AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

AASHTO

COMMITTEE ON MATERIALS and Pavements

2018 Annual Meeting – Cincinnati, OH
Tuesday August 7, 2018
10:15 – 12:00 PM EDT

TECHNICAL SUBCOMMITTEE 4b
Flexible and Metallic Pipe
Minutes

TS 4b 2018 Annual Meeting Summary		
Meeting Date:	8/7/2018	
Items approved by the TS for Committee and or Technical Subcommittee Ballot:		
Standard Designation	**Page Numbers/Section Titles for Proposed Changes in Minutes**	**Technical Subcommittee and/or Committee?**
New Standard	Proposed new Standard Practice for Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled Content R XX. See end of B, TS Ballots Item 1 in minutes.	COMP
New Standard	Proposed new Provisional Standard Specification for Steel-Reinforced Polyethylene (SRPE) Corrugated Pipe MP XX. See end of B, TS Ballots Item 2 in minutes	TS Only
M335	Revise Standard Specification for Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 1500-mm (12- to 60-in.) Diameter M335 -18 to increase diameter to 3000-mm (120 in.). [Note: this was balloted previously and did not pass. Changes are being made and the item balloted again]. see very end of B, TS Ballots Item 3 in minutes	TS Only
M335	Change thickness specified so that it matches what is actually manufactured in the United States. See very end of B, TS Ballots Item 3 in minutes	Concurrent Ballot
M 294	Change to make tolerance match M 330, See agenda item G, Proposed New Task Forces	Concurrent Ballot

M 330	Change to make tolerance match M 294	Concurrent Ballot
New Task Forces Formed: None		
Task Force Name	**Summary of Task**	**Names of TF Members**

Other Action Items:
None.

I. Call to Order and Opening Remarks

The meeting was called to order at 10:15 AM. The chair thanked everybody for attending the meeting today and encouraged discussion amongst members and industry experts.

II. Roll Call

Voting Members

Name	**State**	**Present**
Bailey, William R.	Virginia	X
Peoples, Christopher A. Proxy Brian Hunter	North Carolina	X
Ingram, Steven	Alabama	X
San Angelo, Michael	Alaska	
Pinkerton, Jennifer M.	Delaware	X
Knight, Chase	Florida	X
Douds, Richard Monica Flournoy	Georgia	X
Trepanier, Jim Brian Pfeifer	Illinois	X
Niehaus, Curt	Kansas	X
Davis, Jason	Louisiana	X
Bradbury, Richard L	Maine	X
Fung, Clement	Massachusetts	
Kline, Therese R.	Michigan	X
Trautman, Brett	Missouri	X
Streeter, Donald A.	New York	X
Horner, Ron Matt Linneman	North Dakota	X
Lane, Becca	Ontario	
Ramirez, Timothy	Pennsylvania	X
Short, Temple	South Carolina	X
Egan, Brian	Tennessee	X
Williams, Kurt Dave Jones	Washington	X

Friends and Non-Voting Members

Roll call not done for friends and non-voting members

Name	Affiliation	Present
Malusky, Katheryn	AASHTO - Liaison	
Fragapane, Ryan	AASHTO - Liaison	
Clawson, Chad	AASHTO	
Lenker, Steven E.	AMRL	
Uherek, Greg	AMRL	
Knake, Maria	AMRL	
McGough, Michael	NCSPA	
Chestnut, Brian W	Lane	
Currence, Daniel	PPI	
Christensen, Heather	Prinsco, Inc.	
Beakley, Josiah W	ACPA	
Pluimer, Michael	Crossroads Eng.	
Delery, Oliver	Forterra	
Paredes, Mario	TRI/ENV	
Baryluk, Greg	ADS	
Sarcinella, Robert	AASHTO	
Stolarski, Phil	California	
Kemp, Peter	Wisconsin	

III. Approval of Technical Subcommittee Minutes

Approval of January 3, 2018 Mid-Year Webinar minutes

There were two corrections to the meeting minutes that were discussed- one member was was miscounted as a concrete pipe member and is actually a friend of the TS. Also, Temple Short was in attendance but was not accounted for in the minutes. A motion was made by Missouri to approve the minutes and a second by Alabama. The minutes were approved with corrections unopposed.

IV. Old Business

A. **SOM Ballot Items** – Items were addressed at Mid-Year Webinar

B. TS Ballots

COMP TS4B 18-01 Spring Ballot results - Closed June 19, 2018

Item 1: Propose a new Standard Practice for Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled Materials R XX. This standard practice details the procedure for determining the service life of corrugated high density polyethylene (HDPE) pipes manufactured with recycled materials relative to brittle failures via the slow crack growth mechanism. This standard practice is applicable for pipes containing recycled materials and manufactured in accordance to M 294. It is applicable both for pipes manufactured with post-consumer recycled (PCR) materials and post-industrial recycled (PIR) materials. It is not intended for pipes manufactured with virgin materials.

The standard specification passed technical section ballot with 16 affirmative votes, 0 negatives and 4 no votes. **Show Attachment #1 - Item 1 FDOT.docx**

Pennsylvania Comments:

1. In Section 1.5, this text is same as text in M 294, Section 1.3, but it seems to be lacking clarity on use of the U.S. customary units. Can it be made clear that the U.S. customary units can be used in the calculations? Or, since the SI units are standard, should the SI units always be used? Also, this standard does not always use the SI units as the standard showing equation inputs and calculation results in U.S. customary units (e.g., Section X1.10 and use of "500 psi" and Table X1.1 results in "psi"). However, the SI units for temperature were used for the equation inputs and calculations shown in Section X1.6. Appendix X1 is non mandatory; however, should the equation inputs and calculations in Appendix X1 all show and use the SI units based on existing text in Section 1.5? **Florida has inserted most of the SI unit conversions in the Attachment #1 - Item 1 FDOT.docx. The Chair will check these conversions with Author and publication staff.**
   The comments from Florida will be added in editorially.
2. In Section 3.1.2, 2nd line, revise from "and micro-cracks and around a contaminant" to "and micro-cracks around a contaminant". **Agree** Change will be made editorially
3. In Figure 1, I assume that a better figure will be used in the published standard since the break point between Stage I slope and Stage II slope does not align properly with the dimension for tCI (time for crack initiation). **Since tci and tcp are arbitrary assignments relating to the time for Stage II failures to initiate and propagate, they are unrelated to the Stage I failure mechanism. The Author doesn't see a need to change the figure.** The line is an arbitrary illustrating that there are two points in the stages of breaking, a time for the cracks to initiate and a time for them to propagate- it is completely theoretical component of the figure. It is not meant to line up with the point between Stage I and Stage II. In order to resolve this issue, a footnote will be added to explain the illustrative purposes of the line. This will be added editorially.
4. In Section 4.2, suggest revising from "in accordance to" to "in accordance with". **Agree – FL made same comment**
5. In Section 4.3, 1st line, suggest revising from "in accordance to" to "in accordance with". **Agree - FL made same comment**
6. In Section 4.3, 1st line, consider revising from "on five specimens at each of a minimum of three test conditions" to "on five specimens at each test condition for a minimum of three test conditions" for perhaps slightly better clarity. **Will consider**
7. In Section 4.6, 3rd line, suggest revising from "Step 3" to "Section 4.3". **Agree - FL made same comment**
8. In Section 5.1, 1st line, the text "for at least 8 pipes manufactured with typical recycled material blends" is not very clear as to its intent. Are these 8 sticks from the same lot of pipe with all 8 sticks having the same typical recycled material blend? Or, is the intent that these are 8 sticks of pipe each from a different lot and each potentially having a different recycled material blend (i.e., different % recycled content) representing the typical % recycled blends that the manufacturer will typically use during manufacture at a plant? **The Chair believes the intent is to use 8 sticks of pipe of the same lot with the same recycled percentage.**
9. In Section 5.3, 2nd line, revise from "given service conditions (i.e.," to "given service conditions [i.e.," as the closing symbol in 3rd line is "]". **I think I understand what is being said here. The second line has a parenthesis "(", but there is not a matching**

end to the parenthesis ")", later in the sentence. Or there may be too many [ ] or non-matching [ ].

10. In Section 5.3, 3rd line, suggest revising from "It is suggested to use" to "For the test condition, it is suggested to use" to provide better clarity; otherwise, the intent of this sentence is a little confusing. **Agree**

Florida Comments:

1. Suggest a title change to: **Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled Content** **Author is ok with change.** The Technical Subcommittee agreed with this change and the title will be corrected for COMP ballot.
2. Change Section1.1 to reads: This standard practice details the procedure for determining the service life of corrugated high-density polyethylene (HDPE) pipes ~~manufactured with~~ *containing* recycled materials. *Service life is* relative to Stage II brittle failures via the slow crack growth mechanism. **Author is ok with change. TS?**
3. Section 1.4 insert *only* before virgin materials at the end of the sentence. **Agree**.
4. Section 3.1.1 **Question:** Could lower grade HDPE have the same effect as an inorganic contaminant? **Explanation: No, an inorganic contaminant acts as a stress riser that will shorten the time for crack initiation, while a lower grade virgin HDPE resins will have shorter times for crack propagation**.
5. Section 4.2 and 4.3 same comment as PA 4 and 5. **Agree**.
6. Insert initials for coefficient of variation *(COV)* in Section 4.3. **Agree, will check with Publication staff**.
7. Section 4.5; First sentence says to plot log time on the Y-Axis, should be X-Axis. **Agree, see NY comment.**
8. Rewrite Section 4.5 to read: "Plot the resulting three ~~(or more if additional conditions are evaluated)~~ shifted average data points on a log–log scale, with log time on the X-axis and log stress on the Y-axis. Determine the best-fit curve for the data points, which should be linear on a log–log scale. More data points may be utilized if additional conditions were evaluated." **Agree**
9. In Section 4.6, 3rd line, suggest revising from "Step 3" to "Section 4.3". **Agree See PA comment.**
10. In Section 5.3, 4.3.1, 4.3.2, 4.3.3 4.4, X1.6, X1.7 and X2.1 other places metric conversion placed into standards. **Agree, but will get Publication staff to check.**
11. In Section X1.4: Take the logarithm ~~(Log *t*)~~ of each failure time *(Log t)* and calculate the log-based average of each five-specimen data set. **Agree**
12. X2.2
13. X2.8 reword to: X2.8. ~~Rounding up for conservatism~~ Using the rounding procedure specified, the minimum average UCLS failure time for five specimens at Condition I [80° deg. C (176°F) and 4.48 MPa (650 psi) stress] should be ceiling (33.1) = 34 h to ensure 100-y service life in conditions that result in a factored tensile wall stress of 500 psi at a temperature of 23°C (73.4°F). Furthermore, no single specimen should fail in less than ceiling (17.33) = 18 h. **Will research and discuss with TS then make a decision**. **Author is not familiar with the terminology "ceiling(x,x)". However, if that is an acceptable terminology to indicate "rounding up to the nearest integer", then it is acceptable.** This change will be made before COMP ballot.
14. X2.8 Question for TS Consideration: Since this is in the example, I would suggest making it a requirement in 5.3 and 5.4 i.e. "minimum required average failure time = ceiling(t_T)" and "average failure time needed for 95 percent confidence = ceiling(X_95)" **Will research and discuss with TS then make a decision**. **See answer to 13 above.** See 13 above.

New York Comments:

1. Section 4.5; First sentence says to plot log time on the Y-Axis, should be X-Axis. **Agree**
2. Appendix X1**;** Section X1.1; Last sentence, Table X.1. Should be shown as Table X.1.1 **Agree**
3. Section X1.8; Last sentence, Figure X.1 should be shown as Figure X1.1 **Agree**
   Section X1.10; First sentence; Figure X.1 should be shown as Figure X1.1 **Agree**

South Carolina Comments:

- Section 2.3 - Remove current reference to a dissertation and replace it with NCHRP Report 870. **Will consult with Publication staff**
- Figure 1 and Section 5.3 - Remove references. These aren't needed in an AASHTO standard. If necessary, can just reference NCHRP Report 870. **Will consult with Publication staff**

Virginia Comments:

- Since there is an AASHTO Standard for HDPE pipe made with recycled materials, it makes sense to have a way of determining service life for varying contents if DOTs wish to do so.
- One other comment is that Pluimer 2016 is referenced in Section 5.3, so that references should be listed at the end under a References section. Compared to another AASHTO Practice, R-8, which does it that way. **Will check/discuss with publication staff.**

Comments from Friends of the Committee:

American Concrete Pipe Association (Josiah W Beakley)**:**

- This is supposed to be a standard to determine the service life of the pipe. How can you establish the service life of the pipe if you are not evaluating the pipe in its finished form?
  This standard is an estimate of service life based on introducing recycled resin into the manufacture of HDPE pipe in which the failure mode is anticipated to be a brittle fracture. The NCLS test is a test on the finished pipe. Pipe manufactured with recycled content must pass a UCLS and NCLS test which are performed on finished pipe. The NCLS test is still tested on the finished product, both with pipes made with virgin materials and those made with recycled materials. Compression molded specimens taken from finished product are used for contaminant tests.

Michael Pluimer Ph.D. PE:

This is an important standard practice for states considering the use of corrugated HDPE pipes manufactured with recycled materials in accordance with the new M 294-18 standard. The standard practice details the procedure to determine the service life of any pipe manufactured with post-consumer or post-industrial recycled materials relative to cracking via the slow-crack-growth mechanism. It also provides a methodology to establish minimum un-notched constant ligament stress (UCLS) criteria to ensure a desired service life at a given service temperature and wall stress. The standard practice involves conducting constant-stress tests on coupons of pipe at elevated temperatures and stresses and then using Popelar shift factors to project the failure times to other service conditions. This standard practice utilizes established methodologies and principles that have been used for decades

in the pressure pipe industry and is virtually the same procedure as utilized by the Florida DOT and Pennsylvania DOT for their corrugated HDPE pipes for 100-year service life applications.

Based on the discussions and explanations provided what action should the Technical Subcommittee exercise with this Standard?

Resolution:

A motion was made by Maine and a second by Missouri to move this item to COMP Ballot this fall. The motion passed unopposed.

Item 2: Propose a new Provisional Standard Specification for Steel-Reinforced Polyethylene (SRPE) Corrugated Pipe MP XX. This proposed new specification covers the requirements and methods of tests for steel-reinforced polyethylene (SRPE) corrugated pipe, couplings, and fittings for use in surface and subsurface drainage applications. This new proposed Polyethylene pipe with a corrugated structure contains two reinforcing steel profiles. One steel profile for SRPE pipe is proposed for diameters 300 to 1050 mm (12 to 42 inches) and a separate steel profile is proposed for pipes 1200 to 1800 mm (48 to 72 inches).

The specification passed technical section ballot with 15 affirmative votes, 1 negative and 4 no votes. Show **Attachment #2 -Item 2 FDOT.docx**

The negative from Florida and the comments from others brings up several concerns regarding the standard. In order to addressed the biggest issue regarding the bell and spigot: It is noted that there is room from improvement in the specification of the polyurethane bell and spigot. This language will be removed and the use of a split coupler will be added. Several changes will be made to mirror language in M294 as suggested by Florida. A revised draft has been developed. Florida still has concerns regarding the most recent version of the draft that they have seen and has suggested that a Technical Subcommittee ballot be submitted with revised wording. The results of this ballot can be reviewed during the mid-year meeting, and then can go to COMP after that. The Chair can place an administrative negative at COMP and can specify that this should only pass if this item passes the LRFD Bridge Design Guide to hold the item until we know what will happen with the bridge specification.

Bridge testing is ongoing on pipe diameters and profiles. This test data will be incorporated into the bridge standard once complete. The AASHTO bridge specification is expected to be approved by May 2019. Concerns were expressed that the largest diameter material (72") was is not being tested, 48" is the largest diameter being tested. This is a departure from the way this has been handled in the past, where we have required that the largest diameter pipe be tested.

Florida asked when spiral pipe is cut to length the reinforcing steel is exposed. How is this treated when exposed at the termination point? Typically a coating (asbestos, paint) is placed on the material to prevent coating. Corrugated pipe is different, as you can cut so that the steel is not exposed. Florida would like to see this addressed in the standard as well. The steel used is typically galvanized, and this is specified in the second draft that will be distributed.

Florida Negative:

This specification should be revised to more adequately address the use of a non-HDPE material (polyurethane) for the bell and spigot. Detailed comments and suggested are within the **Attachment #2 -Item 2 FDOT.docx**.

1. The title does not fully describe the pipe, as the bell and spigot are made of polyurethane
2. **Exposure** To what? **Ends of Pipe**
3. **Protection** With what? **Ends of Pipe**
4. Clarify v shaped profile. Label wall **Agree, Clarification is needed**
5. Suggest using terminology similar to M294… inner wall/liner, valley, corrugation/rib, etc. **Agree**
6. Why only pipe barrel? **Clarification needed**
7. Why is this lower than required for MP20? **Clarification needed**
8. Check if cell classification states minimum **Clarification needed**
9. ASTM, AASHTO **Both are ASTM Steel Specifications**
10. Add reference to Figure 2 and clarify where encapsulation will be measured. **Agree**
11. This is a major concern. The spec (title) does not allude to having PU bell/spigot. Immediate question of whether some or all the bell and spigot properties (stiffness, brittleness, impact resistance, etc.) need to be considered/tested separately. **Clarification needed**
12. Figure two does not illustrate location of "sides, top, and bottom." The terminology generally seems confusing and requires clarification. **Agree**
13. Improve figure clarity and labelling **Agree**
14. Suggest specifying a minimum unperforated distance from bell/spigot **Agree**
15. Valleys **Agree**
16. Suggest requirement for PU bell/spigot as well for pipe flattening **Agree**
17. Suggest requirement for PU bell/spigot as well for impact testing **Agree**
18. This statement is unclear, remove or give more details **Clarification needed**
19. What about other properties? **Clarify**
20. Not clear on couplings **Agree**
21. Potentially should be repeated for PU bell/spigot (testing routine) **Agree**
22. Will need some kind of resin test for PU material of bell/spigot as well **Agree**
23. Inner and outer wall not previously defined/illustrated. Provide more specific instructions/standards for knife test. Need to consider evaluating bond between HDPE and PU. **Clarification needed**
24. Add instructions to ensure that steel has not been nicked or cut into **Agree**
25. Will be M 335. Also, why not place requirements here independently? **Clarify**

Pennsylvania comments:

1. In Section 2.2, 2nd bullet, it appears that this bullet contains two ASTM standards, A1008/A1008M and D618. Make ASTM D618 its own bullet in Section 2.2. **Agree**
2. In Section 3.2.1, consider revising from "the wall" to "the pipe wall". **Agree**
3. In Section 3.2.2, consider revising from "an irrecoverable indentation, generally associated with a loss in shape stability" to "a visible irrecoverable indentation" for consistency with same term in M 294, Section 3.7 and its definition of this term. **Agree**
4. In Figure 1, are both profiles shown for the two different pipe ranges both called "V SHAPED PROFILE"? Neither of the profiles shown looks similar to a "V". **Agree; see FL comment on these profiles.**
5. In Section 3.2.11, 1st line, revise from "wall thickness separates the inner surfaces of the pipe wall" to "wall thickness of the inner pipe wall" for better clarity. **Agree**

6. In Section 3, Terminology, consider adding a new subsection for the term "pipe barrel" since this term is used in Section 6.1.1 and in Table 1 with no definition in the standard and this term and a definition are not contained in either of the Section 2.2 Referenced Documents ASTM D883 or ASTM F412. Additional reason for adding this term and definition is that in M 294, Section 7.2.1 it indicates that the pipe nominal size is based on the nominal inside diameter of the pipe, but this does not seem to be the same for this SRPE pipe. **Agree**
7. In Section 5.1.1, revise from "AASHTO designation and year of issue" to "AASHTO designation M XXXX". **Discuss with Publication Staff**
8. In Section 6.1.4, revise from "exceed 4 percent" to "exceed 4.0 percent" for consistency with M 294, Section 6.1.1 which indicates "4.0". **See NY comment. No minimum required?**
9. In Section 6.1.6, 2nd line, revise from "cell class requirements" to "cell classification requirements". **Discuss with Publication Staff**
10. In Section 6.3.1, 1st line, revise from "to mold polyurethane" to "to mold a polyurethane". **Agree**
11. In Section 6.3.1, 4th line, for the text "The fiberglass content shall not exceed 20% of the total mix" is there a test method that can be referenced to verify this requirement or is this requirement something the manufacturer will need to certify based on control/feed rates of raw material components during the manufacturing process? **This a concern in FL negative also.**
12. In Section 6.3.1, next to last line, consider revising from "with the base material" to "with the base polyurethane compound material" for better clarity. **Agree it is not clear what the base material is polyurethane or HDPE.**
13. In Table 1, the first and second columns seem to show that the U.S. customary units are the standard vs. the SI units as indicated in Section 1.4. **In review SI units are listed first and appear to be the standard.** Consider if any changes are needed to the text in Section 1.4 or to the text in the Table 1 footnote "a". **Will review again.**
14. In Table 1, there is a footnote "a" at bottom of table, but there does not appear to be a footnote "a" in the table to show where this footnote is to be applied. **Agree**
15. In Figure 2, the figure is not shown very well in regards to the encapsulation thicknesses. Shouldn't the figure show consistent encapsulation thicknesses? **Need Clarification on thickness.**
16. In Section 7.5, 8th line, revise from "bells and spigots" to "bell and spigot".
17. In Section 7.5, 9th and 10th lines, the text "the radius between this encapsulation and the waterway wall" is confusing. Is this text correct or in the correct location? **Need Clarification on this sentence and the intent.**
18. In Table 2, first column label indicates "Nominal Inside Diameter" but Table 1 does not use this same label. Table 1 uses "Nominal Pipe Size" and "Barrel Inside Diameter". The tables should be consistent in the terms being used to not lead to confusion. **Agree**
19. In Section 7.8, last line, it states "deflected 40%, in accordance with Section 9.2", but Section 9.2 does not include 40% deflection. **Agree**
20. In Section 7.11.1, 2nd line, what does "stiffness equal to or greater than the barrel of the pipe" mean? Is the whole pipe tested or is only the "barrel" to be tested? **Not very Clear**
21. In Section 7.11.1.1, last line, revise from "full corrugations each pipe" to "full corrugations in each pipe". **Not Clear**
22. In Section 7.11.2.2, next to last line, M 288 is referenced, but M 288 does not include any requirements for geotextile wrap for pipe joints.

