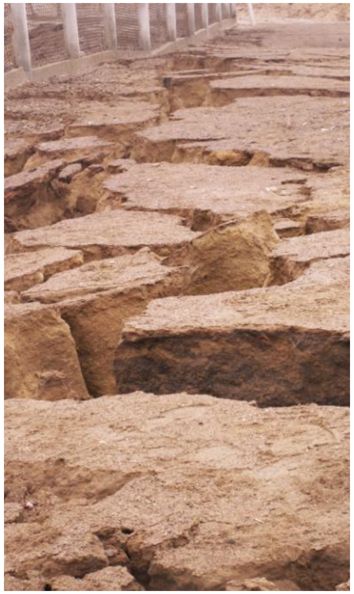
Development of Seismic Design Guidelines for Distribution Piping



PNWS AWWA

Spring Conference, May, 2013

Presented by Donald Ballantyne, PE Principal,
Degenkolb Engineers

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Overview

- Need for Guidelines
- AWWA Process
- Level of Service
- Earthquake Hazards
- Pipe Design
- Pipe Systems
- Questions

Need for Design Guidelines

- No well vetted document exists
- Pipe damage stretches out post-earthquake recovery
- 10,000s of miles of pipe will be replaced in the decades ahead – Do It Right
- 95% of pipe installations not "engineered", off the shelf guideline would fill gap
- "Standard" would encourage manufacturers to develop compliant products

Seattle Pipe Assets

Pipe Material	1,000 Ft	%
Cast Iron	6,481	82
Ductile Iron	810	10
Joint Type		
Lead Joint	4,392	56
Gasket Joint	1,422	18
Slip Joint	1,245	16

AWWA Process

- PNWS, Cal-Nevada Section Engineering Committees have committed to support
- AWWA committees will require representation from manufacturers, utilities, and consultants
- AWWA Standards Council, standard development may be difficult to achieve due to requirements for committee member concurrence – in fighting between pipe manufacturers
