.5)^{1/2} \]

\[ \text{Therefore:} \]
MAX \(D_{\text{horiz}}\) = 2\([(0.5)^{1/2}]^2(V_p^2 / g)\)

Then:

\[\text{MAX } D_{\text{horiz}} = \frac{V_p^2}{g} \quad \text{[Equation 6]}\]

**Key:** Equation 6 is to be used to calculate the farthest horizontal distance of the displacement of the trajectory of a debris particle, as a result of a pipe burst.

**Question:** How can \(V_p\) be determined?

**Answer:** Assuming that there is no air resistance to the projectile motion, then, \(V_p\) may be determined by assuming a water jet completely transforming its energy to a debris particle, thereby moving the debris particle along the same trajectory as the water jet projectile.

Assuming that the velocity of the water jet, \(V_w\), as a result of a water main burst, is derived from the pressure energy contained in the water main at the onset of the pipe burst. By Bernoulli’s theory, for every unit weight of water, the total fluid energy is balanced, therefore:

\[\left(\frac{V_w^2}{2g}\right) + (Z_w) + \left(\frac{P_w}{\gamma_w}\right) = \left(\frac{V_m^2}{2g}\right) + (Z_m) + \left(\frac{P_m}{\gamma_w}\right) \quad \text{[Equation 7]}\]

where:

- \(V_w\) = velocity of the water jet
- \(Z_w\) = vertical elevation of the water jet at its starting point
- \(P_w\) = gage pressure contained in the water jet
- \(V_m\) = velocity of water inside of the water main
- \(Z_m\) = vertical elevation of the water main
- \(P_m\) = gage pressure contained in the water main above atmospheric pressure
- \(\gamma_w\) = unit weight of water

We can assume that:

- **Elevation of the water jet:** \(Z_w = Z_m\),
- **Atmospheric pressure:** \(P_w = 0\),
- **Velocity of water:** \(V_m = 0\) (in the water main, compared to \(V_w\)).

Therefore:

\[\left(\frac{V_w^2}{2g}\right) = \left(\frac{P_m}{\gamma_w}\right) \implies V_w^2 = \left(\frac{2gP_m}{\gamma_w}\right) = 2gH_m,\]

where: \(H_m = \text{pressure head of water (in feet)}\),

Which leads to \(V_w\) for every unit weight of water:

\[V_w = \left(2gH_m\right)^{1/2} \quad \text{[Equation 8]}\]

Using [Equation 7], by extending the balance of the total fluid energy to the transfer of fluid energy and the energy of a debris particle, therefore, let \(V_p\) be the velocity of a debris particle with a unit weight of \(\gamma_p = \rho_p g\) where \(\rho_p = \text{unit density of the debris particle}\).
Therefore, by the energy balance between water and debris particle:

\[
\gamma_p \left[ \frac{V_p^2}{2g} + (Z_p) + \left( \frac{p_p}{\gamma_p} \right) \right] = \gamma_w \left[ \frac{V_w^2}{2g} + (Z_w) + \left( \frac{p_w}{\gamma_w} \right) \right];
\]

Which equals to:

\[
\gamma_p \left[ \frac{V_p^2}{2g} + \left( \frac{p_p}{\gamma_p} \right) \right] = \gamma_w \left[ \frac{V_w^2}{2g} + (Z_w) + \left( \frac{p_w}{\gamma_w} \right) \right];
\]

So:

\[
\gamma_w \left[ \frac{V_m^2}{2g} + (Z_m) + \left( \frac{p_m}{\gamma_w} \right) \right]
\]

Where:

\((Z_p) = (Z_w) = (Z_m) = 0; \)

\((At \ zero \ vertical \ height, \ assuming \ zero \ height \ is \ the \ vertical \ datum \ of \ the \ bursting \ water \ main.)\)

\((p_p / \gamma_p) = \) fluid pressure energy of debris particle which is non-existent because debris is NOT a fluid, therefore, \((p_p / \gamma_p) = 0\) and \((p_w / \gamma_w) = 0\) because they are subject to atmospheric pressure,

Therefore: \([\gamma_p (V_p^2 / 2g)] = \gamma_w [(V_w^2 / 2g)] \]

From [Equation 7] and [Equation 8] above:

\((V_w^2 / 2g) = (P_m / \gamma_w)\).

Therefore:

\([\gamma_p (V_p^2 / 2g)] = \gamma_w [(V_w^2 / 2g)] = \gamma_w [(V_m^2 / 2g) + (P_m / \gamma_w)]\),

Simplified as:

\(V_p = \left[ (\gamma_w / \gamma_p)^{1/2} \right] V_w; \quad [Equation \ 9]\)

From Equation 8:

\(V_w = (2gH_m)^{1/2}\)

Where:

\(H_m = \) fluid pressure of water inside the water main in feet;
\(g = \) gravitational constant \((32.2 \text{ ft/sec}^2)\).

Therefore, Equations 6, 8 & 9 can be used to estimate the horizontal distance traveled by a debris particle as it is carried by a water jet resulting from a burst of a water main.

Note: If introducing an orifice coefficient, \(C_o\), to equation 8 in order to calculate the true velocity of water, \(V_m\), resulting from the burst pipe. This coefficient is dependent upon the pressure and the shape and size of the resulting orifice (the hole resulting from the break). The \(C_o\) relates the water pressure inside the water main to the pressure outside the water main accounting for the energy loss as the water exits the pipeline through the break.