23. In Section 9.1, 1st line, "Pipe Barrel Stiffness" is used, but is this the full SRPE pipe or does this mean only the inside barrel portion of the pipe is to be used in the stiffness test? **Not Clear, Pipe Barrel is not defined**
24. In Section 9.2, 1st line, "Pipe Barrel Flattening" is used, but is this the full SRPE pipe or does this mean only the inside barrel portion of pipe is to be used in the flattening test? **Not Clear**
25. In Section 9.2, 1st line, should the text "Flatten the two pipe barrel samples from Section 9.1" be revised to "Flatten the three pipe barrel samples from Section 9.1, since Section 9.1, 1st line, specifies "Select a minimum of three pipe specimens"? **Not Clear**
26. In Section 9.3, 1st line, "Pipe Barrel Impact" is used, but is this the full SRPE pipe or does this mean only the inside barrel portion of pipe is to be used in the impact test? **Not Clear**
27. In Section 9.6.4, is only one cross section location to be cut and measured for encapsulation thickness? The number of cross section locations to measure should probably be more than one cross section location.
28. In Section 11.1, should "3.5 m (11.5 ft)" be revised to "3 m (10.0 ft)" for consistency with M 294, Section 11.1? **Agree should be consistent with all pipe.**
29. In Section 11.1.3, revise from "Nominal inside diameter" to "Nominal pipe size". **Agree**
30. In Section 11.1.5, 1st line, revise from "The date and location of manufacture or an appropriate production code" to "The date of manufacture or an appropriate code" since location is already addressed in Section 11.1.4. **Agree**
31. In Section 11.2, revise from "AASHTO MP 20" to "M XXXX". **Agree**

__South Carolina Comments__:

1 Change all references from MP20 to M 335 **Agree**

2 Section 2 - add M 335 to referenced documents **Agree**

3 Section 3.2.5 - add standard units to 74 kPa **Agree**

4 Section 6.1.6 - "Reworked" Plastics **Adjust from rework to reworked**

5 Section 6.2.1 - switch SI and standard units **Agree**

6 Section 7.11.1.1 - last sentence "corrugations of each"

7 Table 2 looks like it should be centered on the page. **Agree, Publication Staff could fix this**

8 Does Buy America need to be addressed here for the steel? **Not sure if Buy America needs to be addressed in this Specification**

__New York Comments__:

1 __**Section 2**__.2 __ASTM Standards__ Why no inclusion of ASTM D 618 - Standard Practice for conditioning of Plastic pipe. **D618 is included.**

2 ASTM D 638 - Standard Test method for Tensile Properties of Plastics **This standard is not called out in Specification.**

__**Section 3**__; Terminology

3 3.2.4 - Polyethylene terminology is utilized in 3.2.4, however the testing standards refer to High Density Polyethylene. Suggest using the same terminology throughout the documents **Is this PE pipe made from HDPE resin or just PE resin?**

4 3.2.8 - __*Steel Reinforced Polyethylene Pipe*__ contradicts section 4.1 which calls out __*steel-reinforced PE corrugated pipe*__. **Not Sure**

5 __**Section 4**__; Classification Section 4.1 See 3.2.8 above

__**Section 6**__; Materials

6 6.1.1 - Resin 333400C is called out as distinctly different than MP 20, why?

- Slow Crack Growth resistance should be a stand-alone statement, unless it only applies to the Pipe barrel **Agree TS will need explanation**

7 6.1.1, 6.1.2 & 6.1.3 Pipe Barrel, Rotational Molded Fittings and Couplings and Injection Molded Fittings and Couplings should all be defined in section 3

8 6.1.2 – Resin called out is the same as MP 20, why? **Agree TS will need explanation**

9 6.1.3 – Resin called out is different than MP 20, why? **Agree TS will need explanation**

10 6.1.4 – No minimum Carbon Black content is required? **The Carbon black content is defined in the cell classification by the last letter in the cell classification. For example: 333400C or 213320C. The letter C means the color is black and the UV stabilization is carbon black with content between 2 and 4%. So, there is a minimum 2% carbon black content. The information on interpretation of code number and letters for PE is contained in ASTM D3350.**

11 6.1.5 – First sentence, should "pipe construction" be changed to "pipe manufacturing" **Agree**

12 6.2.1 – No coating requirement? **TS will need explanation**

Section 7; Requirements

13 7.11.2.1, 7.11.2.2 & 7.11.2.3 Suggest using the same style throughout, hyphenated, or unhyphenated. **Publication Staff can help with this.**

Section 9; Test Methods

14 9.1 Suggest reformatting appearance of the itemized list. **Publication Staff can help with this.**

Virginia Comments:

1 It is good to have a standard for corrugated SRPE in addition to the ribbed SRPE.

Comments from Friends of the Committee:

American Concrete Pipe Association (Josiah W Beakley)

1. Section 1.3 says that the design of this pipe is covered in Section 12 of the AASHTO LRFD Bridge Design Specifications I am unaware of a portion of Section 12 that covers this product. **Check with MN DOT Kevin Western T 13 COB**
   Tim Toliver with Advanced Pipe Services sent a letter to the technical Subcommittee on July 20, 2018 (Attachment # 3 Letter to COMP on SRPE) which discusses the design status of SRPE pipe with AASHTO Bridge committee. "During the annual meeting of the AASHTO Committee on Bridges and Structures; T-13 Subcommittee on Culverts (T-13 Committee), technical information was presented regarding Steel Reinforced Corrugated HDPE Pipe (SRPE Pipe). At the conclusion of the presentation, T-13 Committee members asked for additional details regarding structural analysis and research, which was not addressed in the presentation. The additional details included: results of live load analysis, durability of the plastic to steel bond as a result of live loading and design properties for the bell and spigot. A clarification of the requested additional information is being sought. A complete draft standard for the T-13 Committee's consideration will be presented at the next meeting."

2. Section 6.1.1 has the failure times required for the slow crack growth test. I understand that these times should probably be higher than those required for polyethylene pipe, but where did these times come from? There has been no

research provided that correlates a test time in the lab to the stress levels and service life of the product in the field. **Check with Author**

3. Figure 2 shows the waterway wall of the pipe as the bottom of the corrugation profile. If the perforations are located in this area, as stated in Section 7.5, then the pipe is not actually perforated. It simply allows water to enter the corrugation without ever leaving the pipe. **This section needs some work to clarify the location of perforations.**
4. Section 7.11.1.2 - What is an industrial sealant? **Need some clarification**
5. Section 7.12 - Where does the allowance of a stub compression strength of only 50% of the calculated value come from? **Check with Author**
6. Section 9.1 - A test speed of 5 inches per minute is too fast. **What is basis of this claim?**

Forterra Pipe and Precast (Oliver Stanislaus Delery Jr)

- In section 6.2.2 it states: Steel Content – The steel content shall not exceed 75% of the total weight of the pipe. The steel material shall be fully encapsulated by the polyethylene material with a minimum thickness of the polyethylene as shown in Table 1. As shown in section 7.4.4, the steel inside of the corrugations is not encapsulated, but exposed. Therefore any perforation of the inner liner will introduce water directly to the steel surface. There has been much research done determining failure due to corrosion of steel. A simple coating of that steel (not addressed in this standard) may not provide the anticipated material life in real world conditions. **Figure 2 needs more clarity on encapsulation thickness and location of perforations**

The Chair has forwarded the comments to the Author, Tim Toliver. Tim would like an opportunity to address the Florida negative vote at the TS meeting. There are several parts of the specification that TS members would like to have clarified. Tim should be able to update TS on the design methodology for this pipe after his meeting with COB T13.

Based on the letter, negative and explanations provided at meeting what action should the Technical Subcommittee exercise with this Standard?

Resolution:

A motion was made to ballot this item again at the Technical Subcommittee Level by North Carolina and a second was made by New York. If the item passes TS ballot with few negatives and comments the results of this ballot can be reviewed during the mid-year meeting, and then can go to COMP after that. The Chair can place an administrative negative at COMP and can specify that this should only pass if this item passes the LRFD Bridge Design Guide to hold the item until we know what will happen with the bridge specification. In addition, testing on 72" material will be completed before COMP ballot.

Item 3: Revise Standard Specification for Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 1500-mm (12- to 60-in.) Diameter M335 -18 to increase diameter to 3000-mm (120 in.). This standard M 335 was first published in June 2018 after several years as provisional standard MP 20. Based on deep burial research performed by Ian Moore Ph.D. P.E. at Queens University in Ontario Canada, it is proposed to increase the diameter allowed under this specification to 3000 mm (120 in.). **Attachment #4- 10ft diameter Duromaxx test report January 2018v2-from Ian Moore.pdf**

The revision to this standard specification failed technical section ballot with 13 affirmative votes, 3 negatives and 4 no votes. (65%)
Attachment #5 - Use Item 3 FDOT.docx

Darrell Saunders (DJS): (Attachment #6 - DMaxx Presentation..) SRPE Pipe to explain test report above.
See presentation attached to minutes.

Florida Negative:
There is some ambiguity surrounding the conditions for allowing reduced pipe stiffness. Specifically, the requirements for backfill should be clearly identified. Comments and suggested revisions are within the attachment.

1. Label Figure 1 with terminology similar to M294… inner wall/liner, valley, corrugation/rib, etc. **Agree. Will ask DJS to determine the best way to modify the Figure.**
2. Section 3.14 Suggest using terminology similar to M294… inner wall/liner, valley, corrugation/rib, etc. **Agree**
3. Section 7.6 This is potentially a safety concern if the minimum requirements of "more restrictive" backfill are not identified **Explanation: The Standard has restricted the allowable backfill to those materials that meet a Class I designation. In AASHTO terminology, restricting the backfill to an A1 material would be an appropriate equivalent. Additionally, Darrell would like to discuss the idea of allowing the use of shape monitoring as an alternative to modifying the allowable backfills.**

Virginia Negative:

1. The standard should first be submitted as a provisional Standard. This will allow the DOTs to use the pipe and evaluate it, this is the first year M 335 will be a full standard. Updating a full standard gives the impression that these higher diameters have been fully vetted and endorsed by AASHTO. Previous updates to specifications with increases in diameter have been through provisional standards. **DJS has no objection to this being handled as a provisional Standard.**

Tennessee Negative:

1. The Minimum Waterway Thickness shown in Table 1 is significantly less than the Minimum Waterway Thickness shown on the DuroMaxx Specification sheet see: **Attachment #7 - M 335 SRPE Ribbed DuroMaxx_30-120 inch Specification.pdf**

   For example,

Pipe Diameter	M 335	DuroMaxx Spec.
54" & 60"	2.0 mm	3.30 mm
66" & 72"	2.2 mm	5.58 mm
78"- 90"	2.4 mm	5.58 mm
96"- 120"	3.0 mm	5.58 mm

   How were the thicknesses in M 335 determined? **Explanation for TS: The minimum wall thicknesses in M335 match those in ASTM F2562. Contech has chosen to use thicker walls to increase the pressure capacity of the product.**

Pennsylvania comments:

1. In Section 7.6, 4th line, revise from "equivalent to a 0.095" to "equivalent of a 0.095". **Agree**
2. In Section 7.13, why reduce the test frequency for T 341? No reason is given and this is inconsistent with other pipe specification requirements, such as M 294. **Agree this test frequency has been an issue in the past. Taking it out at the same time as moving to larger diameter could be problematic. Explanation: This can be addressed separately if required. The test frequency can be reduced for SRPE profiles because there is significantly less potential variation in the production of the profile. Profile wall thermoplastic pipe profiles have considerably more variables that influence the geometry of the profile. Extrusion speed, ambient temperature, rate of cooling, die wear and many other variables can all influence the final geometry of the profile. For SRPE pipes meeting this standard, the only meaningful variables are the steel rib height, rib thickness and yield point of the steel. All of those variables can be more reliably controlled than the variables in the production of a profile wall thermoplastic pipe. Less variability should mean that less frequent testing is required.**
3. In Section X2, first table, there is a footnote "a" in second column heading, but there is not footnote "a" at bottom of table. **There should be a footnote at the bottom of this table. The footnote should be the same as footnote that is at the bottom of Table 2. It should probably be a different letter also.**

__New York comments__:

Section 3; Terminology

1. Section 3.2.6 - Polyethylene terminology is utilized however the testing standards and other definitions within the document (3.2.4) refer to High Density Polyethylene. Suggest using the same terminology throughout the documents. **Is this PE pipe made from HDPE resin or just PE resin? The pipe uses HDPE resins.**
2. Section 3.2.10 Steel Reinforced Thermoplastic pipe, is not the same terminology as the cover page of the document. **Agree. DJS suggest that Section 3.2.10 be changed to reflect steel-reinforced polyethylene pipe.**

Section 6; Materials

3. Section 6.1.1 Pipe and Fittings - Resin 334452 C or E is called out, which is distinctly different than SRPE Corrugated, why? **Explanation for TS: DJS-I'm not sure I understand the question. Is this a reference as to the difference between the cell class required in the AASHTO Standard versus the ASTM equivalent in F2562? The AASHTO Standard requires a slightly higher performing resin because it more accurately reflects the resin used in the SRPE pipe produced in the US.**
4. Section 6.1.2 Slow Crack Growth resistance should be a stand-alone statement, unless it only applies to the rotational Molded Fittings and Couplings. **Explanation for TS: This is unchanged from the current Standard. When the Standard was originally written, it was determined that NCLS testing was not necessary for pipe because the resins had significantly greater crack resistance than other HDPE pipe used for drainage. Therefore, the NCLS testing was intentionally only applied to rotational molding fittings that may utilize a different resin.**
5. Section 6.1.3 Rotational Molded Fittings and Couplings and Injection Molded Fittings and Couplings should all be defined in section 3. **Describing the two processes separately is consistent with other HDPE pipe Standards. The resin requirements between the two processes are significantly different.**
6. Section 6.1.4 - Injection Molded Fittings and Couplings has a different resin class than SRPE Corrugated, why? **Explanation: It is not uncommon for extrusion grade**

and injection grade resins to be slightly different. This is consistent with other HDPE pipe Standards.

7. Section No minimum Carbon Black content is required? **The Carbon black content is defined in the cell classification by the last letter in the cell classification. For example: 333400C or 213320C. The letter C means the color is black and the UV stabilization is carbon black with content between 2 and 4%. So, there is a minimum 2% carbon black content. The information on interpretation of code number and letters for PE is contained in ASTM D3350.**

   Section 7; Requirements

8. Section7.4.1- Inside Diameter tolerance is a function of %, however, within section 7.11.2, under fitting requirements, the tolerance is a set measurement, suggest using similar metrics. **Section 7.11.2 only refers to the length of the fitting, not the diameter tolerance. Section 7.11.5 refers to the diameter tolerance of fittings. It is a fixed amount at -0.5". Contech would be open to making this a percentage rather than a fixed amount if desired. Would the same +/- 2.0% as applies to the pipe diameter be tolerance be preferable?**
9. Section 7.12.2.1, 7.12.2.2 & 7.12.2.3 within the titles of the sections, suggest using the same style throughout, hyphenated, or unhyphenated **Will discuss with the Publication staff**

<u>Missouri Comment</u>:

1 The Missouri DOT has concerns about increasing the allowable pipe diameter to 120 inches (3000 mm). We believe the pipe will not be substantial enough. MoDOT currently limits SRPE pipe to a maximum diameter of 60 inches (1500 mm). If these proposed changes are approved, MoDOT will continue to limit the pipe diameter to 60 inches. **Explanation: DJS -The proposed diameters greater than 60" have been used with SRPE for many years with no issues. The laboratory test demonstrated that the 120" diameter product performed in a manner consistent with the smaller diameters.**

2. MoDOT is not comfortable with the proposed change in Section 7.6. We are not familiar with the flexibility factor. **Explanation: Increased flexibility factors for metal pipe projects that have installation advantages such as more select backfill, shape control monitoring and advantageous site conditions has been a common practice for years. Contech has been supplying the larger diameters in SRPE with reduced stiffness and more restrictive backfill requirements for several years with good results**.
3. MoDOT specifies the installation method to be used for SRPE pipe. We recommend that language be added to the specification indicating that the agency needs to approve the use of a lower pipe stiffness prior to installing the pipe in the field. **Explanation: Project specifications could dictate the required stiffness level for the pipe. Additionally, pipe submittals would include the pipe stiffness as well as the recommended backfill specifications**
4. ASTM shows a 100 inch diameter pipe while the proposed AASHTO specification shows a 102 inch diameter pipe. To be consistent, recommend the AASHTO specification also list a 100 inch diameter pipe size in Table 1 and Table 2. **DJS: Traditionally, large diameter pipes in the US are offered in full foot and half foot increments. The proposed 102" diameter pipe is consistent with that approach. I have no issues with adding a 100" diameter to the table, but it is unlikely that any US manufacturer would produce that size.**

<u>Georgia Comment</u>:

1. We recommended this as a provisional standard. **DJS has no objection to this being handled as a provisional Standard.**

Comments from Friends of the Committee:

Plastic Pipe Institute (Dan Currence)**:**

1. Has any DOT used ribbed SRPE greater than 72" diameter? For AASHTO to move from a 60" max diameter to 120" max diameter for M335 based on one lab test conducted outside of AASHTO seems like a large increase and very accelerated. What was the pipe stiffness & flexibility factor for the one 120" diameter pipe tested relative to the "Letter to TS 4b members on M335"? As diameters increase on the ribbed SRPE product, maintaining the perpendicular position of the rib throughout transport, handling & installation becomes even more critical. If not within M335, the impact of ribs inadvertently going askew have to pipe performance may need to be considered and addressed by T-4 within the Committee on Bridges & Structures. **Explanation: Several states have installations with SRPE pipes with diameters greater than 60". We've produced diameters up to 120" since 2011. The 120" pipe tested in Dr. Moore's recent study was designed using the 0.095 flexibility factor as is suggested in the ballot. The verticality of the ribs has not shown itself to be an issue and was addressed 5 years ago by the T-4 subcommittee in that there is a published limit as to how much variation is permitted within the ribs.**

American Concrete Pipe Association (Josiah W Beakley)

1. Section 7.6 - This product already requires a high level of installation. Thus, the addition here is meaningless, and is just a way of trying to allow a weaker pipe that would otherwise not be allowed.
2. Table 2 - There are no shape stability limits for the larger pipe sizes. Even the ones that have been added are too low if you expect the pipe to perform in the field.
3. 7.13 - There has been no justification for greatly reducing the stub compression tests. **See answer to PA comment.**
4. There are no material properties provided in the supporting research to justify that what was tested matches the lowest common denominator of the standard it is supposed to be justifying. Using a flat plate to supply uniform load on the pipe is not the same as the installed condition. In fact, the plate allows the load to be supported by the soil on the side of the structure instead of the structure itself, and proves very little about the pipe itself. It is interesting that the tests show the local buckling of the steel ribs, and yet the design method in Section 12 has failed to address it. In fact, this research should have been submitted to the T-13 Culvert Committee for consideration in conjunction with its submittal to Technical Section 4b. **Explanation SRPE pipes are not difficult to install. They require essentially the same installation methods as any other flexible pipe. I'll defer to Dr. Moore to defend the validity of his testing procedures. However, as I recall, Mr. Beakley presented similar arguments against the test procedure when it was used in the 60" test, but was unable to convince others of the merits of his argument.**

Forterra Pipe and Precast (Oliver Stanislaus Delery Jr)

1. Figure 14 of Dr. Moore's report shows areas of exposed steel ribs. While the steel sheets from which these ribs are cut are "coated", from samples I have checked, after the sheets are cut, the "cut" ends are not recoated, therefore exposing this

uncoated steel rib to environmental impacts should a rib become exposed. All steel ribs should be required to be recoated following cutting of the steel sheets. See blown up section from Figure 14 in attachment. **Attachment #8 -Exposed Steel – Moore Report OD.docx** **DJS: The edges of coated steel products are never recoated. This is consistent with corrugated steel pipe, steel deck panels, roofing materials, etc. That is because the zinc coating is a sacrificial coating, not a barrier coating. This galvanic protection covers the thin slit edges of steel sheets just as it does the rest of the product. Also, pipes shown in Figure 14 are of pipe that has just been tested to failure. The singular split in the capping on a damaged rib shown in that photo is not representative of a typical installation. This issue was addressed in a study performed by the University of Kansas expressly designed to establish the impact of typical installation techniques on SRPE pipes. They backfilled pipes with different materials. The pipes were monitored during installation and then exhumed. They found that the ribs were undamaged and had remained vertical throughout the process.**

Discussion of presentation, negatives and explanations what action should the Technical Subcommittee exercise with this Standard?

Resolution:
This ballot did not pass.

For discussion regarding this item, see presentation attached. Comments in addition to presentation:

- *How should these larger diameter pipes be handled? Should this be a provisional or should it be incorporated into M335?*
- *The ASTM standard includes minimum thicknesses that are used internationally, but the thicknesses used in products manufactured in the United States. The AASHTO standard should reflect what is manufactured in the United States.*

A motion was made by Florida and a second by Alabama to move this standard to Concurrent ballot to change the thickness of the walls specified in the standard to what is currently manufactured in the United States. The motion passed unopposed.