- AWWA Technical and Education Council may provide a more straight forward route to getting a "Manual of Practice"

Level of Service

- Resilient OR/WA level of service for existing systems
- Replacement of existing pipe is the biggest financial issue
- New pipe – consider building codes
- ASCE 7-05/ IBC – Classification of Buildings and Other Structures
  - Occupancy Category IV, Essential Facilities - Water facilities and pump station structures required to maintain water for fire suppression
  - Occupancy Category III – Buildings and other structures with potential to cause a substantial impact and/or mass disruption to day-to-day civilian life in the event of failure – Water treatment plants

- Other level of service goals

Earthquake Hazards Affecting Pipe

- **Shaking (PGA/PGV)**
  - Wave propagation acting longitudinally on the pipe
  - Surge/transients
- **Permanent Ground Deformation (PGD)**
  - Fault movement
  - Lateral spread – liquefaction or clay layer failure
  - Landslide
  - Differential settlement

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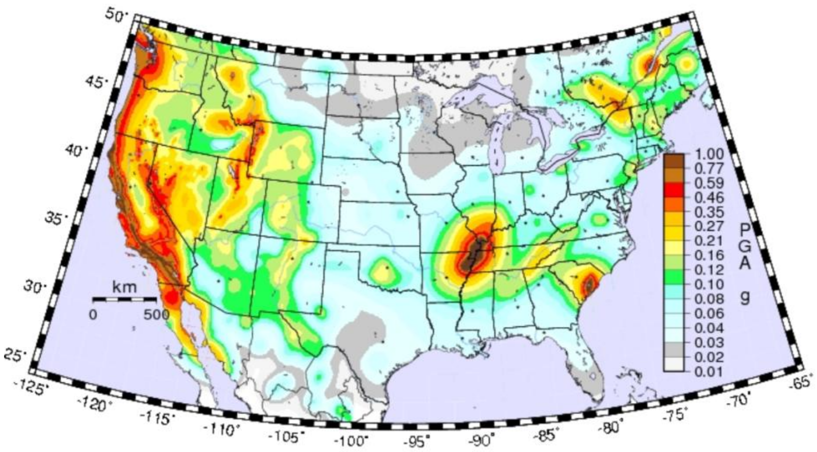
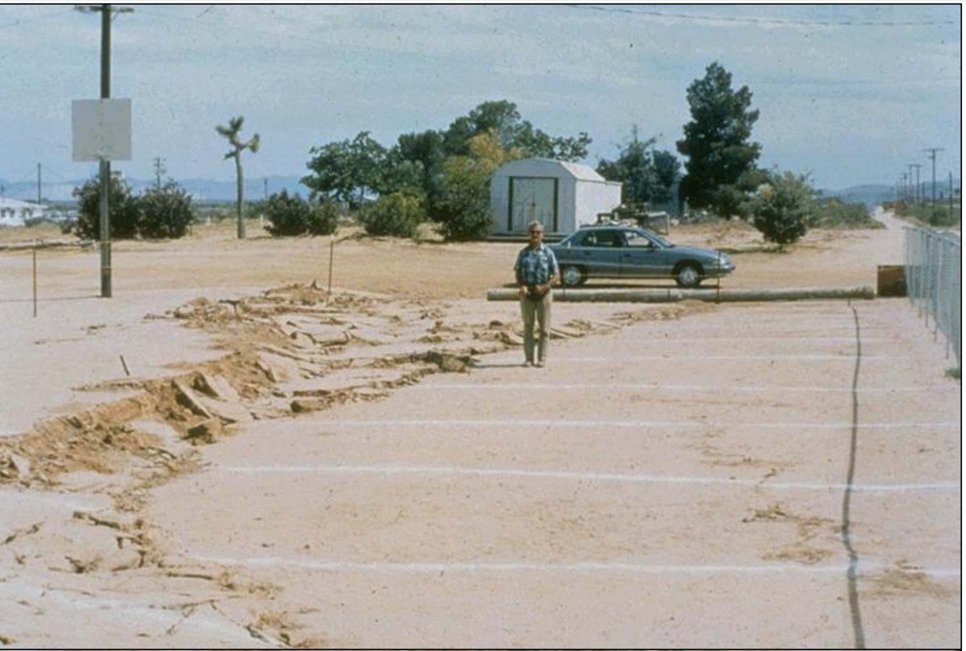
Shaking / Wave Propagation