Then:
\[ V_m = C_0 \left(2gH_m\right)^{1/2} \quad [Equation\ 10] \]

**Calculations of Distance \( \text{MAX } D_{p\ \text{horiz}} \)**

(using Equations 6, 8 and 9)

Since:

\[ V_m = C_0 \left(2gH_m\right)^{1/2} \quad [\text{Eq.}\ 10] \]
\[ V_p = \left(\frac{\gamma_w}{\gamma_p}\right)^{1/2} V_w \quad [\text{Eq.}\ 9] \]
\[ \text{MAX } D_{p\ \text{horiz}} = \left(\frac{V_p^2}{g}\right) \quad [\text{Eq.}\ 6] \]

Since unit weight of a debris particle is \( \gamma_p = \rho_p g \)

Where:

- \( \rho_p \) = unit mass (density) of the debris particle and;
- \( \rho_p = S_p \rho_w \);
- \( S_p \) = specific gravity of a debris particle;
- \( \rho_w \) = unit mass (density) of water.

Therefore:

\( \left(\frac{\gamma_w}{\gamma_p}\right) = \frac{\gamma_w}{\left(S_p \rho_w g\right)} = \frac{\rho_w g}{\left(S_p \rho_w g\right)} \)

So:

\( \left(\frac{\gamma_w}{\gamma_p}\right)^{1/2} = \left(\frac{1}{S_p}\right)^{1/2} \)

**Table of Some Common Debris Specific Gravity**

<table>
<thead>
<tr>
<th>Shale</th>
<th>Granite</th>
<th>Sandstone</th>
<th>Basalt</th>
<th>Asphalt</th>
<th>Concrete</th>
<th>Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.75</td>
<td>2.65</td>
<td>2.2</td>
<td>2.65</td>
<td>2.22</td>
<td>2.38</td>
<td>2.45</td>
</tr>
</tbody>
</table>

Assume an average specific gravity of a debris (rock) particle to be 2.7,

Therefore:

\( \left(\frac{1}{S_p}\right)^{1/2} = \left(\frac{1}{2.7}\right)^{1/2} = 0.61. \)

So:

\[ V_p = 0.61 \ V_m \]

Assume maximum pressure in WSSC water transmission system \( H_m = 150 \ \text{psi} = 346 \ \text{feet} \) and using \( C_0 = 0.80; \)

Therefore:

\[ V_m = 0.8 \left[2(32.2)(346)\right]^{1/5} = 120 \ \text{ft/sec} \]

Since:

\[ V_p = 0.61 \ V_m = 0.61(120) = 73.2 \ \text{ft/sec} \]

\[ \text{MAX } D_{p\ \text{horiz}} = \left(\frac{V_p^2}{g}\right) = \left(73.2^2/32.2\right) = 165 \text{ feet} \]

**Final Formula :**

\[ \text{MAX } D_{p\ \text{horiz}} = \left[ \left(\frac{\gamma_w}{\gamma_p}\right) (2) (C_0^2) (H_m) \right] \ \text{feet} \quad [\text{Equation}\ 11] \]
Based on above Equations, Table 1 is a comparison of horizontal distances of a debris particle thrown out by a water jet as a result of a water main burst. Due to the unpredictable shape and size of the pipe opening, the value of $C_o$ may vary from 0.6 to 0.9. Also, as discussed above, the farthest horizontal distance of $D_{p\text{ horiz}}$ is obtained for $\Theta = 45^\circ$.

$$S_p = 2.7 \Rightarrow (1/S_p)^{1/2} = 0.61 \quad \text{and} \quad \gamma_w/\gamma_p = 1/2.7$$

<table>
<thead>
<tr>
<th>Pressure $H_m\ psi$</th>
<th>Max. Throw @ $C_o = 0.9$</th>
<th>Min. Throw @ $C_o = 0.6$</th>
<th>Average Throw @ $C_o = 0.7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$H_m\ feet$</td>
<td>$V_m\ ft/sec$</td>
<td>$V_p\ ft/sec$</td>
<td>MAX $D_{p\text{ horiz}}$ feet</td>
</tr>
<tr>
<td>150</td>
<td>346</td>
<td>134</td>
<td>82</td>
</tr>
<tr>
<td>140</td>
<td>323</td>
<td>130</td>
<td>79</td>
</tr>
<tr>
<td>130</td>
<td>300</td>
<td>125</td>
<td>76</td>
</tr>
<tr>
<td>120</td>
<td>277</td>
<td>120</td>
<td>73</td>
</tr>
<tr>
<td>110</td>
<td>254</td>
<td>115</td>
<td>70</td>
</tr>
<tr>
<td>100</td>
<td>231</td>
<td>110</td>
<td>67</td>
</tr>
<tr>
<td>90</td>
<td>208</td>
<td>104</td>
<td>63</td>
</tr>
<tr>
<td>80</td>
<td>185</td>
<td>98</td>
<td>60</td>
</tr>
<tr>
<td>70</td>
<td>161</td>
<td>92</td>
<td>56</td>
</tr>
<tr>
<td>60</td>
<td>138</td>
<td>85</td>
<td>52</td>
</tr>
</tbody>
</table>

**Approach 2:**

*To analyze the required set back distance by looking at the size of the hole in the ground resulting from the excavation of soils around a water main burst.*

This is based on an assumption of the seepage force due to groundwater flow in the soil exerting upon the soil particle when the seepage force equals to the force or the weight of the overburden soil strata, the overburden soil will burst open, thereby creating a hole in the ground.