A motion was made by Florida and a second by Alabama to move this standard to Technical Subcommittee ballot to increase diameter to 3000-mm (120 in.).

C. Task Force Reports

Task Force 2017-01 - Assignment was to review the corrugated metal pipe specification for M190 and consider adding a subsection for determining the coating thickness to Section 7. The task force was also asked to review M243 and to determine if a method should be specified to measure the coating thickness of 1.27 mm. Should the specified measurement be modified to "minimum of 1.3 mm" given this is a field applied asphalt mastic coating? **Task Force Members** are Mike McGough (NCSPA), Tim Ramirez (PA) and VA.

No Progress – *not discussed during meeting.*

V. New Business

A. Research Proposals

1. 20-7 RPS
2. Full NCHRP RPS

   No Proposals to date

B. AMRL/CCRL - Observations from Assessments - *None*

C. NCHRP Issues - *None*

D. Correspondence, calls, meetings, webinar,

E. Presentation by Industry/Academia

Darrell Sanders – "Steel Reinforced Polyethylene Pipe"
(Attachment #6 - DMaxx Presentation to AASHTO TS 4b Subcommitte) (20 minutes)

See presentation attached.

Ryan Fragapane – NTPEP HDPE Pipe program update on HDPE Work plan to include recycled HDPE

A revised work plan was issued for ballot on August 3, 2018. The ballot closes August 24. Please make sure your state votes. See presentation from Dan Currence below for more details on NTPEP updates.

Dan Currence with PPI – Industry Perspective on NTPEP Audit Plan and Implementation for M 294 R Recycled HDPE pipe (Attachment #9 PPI TS-4b Presentation)
See presentation attached. **(20 minutes)**

State Approach to NTPEP Audit Plan and Implementation of M 294 V and R
VA, NC, GA, TN, Others
Several states briefly discussed what their approach to acceptance with the new Virgin and Recycled designations. Many states will allow for recycled resin to be used in the manufacturing of products for M 294.

There have been questions regarding whether fittings will be made with virgin or recycled materials. The intent is for virgin materials will be used.

Another question is whether or not materials can be comingled. This is fine as long as the materials are traceable, but it is not recommended.

F. Proposed New Standards

Proposed Changes	Technical Subcommittee and/or Committee?
Proposed new Standard Practice for Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled Content R XX	COMP

Proposed new Provisional Standard Specification for Steel-Reinforced Polyethylene (SRPE) Corrugated Pipe MP XX	TS Only

G. Proposed New Task Forces

John Kurdziel would like to discuss why there is a difference between the two specifications for M 294 and M 330 when the same equipment is used to manufacture both Polypropylene and High Density Polyethylene pipe. The differences are shown below:

M 330

7.2.3. Inside Diameter Tolerances—The tolerance on the specified inside diameter shall be 3.0 percent oversize and 1.5 percent undersize, but not more than 30 mm (1.2 in.) oversize when measured in accordance with Section 9.6.1.

M 294

7.2.3. Inside Diameter Tolerances—The tolerance on the specified inside diameter shall be 4.5 percent oversize and 1.5 percent undersize, but not more than 37 mm (1.5 in.) oversize when measured in accordance with Section 9.6.1.

John Kurdziel briefly discussed the issue: It was proposed that Proposed that the tolerances in M 294 and M 330 be the same. A motion was made by North Carolina and a Second by Maine to ballot this change concurrently (both standards). The motion passed unopposed.

H. Standards Requiring Reconfirmation

M 246, M 278, M 304 and T 341 are required to be revised or reconfirmed this year.

I. COMP Ballot Items (including any ASTM changes/equivalencies)

VI. Open Discussion

VII. Comment

VIII. Adjourn

Chair comments
MP, TT and DJS comments

Attachment #1

Standard Practice for

Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled ~~Materials~~Content

AASHTO Designation: R xxx-yy[1]

Technical Subcommittee: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Practice for

Service Life Determination of Corrugated HDPE Pipes Manufactured with Recycled ~~Materials~~Content

AASHTO Designation: R xxx-yy

Technical Subcommittee: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

1. SCOPE

1.1. This standard practice details the procedure for determining the service life of corrugated high--density polyethylene (HDPE) pipes ~~manufactured with~~containing recycled materials. Service life II brittle failures via the slow crack growth mechanism.

1.2. The service life determination in this standard practice is based on analysis of failure data from testing conducted in accordance with ASTM F3181, the Un-Notched Constant Ligament Stress (UCLS) test.

1.3. This standard practice can be used to establish minimum UCLS performance criteria to ensure a desired service life at given service conditions for corrugated HDPE pipes containing recycled materials.

1.4. This standard practice is applicable for pipes containing recycled materials and manufactured in accordance to M 294. It is applicable both for pipes manufactured with post-consumer recycled (PCR) materials and post-industrial recycled (PIR) materials. It is not intended for pipes manufactured with only virgin materials.

1.5. The values stated in SI units are to be regarded as standard. Within the text, the U.S. Customary units are shown in parentheses, and may not be exact equivalents.

2. REFERENCED STANDARDS

2.1. *AASHTO Standard*:

- M 294, Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

2.2. *ASTM Standards*:

- D4703, Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques, or Sheets
- F3181, Standard Test Method for the Un-notched, Constant Ligament Stress Crack Test (UCLS) for HDPE Materials Containing Post- Consumer Recycled HDPE

2.3. *Other Document*:

- Pluimer, M. L. (2016). Evaluation of Corrugated HDPE Pipes Manufactured with Recycled Materials in Commuter Railroad Applications (Doctoral dissertation). Proquest Publishing, Villanova University.

3. TERMINOLOGY

3.1. *Definitions*:

3.1.1. *contaminant, n*—inorganic particulate matter or other non-HDPE material that creates inclusions or stress risers in the crystalline structure of HDPE.

3.1.2. *crack initiation*—portion of the slow crack growth mechanism associated with the initial development of a craze zone and micro-cracks ~~and~~ around a contaminant, void or discontinuity Figure 1).

3.1.3. *crack propagation*—portion of the slow crack growth mechanism associated with successive yielding of HDPE material ahead of a crack tip (see Figure 1).

3.1.4. *Popelar shift method (PSM)*—method of bidirectionally shifting brittle crack failure data from HDPE specimens tested at elevated temperatures and stresses to other service conditions for lifetime prediction.

3.1.5. *post-consumer recycled (PCR) HDPE materials*—HDPE materials from products that have served a previous consumer purpose (for example, laundry detergent bottles, milk bottles and other consumer goods).

3.1.6. *post-industrial recycled (PIR) HDPE materials*—HDPE materials diverted from the waste stream during a manufacturing process that have never reached the end user.

3.1.7. *slow crack growth (SCG)*—a failure mechanism for HDPE defined by brittle cracks that propagate through the material under conditions of tensile stresses lower than its short-term mechanical strength, also known as Stage II failures (see Figure 1); comprised of two phases: crack initiation and crack propagation.

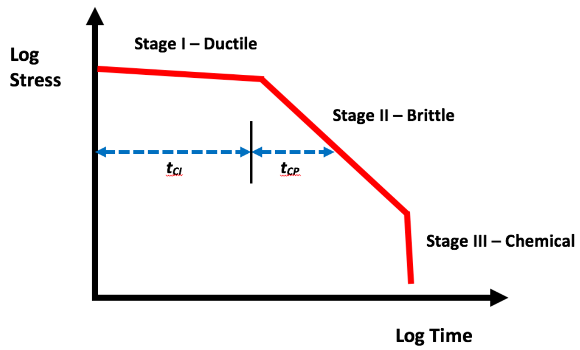

Figure 1—Stage II Brittle Failure, or Slow Crack Growth (SCG) Failure Mechanism. The total time to failure is comprised of two phases: 1) time for crack initiation, t_{CI} and 2) time for crack propagation, t_{CP} (*Pluimer, 2016*). The

hypothetical lines, t_{CI} and t_{CP} are a representation of the time to initiate cracking and propagation and are not intended to line up with the point between Stage I and Stage II.

4. PROCEDURE FOR DETERMINING SERVICE LIFE OF CORRUGATED HDPE PIPES MANUFACTURED WITH RECYCLED MATERIALS

4.1. Prepare compression-molded UCLS plaques according to the procedures outlined in ASTM D4703 and ASTM F3181. The plaques may be prepared either from resin blends or from chips taken directly from the pipe wall. It is important that the materials are properly homogenized prior to compression molding into the plaque. Homogenization may be accomplished by a double pass through a twin-screw lab extruder or at least three passes through a single-screw lab extruder.

4.2. Prepare at least 15 UCLS test specimens from the plaques in accordance ~~to~~ with the dimensions procedures outlined in ASTM F3181.

4.3. Conduct the UCLS test in accordance ~~to~~ with ASTM F3181 on five specimens at each ~~of~~ test for a minimum of three test conditions. Each specimen must be taken to failure. Record the individual and average failure times of the five specimens at each condition, as well as the coefficient of variation (COV). ~~(~~The COV is the standard deviation of the failure times divided by the average failure time~~)~~. The average must be calculated on a log basis. The minimum recommended test conditions are as follows:

4.3.1. Condition I: 80°C (176°F), 4.48 MPa (650 psi) stress,

4.3.2. Condition II: 80°C (176°F), 3.10 MPa (450 psi) stress, and

4.3.3. Condition III: 70°C (158°F), 4.48 MPa (650 psi) stress.

4.4. Use the PSM multiplication factors shown in Equations 1 and 2 to shift the elevated temperature ($T2$, °C) average failure times (determined on a log basis) from Section 4.3 to the projected failure times at the desired in-ground service temperature ($T1$, °C). 23°C (73.4°F) is a conservative assumption for $T1$, though lower temperatures may be specified if appropriate.

$$\text{Stress Shift Factor} = e^{0.0116\,(T2-T1)} \quad (1)$$

$$\text{Time Shift Factor} = e^{0.109\,(T2-T1)} \quad (2)$$

4.5. Plot the resulting three ~~(or more, if additional conditions were evaluated)~~ shifted average data and log stress on the Y-axis. Determine the best-fit curve for the data points, which should be linear on a log–log scale. More data points may be utilized if additional conditions were evaluated.

4.6. Calculate the 95 percent lower confidence limit (LCL) of each of the log-based average data points by using the Student's t-distribution as shown in Equation 3. Use the largest COV from the three (or more) data sets obtained in ~~Step 3~~Section 4.3 for determination of the LCL.

$$LCL_{95\%} = \bar{X} - t_{(n-1)}\left(\frac{COV * \bar{X}}{\sqrt{n}}\right) \quad (3)$$

where:

$LCL_{95\%}$	=	lower 95 percent confidence limit
$\bar{X}$	=	log-based average of 5 test specimens
$t_{(n-1)}$	=	Student's t value at (n – 1) degrees of freedom = 2.132
COV	=	maximum coefficient of variation of five test specimens
n	=	number of test specimens at each condition = 5

4.7. Determine the best-fit curve for the three (or more) LCL data points.

4.8. Extrapolate the LCL curve to the desired factored service stress condition to determine the predicted service life relative to Stage II brittle cracking. The service life is calculated by solving the equation of the LCL curve at the desired stress condition.

4.9. An example of the procedure is illustrated in Appendix X1.

5. PROCEDURE FOR ESTABLISHING MINIMUM UCLS PERFORMANCE CRITERIA FOR A DESIRED SERVICE LIFE FOR CORRUGATED HDPE PIPES MANUFACTURED WITH RECYCLED MATERIALS

5.1. Follow the procedure described in Sections 4.1 through 4.5 for at least eight sticks of pipes from the same lot manufactured with ~~typical~~ the same recycled material blend~~s~~ to determine the average the brittle failure curve, *m*, when plotted on a log–log scale with log time on the X-axis and log stress on the Y-axis. In the absence of this data, a slope of –0.20 can be conservatively used based on the research reported in NCHRP ~~Project 4-39~~Report 870.

5.2. Determine the COV for each five-specimen data set from Section 5.1. Use the maximum COV from these data sets for the following calculations. In the absence of this data, a COV of 0.50 can be conservatively used based on the research reported in NCHRP ~~Project 4-39~~Report 870.

5.3. Using Equations 4 and 5 (Pluimer, 2016), calculate the minimum UCLS failure time at the desired test condition to ensure a desired service life (t_{SVC}, h) at the given service conditions ~~(~~[i.e., service stress (σ_{SVC}, psi) and service temperature (T1, °C)]. For the test condition, ~~It~~ it is suggested to use Test Condition I [80°C (176°F)and 4.48 MPa (650 psi) stress], as this is the most aggressive test condition and will generate the shortest failure times.

$$t_T = \frac{10^c}{SF_t} \tag{4}$$

where:

t_T = minimum required average failure time at test condition, h

m = slope of brittle failure curve

$SF\sigma$ = Popelar stress shift factor from Equation 1

SF_t = Popelar time shift factor from Equation 2

σ_T = stress at test condition, psi

σ_{SVC} = stress at service condition, psi

t_{SVC} = required service life at service conditions, h

$$C = \left[\frac{\log(SF_\sigma * \sigma_T) - \log(\sigma_{SVC})}{m}\right] + \log(t_{SVC}) \tag{5}$$

5.4. To ensure 95 percent confidence that the minimum average failure time calculated from Equation 4 will result in the desired service life, the failure time must be statistically adjusted to account for the scatter in the data. The average failure time needed to ensure 95 percent confidence is calculated from Equation 6.

$$\bar{X}_{95\%} = \frac{t_T}{\left[1 - \frac{t_{(n-1)*COV}}{\sqrt{n}}\right]} \tag{6}$$

Commented [BWRIP(1]: This COV term appears in this equation written to be a subscript? It should not be.

where:

$\bar{X}_{95\%}$	=	Average failure time needed for 95 percent confidence, h
t_T	=	Minimum required average failure time from Equation 4, h
$t_{(n-1)}$	=	Student's t value at (n – 1) degrees of freedom = 2.132
COV	=	Maximum coefficient of variation from test data
n	=	Number of test specimens at each condition = 5

6. KEYWORDS

6.1. Brittle failure; high density polyethylene; PCR; PIR; post-consumer; post-industrial; PSM; Popelar Shift Method.~~First; second; last~~.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE CALCULATIONS FOR SERVICE LIFE DETERMINATION

X1.1. An example process for determining the service life of a typical corrugated HDPE pipe manufactured with recycled materials is illustrated in the steps below. The data for this example analysis are shown in Table X.1.1.

X1.2. First, the UCLS test is conducted on pieces of pipe that have been compression-molded into a plaque and prepared in accordance to ASTM F3181. In this example, a total of 15 specimens were tested, five at each of the minimum conditions described in Section 4.3.

X1.3. Record the failure time t of each specimen and calculate the arithmetic COV of each five-specimen data set.

X1.4. Take the logarithm ~~(Log *t*)~~ of each failure time (Log *t*) and calculate the log-based average of each specimen data set.

X1.5. The LCL of the data is calculated by applying Equation 3 to the calculated log-based average failure times. Conservatively, the largest COV of the three (or more) test conditions is used in the calculations. An example calculation of the LCL for Condition I is shown in Equation X1.1.

$$LCL_{95\%} = \bar{X} - t_{(n-1)}\left(\frac{COV * \bar{X}}{\sqrt{n}}\right) = 93.0 - 2.132 * \left(\frac{0.416 * 93.0}{\sqrt{5}}\right) = 56.1 \text{ h} \quad (X1.1)$$

X1.6. Determine the multiplication factors for each test condition using Equations 1 and 2. For example, to shift the data from Conditions I and II to a service temperature of 23°C, the multiplication factors shown in Equations X1.2 and X1.3 are used; to shift the data from Condition III to a service temperature of 23°C (73.4°F), the multiplication factors shown in Equations X1.4 and X1.5 are used.

$$\text{Stress Shift Factor } = e^{0.0116(T2-T1)} = e^{0.0116(80-23)} = 1.937 \quad (X1.2)$$

$$\text{Time Shift Factor } = e^{0.109(T2-T1)} = e^{0.109(80-23)} = 499.2 \quad (X1.3)$$

$$\text{Stress Shift Factor } = e^{0.0116(T2-T1)} = e^{0.0116(70-23)} = 1.725 \quad (X1.4)$$

$$\text{Time Shift Factor } = e^{0.109(T2-T1)} = e^{0.109(70-23)} = 167.8 \quad (X1.5)$$

X1.7. Shift the log-based average failure times and stresses and the calculated LCL times and stresses to the desired service temperature using the multiplication factors calculated in Section X1.6 for each condition. For example, the log-based average failure time from Condition I is shifted from the test conditions of 80 ~~deg.~~ °C (176°F) and 4.48 MPa (650 psi) stress to a service condition of (93.0)(499.2) = 46,447 h at a stress of (4.48)(1.937) = 8.678 MPa (1259 psi). Similarly, the LCL from Condition I is shifted to (56.1)(499.2) = 28,012 h at a stress of (4.48)(1.937) = 8.678 MPa (1259 psi). Similar calculations are performed for each test condition as shown in Table X1.1.

X1.8. Plot the logarithm of the shifted data points for each condition and determine the best-fit curve. Extrapolate the best-fit curve to a minimum of 106 h (114 y). Determine the equation of the best-fit curve. Figure X.1.1 shows a plotted curve for the data in this example.

X1.9. Repeat X1.8 for the shifted LCL data points to determine the equation of the LCL curve (see Figure X1.1 for the data in this example)

X1.10. To calculate the service life for the material at a given stress, solve the LCL curve shown in Figure X.1.1 for "x". For example, to calculate the service life at a stress of 500 psi (2.699 on a log basis), the service life is calculated as shown in Equations X1.6 and X1.7:

$$2.699 = -0.2175x + 4.0719 \qquad (X1.6)$$

$$\Rightarrow x = \frac{(2.699 - 4.0719)}{-0.2175} = 6.312 \text{ h (log)} = 234 \text{ y} \qquad (X1.7)$$

Table X1.1—Summary of Test Data and Calculations for Example Problem for Pipe Manufactured with 49 percent PCR Materials

Specimen	Condition I: 80°C/ 4.48 MPa (650 psi) t (h)	log (t)	Condition II: 80°C/ 3.10 MPa (450 psi) t (h)	log (t)	Condition I: 70°C/ 4.48 MPa (650 psi) t (h)	log (t)
1	130.0	2.114	773.9	2.889	932.9	2.970
2	75.7	1.879	250.6	2.399	661.2	2.820
3	125.9	2.100	372.4	2.571	539.1	2.732
4	98.6	1.994	702.2	2.846	378.4	2.578
5	57.1	1.757	705.7	2.849	351.0	2.545

Calculations	Condition I	Condition II	Condition III
$\log(\bar{t})$ [a]	1.969	2.711	2.729
COV [b]	0.323	0.416	0.415
$\bar{X}$ [c]	93.0 h	513.7 h	535.8 h
$\bar{X}_{23}$ [d]	46,447 h	256,462 h	89,931 h
$\log(\bar{X}_{23})$ [e]	4.667 h	5.409 h	4.954 h
LCL [f]	56.1 h	309.8 h	323.1 h
LCL_{23} [g]	28,012 h	154,671 h	54,237 h
$\log(LCL_{23})$ [h]	4.447 h	5.189 h	4.734 h
σ_{23} [i]	1259 psi	871.7 psi	1121 psi
$\log(\sigma_{23})$ [j]	3.100 psi	2.940 psi	3.050 psi

[a] Average of the five log failure times (see Equation X1.4)
[b] Arithmetic COV of the five failure times
[c] Average log-based failure time (see Equation X1.4)
[d] Average log-based failure time shifted to 23°C condition (see Equations X1.6 and X1.7)
[e] Logarithm of the shifted failure time

[f] Lower 95 percent confidence limit of the average log-based failure times, based on the maximum COV of the three conditions (see Equation X1.5)
[g] Lower 95 percent confidence limit shifted to 23°C condition (see Equations X1.6 and X1.7)
[h] Logarithm of the shifted 95 percent LCL
[i] Stress shifted to 23°C condition (see Equations X1.6 and X1.7)
[j] Logarithm of the shifted stress

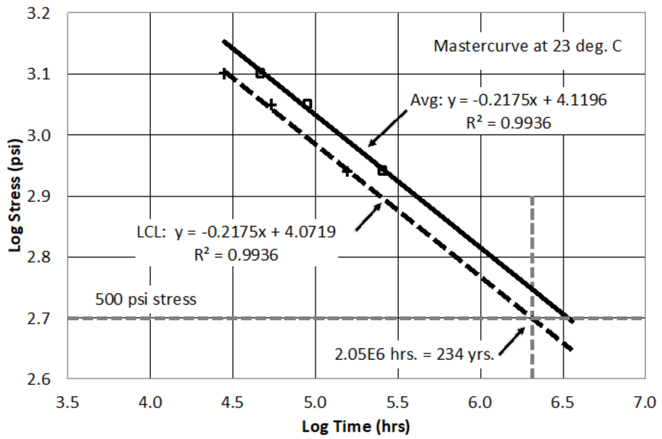

Figure X1.1—Average and LCL Curves for a Typical Pipe Containing 49 percent PCR Materials. In this example, the predicted service life relative to Stage II brittle cracking is 234 y.

X2. EXAMPLE CALCULATIONS FOR DETERMINING MINIMUM UCLS CRITERIA TO ENSURE DESIRED SERVICE LIFE AT GIVEN SERVICE CONDITIONS

X2.1. An example process for determining the minimum UCLS failure time at Condition I (80°C (176°F) and 4.48 MPa (650 psi) stress) for a given set of service conditions is illustrated below.

X2.2. For this example, the service conditions required by the Florida DOT for 100-y applications for corrugated HDPE pipes with virgin resins are used. ~~Namely, t~~The Florida DOT requires Class II HDPE pipes to last 100 y (876,000 h) at a factored tensile wall stress of 3.4 MPa (500 psi) and an underground service temperature of 23°C (73.4°F).

