

APPENDIX 5B

Settlement Monitoring Requirements for Ductile Iron Water Mains

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I. INTRODUCTION

When any project in the City of Seattle water service area can cause potential ground movement, Seattle Public Utilities (SPU) requires that the City's water mains be monitored. These projects are generally those that involve large scale earth work, which can create ground settlement. This appendix presents Seattle Public Utilities (SPU) requirements for settlement monitoring for ductile iron water mains. See DSG Chapter 5 **Appendix 5A** for settlement monitoring requirements for cast iron water mains.

The audience for this document includes SPU design engineers, consultant engineers, or other agency engineers if necessary.

I.1 GENERAL REQUIRMENTS

Settlement monitoring is required to provide reliable information and documentation during construction to minimize potential ground movement impacts on ductile iron water mains. The following are SPU general requirements for this monitoring:

1. Settlement monitoring work must include furnishing all equipment, material, and labor for installing, maintaining, monitoring, analyzing, reporting, and removing instrumentation for monitoring ductile iron water main displacement.
2. The contractor must maintain and protect new and existing instrumentation at no additional cost to the City of Seattle. The contractor must replace damaged instruments at no additional expense to City of Seattle.

I.2 CONDITIONS THAT REQUIRE MONITORING

Though less susceptible to ground movement than cast iron pipe, ductile iron pipe may require settlement monitoring during trenching, tunneling, or excavating in the area of influence of the water main (Figure 5B-1). The following conditions require monitoring:

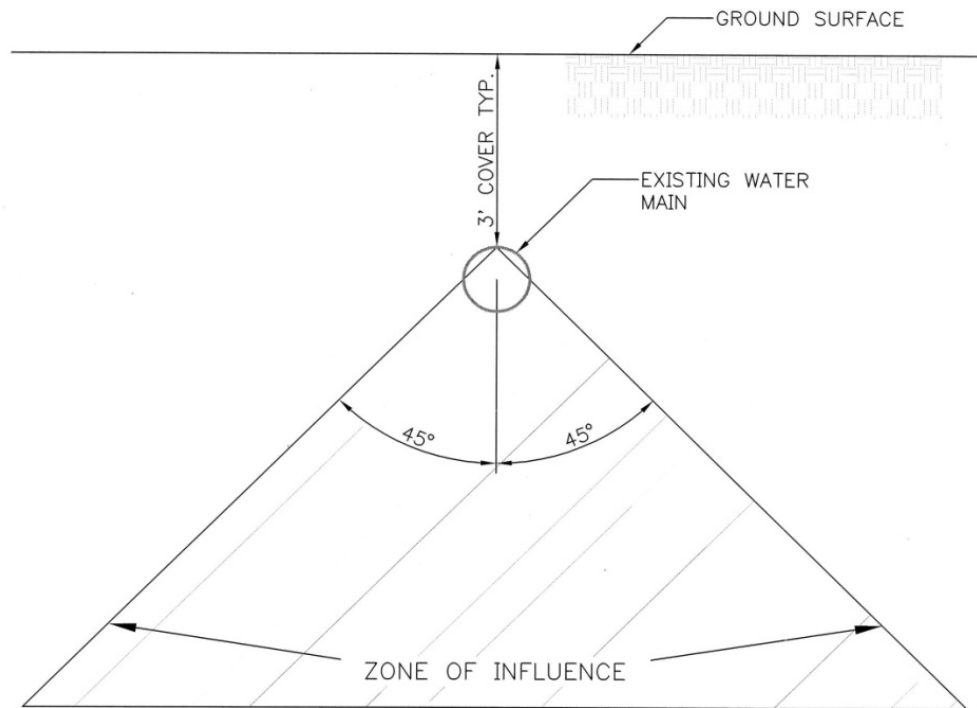
- When excavations, de-watering, tunneling and/or trenching enters the zone of influence of the water main or anticipated ground movements are expected to be 25% of the values shown in Table 5B-1 and Table 5B-2. See Figure 5B-1 for the typical zone of influence.
- When any construction activity might cause horizontal displacements in addition to vertical displacements, horizontal displacement should be monitored as well, and the total displacement calculated.

The design engineer or SPU may require monitoring, for reasons other than those noted above. Such reasons might include:

- For construction activities in areas with poor soil conditions
- Where the ductile iron water main is believed to have been previously deflected.
- In environmentally critical areas

SPU may waive settlement monitoring requirements at a given site with concurrence from SPU Water Design or the SPU Materials Lab.

Figure 5B-1
Zone of Influence



1.3 DEFLECTIONS TRIGGERING REPLACEMENT

The following are SPU requirements for projects that will trigger the need to replace water mains:

1. When an outside agency proposes a project that will likely cause settlement, that agency must provide predicted ground movement data and settlement contours to SPU early in the design process. This information will be used to identify pipelines that are candidates for monitoring, pre-construction modification, or replacement.