If, the seepage force in soil due to seepage flow is $F_{seepage}$,

Then:

$$F_{seepage} = (\gamma_w) i \quad [Equation 12]$$

where:

- $\gamma_w$ = unit weight of water
- $i$ = hydraulic gradient of groundwater

where:

$$i = \Delta H/\Delta \text{dist} \quad [Equation 13]$$

$\Delta H =$ Change in hydrostatic pressure due to groundwater flow
$\Delta_{dist} = \text{Change in horiz. distance due to hydrostatic pressure change in groundwater flow}$

The seepage force has an effect on the soil strata causing movement of the particle along the seepage line depending on the vector sum of the seepage force and the submerged unit weight, $\gamma_{sub}$ of the soil.

$$\gamma_{eff} = (\gamma_{sub}) - F_{\text{seepage}}$$

where:

$\gamma_{eff} = \text{effective unit weight of soil}$

$\gamma_{sub} = \text{submerged soil unit weight}$

When $F_{\text{seepage}}$ reaches a critical value such that $i = i_{\text{critical}}$, then $F_{\text{seepage}} \geq (\gamma_{sub})$

Therefore, when soil becomes loosened, boils and lifts up forming a hole in the ground:

$$\gamma_{eff} \leq 0$$

$$\gamma_{w} (\Delta H/\Delta_{dist}) \geq (\gamma_{sub})$$

Where:

$$\gamma_{sub} = (\rho_{\text{soil}} - 1) \gamma_{w}$$

$\rho_{\text{soil}} = \text{specific gravity of a soil particle}$

Assume $\rho_{\text{soil}} = 2.7$,

Therefore:

$$\Delta_{dist} \leq [1/(2.7-1)] \Delta H$$

$$\Delta_{dist} \leq 0.588 \Delta H$$

[Equation 15]

Using Equation 14:

$$\Delta_{dist} \leq (\gamma_{w}/\gamma_{sub}) \Delta H;$$

Note: This derivation supposes that the break in the pipeline is toward the side and thus the distance calculated would extend beyond the break (a worst case). Should the break be at the very top, for instance, while the value calculated would be the associated with a crater of the approximate same size, it would span both sides of the pipe, thus lessening the distance needed to be away from the pipeline.

An important assumption:

The seepage pressure gradient, or the change in hydrostatic pressure in groundwater flow, is assumed to vary linearly with respect to $\Delta_{dist}$.

For submerged soil unit weight using a particle with a specific gravity of 2.7:

$$\gamma_{sub} = (\rho_{\text{soil}} - 1) \gamma_{w}$$

$$\gamma_{w}/\gamma_{sub} = \gamma_{w} / [(2.7-1) \gamma_{w}] = 1/1.7 = 0.588$$
Therefore:

\[ \Delta_{\text{dist, max}} \leq 0.588 \Delta H \]

<table>
<thead>
<tr>
<th>Pressure in Main, ( H_m ), (psi)</th>
<th>Pressure in Main, ( H_m ), (feet)</th>
<th>( \Delta_{\text{dist, max}} ) (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>346</td>
<td>204</td>
</tr>
<tr>
<td>140</td>
<td>323</td>
<td>190</td>
</tr>
<tr>
<td>130</td>
<td>300</td>
<td>176</td>
</tr>
<tr>
<td>120</td>
<td>277</td>
<td>163</td>
</tr>
<tr>
<td>110</td>
<td>254</td>
<td>149</td>
</tr>
<tr>
<td>100</td>
<td>231</td>
<td>136</td>
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<tr>
<td>90</td>
<td>208</td>
<td>122</td>
</tr>
<tr>
<td>80</td>
<td>185</td>
<td>109</td>
</tr>
<tr>
<td>70</td>
<td>161</td>
<td>95</td>
</tr>
<tr>
<td>60</td>
<td>138</td>
<td>81</td>
</tr>
</tbody>
</table>

Remember that \( C_o \) was introduced representing the coefficient relating pressure (and resulting speeds) of the water within the pipe and as it exits, then \( \Delta H \) and \( H_m \) can be related by:

\[ \Delta H = C^2_o H_m \]

Therefore, we can modify Equation 13 to:

\[ i = \left( C^2_o H_m / \Delta_{\text{dist}} \right) \]

[Equation 16]

Evaluating particular site conditions we can specify soil characteristics based on soil type, including angle of internal friction (\( \phi \)) and the coefficient of internal resistance \( \tan(\phi) \) of the soil. Replacing \( (\Delta H) \) by \( (C^2_o H_m) \) in Equation 14 and using coefficient of internal resistance \( \tan(\phi) \) will give us the maximum size in plan of the crater developed in the ground:

\[ \Delta_{\text{dist}} \leq \left( \gamma_w / \gamma_{\text{sub}} \right) \left[ C^2_o (H_m) \left( 1 - \tan(\phi) \right) \right]; \]