X2.3. In the absence of other data, a brittle slope of –0.20 and a COV of 0.50 are conservatively assumed for the calculations.

X2.4. Using Equations 1.1 and 1.2, the stress and time shift factors are calculated as shown in Equations X2.1 and X2.2.

$$\text{Stress Shift Factor } = SF_\sigma = e^{0.0116(80-23)} = 1.937 \qquad (X2.1)$$

$$\text{Time Shift Factor } = SF_t = e^{0.109(80-23)} = 499.2 \qquad (X2.2)$$

X2.5. Using Equation 5, calculate C as illustrated in Equation X2.3.

$$C = \left[\frac{\log\left(SF_{\sigma} * \sigma_{T}\right) - \log\left(\sigma_{SVC}\right)}{m}\right] + \log\left(t_{SVC}\right)$$

$$= \left[\frac{\log\left(1.937 * 650\right) - \log\left(500\right)}{-0.20}\right] + \log\left(876000\right) \qquad (X2.3)$$

$$= 3.937$$

X2.6. Using Equation 4, calculate the minimum average failure time, $t_{T,650,80}$, for Condition I. This is shown in Equation X2.4.

$$t_{T,650,80} = \frac{10^{c}}{SF_{t}} = \frac{10^{3.937}}{499.2} = \mathbf{17.33\ h} \qquad (X2.4)$$

X2.7. To ensure 95 percent confidence that the average failure time meets this requirement, use Equation 6 to statistically adjust this number to determine the test requirement for the minimum average failure time. This is demonstrated in Equation X2.5.

$$X_{95\%,650,80} = \frac{t_{T,650,80}}{\left[1 - \left(\frac{t_{n-1} * COV}{\sqrt{n}}\right)\right]} = \frac{17.33}{\left[1 - \left(\frac{2.132 * 0.5}{\sqrt{5}}\right)\right]} = \mathbf{33.1\ h} \qquad (X.5)$$

X2.8. ~~Rounding up for conservatism~~Using the rounding procedure specified, the minimum average specimens at Condition I [80° ~~deg.~~ C (176°F) and 4.48 MPa (650 psi) stress] should be ceiling **34 h** to ensure 100-y service life in conditions that result in a factored tensile wall stress of 500 psi at a temperature of 23°C (73.4°F). Furthermore, no single specimen should fail in less than ceiling (17.33) = **18 h**.

Attachment #2

Standard Specification for

Steel-Reinforced Polyethylene (SRPE) Corrugated Pipe

AASHTO Designation: MP ZZZ-YY

Technical Section: 4b, Flexible and Metallic Pipe

Release: Group 2

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel-Reinforced Polyethylene (SRPE) Corrugated Pipe

AASHTO Designation: MP ZZZ-YY

Technical Section: 4b, Flexible and Metallic Pipe

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1. SCOPE

1.1. This specification covers the requirements and methods of tests for steel-reinforced polyethylene (SRPE) corrugated pipe, couplings, and fittings for use in surface and subsurface drainage applications.

1.1.1. Nominal sizes of 300 to 1800 mm (12 to 72 in.) are included.

1.1.2. Materials, workmanship, dimensions, pipe stiffness, impact resistance, joining systems, and form of markings are specified.

1.2. SRPE corrugated pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow as culverts, storm drains, etc.

Note 1—When SRPE corrugated pipe is to be used in locations where the ends may be exposed, above ground, consideration should be given to protection of the exposed portions due to combustibility of polyethylene and the effects of prolonged exposure to ultraviolet radiation, as well as corrosion of steel reinforcement.

1.3. This specification only deals with this pipe's materials requirements. The structural design of steel reinforced thermoplastic culverts and the proper installation procedures are given in the *AASHTO LRFD Bridge Design Specifications*, Section 12, and *AASHTO LRFD Bridge Construction Specifications*, Section 26, respectively. Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

1.4. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. Customary units are shown in parentheses and may not be exact equivalents.

1.5. The following precautionary caveat pertains only to the test method portion, Section 9, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 288, Geosynthetic Specification for Highway Applications

- T 341, Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading
- *AASHTO LRFD Bridge Design Specifications*, Section 12
- *AASHTO LRFD Bridge Construction Specifications*, Section 26

2.2. *ASTM Standards*:

- A653/A653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- A1008/A1008M Standard Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy with Improved Formability, Solution Hardened, and Bake Hardenable
- D618, Standard Practice for Conditioning Plastics for Testing
- D883, Standard Terminology Relating to Plastics
- D2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- D4703, Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques, or Sheets
- D7091, Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
- F412, Standard Terminology Relating to Plastic Piping Systems
- F477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D883 and ASTM F412 unless otherwise specified.

3.2. *Definitions*:

3.2.1. *crack*—any break or split that extends through the pipe wall.

3.2.2. *crease*—a visible irrecoverable indentation.

3.2.3. *delamination*—a gap extending through the fused PE between two adjacent Corrugated Profiles.

3.2.4. *encapsulation thickness*—the thickness of the high density polyethylene (HDPE) bonded to either side of the steel reinforcement (see Figure 2).

3.2.5. *gravity flow*—a condition in which liquid flow through a piping system results from a downward pipeline slope, but flow is less than full, except during conditions when the system may become

temporarily surcharged, in which case the system is subject to temporary internal hydrostatic pressure that is limited to 74 kPa [10.7 psi].

3.2.6. *polyethylene (PE) plastics*—plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D883).

3.2.7. *reworked plastic*—a plastic from a processor's own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D883).

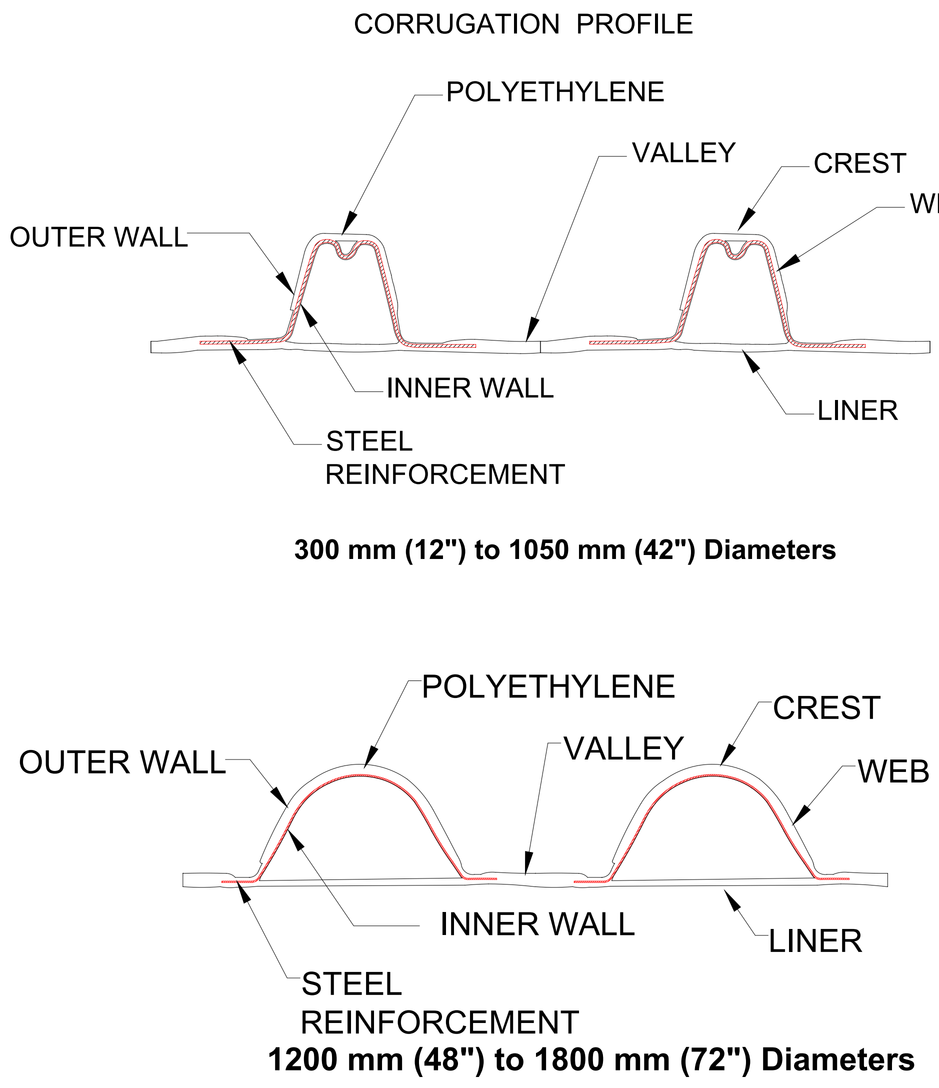

Figure 1—Cross Section of Corrugated Profile

3.2.8. *steel-reinforced polyethylene corrugated pipe*—Polyethylene pipe with a corrugated profile containing reinforcing steel (see Figure 1).

3.2.9. *slow crack growth*—A phenomenon by which a stress crack may form. A stress crack is an external or internal crack in plastic caused by tensile stresses less than its short-term mechanical strength.

3.2.10. *virgin polyethylene material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

4. CLASSIFICATION

4.1. The SRPE corrugated pipe covered by this specification is classified as follows:

4.1.1. *Type S*—This pipe shall have a full circular cross section with an essentially smooth inner wall.

4.1.2. *Type SP*—This pipe shall be Type S with perforations.

4.2. Perforations are described in Section 7.5.

5. ORDERING INFORMATION

5.1. Orders using this specification shall include the following information as necessary to adequately describe the desired product:

5.1.1. AASHTO MP XXXX;

5.1.2. Perforation, if applicable (Section 7.5);

5.1.3. Diameter and length required, either total length or length of each piece and number of pieces;

5.1.4. Certification, if desired (Section 12.1); and

5.1.5. Type of pipe joint (Section 7.11.1).

6. MATERIALS

6.1. *Polyethylene Materials*:

6.1.1. *Pipe and fittings* — Pipe and fittings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 324452C or E. Resins that have higher cell classifications in one or more properties are acceptable provided the product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 213320C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met. For slow crack resistance, acceptance of resins shall be determined by using notched, constant ligament-stress (NCLS) test according to the procedure described in Section 9.4. The average failure time of the five test specimens must exceed 24 h with no single specimen's failure time less than 17h.

6.1.3. *Injection Molding Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 324452C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.4. *Carbon Black Content*—The carbon black content shall not exceed 4.0 percent of the total PE compound weight.

6.1.5. *Other Materials*—It is permissible to use materials other than the cell classification in Section 6.1.1 as part of the pipe manufacturing, for example to weld pipe joints, provided these materials have higher cell classifications in one or more properties and in no way compromise the performance of the pipe products in the intended use.

6.1.6. *Reworked Plastics*—In lieu of virgin PE, it is permissible to use clean reworked plastic generated from the manufacturer's own pipe production, provided that it meets the cell classification requirements as described in Section 6.1.1.

6.2. *Steel Materials*:

6.2.1. *Steel Dimensions and Properties* – The minimum thickness of the steel sheet shall be as listed in Table 1. The steel substrate shall conform to Specification ASTM A1008/A1008M or ASTM A653/A653M, and the minimum yield strength of the steel sheet shall not be less than 358 MPa [52 ksi]. All steel materials shall be galvanized per the requirements of ASTM A653/A653M with a G40 minimum coating weight.

6.2.2. *Steel Content* – The steel content shall not exceed 75% of the total weight of the pipe. The steel material shall be fully encapsulated by the polyethylene material with a minimum thickness of the polyethylene as shown in Table 1.

6.3. *Gaskets*—Elastomeric gaskets shall meet the requirements of ASTM F477.

6.4. *Industrial Sealant*-Sealants, such as moisture cure urethane or asphalt-based sealant materials used for repairs, cut pipe end or assembly of coupling joints, as recommended by the manufacturer may be used.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. Visible defects shall not affect the wall integrity or the encapsulation of the steel reinforcement. The steel reinforcing materials shall not be exposed.

7.2. *Visible Defects*—Cracks, creases, delaminations, and unpigmented or nonuniformly pigmented pipe that are visible by the unaided eye are not permissible in the pipe or fittings.

7.3. There shall be no evidence of delamination when tested in accordance with Section 9.2.

7.4. *Pipe Dimensions and Tolerances*:

7.4.1. *Inside Diameter*—The tolerance on the inside diameter shall be ±2.0 percent, when measured in accordance with Section 9.6.1. Pipe dimensions (for both perforated and nonperforated pipe) shall comply with Table 1.

7.4.1.1. Other diameters that are within the range of pipe sizes shown in Table 1 are permissible. The minimum wall thickness and other properties shall be interpolated from the adjacent values given in Table 1.

Table 1—Pipe Sizes, Diameters, Steel Thickness and Minimum Valley Wall Thicknesses

[a]

Nominal Pipe Size, mm (in.)	Inside Diameter, mm [in.]	Outside Diameter, mm [in.]	Minimum Steel Thickness mm [in.]	Minimum Valley Wall Thickness mm [in.]	Minimum Encapsulation Thickness mm [in.]	Minimum Inner Wall Thickness mm [in]
300 (12)	305 [12.01]	338 [13.31]	0.30 [0.012]	3.3 [0.13]	0.9 [0.035]	2.3 [0.09]
375 (15)	381 [15.00]	413 [16.26]	0.30 [0.012]	3.3 [0.13]	1.0 [0.039]	2.3 [0.09]
450 (18)	457 [17.99]	489 [19.25]	0.30 [0.012]	4.2 [0.17]	1.3 [0.051]	2.9 [0.11]
600 (24)	610 [24.02]	653 [25.71]	0.30 [0.012]	4.2 [0.17]	1.5 [0.059]	2.9 [0.11]
750 (30)	762 [30.00]	817 [32.17]	0.30 [0.012]	5.2 [0.20]	1.5 [0.059]	3.6 [0.14]
900 (36)	915 [36.02]	970 [38.19]	0.30 [0.012]	6.9 [0.27]	1.7 [0.067]	4.8 [0.19]
1050 (42)	1067 [42.01]	1128 [44.41]	0.30 [0.012]	9.7 [0.38]	1.8 [0.071]	6.8 [0.27]
1200 (48)	1220 [48.03]	1320 [51.97]	0.30 [0.012]	10.8 [0.43]	1.8 [0.071]	7.6 [0.30]
1500 (60)	1524 [60.00]	1656 [65.20]	0.30 [0.012]	11.9 [0.47]	2.0 [0.079]	8.3 [0.33]
1800 (72)	1842 [72.52]	1982 [78.03]	0.30 [0.012]	13.0 [051]	2.0 [0.079]	9.1 [0.36]

7.4.2. *Valley Wall*—Minimum wall thickness shall be as required in Table 1 and measured in accordance with Section 9.6.2.

7.4.3. *Length*—The pipe shall be sold in any length agreeable to the user. Length shall not be less than 99 percent of the specified length, when measured in accordance with Section 9.6.3.

7.4.4. *Encapsulation Thickness*—The minimum thickness of the PE encapsulation of steel reinforcement, measured at any location, shall be as specified in Table 1. Factory cut pipe ends shall have the cut corrugation ends encapsulated with PE material meeting the requirements of Section 6.1, to maintain the requirements of Table 1. Encapsulation thicknesses shall be measured in accordance with Section 9.6.4. Field cut pipe ends shall have the cut corrugation ends encapsulated with industrial sealant meeting the requirements of Section 6.4.

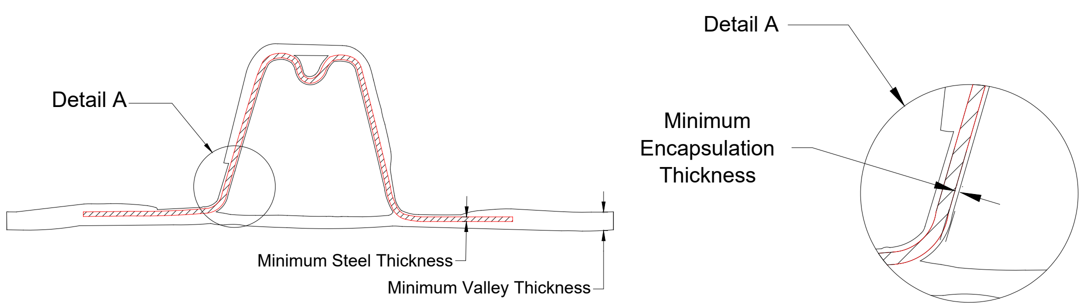

Figure 2—Encapsulation and Wall Thickness

7.5. *Perforations*—When perforated pipe is specified, the perforations shall be cleanly cut and uniformly spaced along the length and circumference of the pipe. Circular perforations shall be a minimum of 5 mm (0.2 in.) and shall not exceed 10 mm (0.4 in.) in diameter. The water inlet area shall be a minimum of 30 cm^2/m (1.5 $in.^2/ft$) for pipe sizes 300 to 450 mm (12 to 18 in.) and 40 cm^2/m (2.0 $in.^2/ft$) for pipe sizes larger than 450 mm (18 in.). All measurements shall be made in accordance with Section 9.6.5. The perforations shall be cleanly cut so as not to restrict the inflow of water. Perforations shall be located in the valley portion of the pipe between the corrugations. The reinforcing steel material shall not be exposed by these perforations.

7.6. *Pipe Stiffness*—The pipe shall have minimum pipe stiffness at 5 percent deflection as listed in Table 2. Pipe stiffness shall be tested in accordance with Section 9.1.

Table 2—Pipe Stiffness

Nominal Pipe Size, mm (in.)	Pipe Stiffness, kPa [psi] [a]
300 (12)	400 [58]
375 (15)	400 [58]
450 (18)	275 [40]
600 (24)	235 [34]
750 (30)	200 [29]
900 (36)	155 [22.5]
1050 (42)	145 [21]
1200 (48)	140 [20]
1500 (60)	105 [15]
1800 (72)	105 [15]

Note 2—The 5 percent deflection criterion was selected for testing convenience and should not be considered as a limitation with respect to in-use deflection.

7.7. *Pipe Flattening*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.2. Additionally, there shall be no downturn of the load-deflection curve prior to 20% vertical deflection.

7.8. *Bonding of the Steel to the Polyethylene*—The mechanical bond between the steel reinforcement and the polyethylene shall be greater than the tensile strength of the polyethylene resin required for this standard. It shall not be possible to separate any two layers with a probe or with the point of a knife blade so that the layers separate cleanly, or the probe or knife moves freely between the layers. There shall be no separation of the polyethylene from the steel reinforcing plate, when the pipe is deflected 40%, in accordance with Section 9.2.

7.9. *Impact*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.3.

7.10. *Fitting Requirements*:

7.10.1. Only fittings supplied or recommended by the manufacturer shall be used. Fabricated fittings shall be supplied with joints compatible with the overall system requirements.

7.10.2. All fittings shall be within an overall length dimensional tolerance ±12 mm (0.5 in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.6.3.

7.10.3. The fittings shall not impair the overall integrity or function of the pipe.

7.10.4. Common fittings include in-line joint fittings, reducers, and branch or complementary assembly fittings such as tees and wyes. These fittings shall be installed or coupled to the pipe by split couplers or other methods meeting the requirements of Section 7.11.

7.10.5. Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm (0.5 in.). Reducer fittings shall not reduce the cross-sectional area of the small size diameter by more than 3 percent.

7.11. *Jointing Requirements*:

7.11.1. Pipe joints and couplings shall be split-collar bands meeting the material requirements of Section 6.1. Split-collar bands shall be corrugated to match the pipe corrugations and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Split-collar band couplings shall engage at least two full corrugations of each pipe section. The two ends of the split-collar band shall overlap a minimum of 50.8 mm (2.0 in.). Split-collar bands shall meet the soil-tight requirements of Section 7.11.2.1 or the silt-tight requirements of Section 7.11.2.2.

7.11.1.1. Other types of couplings or fastening devices that are equally effective as one of those described in Section 7.11.2, may be used when approved by the purchaser.

7.11.1.2. *Internal Coupling, Sealant Type*—Joint seal is affected by applying an industrial sealant between the external surface of the coupling and the internal surface of the pipe. This jointing system may be used when approved by the purchaser.

7.11.1.3. Other types of jointing methods such as flanging, internal coupling (gasket type), extrusion welding, electro-fusion, butt fusion, and others may be used when approved by the purchaser.

7.11.2. *Joint Tightness*—The pipe or fitting joint shall meet the requirements defined as one of the following types:

7.11.2.1. *Soil-tight Joints*—Soil-tight joints are specified as a function of opening size (maximum dimension normal to the direction that soil may infiltrate), channel length (length of the path along which the soil may infiltrate) and backfill particle size. If the size of the opening exceeds 3 mm ($^1/_8$ in.), the length of the channel must be at least four times the size of the opening. No opening may exceed 25 mm (1 in.). Backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration.

7.11.2.2. *Silt-Tight Joints*—A silt-tight joint is resistant to infiltration of particles that pass the No. 200 sieve. Silt-tight joints are specified to provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile wrap. Geotextile wraps are manufactured to tolerances that assure silt will not pass through them. The successful performance of these wraps in the field is dependent on their installation. If a geotextile wrap is specified for use, the material specified should meet the requirements of M 288, with an Apparent Opening Size (AOS) > 70.

For joints that utilize an elastomeric rubber seal, silt-tight performance shall have been demonstrated in a laboratory test to meet the hydrostatic requirements of ASTM D3212, with the exception that the hydrostatic test pressure shall be a minimum of 14 kPa (2 psi).

7.11.2.3. *Leak-Resistant Joints*—Leak-resistant joints shall be bell and spigot and utilize an elastomeric rubber seal meeting the requirements of ASTM F477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 7.11.2.3.1 are achieved.