- USGS
- Occupancy Categories
  - III – 2,475 year return X 2/3 X 1.25
  - IV - 2,475 year return X 2/3 X 1.5
- Take into account site amplification using soil classifications A (rock) -E (liquefiable)
- PGA used to calculate liquefaction probability
- PGV used to calculate differential longitudinal movement along the pipe

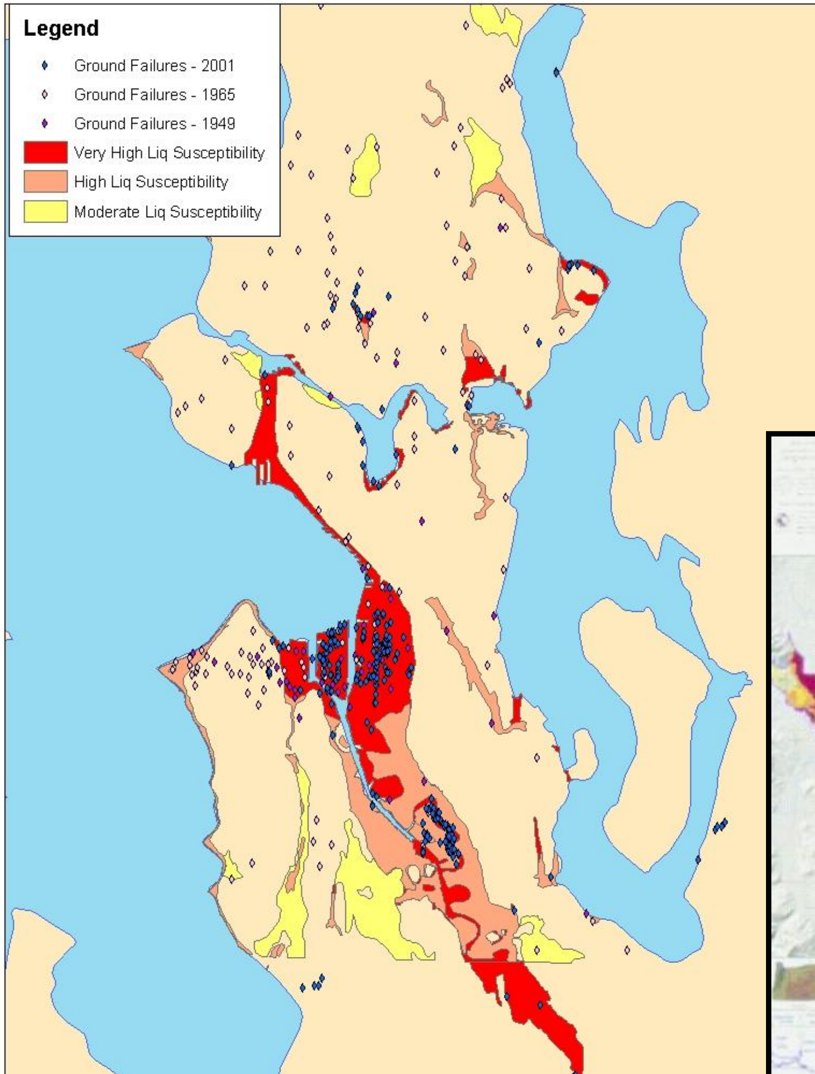


Fault Crossings

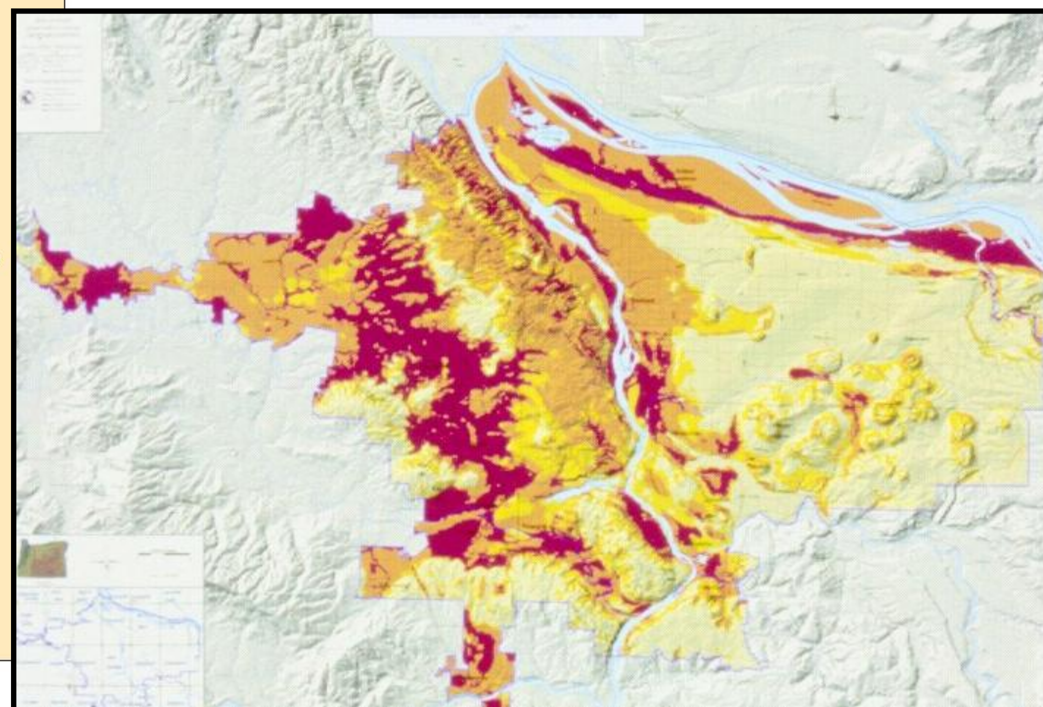
- Many faults in PNW are normal, and may not have clearly defined trace
- Probably do site specific assessment to define geometry and displacements

Liquefaction Susceptibility, Probability

- Susceptibility a function of soil parameters
- Probability a function of susceptibility, PGA, duration, and groundwater table
- Susceptibility mapping available for many populated areas