[Equation 17]

Equation 15 becomes:

\[ \Delta_{\text{dist}} \leq \left( 1 / 1.7 \right) \left[ C^2_o (H_m) \right] \left( 1 - \tan(\phi) \right); \]

[Equation 18]

Based on the above Equations, Table 2 is a comparison of horizontal size of a crater, in feet. Due to the unpredictable shape and size of the pipe opening value of \( C_o \) may vary from 0.6 to 0.9. The range of internal friction angle (\( \phi \)) varies based upon soil types between 25° (softer soil) to 35° (stiffer soil). Intermediate values can be obtained by interpolating.
Table 2. Size of the crater developed by water main burst

<table>
<thead>
<tr>
<th>Pressure (H_m, psi)</th>
<th>Crater @ C_o = 0.9</th>
<th>Crater @ C_o = 0.6</th>
<th>Crater @ Average C_o = 0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_m feet</td>
<td>Φ 25 30 35</td>
<td>Φ 25 30 35</td>
<td>Φ 25 30 35</td>
</tr>
<tr>
<td>150</td>
<td>346</td>
<td>104</td>
<td>29</td>
</tr>
<tr>
<td>140</td>
<td>323</td>
<td>97</td>
<td>27</td>
</tr>
<tr>
<td>130</td>
<td>300</td>
<td>90</td>
<td>23</td>
</tr>
<tr>
<td>120</td>
<td>277</td>
<td>83</td>
<td>19</td>
</tr>
<tr>
<td>110</td>
<td>254</td>
<td>76</td>
<td>16</td>
</tr>
<tr>
<td>100</td>
<td>231</td>
<td>69</td>
<td>14</td>
</tr>
<tr>
<td>90</td>
<td>208</td>
<td>63</td>
<td>12</td>
</tr>
<tr>
<td>80</td>
<td>185</td>
<td>56</td>
<td>10</td>
</tr>
<tr>
<td>70</td>
<td>161</td>
<td>49</td>
<td>8</td>
</tr>
<tr>
<td>60</td>
<td>138</td>
<td>42</td>
<td>6</td>
</tr>
</tbody>
</table>

Example:
At Piney Meetinghouse Road/ Palantine Drive intersection, the existing 60” PCCP is under a HHG of 675 feet and the ground elevation = 390 feet, therefore, the pressure under HHG inside the 60” PCCP = (675 – 390) + 5). Therefore based on a specific gravity of 2.7 for rock (168 lb/ft³) = unit weight of rock), ΔH = 290 feet. By using Approach 1 with ΔH = 290 feet, with C_o = 0.7 and using Equation 11:

\[
\text{MAX D_p horiz} = 105 \text{ feet}
\]

Using Approach 2 with ΔH = 290 feet w/average Φ = 30° and using Equation 18:

\[
\Delta_{\text{dist.max}} = 35 \text{ feet with C_o = 0.7}
\]

The measurement of the crater at Piney Meetinghouse Road/ Palantine Drive water main burst showed 35-40 feet which is in the range of the calculated values.
APPENDIX II. WSSC PIPELINE DESIGN MANUAL

Excerpts from Part Three, Sections 2 and 3
2. Rights of Way and Construction Strips.

a. General.

1) When a water or sewer pipeline(s) extends into property that is not publicly owned, show the limits of the right of way and construction strip on the drawings, see the requirements listed in this section and in Appendix "D" (WSSC Survey and Right of Way Criteria). WSSC will review the widths of both the right of way and the construction strip for maintenance and constructability due to the depth and/or soil conditions and make any necessary changes to the widths.

2) After determining the limits of the right of way and construction strips and receiving concurrence from WSSC, prepare the right of way documents.

b. Existing Pipeline Width Requirements.

1) The existing widths of right of ways shown/provided for existing large diameter pipelines (30-inch and larger) may be inadequate from both public safety and operation and maintenance perspectives. The most serious risks are posed in situations where occupied spaces are built within short distances of large diameter Pre-Stressed Concrete Cylinder Pipe (PCCP). PCCP fail catastrophically and result in serious public safety concerns. For any new development proposed within two hundred (200) feet of these pipelines, special considerations and modifications may be imposed.

c. Proposed Pipeline Width Requirements.

1) For right of way and construction strip minimum width requirements for water and sewer pipelines, see Tables "20" and "21". WSSC may require an increase in the width of the right of way and/or construction strip, greater than those indicated in Tables "20" and "21".

2) Consider the construction and maintenance requirements when determining the required widths for the construction strip(s) and the right of way.

   a) Construction strip(s). Take into account the topography along the alignment, when determining the area necessary to construct the pipeline (i.e., steep side slopes which may require the contractor to bench an area to be able to construct the alignment, deep excavations, etc.). If additional area is required to construct the pipeline due to stockpiling material along the alignment, consider the following items: storing the pipe along the trench; stockpiling stone, gravel and/or select backfill, and excavated trench material; contractor's access along the alignment; trench width and equipment area; and the area along the trench for other construction equipment (i.e., front-end loader, etc.).

   b) Right(s) of way. Take into account when determining the width of the right of way, the area required to facilitate future maintenance, excavation, and repairs. Additional access points along the alignment may be required to facilitate the mobility of equipment and personnel.