2. Sufficient utility monitoring points must be installed on all pipes that are anticipated to be in the settlement trough to identify the shape of the actual settlement trough and the actual pipe deflections.
3. When any of the maximum pipe displacement criteria shown in pipe replacement tables (Table 5B-1 and Table 5B-2) have been exceeded, the affected water main must be replaced by the contractor back to the point of zero displacement along the water main. SPU will determine where the point of zero displacement occurred based on available settlement data.

Table 5B-1 and Table 5B-2 assume that the pipe was installed in a straight line with no planned joint deflections. If the record drawings (as-builts) show that the pipe was installed with joint deflections, the maximum allowable joint deflection of the installed pipe plus settled deflection must be the following:

- No more than 80% of manufacturer's allowable deflection (only 40% for poor soil zones).
- In no case shall settlement induced displacements exceed the values shown in the pipe replacement tables.

If any of these criteria are exceeded, the pipe must be replaced back to the point of zero displacement as described above.

Notes:

Most restrained joint pipe in the SPU water system is installed with the joints fully extended according to the manufacturer's recommendations. There are typically no expansion fittings installed in restrained joint pipelines. This means that if the pipe settles, while flexible and capable of deflection, it has no elongation capacity. If securely anchored at both ends, the deflecting pipe metal will then strain.

If predicted settlements are within 50% of the amounts shown in s 1 or 2, restrained expansion fittings should be installed before a project that will cause settlement starts. These expansion fittings will significantly increase the allowable settlement of the restrained joint pipe as shown on the bottom of Table 5B-1 and Table 5B-2.

1.3.1 Maximum Joint Pullout Criteria

Pipe movement that exceeds any of the values listed in Table 5B-1, triggers replacement. Movement may be in any direction: top, bottom, side, or in combination. The pipe must be replaced back to the location where SPU detects or interpolates zero displacement to have occurred. Maximum joint rotation is calculated from maximum joint pullout.

Note: A staggered factor of safety is used to compute the values in Table 5B-1. The factor of safety is set at 1.5 for pipes 12-inches and smaller, rising to 1.6 for 16-inch pipe, 1.75 for 20-inch pipe, and 2.0 for pipes larger than 20-inches.

1.3.2 Geographical Deflection Criteria

For Seattle areas that have poor soils (i.e. defined by geologic units Qw, Qp, Qb, Qbu, Qtf, Qal, Qyal, Ql, Qf, Qt, Qmw or Qls) as shown on the Geology (in review at time of DSG publication)

layer in SPU GIS, SPU has developed maximum deflection values (see Table 5B-1). These values are approximately half of those used for the rest of the city.

Note: The name of the Geology GIS layer may change. The maximum values in these parts of Seattle are reduced to account for prior and future natural movements. Should the area in question border two different geologic units, check to confirm the geologic unit of the project (<http://pubs.usgs.gov/of/2005/1252/>).

1.3.3 Maximum Allowable Settlement

Unlike cast iron pipe, there is no maximum allowable settlement trough depth for ductile iron pipe. The only criteria used for ductile iron pipe is the allowable rate of slope change shown in the pipe replacement tables (see Table 5B-1 and Table 5B-2).

The data in the tables are subject to rounding. Attempting to back calculate the values will not yield exact results.

**Table 5B-1
Pipe Replacement Triggers for Normal Soil Conditions¹**

Pipe Size	4"	6"	8"	10"	12"	16"	20"	24"	30"	36"
Non-Restrained Joint Pipe										
Degrees of maximum joint rotation any direction	2.9°	2.0°	1.5°	1.2°	1.0°	0.7°	0.5°	0.4°	0.4°	0.3°
Maximum deflection inches per 18-ft pipe length	11.2"	7.8"	6.0"	4.8"	4.1"	2.9"	2.1"	1.6"	1.7"	1.4"
Restrained Joint Pipe Without Expansion Fittings										
Degrees of maximum joint rotation any direction	0.05°	0.03°	0.06°	0.06°	0.05°	0.05°	0.04°	0.03°	0.02°	0.02°
Maximum deflection inches per 18-ft pipe length	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"
Restrained Joint Pipe With Expansion Fittings²										
Degrees of maximum joint rotation any direction ²	2.9°	2.0°	1.5°	1.2°	1.0°	0.7°	0.5°	0.4°	0.4°	0.3°
Maximum deflection inches per 18-ft pipe length ²	11.2"	7.8"	6.0"	4.8"	4.1"	2.9"	2.1"	1.6"	1.7"	1.4"

Notes

¹No values are given for maximum joint pullout on RJ pipe since it is not possible to pull the joint apart. Assumes no joint deflection at installation for all joint types and sizes.