7.11.2.3.1. Leak resistance shall be verified in the lab by meeting all of the requirements of ASTM D3212. The hydrostatic test pressure and vacuum specified in the test method shall be 74 kPa (10.8 psi).

7.11.3. *Special Design Joints*—Special design joints shall include joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, flanged and bolted joints for high pressures, high heads, or velocities. Watertight joints that provide zero leakage for a specified head or pressure application are included in this type of joint.

7.12. *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test shall not be less than 50 percent of the gross cross section of the steel reinforcing area times the minimum specified yield strength of the steel when tested in accordance with Section 9.7. The stub compression test, AASHTO T 341, shall be a material and wall design qualification test conducted twice a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be accomplished conveniently by optically scanning the profile and determining the section properties using a computer drafting program.

8. CONDITIONING

8.1. *Conditioning*—Condition the specimen prior to test at 21 to 25°C (70 to 77°F) for not less than 24 h in accordance with Procedure A in ASTM D618 for those tests where conditioning is required, and unless otherwise specified.

8.2. *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25°C (70 to 77°F) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a minimum of three pipe specimens from the pipe and test for pipe stiffness $F/\Delta y$, as described in Test Method D2412, except for the following conditions:

1. Specimens shall be cut mid valley to mid valley along the corrugation, and then cut across the corrugation.
2. Specimens shall be longer than 18 inches (457 mm) in length.
3. Locate the first specimen in the loading machine with the imaginary line between two corrugations parallel to the loading plates. The specimen must lie flat on the plate within 1⁄8 in. (3 mm). Use the first location as a reference point for rotation of the other two specimens. Rotate the second specimen 45° and the third specimen 90°. Test each specimen in one position only.
4. Testing speed of the specimens shall be 0.5 inches (12.7 mm) per minute for testing up to 5 % deflection. For testing beyond 5% deflection, test at a speed of 5 inches (127 mm) per minute.
5. The deflection indicator shall be readable and accurate to +0.001 in. (+0.02 mm).
6. The parallel plates must exceed the samples in length.

9.2. *Pipe Flattening*—Flatten the three pipe samples from Section 9.1 until the vertical inside diameter is reduced by 40 percent. The length of the test specimen and the rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination.

9.3. *Pipe Impact*—Test pipe specimens in accordance with ASTM D2444 except that six specimens shall be tested. Specimens shall be at least 18 inches (457 mm) in length and impact points shall be at least 152 mm (6 in.) from the end of the specimen. Impact resistance shall not be less than 136 J. Tup B and a flat plate specimen holder shall be used. Condition the specimens for 24 h at a temperature of 0 ± 1°C (32 ± 2°F), and conduct all tests within 60 s of removal from this atmosphere.

9.4. *Slow Crack Growth Resistance of HDPE Resin Compounds*—Test basic resin compounds for stress crack resistance in accordance with the ASTM F2136, the NCLS test, except for the following modifications:

9.4.1. The applied stress for the NCLS test shall be 4100 kPa (600 psi).

9.4.2. The specimens shall be prepared from pieces of the pipe liner that have been compression molded into a plaque in accordance with ASTM D4703 Procedure C.

Note 3—The notched depth of 20 percent of the nominal thickness of the specimen is critical to this procedure.

9.5. *Delamination*—Test the fusion of the bond between the inner and outer wall of the corrugated profile width (see Figure 2) with a probe or knife point. It shall not be possible to separate cleanly the two walls. Test samples at eight equally spaced points around its circumference.

9.6. *Dimensions*:

9.6.1. *Inside Diameter*—Measure the inside diameter of three specimens, each a minimum of 300 mm (12 in.) long with any suitable device accurate to 0.8 mm (0.03 in.), at two positions, namely, any point in the circumferential direction and 90 degrees from this point, and average the six measurements. Inside diameter shall meet the requirements of Section 7.4.1.

9.6.2. *Valley Wall*—Locate and measure the wall thickness between the corrugations at four equally spaced locations around the circumference of the pipe, in accordance with ASTM D2122.

9.6.3. *Length*—Measure pipe with any suitable device accurate to ±6.0 mm in 3 m (±0.25 in. in 10 ft). Make all measurements on the pipe while it is resting on a relatively flat surface, in a straight line, with no external tensile or compressive forces exerted on the pipe. These measurements may be taken at ambient temperatures.

9.6.4. *Encapsulation Thickness*—Locate and measure the encapsulation thickness by cutting a minimum of 2 equally spaced cross sections. Pipe specimens shall be cleanly cut and burrs removed. A flat-anvil micrometer or Vernier calipers, accurate to ±0.02 mm (±0.001 in) shall be used to measure the encapsulation thickness at 8 equally spaced locations around the pipe circumference. Encapsulation thickness shall be measured for inner wall and outer wall.

Note 4— Alternatively, direct measurements may be used. To measure inner wall encapsulation thickness, remove HDPE from outer wall. Measure the combined thickness of the steel and inner wall. Care should be taken to avoid misalignment of the anvil or Vernier calipers with the longitudinal axis of the specimen. Remove the HDPE from the inner wall. Measure the thickness of the steel reinforcement. Subtract the steel reinforcement thickness from combined thickness of the steel and inner wall thickness to obtain the inner wall encapsulation thickness. To measure the outer wall, repeat this process by interchanging the outer and inner wall thickness described above. Care should be taken to avoid removing steel thickness when removing the HDPE.

9.6.5. *Perforations*—Measure dimensions of perforations on a straight profile specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.08 in.).

9.7. *Stub Compression Capacity*:

9.7.1. Determine the stub compression capacity of the pipe section in accordance with AASHTO T 341. Conduct four tests on specimens cut from the same ring of pipe at 90-degree intervals around the circumference.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed on by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—Retesting in the event of a test failure shall be conducted on samples from the failed lot only under an agreement between purchaser and seller. There shall be no changes to the test procedures or the requirements.

11. MARKING

11.1. *All pipe shall be clearly marked at intervals of no more than 3 m (10.0 ft) as follows*:

11.1.1. Manufacturer's name or trademark.

11.1.2. AASHTO MP XXXX.

11.1.3. Nominal pipe size.

11.1.4. The plant designation code.

11.1.5. The date of manufacture or an appropriate code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 5—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

11.2. Fittings shall be marked with the designation number of this specification, AASHTO MP XXXX, and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1. A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results and the date each test was completed shall be furnished on request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

13. KEYWORDS

13.1. SRPE; crack; crease; delamination; gravity flow.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/manufacturer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on the manufacturer to control the quality of the material they produce and to provide the quality control.

X1.2. *Program Requirements*:

X1.2.1. The manufacturing company must have a quality control plan approved by the specifying agency.

X1.2.2. The manufacturing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The manufacturing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The manufacturer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to ensure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s).

X1.3.1.2. The physical location of the plant(s).

X1.3.1.3. The methods of identification of each lot of material during manufacturing, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider.

X1.3.1.4. The method of sampling and testing of raw materials and of finished product, including lot sizes and types of tests performed.

X1.3.1.5. A plan for dealing with nonconforming product, including how the manufacturer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by quality control technicians designated by the manufacturer. The designated quality control technicians will be responsible for overall Quality Control at the manufacturing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31st of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan, and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been

implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, or manufacturer's location, or both, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in MP XXXX.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's quality control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency on request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

Attachment #3

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 1650- to 3000-mm (66- to 120-in.) Diameter

AASHTO Designation: MP XXX-YY[1]

Technical Subcommittee: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 1650- to 3000-mm (66- to 120-in.) Diameter

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1. SCOPE

1.1. This specification covers the requirements and methods of tests for steel-reinforced polyethylene (PE) ribbed pipe, couplings, and fittings for use in surface and subsurface drainage applications.

1.1.1. Nominal sizes of 1650 to 3000 mm (66 to 120 in.) are included.

1.1.2. Materials, workmanship, dimensions, perforation, pipe stiffness, impact resistance, tensile strength of seams, shape stability, joining systems, and form of markings are specified.

1.2. Steel-reinforced PE ribbed pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow as culverts, storm drains, etc.

Note 1—When PE pipe is to be used in locations where the ends may be exposed, consideration should be given to protection of the exposed portions due to combustibility of the PE and the effects of prolonged exposure to ultraviolet radiation.

1.3. This specification only deals with this pipe's materials requirements. The structural design of steel reinforced thermoplastic culverts and the proper installation procedures are given in the *AASHTO LRFD Bridge Design Specifications*, Section 12, and *AASHTO LRFD Bridge Construction Specifications*, Section 26, respectively. Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

1.4. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. Customary units are shown in parentheses and may not be exact equivalents.

1.5. The following precautionary caveat pertains only to the test method portion, Section 9, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 288, Geosynthetic Specification for Highway Applications
- T 341, Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading
- *AASHTO LRFD Bridge Design Specifications*, Section 12
- *AASHTO LRFD Bridge Construction Specifications*, Section 26

2.2. *ASTM Standards*:

- A653/A653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- D618, Standard Practice for Conditioning Plastics for Testing
- D638, Standard Test Method for Tensile Properties of Plastics
- D883, Standard Terminology Relating to Plastics
- D2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- F412, Standard Terminology Relating to Plastic Piping Systems
- F477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D883 and ASTM F412 unless otherwise specified.

3.2. *Definitions*:

3.2.1. *crack*—any break or split that extends through the wall.

3.2.2. *crease*—a visible irrecoverable indentation, generally associated with a loss in shape stability.

3.2.3. *delamination*—a gap extending through the weld seam between two adjacent wrap widths.

3.2.4. *encapsulation thicknesses*—the thicknesses of the high-density polyethylene (HDPE) covering on both sides of the steel reinforcement as well as the thickness of the closure at the top (outside) of the rib and the thickness of the profile directly under (inside) the reinforcement (see Figure 2).

3.2.5. *gravity flow*—a condition in which liquid flow through a piping system results from a downward pipeline slope, but flow is less than full, except during conditions when the system may become temporarily surcharged, in which case the system is subject to temporary internal hydrostatic pressure that is limited to 74 kPa (10.8 psi).

3.2.6. *polyethylene (PE) plastics*—plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D883).

3.2.7. *reworked plastic*—a plastic from a processor's own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D883).

3.2.8. *weld seam*—the portion of the helically wrapped strip that overlaps and is fused to adjacent helically wrapped strips (see Figure 1).

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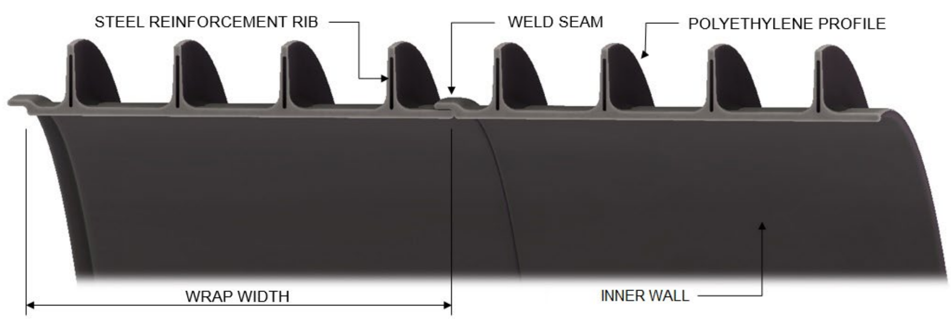

Figure 1—Cross Section of Profile

3.2.9. *shape stability*—a general measure of the pipe's ability to maintain geometric and structural stability while deflected and carrying a load equal to or greater than 75 percent of its peak load-carrying capability. Peak load-carrying capability is identified as the maximum load in the load/deflection curve as measured during the flattening test as described in Section 9.2.

3.2.10. *steel-reinforced polyethylene pipe*—ribbed thermoplastic pipe with steel reinforcing strips encapsulated within the ribs (see Figure 1 and Figure 2).

3.2.11. *slow crack growth*—a phenomenon by which a stress crack may form. A stress crack is an external or internal crack in plastic caused by tensile stresses less than its short-term mechanical strength.

3.2.12. *virgin polyethylene material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

3.2.13. *wrap width*—the width the helically wrapped strip covers when measured across the strip, perpendicular to the ribs (see Figure 1).

3.2.14. *inner wall*—the minimum wall thickness separating the inner and outer surfaces of the pipe wall, which is measured between pipe ribs (see Figure 2).

4. CLASSIFICATION

4.1. *The steel-reinforced PE ribbed pipe covered by this specification is classified as follows*:

4.1.1. *Type S*—This pipe shall have a full circular cross section with an essentially smooth inner wall.

4.1.2. *Type SP*—This pipe shall be Type S with perforations.

4.2. Perforations are described in Section 7.5.

5. ORDERING INFORMATION

5.1. *Orders using this specification shall include the following information as necessary to adequately describe the desired product*:

5.1.1. AASHTO designation and year of issue;

5.1.2. Perforation, if applicable (Section 7.5);

5.1.3. Diameter and length required, either total length or length of each piece and number of pieces;

5.1.4. Certification, if desired (Section 12.1); and

5.1.5. Type of pipe joint (Section 7.12.1).

6. MATERIALS

6.1. *Polyethylene Materials*:

6.1.1. *Pipe and Fittings*—Pipe and fittings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 334452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided the product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 213320 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met. For slow crack resistance, acceptance of resins shall be determined by using the notched, constant ligament-stress (NCLS) test according to the procedure described in Section 9.6. The average failure time of the five test specimens must exceed 24 h with no single test specimen's failure time less than 17 h.

6.1.3. *Injection Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 324452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.4. *Carbon Black Content*—The carbon black content shall be a minimum of 2 percent and not exceed 4 percent of the total PE compound weight.

6.1.5. *Other Materials*—It is permissible to use materials other than the cell classification in Section 6.1.1 as part of the welding processes, provided these materials have higher cell classifications in one or more properties and in no way compromise the performance of the pipe products in the intended use.

6.1.6. *Rework Plastics*—In lieu of virgin PE, it is permissible to use clean reworked plastic generated from the manufacturer's own pipe production, provided that it meets the cell class requirements as described in Section 6.1.1.

6.2. *Steel Materials*:

6.2.1. *Steel Material*—The steel material shall be cold- or hot-rolled, formable steel meeting the requirements of ASTM A653/A653M and the mechanical requirements for strength in Table 4 of ASTM A653/A653M for the grade defined by the manufacturer as required for their pipe's design.

The steel shall have a galvanized coating. All steel materials shall be galvanized per the requirements of ASTM A653/A653M with a G60 minimum coating weight.

Note 2—The actual strength of the steel and the rib dimensions are dependent on the manufacturer's design. If requested by the purchaser, the manufacturer shall provide before purchase and delivery their pipe design and certify with delivery that the grade of steel and rib dimensions in the pipe supplied conform to their design.

6.2.2. *Gaskets*—Elastomeric gaskets shall meet the requirements of ASTM F477.

6.2.3. *Industrial Sealant*—Sealants, such as moisture cure urethane or asphalt-based sealant materials used for repairs or assembly of the internal coupling joint, as recommended by the manufacturer, may be used.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. Visible defects shall not affect the wall integrity or the encapsulation of the steel reinforcement. The steel reinforcing materials shall not be exposed.

7.2. *Visible Defects*—Cracks, creases, delamination, and unpigmented or nonuniformly pigmented pipe that are visible by the unaided eye are not permissible in the pipe or fittings.

7.3. There shall be no evidence of cracking or delamination when tested in accordance with Section 9.2.

7.4. *Pipe Dimensions and Tolerances*:

7.4.1. *Inside Diameter*—The tolerance on the inside diameter shall be ±2.0 percent, when measured in accordance with Section 9.8.1. Pipe dimensions (for both perforated and nonperforated pipe) shall comply with Table 1.

7.4.1.1. Other diameters that are within the range of pipe sizes shown in Table 1 are permissible. The minimum wall thickness and other properties shall be interpolated from the adjacent values given in Table 1.

Table 1—Nominal Pipe Sizes, Inside Diameters, and Minimum Inner Wall Thicknesses

Nominal Pipe Size, mm (in.)	Inside Diameter, mm [in.] [a]	Minimum Inner Wall Thickness, t_1, mm [in.]	Minimum Encapsulation Thickness (Bottom), t_2, mm [in.]
1650 (66)	1650 [64.96]	5.5 [0.217]~~2.2 [0.087]~~	5.5 [0.217]~~2.2 [0.087]~~
1800 (72)	1800 [70.87]	5.5 [0.217]~~2.2 [0.087]~~	5.5 [0.217]~~2.2 [0.087]~~
1950 (78)	1950 [76.77]	5.5 [0.217]~~2.4 [0.094]~~	5.5 [0.217]~~2.4 [0.094]~~
2100 (84)	2100 [82.68]	5.5 [0.217]~~2.4 [0.094]~~	5.5 [0.217]~~2.4 [0.094]~~
2250 (90)	2250 [88.58]	5.5 [0.217]~~2.4 [0.094]~~	5.5 [0.217]~~2.4 [0.094]~~
2400 (96)	2400 [94.49]	5.5 [0.217]~~3.0 [0.118]~~	5.5 [0.217]~~3.0 [0.118]~~
2550 (102)	2550 [100.39]	5.5 [0.217]~~3.0 [0.118]~~	5.5 [0.217]~~3.0 [0.118]~~
2700 (108)	2700 [106.30]	5.5 [0.217]~~3.0 [0.118]~~	5.5 [0.217]~~3.0 [0.118]~~
2850 (114)	2850 [112.20]	5.5 [0.217]~~3.0 [0.118]~~	5.5 [0.217]~~3.0 [0.118]~~
3000 (120)	3000 [118.11]	5.5 [0.217]~~3.0 [0.118]~~	5.5 [0.217]~~3.0 [0.118]~~

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

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7.4.2. *Inner Wall*—Minimum inner wall thickness shall be as required in Table 1 when measured in accordance with Section 9.8.2.

7.4.3. *Length*—The pipe shall be sold in any length agreeable to the user. Length shall not be less than 99 percent of the specified length, when measured in accordance with Section 9.8.3.

7.4.4. *Encapsulation Thickness*—The minimum thickness of the HDPE encapsulation at the sides, top (outside), and bottom (inside) of the reinforcement shall be as shown in Figure 2. Factory cut pipe ends shall have the cut rib ends encapsulated to meet the requirements of Figure 2 for the top (outside) of the ribs. Encapsulation thicknesses shall be measured in accordance with Section 9.8.4.

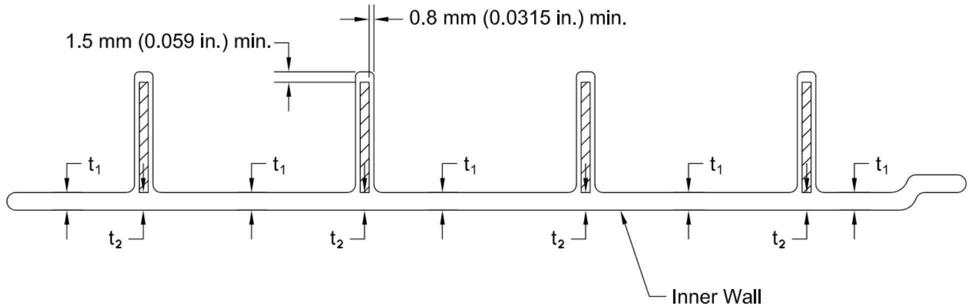

Figure 2—Schematic Representation of Steel-Reinforced Thermoplastic Pipe Profile

7.5. *Perforations*—When perforated pipe is specified, the perforations shall be cleanly cut and uniformly spaced along the length and circumference of the pipe. Circular perforations shall be a minimum of 5 mm (0.2 in.) and shall not exceed 10 mm (0.4 in.) in diameter. The water inlet area shall be a minimum of 30 cm^2/m (1.5 $in.^2/ft$) for pipe sizes 300 to 450 mm (12 to 18 in.) and 40 cm^2/m (2.0 $in.^2/ft$) for pipe sizes larger than 450 mm (18 in.). All measurements shall be made in accordance with Section 9.8.5. The perforations shall be cleanly cut so as not to restrict the inflow of water. Pipe connected by bell and spigot joints may not be perforated in the area of the bells and spigots. Perforations shall be located in the inner wall portion of the pipe between the ribs and shall not cut into encapsulation of the reinforcement, the radius between this encapsulation and the inner wall, or the fused seam. The reinforcing steel material shall not be exposed by these perforations.

7.6. *Pipe Stiffness*—The pipe shall have minimum pipe stiffness at 5 percent deflection as listed in Table 2. Pipe stiffness shall be tested in accordance with Section 9.1. For installations that utilize improved installation techniques the allowable pipe stiffness can be decreased to the equivalent to a 0.095 flexibility factor. Improved installation techniques shall include limiting the use of structural backfill material to that meeting an A-1 gradation per M145 or on-site shape control monitoring. Table X.2 in the Appendix provides pipe stiffness values based on this limit.

Table 2—Pipe Stiffness and Shape Stability Limits

Nominal Pipe Size, mm (in.)	Pipe Stiffness, kPa [psi] [a]	Shape Stability Limit, %
1650 (66)	90 [13]	12
1800 (72)	83 [12]	12
1950 (78)	76 [11]	10
2100 (84)	69 [10]	10
2250 (90)	69 [10]	10
2400 (96)	63 [9]	--
2550 (102)	56 [8]	--
2700 (108)	56 [8]	--
3000 (120)	49 [7]	--

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

Note 3—The 5 percent deflection criterion was selected for testing convenience and should not be considered as a limitation with respect to in-use deflection.

7.7. *Pipe Flattening*—There shall be no visual evidence of splitting or cracking when tested in accordance with Section 9.2. Additionally, there shall be no separation or delamination of the spiral seam or the rib at the top of its junction with the inner wall of the pipe when tested in accordance with Section 9.7.