      1) Provide sufficient right of way to minimize the potential for personal injury to the public and/or significant property damage caused by water or sewer pipeline breaks.
**TABLE "20"**

Right of Way and Construction Strip Minimum Width Requirements for Water Pipelines

<table>
<thead>
<tr>
<th>Pipeline Diameter</th>
<th>Width of Right of Way</th>
<th>Total Width of Construction Strips</th>
</tr>
</thead>
<tbody>
<tr>
<td>14-inch and smaller</td>
<td>20 feet</td>
<td>15 feet</td>
</tr>
<tr>
<td>16-inch to 24-inch</td>
<td>25 feet</td>
<td>20 feet</td>
</tr>
<tr>
<td>30-inch</td>
<td>30 feet</td>
<td>20 feet</td>
</tr>
<tr>
<td>36-inch to 42-inch</td>
<td>40 feet</td>
<td>To be determined by WSSC</td>
</tr>
<tr>
<td>48-inch to 66-inch</td>
<td>50 feet</td>
<td>To be determined by WSSC</td>
</tr>
<tr>
<td>72-inch and larger</td>
<td>75 feet</td>
<td>To be determined by WSSC</td>
</tr>
</tbody>
</table>

**TABLE "21"**

Right of Way and Construction Strip Minimum Width Requirements for Sewer Pipelines

<table>
<thead>
<tr>
<th>Pipeline Diameter</th>
<th>Width of Right of Way</th>
<th>Total Width of Construction Strips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller than 15-inch</td>
<td>20 feet</td>
<td>20 feet</td>
</tr>
<tr>
<td>15-inch to 24-inch</td>
<td>45 feet</td>
<td>20 feet</td>
</tr>
<tr>
<td>30-inch to 36-inch</td>
<td>50 feet</td>
<td>To be determined by WSSC</td>
</tr>
<tr>
<td>42-inch and larger</td>
<td>55 feet</td>
<td>To be determined by WSSC</td>
</tr>
</tbody>
</table>

(For Right of Way widths for deep sewers, see information below)

c). Right of Way for Deep Sewers

1) For requirements for Deep Sewers, see Part Two, Section 8 (Vertical Alignment (Profile)).

2) For determining width of right of way for sewer pipelines over twenty-two (22) feet of cover, use the following:

(a) For sewers 12-inch and smaller with depth greater than twenty (22) feet, multiply two (2) feet of right of way width by each foot of cover pipeline depth. If Deep Sewer is sharing the right of way with another pipeline, see additional in this section.

Example: For a 12-inch diameter sewer pipeline with twenty (23) feet of cover:
2 (feet of right of way) times 23 (feet of cover) equals 46 feet.
Total ROW width shall be 46 feet width.

(b) For sewers 15-inch and larger, with depth greater than 22 feet, multiply one (1) foot of right of way width from the edge of the right of way to the centerline of the deep sewer for each foot of cover pipeline depth. Also, see requirements for Location of Pipelines Within Rights of Way and Construction Strips

Example: For a 15-inch diameter sewer pipeline with twenty (23) feet of cover:
1 (feet of right of way) times 23 (feet of cover) equals 23 feet for both pipelines (new sewer and future relief sewer). Offset the sewer for future relief sewer, add minimum of 10 feet separation; Total ROW width shall be 56 feet width.

d. Location of Pipelines Within Rights of Way and Construction Strips

1) One (1) pipeline within the right of way. Typically, locate one pipeline in the center of the right of way and equally divide construction strip on both sides of the right of way, except for the following:
3. **Pipeline Crossings and Clearances.**

a. **General.**

1) When determining pipeline clearances, measure the distance between pipelines or utilities, from the outside diameter (OD) or edge of each pipe or utility unless otherwise noted.

2) When sewer pipelines (which include gravity sewers, small diameter pressure sewers, force mains, and SHCs) run parallel or cross water pipelines and WHCs, special clearance/separation requirements are necessary to protect the water supply from contamination due to possible sewerage leaks. See Vertical Separation for Water Pipelines Crossing Sewer Pipelines, Horizontal Separation Between Water and Sewer Pipelines and Horizontal Separation Between WHCs and SHCs in this section.

b. **Vertical Clearances for Pipeline or Utility Crossings.**

1) Provide minimum of one (1) foot vertical clearance between two (2) pipelines or utilities.

2) When two (2) pipelines or utilities cross each other and are not perpendicular ninety (90°) degrees check the plotting of the entire pipeline or utility crossing in the vertical plane. In the profile, when the crossing is not perpendicular, the total length of the crossing may be greater than one (1) pipe diameter. The vertical clearance requirements may be several feet from the centerline of the two (2) pipelines or utilities. Sketch "AA" is an example of two pipelines, in which the required pipeline clearances are satisfied at the centerline of the two crossings, but the entire pipeline crossing does not meet the required pipe clearances, see the example below.

---

**Example.**

8-inch sewer at station 2+00 crosses a 36-inch storm drain at an angle of 45°. At the centerline of the two pipelines, the design shows that the two pipelines have a 12-inch clearance, but at station 2+05 the two pipelines have only 6-inch of clearance. This is due to the slope of the two...
pipelines, see "Section" of Sketch "AA".