²Must install adequately spaced expansion fittings to eliminate pipe wall stress.

Table 5B-2
Ductile Iron Pipe Replacement Triggers in Poor Soils, Liquefaction Zones and Known Landslide areas defined by SPU GIS¹

Pipe Size	4"	6"	8"	10"	12"	16"	20"	24"	30"	36"
Non-Restrained Joint Pipe										
Degrees of maximum joint rotation any direction	1.4°	1.0°	0.7°	0.6°	0.5°	0.3°	0.2°	0.2°	0.2°	0.2°
Maximum deflection inches per 18-ft pipe length	5.6"	3.9"	3.0"	2.4"	2.0"	1.4"	1.0"	0.8"	0.8"	0.7"
Restrained Joint Pipe Without Expansion Fittings										
Degrees of maximum joint rotation any direction	0.025°	0.015°	0.03°	0.03°	0.025°	0.025°	0.02°	0.015°	0.01°	0.01°
Maximum deflection inches per 18-ft pipe length	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"	0.2"
Restrained Joint Pipe With Expansion Fittings²										
Degrees of maximum joint rotation any direction ²	1.4°	1.0°	0.7°	0.6°	0.5°	0.3°	0.2°	0.2°	0.2°	0.2°
Maximum deflection inches per 18-ft pipe length ²	5.6"	3.9"	3.0"	2.4"	2.0"	1.4"	1.0"	0.8"	0.8"	0.7"

Notes

¹ Strictest criteria from Table 5B-1 and Table 5B-2. always apply to a particular situation. Assume no joint deflection at installation.

² Must install adequately spaced expansion fittings to eliminate pipe wall stress.

1.4 EQUIPMENT REQUIREMENTS

The following are requirements for equipment setup, use, quality assurance, and data collection for ductile iron water main settlement monitoring:

1. The owner must provide monitoring point locations, either on the contract drawings or as a separate drawing. This information will be provided with the contract documents.
2. The installation, calibration, data collection, and analysis of results from the instrumentation must be performed by qualified individuals with a minimum of 5 years of previous experience with the devices or systems specified here. The contractor must provide an instrumentation specialist to be responsible for oversight of all monitoring at the site.
3. An equipment monitoring plan is required. SPU engineering and/or the SPU Materials Lab must approve monitoring methods and equipment in writing before the plan can be approved. Any comments from SPU must be addressed and the engineer must approve the plan before construction may begin.

4. The contractor must provide instrumentation systems for this monitoring and at all times during the monitoring program must be able to show that the equipment's calibration meets the manufacturer's minimum calibration requirements. Equipment to be used along with copies of specification sheets for the monitoring equipment must be included in the settlement monitoring plan. In case of equipment failure, the contractor must replace failed instruments within 24 hours of detection.

1.5 SETTLEMENT MONITORING PLAN

A settlement-monitoring plan is required before work can begin. The plan must detail the equipment and methods to be used to monitor settlement at the site. The plan should include how, where, when and who will set up the equipment, calibrate, and use it during construction at the site. The settlement monitoring plan must also list the information that will be included in settlement monitoring report and give an example of the report format (see section 1.6, Data Summary Reports). The monitoring plan must describe how the following will be met:

1. **Equipment.** What equipment will be used at the monitoring point locations to check for settlement? An example of this is utility settlement markers using a 1-inch fiberglass bar attached to the utility and placed inside a 1.5-inch PVC pipe riser.
2. **Equipment Protection.** Details on how the monitoring point equipment will be protected from damage or vandalism (e.g. locking covers or fencing the area off).
3. **Monitoring Point Installation.** How will the settlement points be installed before beginning excavation, tunneling, or dewatering near the utility? For example, the utility settlement markers cited in item #1 above would be installed by:
 - a. Excavating a small pit or hole above the pipe at each monitoring point
 - b. Cleaning the exposed pipe of debris in the area where the marker is to be attached
 - c. Affixing the fiberglass bar to the pipe
 - d. Encasing the rod with the PVC pipe riser that is cut to form a tight fit at the pipe
 - e. Back-filling the excavated area with the removed material or approved equal
 - f. Install pavement patch to match existing pavement
4. **Monitoring Frequency.** The monitoring plan must describe how and when the contractor will establish a baseline reading for the utility. At a minimum, the reading should be performed when within 50 feet of any utility monitoring point locations. When construction activities are adjacent to the utility, monitoring must be implemented. Monitoring frequency should in general occur as noted in Table 5B-3 (below) for a typical project. Project-specific frequencies differing from those in Table 5B-3 may be allowed but must first be approved by the engineer.

Note: Large and very deep excavations and tunnels generally have far-reaching long-duration settlement. They should have a settlement monitoring plan that modifies both duration and frequency to time frames that make sense for the project.