7.8. *Shape Stability*—In the flattening test described in Section 9.2, the load shall not decrease with increasing deflection until after the percentage shape stability limit tabulated for the relevant diameter (in Table 2) has been exceeded. Additionally, if the peak load is reached before 20 percent deflection, the load at 20 percent deflection shall be a minimum of 75 percent of the peak load. Shape stability limit is calculated as follows:

$$SSL = \frac{\Delta Y}{ID} \times 100\% \tag{1}$$

where:

SSL = shape stability limit

ΔY = change in vertical deflection

ID = inside diameter of pipe

7.9. *Impact*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.3. Additionally, there shall be no separation of the spiral seam or the rib at its junction with the inner wall when tested in accordance with Section 9.7.

7.10. *Tensile Strength of Seam*—There shall be no breaking or separation of the weldment material in the lap seam when tested in accordance with Section 9.4. Excess weldment material located outside of the lapped seam is not considered as part of the test.

7.11. *Fitting Requirements*:

7.11.1. Only fittings supplied or recommended by the manufacturer shall be used. Fabricated fittings shall be supplied with joints compatible with the overall system requirements. A bell-and-spigot joint is an example of a typical design.

7.11.2. All fittings shall be within an overall length dimensional tolerance ±12 mm (0.5 in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.8.3.

7.11.3. The fittings shall not impair the overall integrity or function of the pipe.

7.11.4. Common fittings include in-line joint fittings, reducers, and branch or complementary assembly fittings such as tees and wyes. These fittings shall be installed or coupled to the pipe by various methods.

7.11.5. Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm (0.5 in.). Reducer fittings shall not reduce the cross-sectional area of the small size diameter by more than 3 percent.

7.12. *Jointing Requirements*:

7.12.1. Pipe joints and couplings shall be bell and spigot or screw-on collar. Only couplings supplied or recommended by the manufacturer shall be used. Couplings shall be supplied with joints compatible with the overall system requirements.

7.12.1.1. Other types of couplings or fastening devices that are equally effective as those described in Section 7.12.2.1 and that comply with the soiltight joint performance criteria of the *AASHTO LRFD Bridge Construction Specifications*, Article 26.4.2.4, may be used when approved by the purchaser. An example of another type of coupler is a split-collar coupling, which shall match the pipe profile and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Split-collar couplings shall engage at least three full ribs on each pipe section.

7.12.1.2. *Internal Coupling, Sealant Type*—Joint seal is affected by applying an industrial sealant between the external surface of the coupling and the internal surface of the pipe. This jointing system may be used when approved by the purchaser.

7.12.1.3. Other types of jointing methods such as flanging, internal coupling (gasket type), extrusion welding, electro-fusion, butt fusion, and others may be used when approved by the purchaser.

7.12.2. *Joint Tightness*—The pipe or fitting joint shall meet the requirements defined as one of the following types:

7.12.2.1. *Soiltight Joints*—Soiltight joints are specified as a function of opening size (maximum dimension normal to the direction that soil may infiltrate), channel length (length of the path along which the soil may infiltrate), and backfill particle size. If the size of the opening exceeds 3 mm ($^1/_8$ in.), the length of the channel must be at least four times the size of the opening. No opening may exceed 25 mm (1 in.). Backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration.

7.12.2.2. *Silt-Tight Joints*—A silt-tight joint is resistant to infiltration of particles that pass the No. 200 sieve. Silt-tight joints are specified to provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile wrap. Geotextile wraps are manufactured to tolerances that assure silt will not pass through them. The successful performance of these wraps in the field is dependent on their installation. If a geotextile wrap is specified for use, the material specified should meet the requirements of M 288, with an Apparent Opening Size (AOS) > 70.

For joints that utilize an elastomeric rubber seal, silt-tight performance shall have been demonstrated in a laboratory test to meet the hydrostatic requirements of ASTM D3212, with the exception that the hydrostatic test pressure shall be a minimum of 14 kPa (2 psi).

7.12.2.3. *Leak-Resistant Joints*—Leak-resistant joints shall be bell and spigot and utilize an elastomeric rubber seal meeting the requirements of ASTM F477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 7.12.2.3.1 are achieved.

7.12.2.3.1. Leak resistance shall be verified in the lab by meeting all of the requirements of ASTM D3212. The hydrostatic test pressure and vacuum specified in the test method shall be 74 kPa (10.8 psi).

7.12.3. *Special Design Joints*—Special design joints shall include joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, flanged and bolted joints for high pressures, high heads, or velocities. Watertight joints that provide zero leakage for a specified head or pressure application are included in this type of joint.

7.13. *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test shall not be less than 50 percent of the gross cross section of the steel reinforcing area times the minimum specified yield strength of the steel when tested in accordance with Section 9.9. The stub compression test, T 341, shall be a material and wall design qualification test conducted twice a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be accomplished conveniently by optically scanning the profile and determining the section properties using a computer drafting program.

8. CONDITIONING

8.1. *Conditioning*—Condition the specimen prior to test at 21 to 25°C (70 to 77°F) for not less than 24 h in accordance with Procedure A in ASTM D618 for those tests where conditioning is required, and unless otherwise specified.

8.2. *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25°C (70 to 77°F) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a minimum of two pipe specimens and test for pipe stiffness $F/\Delta y$, as described in ASTM D2412, except for the following conditions:

1. The length of the test specimen shall be a whole number of wraps, with a minimum length of four wrap widths or half the pipe diameter, whichever is greater.
2. Randomly orient each specimen in the loading machine.
3. Testing speed of the specimens shall be 12.5 mm/min (0.5 in./min) for testing up to 5 percent deflection. For flattening beyond 5 percent deflection (see Section 9.2), it is permissible to increase test speeds up to 125 mm/min (5 in./min).
4. The deflection indicator shall be readable and accurate to ±0.02 mm (0.001 in.).
5. The beginning point for deflection measurement shall be at a load of 20 ± 5 N (4.5 ± 1.1 lbf). The point shall be considered as the origin of the load deflection curve.

9.2. *Flattening*—Flatten the two pipe samples from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The length of the test specimen and the rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination. It is permissible for the ribs to lean during this test only to the extent that neither the above requirements nor the shape stability requirements (Section 7.8) are failed.

9.3. *Impact*—Test pipe specimens in accordance with ASTM D2444 except that six specimens shall be tested. Specimens shall be at least four wrap widths in length and impact points shall be at least 152 mm (6 in.) from the end of the specimen. Impact resistance shall not be less than 136 J. Tup B and a flat plate specimen holder shall be used. Condition the specimens for 24 h at a temperature of 0 ± 1°C (32 ± 2°F), and conduct all tests within 60 s of removal from this atmosphere.

9.4. *Tensile Strength of Seam*—Test in accordance with ASTM D638, with the following conditions:

1. The sample shall be prepared according to the dimensions for Type I specimens, with the weld seam arranged centrally and perpendicular to the tensile test axis.
2. All steel reinforcement shall be removed from the profile.
3. It is permissible to reduce the height of the HDPE ribs to no less than 2.5 mm (0.1 in.) if required to facilitate testing.

9.5. *Joint Integrity*—Assemble each fitting or coupling to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Load the connected pipe and fitting between parallel plates at the rate of 12.5 mm/min (0.5 in./min) until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the pipe. Inspect for splitting, cracking, delamination, or other damage while at the specified deflection and after load removal.

9.6. *Slow-Crack-Growth Resistance of Resin Compounds*—Test basic resin compounds for stress-crack resistance in accordance with the ASTM F2136, the NCLS test, except for the following modifications:

9.6.1. The applied stress for the NCLS test shall be 4100 kPa (600 psi).

9.6.2. Resin test specimens shall be plaques molded from the reground resin from the rotomolded or injection-molded parts.

Note 4—The notched depth of 20 percent of the nominal thickness of the specimen is critical to this procedure.

9.7. *Delamination*—Test the fusion of the weld between the inner and outer wall of the wrap width with a probe or knife point. It shall not be possible to separate cleanly the two walls at the lap seam weld. Test samples at eight equally spaced points around its circumference.

9.8. *Dimensions*:

9.8.1. *Inside Diameter*—Measure the inside diameter of three specimens, each a minimum of 300 mm (12 in.) long with any suitable device accurate to 0.8 mm (0.03 in.), at two positions, namely, any point in the circumferential direction and 90 degrees from this point, and average the six measurements. Inside diameter shall meet the requirements of Section 7.4.1.

9.8.2. *Inner Wall*—Locate and measure the wall thickness between the ribs at four equally spaced locations around the circumference of the pipe, in accordance with ASTM D2122.

9.8.3. *Length*—Measure pipe with any suitable device accurate to ±6.0 mm in 3 m (±0.25 in. in 10 ft). Make all measurements on the pipe while it is resting on a relatively flat surface, in a straight line, with no external tensile or compressive forces exerted on the pipe. These measurements may be taken at ambient temperatures.

9.8.4. *Encapsulation Thickness*—Locate and measure the encapsulation thickness by cutting a cross section and measuring in accordance with ASTM D2122.

9.8.5. *Perforations*—Measure dimensions of perforations on a straight profile specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.08 in.).

9.9. *Stub Compression Capacity*:

9.9.1. Determine the stub compression capacity of the pipe section in accordance with T 341. Conduct four tests on specimens cut from the same ring of pipe at 90-degree intervals around the circumference.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed on by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—Retesting in the event of a test failure shall be conducted on samples from the failed lot only under an agreement between purchaser and seller. There shall be no changes to the test procedures or the requirements.

11. MARKING

11.1. *All pipe shall be clearly marked at intervals of no more than 3.5 m (11.5 ft) as follows*:

11.1.1. Manufacturer's name or trademark;

11.1.2. AASHTO MP XXX;

11.1.3. Nominal inside diameter;

11.1.4. The plant designation code; and

11.1.5. The date of manufacture or an appropriate production code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 5—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

11.2. Fittings shall be marked with the designation number of this specification, AASHTO M 335, and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1. A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results and the date each test was completed shall be furnished on request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

13. KEYWORDS

13.1. Crack; crease; delamination; gravity flow; polyethylene; pipe; steel reinforced.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/manufacturer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on the manufacturer to control the quality of the material they produce and to provide the quality control.

X1.2. *Program Requirements*:

X1.2.1. The manufacturing company must have a quality control plan approved by the specifying agency.

X1.2.2. The manufacturing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The manufacturing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The manufacturer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to ensure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s).

X1.3.1.2. The physical location of the plant(s).

X1.3.1.3. The methods of identification of each lot of material during manufacturing, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider.

X1.3.1.4. The method of sampling and testing of raw materials and of finished product, including lot sizes and types of tests performed.

X1.3.1.5. A plan for dealing with nonconforming product, including how the manufacturer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by quality control technicians designated by the manufacturer. The designated quality control technicians will be responsible for overall Quality Control at the manufacturing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31st of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan, and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, or manufacturer's location, or both, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in M 335.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's quality control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency on request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

X2. ALLOWABLE PIPE STIFFNESS VALUES BASED ON FF-0.095

Nominal Inside Diameter, mm (in.)	Pipe Stiffness, kPa [psi] [a]
1650 (66)	62 [9]
1800 (72)	55 [8]
1950 (78)	55 [8]
2100 (84)	48 [7]
2250 (90)	48 [7]
2400 (96)	41 [6]
2550 (102)	41 [6]
2700 (108)	41 [6]
3000 (120)	34 [5]

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

[1] This provisional standard was first published in [YYYY].

Deep Burial Test on 10 ft diameter DuroMaxx pipe

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May 8, 2018

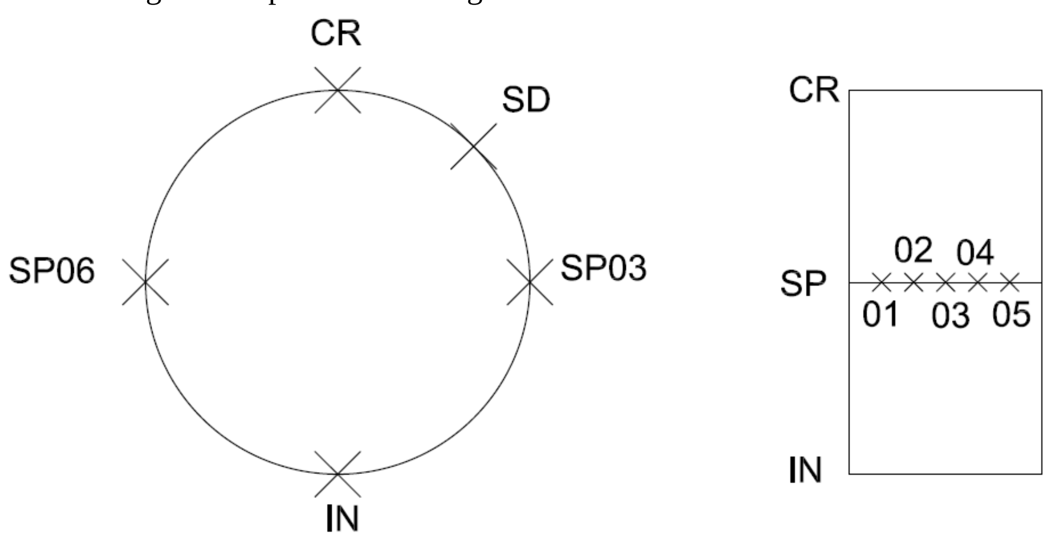
Introduction

This report provides details of the performance of the steel-reinforced ribbed HDPE pipe under simulated embankment loading. The test was conducted in the GeoEngineering Laboratory at Queen's University on the 14th of November 2017. The experiment was conducted as the commissioning test of a new test facility funded by the Canada Foundation for Innovation, the Province of Ontario, Queen's University and various industry partners. This report was prepared for Darrell Sanders of Contech Construction Products who donated the pipe product that was tested.

Instrumentation and Test Procedure

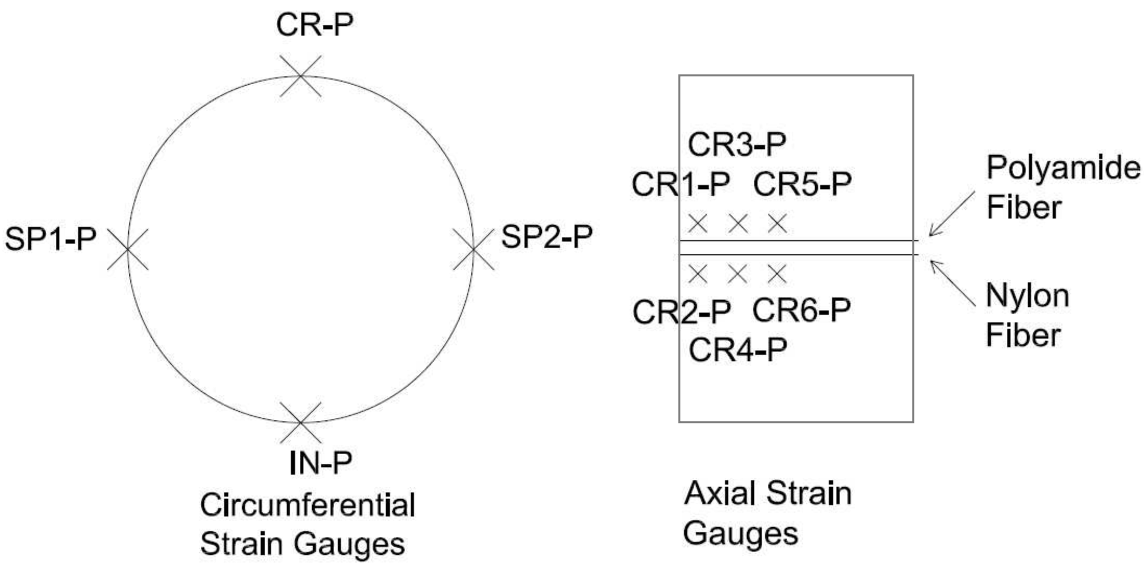
A 3 m long segment of 3 m (10 ft) diameter DuroMaxx pipe was fitted with four Linear Potentiometers (LPs) to measure changes in diameter. One vertical LP was positioned at the midpoint of the sample (1.5 m from each end), one was positioned at one end, and a third was located at a quarter point (0.75 m from that end). A fourth LP was mounted horizontally across the pipe to measure change in horizontal diameter at the mid-point.

The pipe was instrumented with conventional strain gages and optical fibers. A number of the steel ribs were instrumented with strain gages to record circumferential strains. Figure 1a shows the locations of strain gages placed around the rib at the mid-point of the sample, with measurements taken at the crown, shoulder, invert, and at the East and West springlines. Along one of the springlines, four additional ribs were monitored, with locations along the sample shown in Figure 1b.



a. Circumferential locations at pipe midpoint b. Axial locations of springline gages.
Figure 1. Location of gages used to monitor circumferential strains in the steel ribs.

Figure 2 shows the locations of gages used to monitor axial strains in the polyethylene, in each case on the inner surface of the liner midway between two ribs. Figure 3 is an image of one side of one rib, illustrating how the polethylene was removed from over the rib at that location, and two strain gages were glued on each side of the rib. Since four strain gages were employed on the rib at each location that was instrumented, the impact of any circumferential moment and any torsion or other complex response resulting from the helical geometry could be eliminated from the calculation of average strain, and therefore hoop force. Optical fibers were also installed, to measure both circumferential and axial strains, Figure 2b. Figure 4 shows two views on the inside of the pipe sample, showing the longutidinal fibers along the crown (one coated in nylon, and one in polyimide), and the single fiber measuring hoop strains following the helix around the circumference. Details of the measurement of strains using optical fibers attached around the circumference of a buried pipe are provided by Simpson et al. (2015).



a. Gage locations around circumference b. Axial locations of gages and fibers.
Figure 2. Strain gage and optical fiber locations on the polyethylene

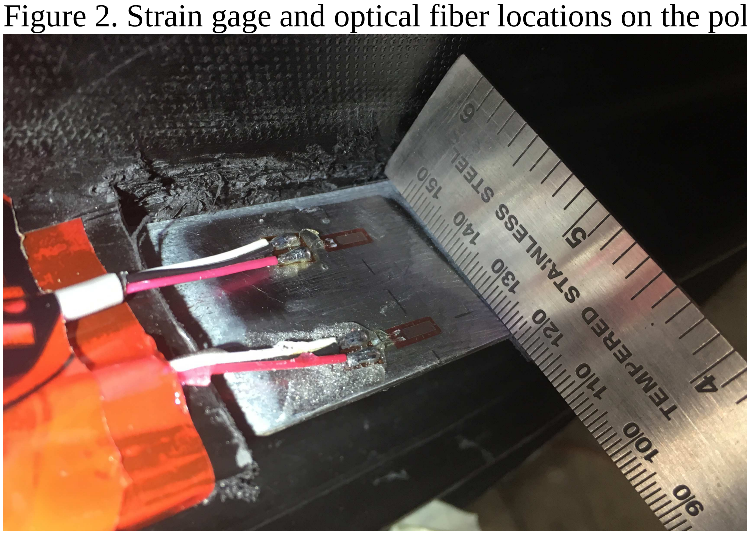
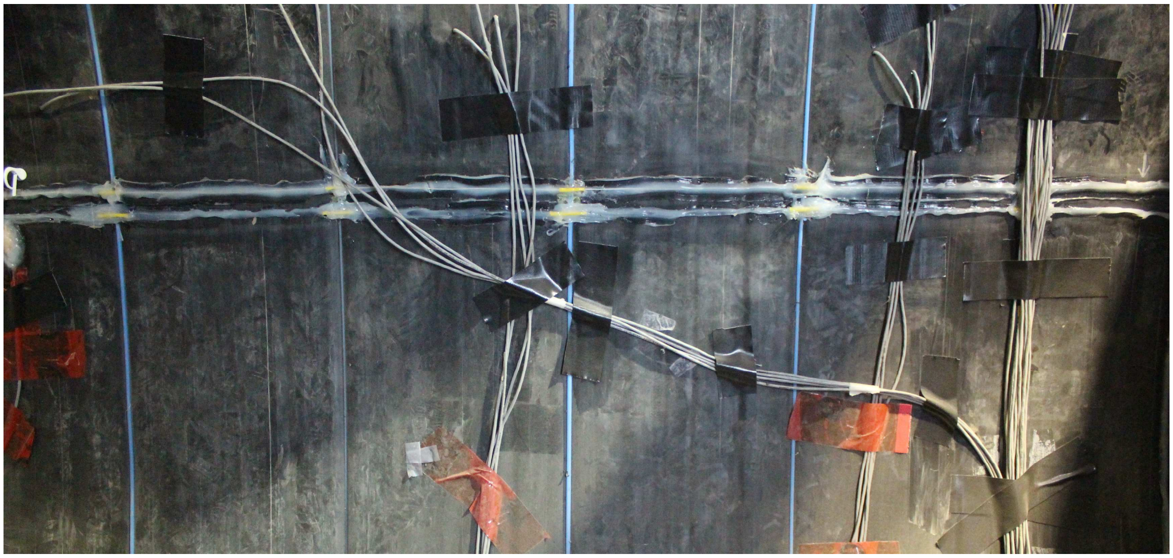
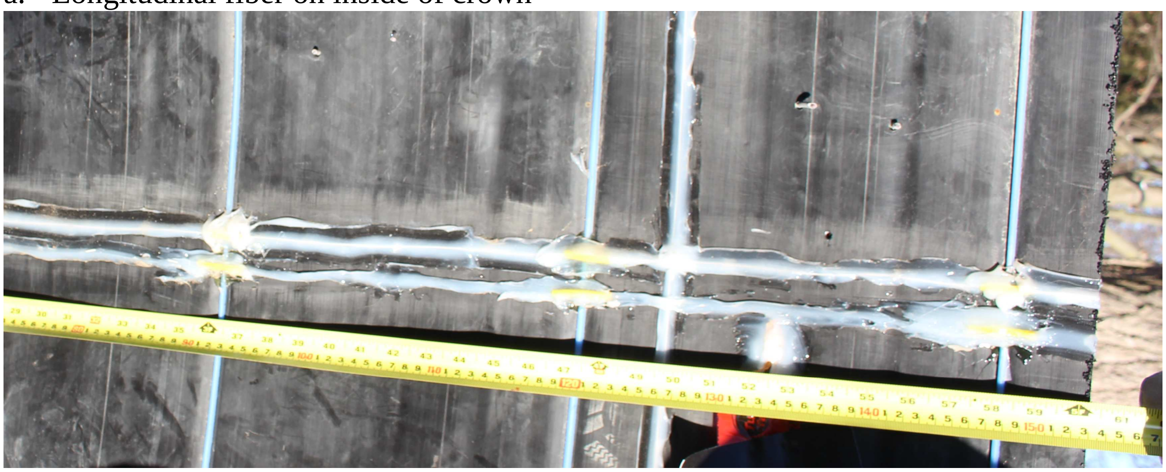


Figure 3. Two gages on one side of a steel rib before placement of protection.



a. Longitudinal fiber on inside of crown



b. Circumferential and longitudinal fibers

Figure 4. Optical fibers attached to the inside of the pipe.