To have the required pipe clearance at the centerline of the two pipelines, the clearance at station 2+00 will need to be at least two (2) feet so that the centerline crossing will have the required one (1) foot clearance over the entire pipeline crossing, see Sketch "AA".

3) The minimum vertical clearance for other jurisdiction's utilities, is governed by that utility (i.e., Colonial Pipeline requires a minimum of two (2) feet of vertical clearance).

c. **Horizontal Separation With Other Utilities/Structures.**

1) Provide a minimum of five (5) feet horizontal separation between water/sewer pipelines and other utilities and structures (manholes, inlets, vaults, poles, etc.).

2) Provide the following minimum separation when a water/sewer pipeline is parallel or adjacent to existing or proposed buildings or dwellings:

a) For pipelines 12-inch and smaller in diameter, provide a minimum separation from a building or dwelling the greater of the following: fifteen (15) feet horizontal separation or 1:1 slope from the bottom of the foundation of the existing or proposed building or dwelling to the bottom edge of the pipeline trench.

b) For pipelines larger than 12-inch diameter, the minimum separation from a building or dwelling is to be determined based on the following factors: maintain a minimum horizontal separation of twenty-five (25) feet and consider potential property damage and physical injury during construction, maintenance and failure of the pipeline in assessing whether a greater separation is warranted. Select the separation so that the existing or proposed foundation of the building or dwelling will not be damaged during the construction, maintenance and failure of the pipeline.

c) For exceptions to the above, submit supporting documentation showing that the pipeline can be constructed and maintained.

3) Minimum separation requirements between existing and proposed or relocated water pipelines, where the existing water line is to remain in service.

a) For pipelines 14-inch and smaller in diameter, provide a minimum of ten (10) feet separation centerline to centerline of the two pipelines.

b) For pipelines 16-inch to 24-inch in diameter, provide a minimum of ten (10) feet separation OD to OD of the two pipelines.

c) For pipelines 30-inch and larger in diameter, provide a minimum of twenty (20) feet separation OD to OD of the two pipelines.

d) Horizontal separation between the existing and proposed pipelines may have to be increased when the pipeline is within the zone of influence of existing concrete blocking. To determine if there is adequate passive soil resistance, see Passive Soil Pressure for Concrete Thrust Blocks in Part Three, Section 27 (Thrust Restraint Design for Buried Piping).
Treatise on Water Jet Force and Kinetic Energy

Others have developed analysis and a report determining that, based upon the resulting crater size and debris throw distance from a transmission main break, the setback distance from these mains should be 80 feet. A question regarding any resulting reduction in adverse affect from doing this has resulted in this effort. This document provides a brief examination of the reduction of energy and force of water from a broken water main as a function of distance away from the break. This shows derivations for and results of a supporting spread sheet. The tables and graphs below summarize results portrayed in that spread sheet where more detailed results can be found.

The drawing above attempts to portray a water main break and the resulting water jet moving along a path that includes a structure before the jet terminates at the surface of the earth.

Kinetic Energy:

Let’s begin by looking quickly at the energy involve in a water main break. Kinetic energy is the energy associated with motion. The water jet is definitely moving so we begin by looking at kinetic energy.

\[ E_k = \frac{1}{2}mv^2 \]

Energy is directly proportional to \( V^2 \) and any energy reduction will also be directional proportional to any reduction in \( V^2 \)
Looking at the reduction of energy as a function of the setback distance away from the break in the pipe yielded a summary table and associated graph as below:

<table>
<thead>
<tr>
<th>Setback Distance (feet)</th>
<th>Average Amount of Energy Reduction (in %)</th>
<th>Setback Distance (feet)</th>
<th>Average Amount of Energy Reduction (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>20</td>
<td>60</td>
<td>38.4</td>
</tr>
<tr>
<td>30</td>
<td>23.3</td>
<td>65</td>
<td>40.2</td>
</tr>
<tr>
<td>35</td>
<td>26.4</td>
<td>70</td>
<td>41.7</td>
</tr>
<tr>
<td>40</td>
<td>29.3</td>
<td>80</td>
<td>44</td>
</tr>
<tr>
<td>45</td>
<td>31.9</td>
<td>90</td>
<td>45.3</td>
</tr>
<tr>
<td>50</td>
<td>34.3</td>
<td>100</td>
<td>45.8</td>
</tr>
<tr>
<td>55</td>
<td>36.5</td>
<td>110</td>
<td>45.4</td>
</tr>
</tbody>
</table>

One can see from the graph above that the gain in energy reduction starts to lose effectiveness after the setback extends beyond 80 to 90 feet.
Force:

Water striking a structure results in an impulse to that structure as designated below.

$$\text{Force} = \int F \, dt = \Delta p = m \Delta v$$

Force will be directly proportional to the velocity component of momentum, thus the reduction in force will also be directly proportional to the velocity (or speed).