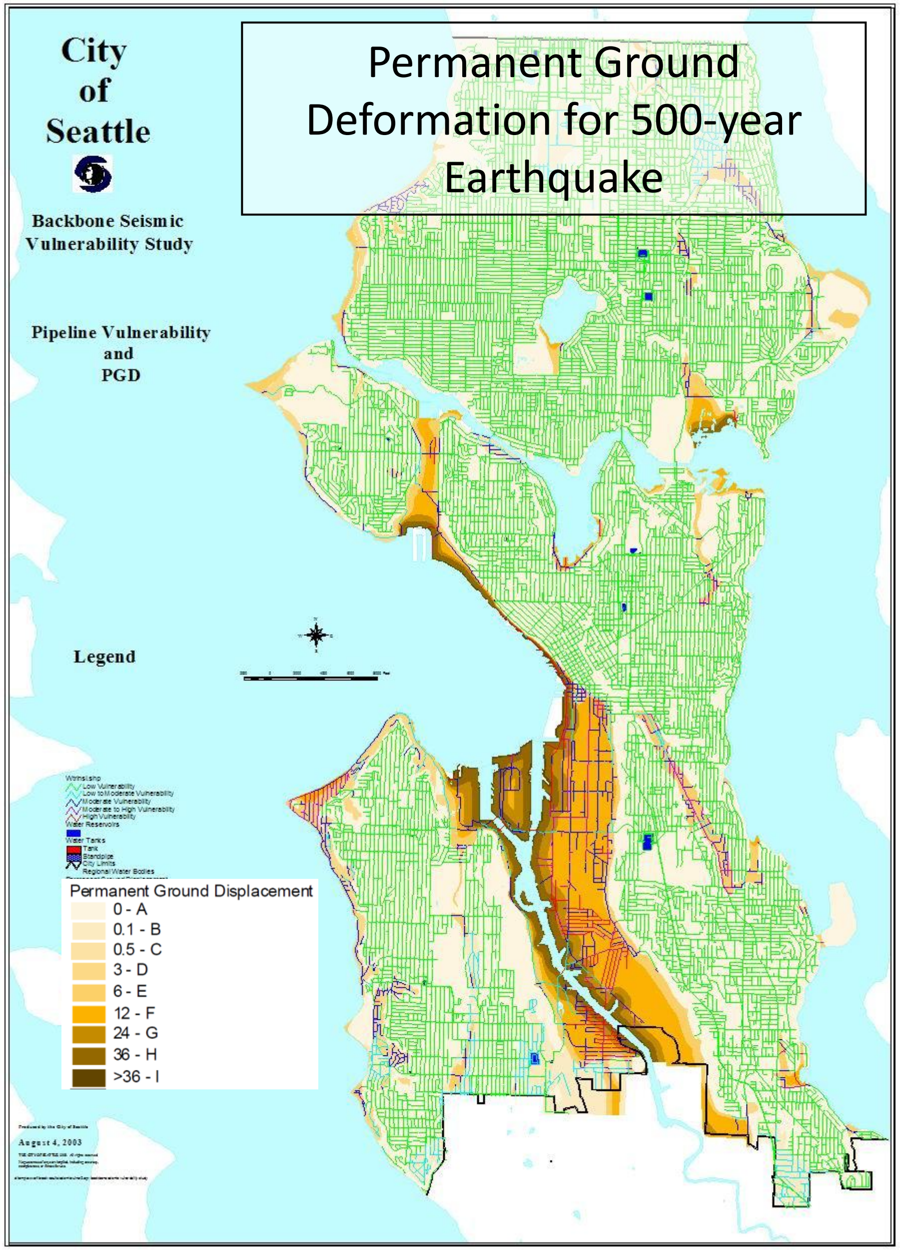


Seattle - Susceptibility



Portland Metropolitan Area - Susceptibility

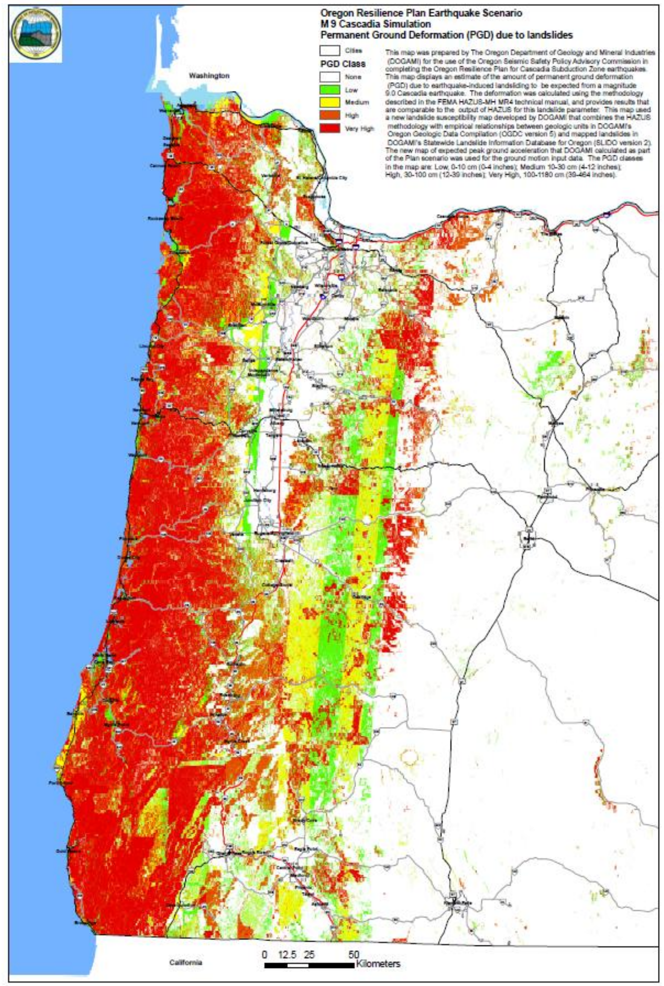
PGD - Lateral Spread, Settlement



- Function of liquefaction susceptibility, PGA, duration, and soil parameters
- Liquefaction PGD developed by DOGAMI for Resilient Oregon
- Otherwise limited availability
- No mapping available for settlement
- Question – what level of detail is required?