**Table 5B-3
Monitoring Frequency**

When	Duration	Frequency
Baseline: Before coming w/in 50 ft of first utility monitoring point	Once	Once
During Construction	While within 50ft of utility monitoring point	Once a day
After Construction	2 Months*	Every month*

*Or until two consecutive readings show no movement of the utility

5. Fixed Points. Describe how all elevations will be referenced to fixed points, which must be a minimum of 200 feet away from all excavations to assure that the reference points remain accurate. These fixed points (control points) must be shown in the monitoring plan.
6. Minimum Tolerance. The settlement monitoring plan must describe how the following minimum tolerance requirements for monitoring will be met:
 - a. Establish the initial elevations of monitoring points on all instrument elevation points to 0.01 foot.
 - b. Record the subsequent elevations of monitoring points and all instrument elevation points to 0.01 foot.
 - c. Establish the initial horizontal coordinates of deep cased bench marks, settlement points and all instruments to 0.01 foot.
 - d. Install instrument casings within 2° of vertical for the entire length and to the specified depth.

1.6 DATA SUMMARY REPORTS

Contractors must perform instrumentation readings and data collection, analyses, record keeping, and prepare daily data reports. Reports and monitoring frequencies can be scalable to the project. Smaller projects will not require the same level of reporting as that of large-scale earthwork projects. SPU requires two types of data summary reports:

1. Daily Data Report. This is a summary of data collected each day.
2. Project Data Report. This summary report must include an analysis of all monitoring data collected. This report is to be submitted to the engineer and the SPU Materials Lab at the end of the work. The overall analysis should include information from the daily reports (see below) and an overall evaluation of the data taken as a whole.

A daily summary of the data collected is required. This summary is due by the following morning, before construction resumes and shall include the items listed in the following section.

1.6.1 Daily Data Report

The report must include the following:

1. A short summary of the day's work that notes the work being performed, times that monitoring was conducted, and what work required the monitoring. The contractor should also include any observations that will help describe monitoring for the day.
2. A description of the work occurring when settlement monitoring indicates a vertical displacement of greater than 50% ($\frac{1}{2}$) the maximum allowed displacement from Table 5B-1 or Table 5B-2 above based on pipe size and soil conditions.
3. A copy of the day's raw data (electronic and hard copy)
4. A chart detailing the monitoring data that includes:
 - a. Time
 - b. Mean temperature
 - c. Reference elevation (last recorded elevation prior to the start of any construction for the project.) of each Monitoring point
 - d. Current elevation of each Monitoring point
 - e. Change in elevation if any between the reference and current elevations of each Monitoring point
 - f. Brief description of the work being done

1.6.2 Project Data Summary

This report will vary with project and is specified in the contract.

1.7 NOTIFICATION AND CORRECTION REQUIREMENTS FOR EXCEEDING

Any ductile iron water main settlement noted during monitoring must be reported to the engineer for evaluation as soon as possible and entered into the daily data report.

1.7.1 Non-Restrained Joint Pipe

If 50% ($\frac{1}{2}$) of the maximum deflection is detected, at the discretion of SPU's engineer, SPU will require leak tests and dig-ups of the pipe to determine conditions at the expense of the contractor. Based on the conditions found by this testing and investigation, repairs will be made to the pipe at the expense of the contractor where SPU's Engineer has determined the pipe to have been adversely impacted. The contractor may opt to replace the impacted pipe rather than pay SPU to perform dig ups and leak tests when less than maximum settlement has been detected.

If ductile iron water main displacements in excess of 75% ($\frac{3}{4}$) of the maximum settlement allowance are detected, the contractor is required to stop work and consult with SPU to determine how work can proceed and whether remedial action is required.

If ductile iron water main displacements exceed the maximum settlement allowed per the pipe replacement trigger tables (Table 5B-1 and Table 5B-2), SPU requires replacement of all affected sections of ductile iron pipe at no additional cost to SPU.

1.7.2 Restrained Joint Pipe

The same criteria shall be applied to Restraint Joint Pipe as is described in Non-Restrained Joint Pipe (section 1.71.) If there are no existing expansion fittings in the pipe segment and 50% ($\frac{1}{2}$) of the maximum displacement is detected, expansion fittings must be cut into the pipe on each side and possibly in the middle of the settlement trough to relieve stress in the pipeline and allow further movement.

1.7.3 Further Actions

If any abnormal displacements, settlements in excess of allowable, or damage is noted, immediate steps must be taken to stop the causes of displacements or settlements. The contractor must prepare and execute a corrective program within 24 hours of identification of the problem at no additional cost to the City of Seattle. This plan must be reviewed and stamped by a Registered Geotechnical Engineer familiar with the work. Remedial measures may require modifications of construction procedures, up to and including replacement of the effected section of ductile iron water main with ductile iron pipe.