Looking at the reduction of applied force as a function of the setback distance away from the break in the pipe yielded a summary table and associated graph as below:

<table>
<thead>
<tr>
<th>Setback Distance (feet)</th>
<th>Average Amount of Force Reduction (in %)</th>
<th>Setback Distance (feet)</th>
<th>Average Amount of Force Reduction (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>10.6</td>
<td>70</td>
<td>23.7</td>
</tr>
<tr>
<td>30</td>
<td>12.5</td>
<td>80</td>
<td>25.2</td>
</tr>
<tr>
<td>35</td>
<td>14.3</td>
<td>90</td>
<td>26.1</td>
</tr>
<tr>
<td>40</td>
<td>16</td>
<td>100</td>
<td>26.4</td>
</tr>
<tr>
<td>45</td>
<td>17.6</td>
<td>110</td>
<td>26.2</td>
</tr>
<tr>
<td>50</td>
<td>19.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>21.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Looking at the graph above portraying force reduction one can again see that the percent reduction of the force becomes less effective with setbacks beyond 80 feet.
Continuing the look at force using the impulse equation shown above, it can be derived that the Force from the water jet striking the structure is the time rate of change of the momentum of the water as it strikes the structure.

The drawing above shows the horizontal component of the water jet striking a structure (blue arrow). The other colored arrows show potential rebound directions and \( \theta \) is the angle of that rebound to the horizontal. First look at the result when \( \theta \) is 90˚ or when the water does not rebound away at all and runs along the structure vertically. This will be the case where the force is least. Note the symbol \( \theta \) is again used (before to represent the angle of the water jet leaving the break) this time as the rebound angle noted in this paragraph.

Mass of water, \( m \), is constant

\[
\frac{d}{dt} \left( \int F \, dt \right) = \frac{d(m \Delta v)}{dt} = \Delta P \frac{dm}{dt} + m \frac{d\Delta v}{dt}
\]

\( a_x = 0, \frac{dv}{dt} = 0 \)

\( F = m \, (V_m - V_m') \) \( V_m \) along x axis goes to zero as water is diverted up and down along structure

\( F = mV_m \) \( m \) is mass of the water

\( F = \rho Q V_m \) \( \rho \) is the density of water in lbm (so \( g \) will need to be introduced to get lbf), \( Q \) is the flow rate of the water of the jet

\( F = \rho V_m A V_m \) \( A \) is the cross sectional area of the water jet striking the structure

\( F/A = \rho V_m^2 \)
To Calculate \( V_m \)

From Appendix I, \( V_w = \sqrt{2gH_w} = (2gH_w)^{1/2} \)

\[
V_m = C_o \sqrt{2gH_w} \quad \text{Assume} \ C_o = 0.7
\]

Or

\[
V_m = C_o (2gH_w)^{1/2}
\]

\[
\vec{v}_m = V_m \cos \theta \hat{i} + V_m \sin \theta \hat{j} \quad S = S_o + V_m \cos \theta t
\]

\[
\vec{v}_{m(t)} = V_m \cos \theta + (V_m \sin \theta - gt) \hat{j} \quad t = S/V_m \cos \theta \quad \text{t is time to travel horizontal distance} \ S
\]

So

\[
\left| \vec{v}_{m(t)} \right| = ((V_m \cos \theta)^2 + (V_m \sin \theta - gt)^2)^{1/2}
\]

\[
= (V_m^2 \cos^2 \theta + V_m^2 \sin^2 \theta - 2V_m \sin \theta \cos \theta \cos \theta - g^2 t^2)^{1/2}
\]

And substituting for \( t \) to travel distance \( S \)

\[
V_m(s) = (V_m^2 \sin^2 \theta + \cos^2 \theta - 2V_m \sin \theta \cos \theta + g^2 S^2 / V_m^2 \cos^2 \theta)^{1/2}
\]

\[
= (V_m^2 - 2gS \tan \theta + g^2 S^2 / V_m^2 \cos^2 \theta)^{1/2}
\]

When \( \theta = 45^\circ \), the optimum angle of the water jet yielding the maximum distance from the break that water will travel. Here this angle \( \theta \) refers to the angle of the water jet exiting the broken pipe.

\( \sin \theta = \cos \theta = 0.707 \) and \( \tan \theta = 1 \) and so,

\[
V_m(s) = (V_m^2 - 2gS + 32.22S^2 / 0.707^2)^{1/2}
\]

So for the best case (lowest force) the results can be summarized in the table below and subsequent graph (this is when the water does not rebound – \( \theta = 90^\circ \)):

<table>
<thead>
<tr>
<th>Setback Distance (feet)</th>
<th>25</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (K/SF)</td>
<td>6.03</td>
<td>5.38</td>
<td>5.01</td>
<td>4.70</td>
<td>4.45</td>
<td>4.25</td>
<td>4.11</td>
<td>4.03</td>
<td>4.00</td>
</tr>
</tbody>
</table>
A quick review of the graph shows that the value where the plot begins to approach an asymptote is just after 80 feet.

The force will actually be larger when water rebounds from the structure as portrayed above by the red and green arrows. For those cases it can be shown that the equation derived above changes slightly to:

\[ V_{m(u)} = (V_m^2 - 2gS + 32.2^2S^2 / 0.707^2V_m^2)^{1/2} (1 + \cos \theta) \]

This \( \theta \) is the rebound angle to the horizontal.