PGD - Landslide

Seattle



Western Oregon

- Methodology not well developed
- Limited availability and/or large scale
- Qualitative

Pipe Design – Wave Propagation

- Brittle pipe joints (lead, mortar) vulnerable)
- Modern pipe OK – unrestrained DIP and PVC, continuous pipe
- Caution about fill, other unknowns
- Potential concern in soft soils with very large PGVs
- Concern about hydraulic transients

Pipe Design – PGD

- Unrestrained segmented pipe (bell and spigot joints) have limited capability – dependent on bell depth
  - PVC has deeper bells and would be expected to perform better
  - Possible use for areas with small settlements and no PGD
  - PGD threshold from unrestrained to restrained/continuous is TBD

Pipe Failure Rates - Kobe, Japan, 1995

Due to PGD

- DIP (unrestrained joint) performed well except for joint pull-out, i.e., the pipe did not break
- PVC pipe suffered barrel, fitting, and joint failures in addition to joint pull-out

Failure Mode	Failure Rates/km - Number of Failures									
	DIP		CIP		PVC		Steel		AC	
PipeLlength (km)	1874		405		232		30		24	
Barrel	0	9	0.63	257	0.38	88	0.33	10	1.24	30
Fitting	0	1	0.31	124	0.17	40	0.03	1	0.04	1
Pulled Joint	0.47	880	0.49	199	0.33	76	0	0	0.37	9
Joint Failure	0	2	0.06	25	0.50	115	0.07	2	0.08	2
Joint Intrusion	0	5	0	1	0.01	3	0	0	0	0

Pipe Design – PGD

- Restrained joint segmented pipe (DIP, PVC)
  - Assumes the pipe can withstand shear and bending (PVC?)
  - Pipe joints will not separate
  - Designed so pipe segments will be pulled through the soil to distribute the PGD.
  - Movement 1,000'+ from PGD
  - Dependent on the pipe joint/barrel system capacity to transfer longitudinal load to the next pipe
  - At some level of PGD (TBD), the longitudinal displacement must be released or the joint/barrel system will fail at the weakest point
  - Incorporate extension/compression release joints/fittings

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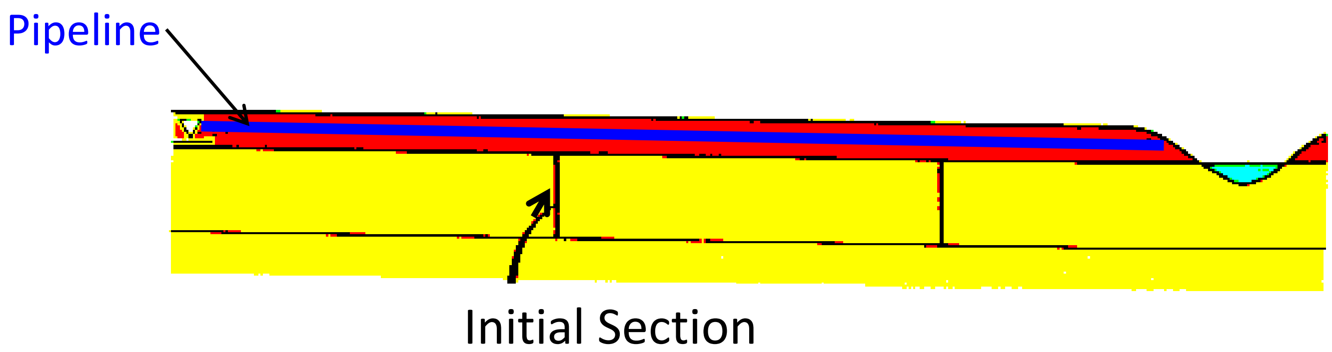
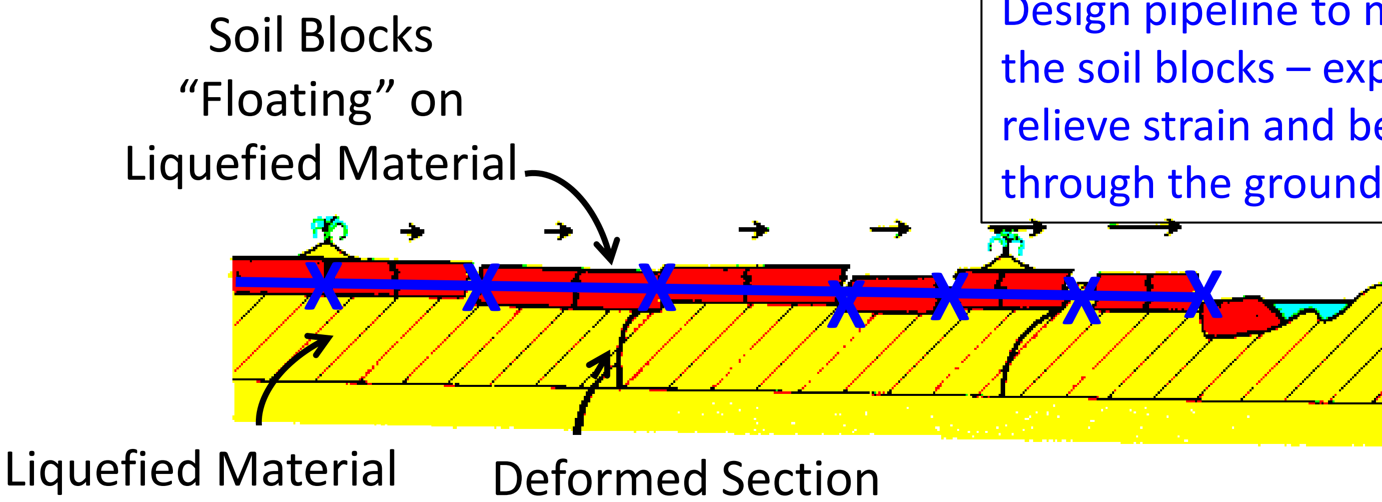
Lateral Spread