Test Facility

The test was performed in a new deep burial simulator in the GeoEngineering Laboratory at Queen's University, Figure 5. This facility features a 3m wide, 5m long, 4.6m deep test pit suitable for testing pipes up to 3m in diameter (Mai et al., 2018). The sides of the pit are covered with ultra high molecular weight polyethylene (PE) material, normally used for bridge bearings. When covered with a layer of thin polyethylene sheet, this acts to limit the magnitude of the vertical friction that develops between the backfill soil and the walls. When dry, any PE to PE contact has friction coefficient of 0.19. When lubricant is added between them, the friction coefficient drops to 0.07.

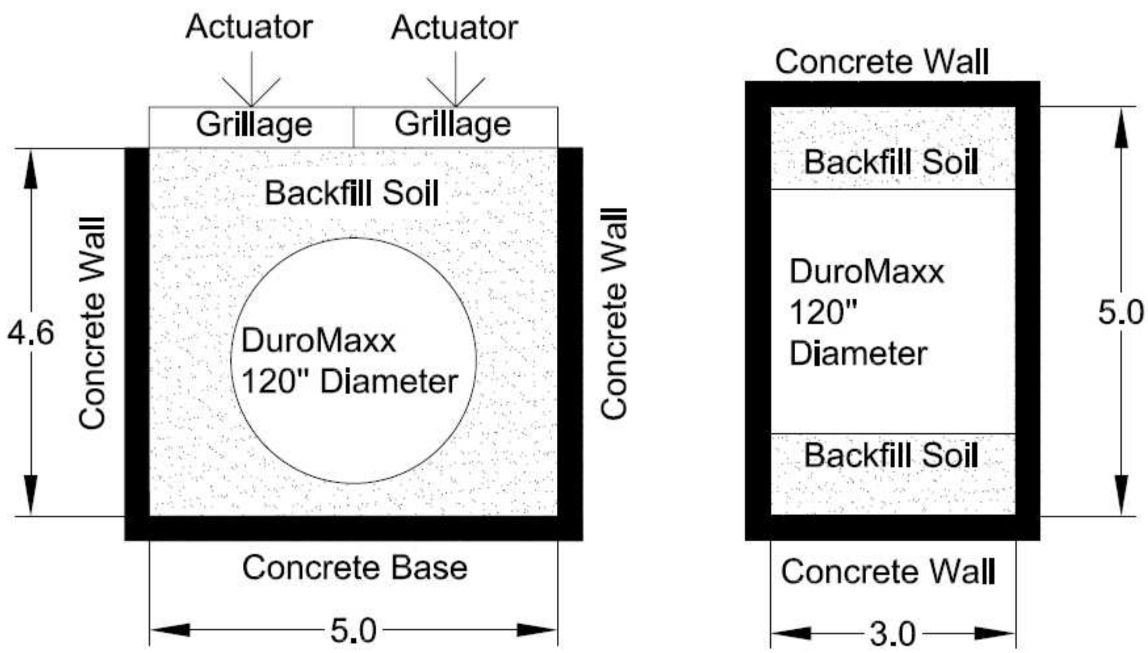
a. View showing walls covered with ultra high density polyethylene sheeting
b. Pipe in place; far wall lubricated with PE sheets protected with geotextile

Figure 5. Two views of the test pit (before and after placement of the pipe)

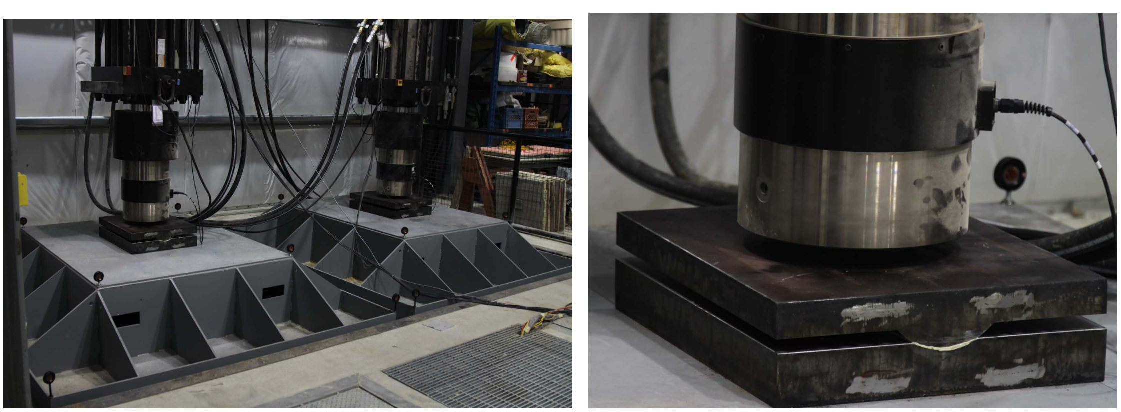
The backfill soil used for this test was well-graded sand and gravel with trace fines (Unified Soil Classification System (ASTM D2487-06): SW; AASHTO Classification: A-1-a). This soil has been used in most of the scores of large scale buried pipe tests conducted in the GeoEngineering Laboratory since it was commissioned more than a decade ago. Firstly, backfill was placed and compacted at the base of the test pit, to form a stiff foundation 0.3m deep. The pipe was then placed on top of a layer of loose backfill 0.15m deep. Finally, the pit beside and above the pipe was backfilled in lifts 0.3 m thick that were compacted using a walk-behind vibrating plate. The final depth of cover soil was 0.9 m. The foundation was compacted to 95% standard Proctor (i.e. 95% of the maximum dry unit weight achieved in a standard Proctor test). The backfill between the invert and crown, and the cover over the crown were both compacted to 92% of standard Proctor (unit weight of 22.2 kN/m^3), so the cover soil represents an initial overburden pressure of 20 kPa.

Figure 6 provides schematics showing vertical and horizontal views of the pipe within the pit, and the proximity of the pipe boundaries 1 m from the side walls. The boundary effects of this testing configuration have been analyzed in detail (Mai et al., 2018), where it is shown that the use of two actuators on steel loading plates stiffened by the grillages (Figure 7a) together with a cylindrical bearing that prevents application of any moment by the actuator, induces vertical stresses on the ground surface that are almost uniform (it eliminates non-uniform stresses associated with the rigid or flexible pipes buried in the

soil below). The result is an effective simulation of the geostatic stresses associated with deep burial. The testing system has a vertical load capacity of 2600 kN in each actuator, applied over a surface area of 7.5 m^2 per actuator, representing a vertical stress of 347 kPa, equivalent to about 17 m of overburden. The mass of each loading grillage plus bearing was calculated to be 2657 kg, which represents an additional 3.5 kPa of overburden pressure (or 0.18 m of burial).



a. Vertical profile through pipe mid-point b. Plan view through horizontal diameter
Figure 6. Pipe arrangement in the deep burial simulator



a. Actuators acting on two grillages b. Moment-release bearing under load cell
Figure 7. Surface loading system using two actuators applying vertical force to grillages

Loading Sequence

Actuator loads were increased in a series of 150 kN steps, representing 20 kPa or 1m of additional burial in soil of unit weight 20 kN/m^3. Measurements of diameter change and strain from the conventional resistance strain gages were taken 10 times per second throughout the duration of the experiment. At the end of each step, load was held constant while an optical backscatter reflectometer (the 4600 OBR system produced by Luna Technologies of Roanoke, Virginia) was used to read the optical fibers and measure strain along each optical fiber. Loading increased in those steps up to applied actuator forces of 956 kN (a surface load of 127 kPa, or total overburden pressure of 151 kPa when the weight of the cover soil and grillages is included). This loading was kept constant for an hour. This load level corresponds to burial of 7.6 m under 20 kN/m^3 soil, or 26.1 ft of 120 lbs/ft^3 soil. During this time period, increases of about 15% were observed in diameter and strains measured on the surface of the pipe steel and high density polyethylene components of the pipe.

The test then continued with the addition of further load steps. An attempt was made to increase each actuator force from 1650 to 1800 kN, but without success. Instead, peaks of 1734 kN in the North actuator and 1778 kN in the South actuator were obtained, corresponding to a total average surface pressure of 234 kPa or total overburden pressure to the crown of the culvert of 257 kPa (equivalent to a burial depth of 44.4 ft of soil with density 120 lb/ft^3). At the same time, significant local bending strains were observed to develop in the steel ribs at the location of the springline, suggesting that local buckles were developing in various ribs along the springline.

Results

Figures 8 to 13 summarize the key measurements made during the test:

- Figure 8 presents the changes in vertical and horizontal diameter as a function of applied surface pressure
- Figures 9 and 10 present, respectively, the circumferential and axial strains measured on the inside surface of the polyethylene liner, midway between ribs.
- Figure 11 presents one set of circumferential strains measured in one of the steel ribs at the springline (that denoted S4 in Figure 1b); similar measurement sets were obtained for ribs S5 and S6 at the springlines; at least one gage failed at each of locations S1 to S3
- Figure 12 presents calculated values of springline thrust in the ribs denoted S4, S5 and S6 (calculated using strain sets like that seen in Figure 11). These calculations were undertaken assuming elastic material response for the steel rib (modulus E of 200 GPa), together with its cross-section area A = 100 mm^2. In each case, the measured radial positions of each pair of strain gages on the East or West side of the rib (like those shown in Figure 3) were used to interpolate the circumferential strain at the neutral axis (mid-height position on the rib) on that side, then the East and West side values were averaged to estimate the mean strain value at that location ε. Thrust per unit length along the springline was then calculated as $N_{sp} = EA\, \varepsilon / \lambda$ where λ is the center to center axial spacing of the ribs (69.85 mm).

- Figure 13 presents calculated values of circumferential bending moment calculated using the strains at the four locations in each rib to calculated curvatures κ, and then moment $M = EI \kappa / \lambda$ for the ribs at locations S4, S5 and S6, where I for each rib (taken about the strong axis) is 10200 mm^4.

Discussion and Conclusions

The pipe was exhumed and photographs were taken of its exterior as it was being lifted out of the test pit. Images of the North and South springlines are given in Figure 14, which clearly show the local buckles that have developed on most of the ribs on each side. The development of these local buckles is evident in Figure 11 where the strain traces on opposite sides of the rib (the East and West sides) start to converge together (ET towards WT and EB towards WB) between 150 and 234 kPa.

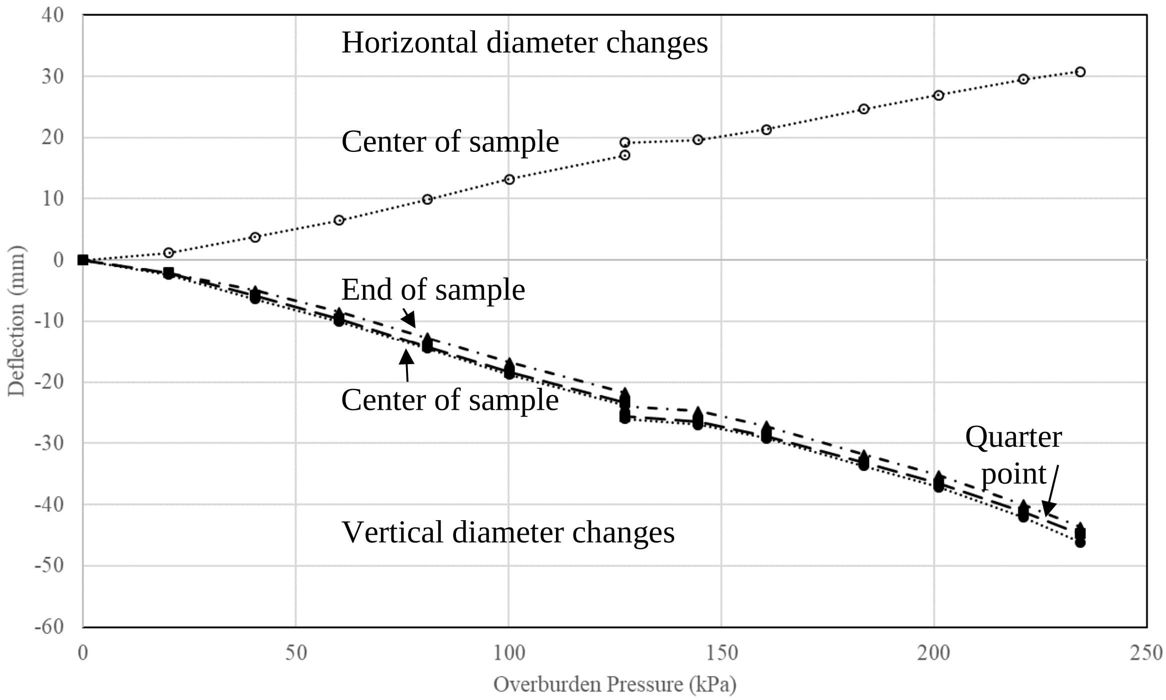


Figure 8. Deflections (changes in vertical and horizontal pipe diameter) with overburden pressure; vertical diameter at end of sample, center and quarter point.

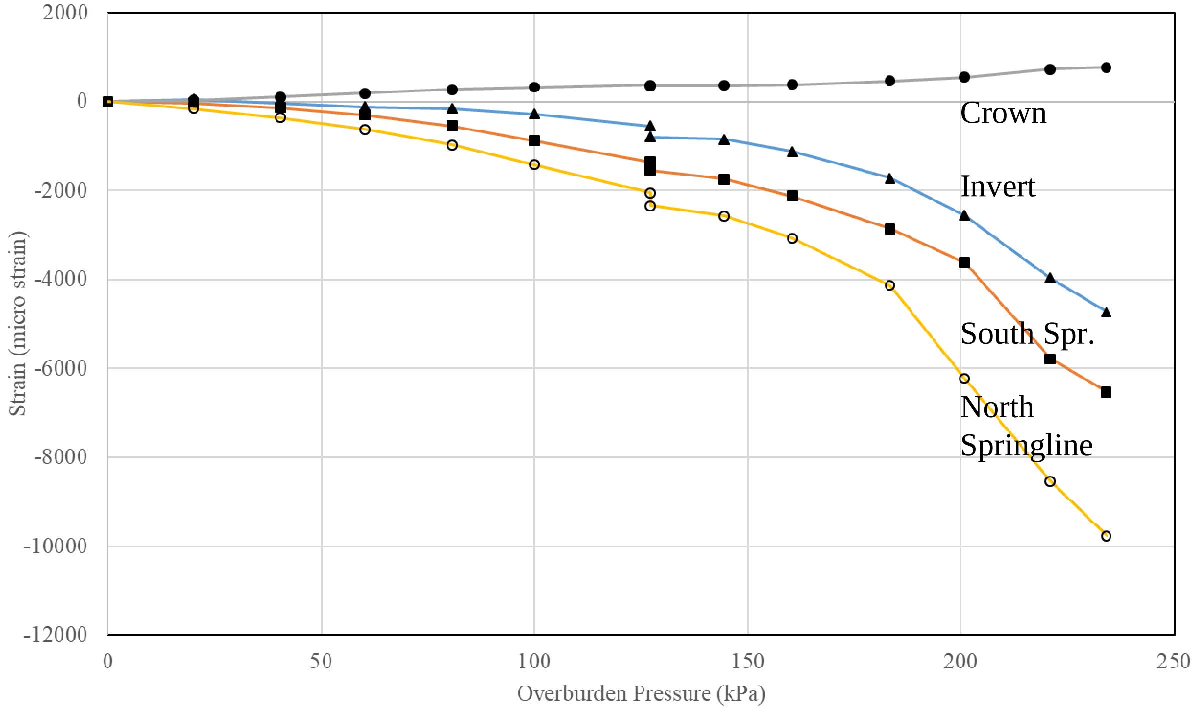


Figure 9. Circumferential strains on the inside surface of the polyethylene from gages attached on the inside of the liner midway between ribs.

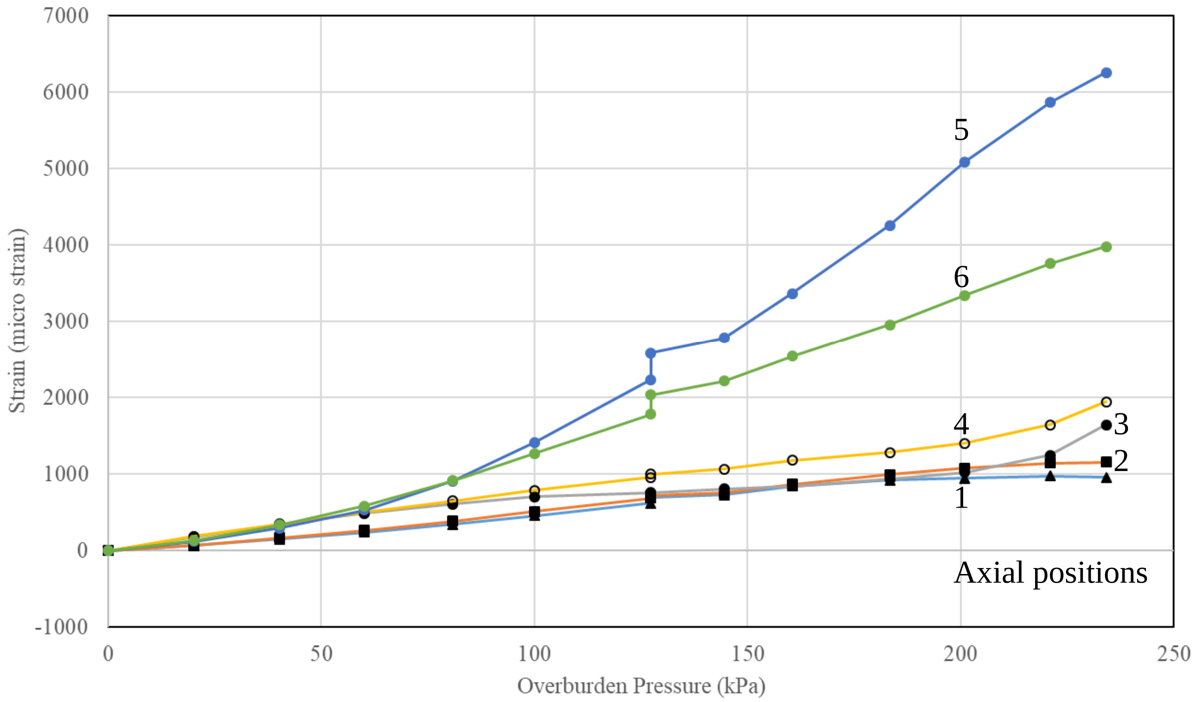


Figure 10. Axial strains on the inside surface of the polyethylene from gages attached on the inside of the liner midway between ribs; axial positions 1 to 6 defined in Figure 1.