In the case where \( \theta = 30^\circ \), the results are summarized below:

<table>
<thead>
<tr>
<th>Setback Distance (feet)</th>
<th>25</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force (K/SF)</td>
<td>11.26</td>
<td>10.03</td>
<td>9.35</td>
<td>8.77</td>
<td>8.3</td>
<td>7.93</td>
<td>7.67</td>
<td>7.52</td>
<td>7.47</td>
</tr>
</tbody>
</table>
And though with this less optimal case (more force) the asymptote is shifting slightly to the right, the 80 feet setback is still a pretty good figure to use.

Summary:

One sees a common trait when looking at all of the graphs above, whether percent energy, or force reduction, versus setback distance or a look at the values of the forces themselves versus setback distance. At greater than 80 feet setbacks, there is little to be gained by way of reduction of adverse effects. That they all consistently point to this should not be surprising. By looking at the equations governing these phenomena one can see they are indeed directly related – in fact energy and force are two ways physicists utilize to describe the same physical phenomenon that they experience. But in this case it is comforting to see the consistency and it provides some corroboration that an 80 feet setback is a good figure. To make it larger would not gain much. To make it smaller would run afoul of the analysis described in the earlier work.
2. Rights of Way and Construction Strips.

Changes to this Section are as follows:

b. DELETE in its entirety. “Existing Pipeline Width Requirements.”

b. Existing Pipeline Width Requirements.

1) The existing widths of right of ways shown/provided for existing large diameter pipelines (30-inch and larger) may be inadequate from both public safety and operation and maintenance perspectives. The most serious risks are posed in situations where occupied spaces are built within short distances of large diameter Pre-Stressed Concrete Cylinder Pipe (PCCP). PCCP fail catastrophically and result in serious public safety concerns. For any new development proposed within two hundred (200) feet of these pipelines, special considerations and modifications may be imposed.
3. Pipeline Crossings and Clearances.

Changes to this Section are as follows:

c. Horizontal Separation With Other Utilities/Structures.

2) Provide the following minimum separation when a water/sewer pipeline is parallel or adjacent to existing or proposed buildings or dwellings:

a) Water Pipelines.

(1) For water pipelines 12-inch and smaller in diameter, provide a minimum separation from a building or dwelling the greater of the following: fifteen (15) feet horizontal separation or 1:1 slope from the bottom of the foundation of the existing or proposed building or dwelling to the bottom edge of the pipeline trench.

(2) For water pipelines larger than 12-inch diameter, but less than 36-inch diameter if PCCP or cast iron pipe, the minimum separation from a building or dwelling is to be determined based on the following factors: maintain a minimum horizontal separation of twenty-five (25) feet and consider separation required for construction and maintenance and potential structural damage and personal injury during a potential failure of the pipeline in assessing whether a greater separation is warranted. Select the separation so that the existing or proposed foundation of the building or dwelling will not be structurally damaged during the construction, maintenance, or potential failure of the pipeline.

(3) For PCCP or cast iron water pipelines with a 36-inch diameter or larger, WSSC studies have indicated that damage from a catastrophic failure can extend in excess of eighty (80) feet beyond the pipeline. A minimum horizontal separation of eighty (80) feet from a building or dwelling is required. Developments with buildings, building foundations or building slabs proposed less than 80 feet from the edge of the large diameter water main shall be required to submit structural and soil calculations, signed and sealed by a registered Maryland professional engineer, which verify the integrity of structures located within 80 feet of the large diameter water main in the event of a water main failure. This requirement does not apply to:

(a) redevelopment of existing of existing buildings, which can retain the existing setback distance; or,

(b) infill development (development that takes place on vacant or underutilized parcels within an urban area) of less than 40 acres of property located within a high density residential, mixed use, commercial, industrial, land use area as designated by the local zoning map

(a) Should the designer/applicant propose a separation of less than eighty (80) feet, the diminished separation must be mitigated through use of structural enhancements, building material selections rated to withstand a potential pipeline failure or other site-specific engineering solutions approved by WSSC Technical Services Group Leader using the below review process.
The designer must develop an appropriate solution to ensure that a building or dwelling foundation will not be structurally damaged in the event of a pipeline failure and that the public is not subject to significant risk. Adequate documentation, including, but not limited to, diagrams, calculations and/or drawings, must be provided to support a deviation of the required horizontal separation. All such documentations must be sealed, dated, and signed by a Professional Engineer registered in the State of Maryland. If, after review and a written decision issued by the WSSC Technical Services Group Leader, the proposed engineering solution is denied, the designer/applicant may appeal the denial to the Chief Engineer within fifteen days of the date of the written denial. The appeal will be handled as an adjudicatory hearing pursuant to WSSC Standard Procedure L-07-02.

b) Sewer Pipelines.

(1) For sewer pipelines 12-inch and smaller in diameter, provide a minimum separation from a building or dwelling the greater of the following: fifteen (15) feet horizontal separation or 1:1 slope from the bottom of the foundation of the existing or proposed building or dwelling to the bottom edge of the pipeline trench.

(2) For sewer pipelines larger than 12-inch diameter, the minimum separation from a building or dwelling is to be determined based on the following factors: maintain a minimum horizontal separation of twenty-five (25) feet and consider separation required for construction and maintenance and potential structural damage and personal injury during a potential failure of the pipeline in assessing whether a greater separation is warranted. Select the separation so that the existing or proposed foundation of the building or dwelling will not be structurally damaged during the construction, maintenance, or potential failure of the pipeline.