Design pipeline to move with the soil blocks – expand to relieve strain and be dragged through the ground.



Pipe Design – PGD

- Restrained joint segmented pipe (DIP, PVC) – continued
  - Potential failure locations at hard points
    - Services
    - Tees and crosses
    - Valves
    - Vaults
  - Special designs for hard points
  - Reduce longitudinal loading:
    - Reduce soil-pipe friction using wraps or coatings
    - Reduce the joint cross section

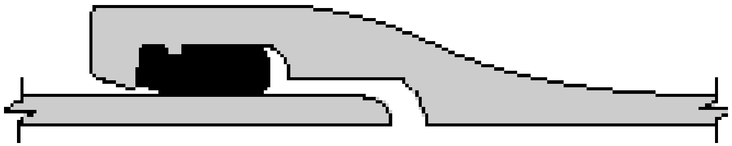
Pipe Design – PGD

- Continuous pipe (Steel with welded joints, HDPE, Fused PVC)
  - Assumes the pipe can withstand shear and bending
  - Designed so pipe will be pulled through the soil to distribute the PGD
  - Movement 1,000'+ from PGD
  - Dependent on the pipe capacity to transfer longitudinal load along the pipe
  - **PGD is accommodated by pipe strain in compression or tension**
  - Potential failure locations at hard points
  - Reduce longitudinal loading:
    - Reduce soil-pipe friction using wraps or coatings

Modern and Emerging Pipe Systems

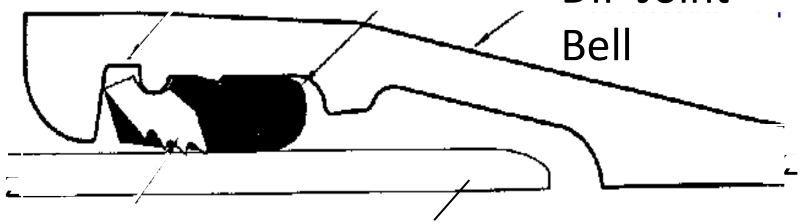
- Ductile Iron C-150
  - Field lock gasket - restrained joint
  - Joint harness - restrained joint
  - Mechanical - restrained joint
  - Restrained Joint with Expansion Sleeve
  - Seismic Joint
- PVC C-900
  - Traditional push-on
  - Deep Bell – 2X depth to accommodate expansion (Kubota)
  - Joint harnesses - restrained joint
  - Bulldog joints - restrained joint
  - Deep Bell/Restrained joint
- PVCO C-909 – same as C-900
- HDPE C-906 – fused joint

Ductile Iron Pipe AWWA C-150, Push-On Joint



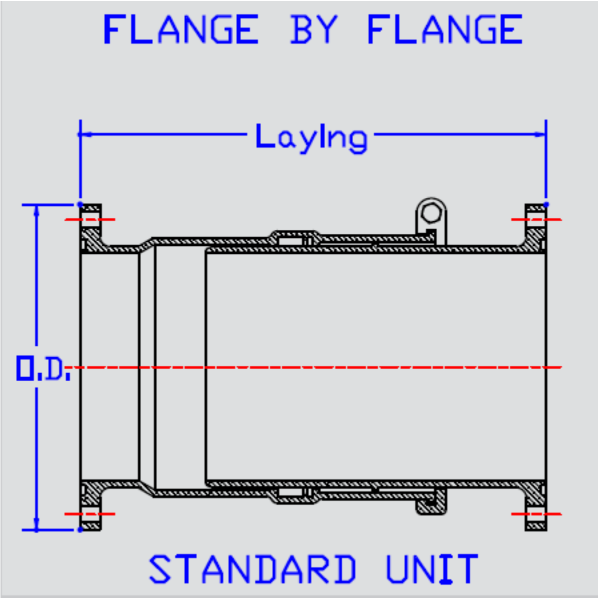
- Material strength and ductility
- Wedge effect - lessens potential for telescoping ?
- Joint depth and potential pull out – not as deep as PVC

Ductile Iron Pipe (DIP) AWWA C-150 with Restrained Joint (Field-Lok Gasket)



- Design to resist ground movement
- Material strength and ductility
- Restrained joint
- Does not allow release of strain due to ground deformation
- Can be installed with expansion sleeves for strain relief

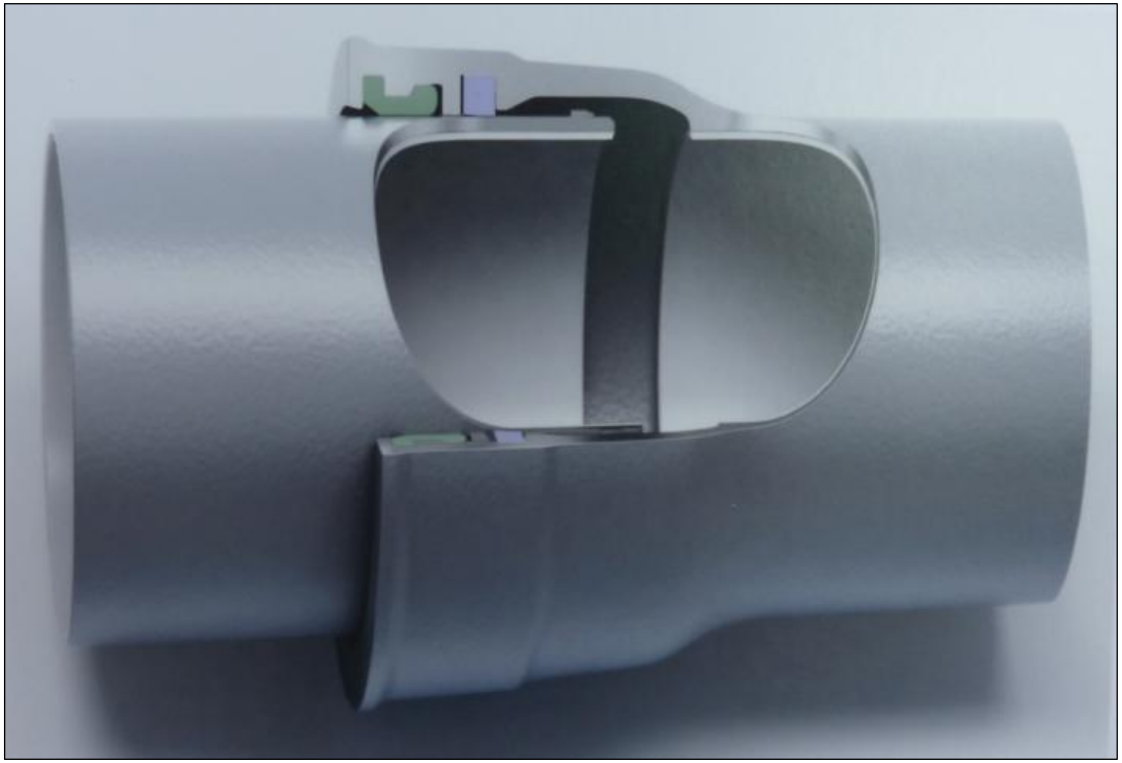
Ductile Iron Pipe Expansion Sleeve



EBAA Ex-Tend

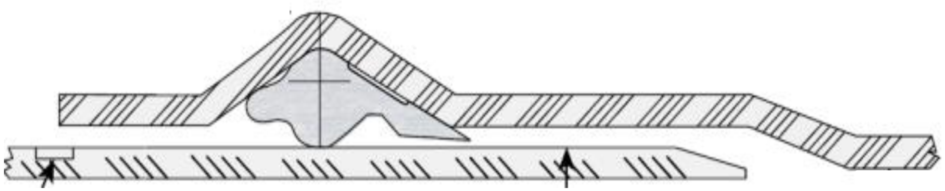
- Expansion sleeve for strain relief
- \$900 - 8”; \$1,200 – 12” EBAA Ex-Tend
- Proposed “custom” expansion sleeve – hook into the bell with a split harness; about half the above cost

Genex Japanese Seismic Joint DIP



- Restrained joint
- Allows expansion/compression

Polyvinyl Chloride Pipe - AWWA C-900 with Push-On Joint



- Brittle compared to DIP
- Less joint rotation capacity than DIP
- Wedge effect worse than DIP
- Joint depth (potential pull out) deeper than DIP
- Good in corrosive soils

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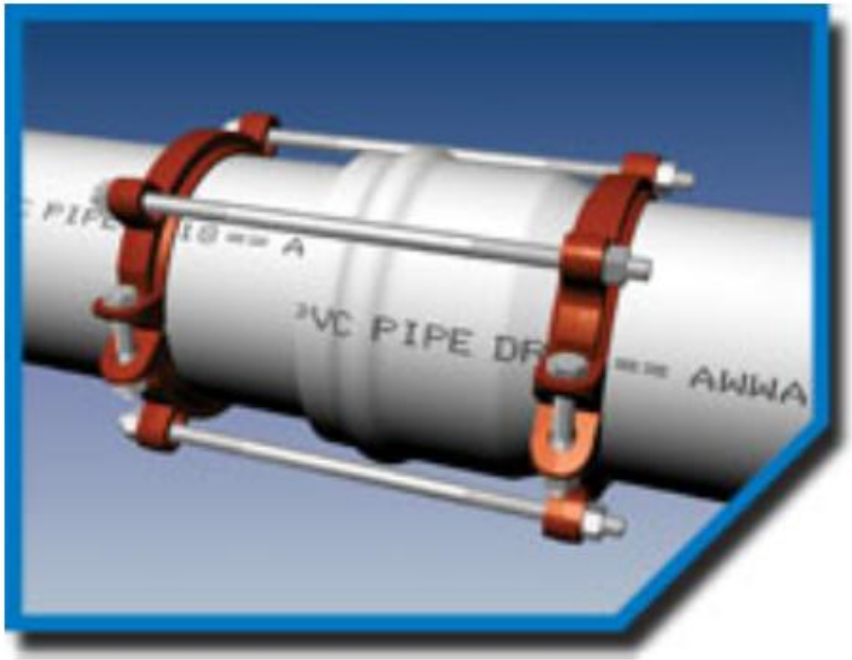
PVC (C-900) with 2X Deep Bell and Joint Harness

(Manufactured by Kubota)

- Vulnerable to corrosive soils
- Expansion can be provided for strain relief

Polyvinyl Chloride (PVC) AWWA C-900 with joint restraint



Joint Harness – Add anode caps on bolts?

Bulldog Joint – "Wedge" Ring Embedded in Joint

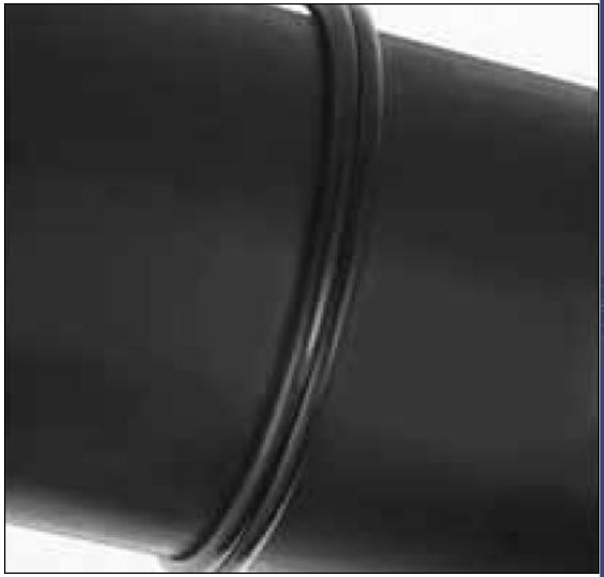
- Vulnerable to corrosive soils ?
- No expansion allowed for strain relief

Molecularly Oriented PVC AWWA C-909

- Stronger and more ductile than C-900 PVC
- Used in the UK
- Little track record in the US
- Joint types
  - Push-on with harness
  - Bulldog
- Appears to have capability to telescope (compress) without loss of hydraulic integrity with joint harness

High Density Polyethylene (HDPE) AWWA C-906 – Fused Joint

- Excellent performance in Christchurch and Tohoku earthquakes as well as Northridge (Gas)
- Relieves strain through ductility
- Widely used in the UK
- Varied experiences
  - Palo Alto – moving to HDPE, use for gas, water, and sewer
  - Burnaby, BC – no longer using due to joint failures (lack of QC during joint cooling)



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Questions?

Criteria	CIP*	PVC	PVC w/ Restraint	PVCO	PVCO Deep Bell/ Restraint	DIP	DIP w/ Restraint	DIP w/ Restraint, Expansion Sleeve	DIP Seismic	HDPE
Ruggedness	1	2	2	3	3	3	3	3	3	3
Bending	1	2	2	3	3	3	3	3	3	3
Joint Flexibility	1	2	2	2	2	3	3	3	3	3
Joint Restraint	1	1	3	1	3	1	3	3	3	3
Strain Relief	1	2	1	1	3/1	1	1	3	3	3
Corrosion Resistance	1	3	2	3	2	1	1	1	1	3
Familiarity with Use	3	3	3	2	2	3	3	3	2	1
Availability	1	3	3	1	1	3	3	3	1	3

Legend: * for comparison purposes
3-High/Excellent, 1-Low/Poor

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