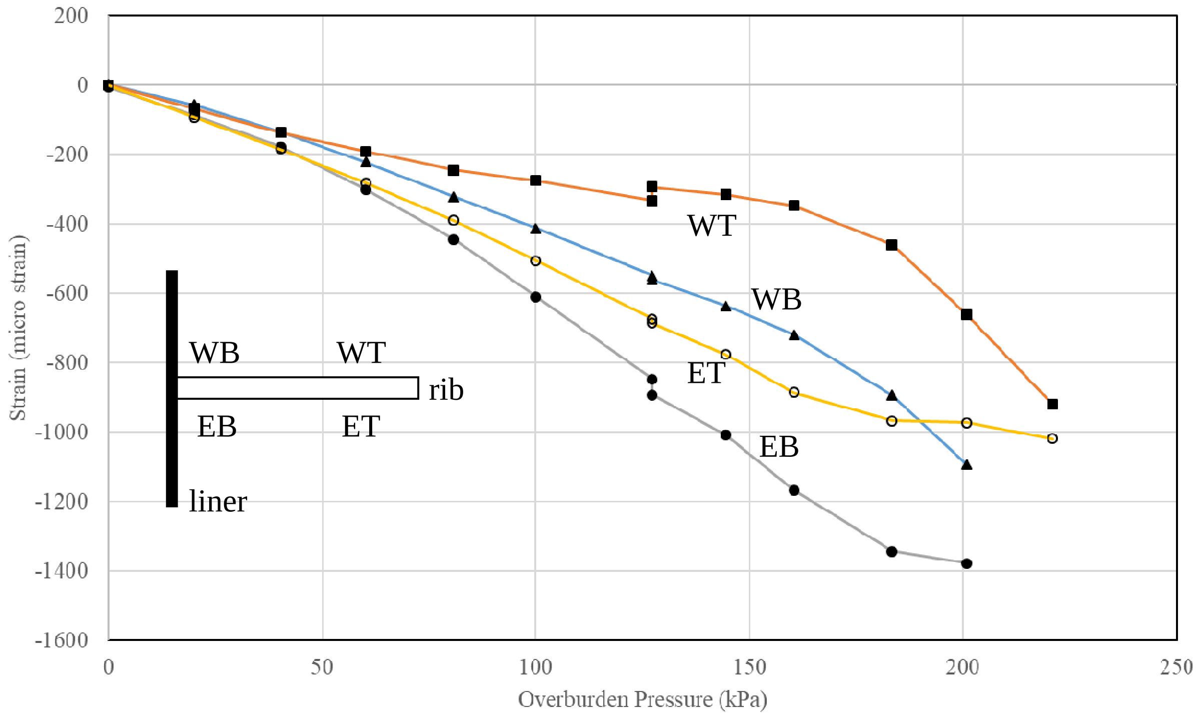


Figure 11. Circumferential strains on steel rib at springline location 4 (1.9 m along the pipe)

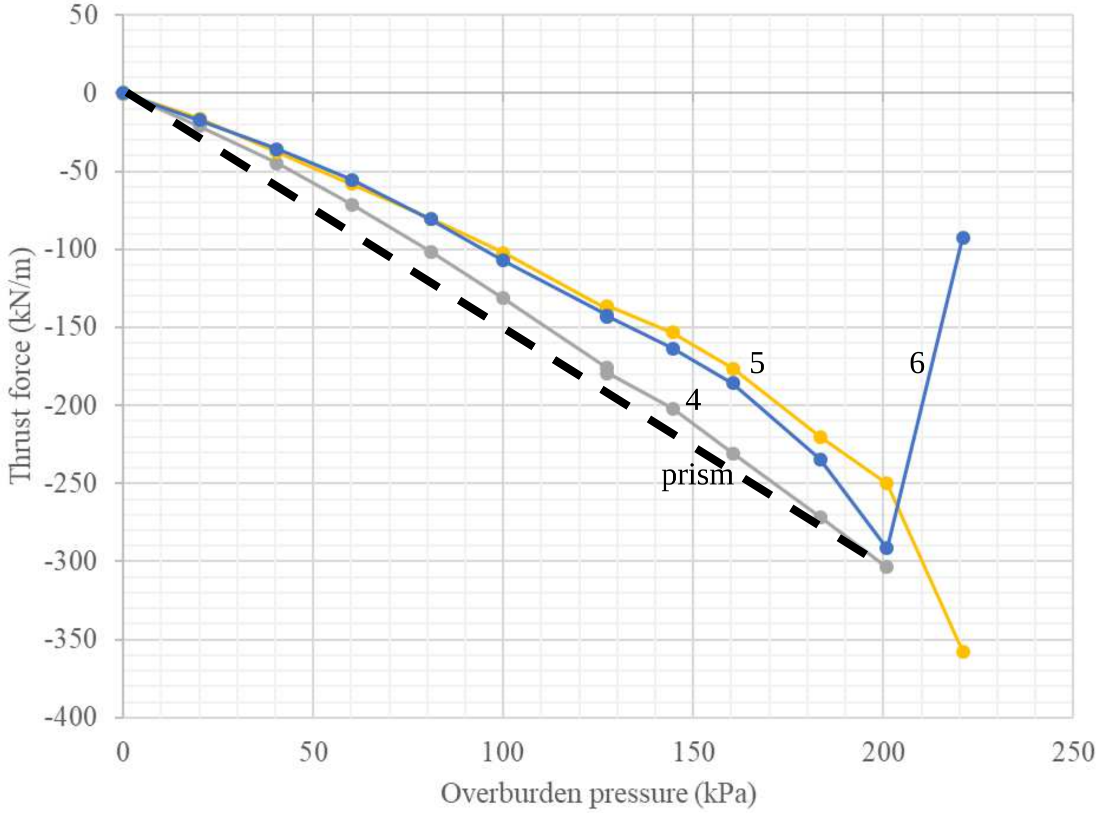


Figure 12. Hoop thrusts calculated at springline locations 4, 5, and 6 from measured strains; dashed line shows half the prism load

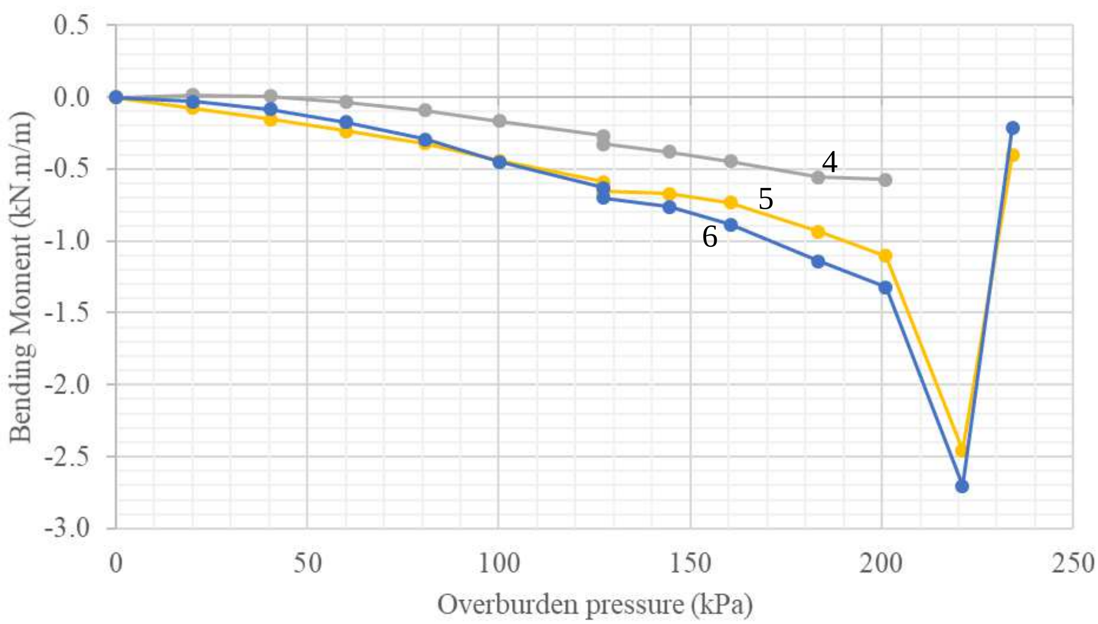
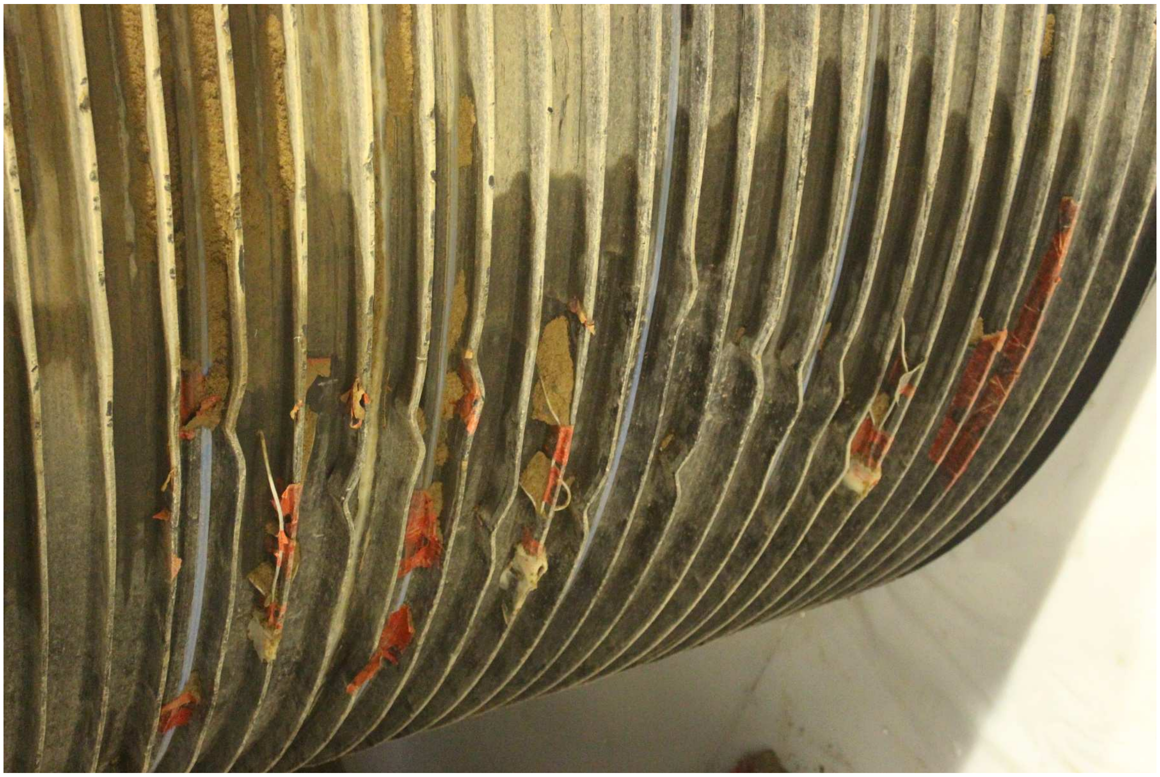
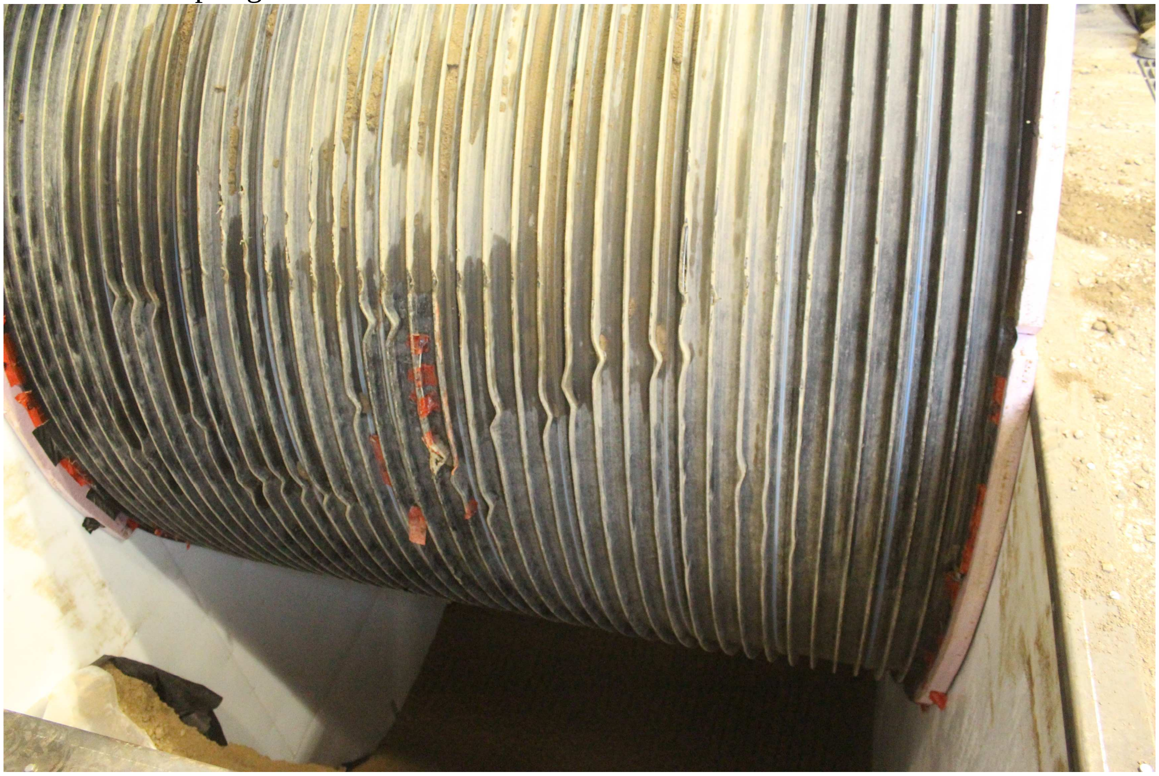


Figure 13. Bending moments calculated at springline locations 4, 5, and 6 from measured strains



a. South springline



b. North springline

Figure 14. Local buckling in ribs along the springlines seen as pipe is being extracted from the pit.

After 200kPa of overburden pressure applied by the actuators, some strain gages on the ribs ceased to function, as seen for gages EB and WB in Figure 11, while others started to experience rapid strain changes (as seen in the rapid changes in some calculated values of thrust and moment reported in Figures 12 and 13). These results indicate that the product is able to support a maximum overburden pressure of at least 223 kPa (the 200 kPa applied by the actuators and the 23 kPa applied by the weight of the cover soil and grillages), equivalent to 11.1 m of burial with soil having unit weight of 20 kN/m^3, or 38.5 ft of burial under soil having unit weight of 120 lb/ft^3.

Small values of moment are calculated – much lower than those that would develop for a rigid pipe. The maximum moment reported in Figure 12 at 200 kPa of actuator pressure is 1.3 kN.m/m, whereas the rigid pipe moment for a structure of this size would be approximately 80 kN.m/m (using equation 18.48 in Moore, 2001). This is consistent with the pipe behaving like a conventional flexible steel pipe, with small levels of circumferential shortening, and increase in horizontal diameter of approximately the same magnitude as the decrease in vertical diameter.

There is no evidence of change in stiffness (increased rates of diameter change) of the pipe-soil system in the plots of diameter change versus overburden pressure, Figure 8, until the ultimate strength was reached.

The measurements of vertical diameter change at the three different axial positions vary by about 6% from smallest to largest. There is some change in hoop thrust in the three different ribs that were successfully monitored at the springlines (ribs 4 and 5 on the South side, and rib 6 on the North side). All values remained below thrust values calculated using vertical arching factor of 1 (the normal design assumption used for corrugated steel pipes).

Strains measured on the surface of the high density polyethylene using conventional strain gages had maximum values of 6300 microstrain (0.6%) in the axial direction, and almost -10000 microstrain (-1%) in the circumferential direction. Values obtained using the optical fibers were generally of similar magnitude, though exhibiting some variation between the ends of the pipe and midpoint (near the locations of peak measured strain). These are well within the limits required for high density polyethylene.

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Field Installation Effect on Steel-Reinforced High-Density Polyethylene Pipes

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Abstract: A full-scale field study was conducted in Kansas to investigate the installation effect on steel-reinforced high-density polyethylene (SRHDPE) pipes. Four 2.13 m-long SRHDPE pipes with a diameter of 0.61 m were connected and buried in a trench with dimensions of 1.52 m wide, 9.15 m long, and 1.40 m deep. Two types of backfill material were used in the trench, namely, Aggregate Base Class 3 (AB3) aggregate and crushed stone. Two pipes were buried in the AB3 aggregate section with an average degree of compaction of 90.4% whereas the other two pipes were installed in the crushed stone section with an average degree of compaction of 89.5%. The soil cover thickness in both the AB3 aggregate and the crushed stone sections was 0.65 m. A vibratory plate compactor was used to compact the backfill material inside the trench. Pipe deflections in the vertical, horizontal, and 45° directions from the pipe crown were monitored during backfilling. Earth pressures around the pipes were measured during the construction. Test results indicate that (1) the peaking deflection of the pipe in the AB3 aggregate section was 1.5 times that in the crushed stone section; however, the vertical diameter change of the pipe in the crushed stone section was 3.5 times that in the AB3 aggregate section after backfilling above the top of the pipe. The pipe diameter change in the crushed stone section in the 45° direction from the pipe crown was greater than that in the AB3 aggregate section. The deflections of the SRHDPE pipe in these two types of backfill material with a soil cover thickness of 0.65 m were much less than the 5% deflection limit suggested for steel and high-density polyethylene (HDPE) pipes by the AASHTO; and (2) the soil arching factors at the top of the pipe in both sections are greater than one (i.e., negative soil arching). The measured lateral earth pressure data verified that the lateral pressure induced by compaction was constant with depth within the pipe range. The measurement of the displacements of ribs at the springlines of pipes in both sections demonstrated that the ribs in the crushed stone section deformed more than those in the AB3 section. A visual inspection of the exhumed pipes did not find any obvious damage to the pipe ribs and liner. Overall, the SRHDPE pipe performed well in these two types of backfill material during installation. **DOI: 10.1061/(ASCE)PS.1949-1204.0000211.** *© 2015 American Society of Civil Engineers.*

Introduction

High-density polyethylene (HDPE) pipes have been widely used in the world for several decades due to their light weight, low cost, and chemical resistance (Masada and Sargand 2007). However, HDPE pipes have some disadvantages, including low strength, high creep deformation, limited pressure rating, and high potential for buckling and cracking of the inner liner, which limit the use of HDPE pipes in some specific applications. Corrosion is an obvious problem for steel pipes especially under moist conditions. Steel-reinforced high-density polyethylene (SRHDPE) pipes combine the advantages of steel and HDPE pipes and were developed and introduced to the market to overcome the above disadvantages (Khatri et al. 2013; Corey et al. 2014). This new product uses steel ribs for load-carrying capacity and stiffness and high-density polyethylene material covering the steel ribs for corrosion resistance.

Khatri et al. (2013) conducted parallel plate load tests on SRHDPE pipes to investigate their stiffness and deformed shapes under static loading. The diameter of the pipe used in their study was 610 mm; the ribs were 2.25 mm wide and 17.0 mm high, with a center to center spacing of 25.4 mm, and included a 1.5 mm thick steel reinforcement in the middle. Khatri et al. (2013) found that the pipe started to yield at a vertical deflection of 6% the initial pipe diameter and reached the ultimate load capacity at a vertical deflection of 10% the initial pipe diameter. The vertical deflection was observed as 1.5 times the horizontal deflection. The behavior of the SRHDPE pipes during installation and under working conditions is important for the performance and applications of this new product. Khatri et al. (2015) conducted a laboratory test in a large test box to evaluate the behavior of the SRHDPE pipe during the installation in soil. They found that the SRHDPE pipe behaved like a steel pipe, which has a soil arching factor greater than 1.0. Corey et al. (2014) investigated the benefits of the geogrid layers to protect the shallowly buried SRHDPE pipe through

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laboratory tests. They found that the geogrid could reduce the longitudinal strain in the plastic shell of the SRHDPE pipe under static loading. A field installation study is necessary to verify the behavior of the SRHDPE pipe under a field condition.

Field tests have been commonly used to investigate the behavior of HDPE pipes. Fleming et al. (1997) found that the vertical diametric strain of the pipes at the end of the installation was one-third of that under the traffic loading. Watkins et al. (1983) pointed out that a 305 mm thick soil cover could provide sufficient protection for the polyethylene (PE) pipes with diameters ranging from 381 to 610 mm. Conard et al. (1998) evaluated the deflections of buried PE pipes when loaded from the ground surface at the location of one end of the pipe at one time. They found that the pipe with sand or till as backfill failed with a mode of local wall bending when high truck tire contact pressure was applied at that location.

Deflection of a pipe is one of the essential design parameters for flexible pipes. Spangler (1941) proposed a method to calculate the pipe horizontal deflection with an assumption of a pressure distribution pattern around the pipe. In his method, the vertical deflection was recognized to decrease during backfilling without any consideration of compaction effect. However, from pipe installations both in the field and in the laboratory, it was found that the vertical diameter of the pipe increased before the backfill reached the top of the pipe and then decreased with an increase of the soil cover thickness (Arockiasamy et al. 2006; Mai et al. 2013). Masada and Sargand (2007) pointed out that a flexible pipe deformed into a vertical ellipse shape when the backfilling surface was lower than the top of the pipe due to the compaction effect of the backfill material around the pipe. After the trench was backfilled above the top of the pipe, the vertical diameter of the pipe decreased. They referred to this phenomenon as the *peaking behavior*, which is beneficial to the vertical load carrying capacity of the pipe. They also developed a formula to predict the pipe deflection caused by this peaking behavior. However, the pipe deflection after the backfill above the top of the pipe was not addressed.

Marston and Anderson (1913) considered the friction between the side walls of the trench and the backfill material above the pipe and derived *the Marston load theory* to calculate the load applied on the top of the pipe. It should be noted that the deformations of the backfill material and the pipe caused by the overburden stress of the soil were considered in this theory; however, the compaction effect during backfilling was not included. Spangler (1941) assumed that the lateral earth pressure at the springline of the pipe around the pipe is proportional to the deflection of the pipe into the soil, and the constant of proportionality is called the modulus of passive resistance of the soil. Watkins and Spangler (1958) suggested using the modulus of subgrade reaction instead of the modulus of passive resistance because the modulus of subgrade reaction is a true soil-structure interaction property. A more reliable estimation of the modulus of soil reaction was achieved by Howard (1996) using the back-calculation method. However, Spangler's (1941) method assumed that the pipe would deform like a horizontal ellipse, which is not consistent with the peaking behavior of the pipe considering the compaction effect. Masada and Sargand (2007) treated the lateral earth pressure around the pipe as the summation of the lateral earth pressure at the rest and a constant lateral pressure generated by a compactor when the backfill is below the top of the pipe. They also recommended using the typical value of the lateral pressure generated by the compactor suggested by McGrath et al. (1999).

The studies reviewed above mostly focused on the field installation effect on HDPE pipes. Few studies have been done so far on the field installation effect on SRHDPE pipes. In this study, a full-scale field test was conducted to investigate the installation effect on the SRHDPE pipes. Four 2.13 m-long SRHDPE pipes with a diameter of 0.61 m were buried in a 1.52 m wide, 9.15 m long, and 1.40 m deep trench with two types of backfill material, namely, AB3 aggregate [a typical base course material used by Kansas Department of Transportation (KDOT)] and crushed stone. During backfilling, the deflections of the pipes in three directions (vertical, horizontal, and 45° from the pipe crown) were monitored to investigate their deformation characteristics during installation. Earth pressures around the pipes were measured to investigate stress distribution and transfer mechanisms between pipes and soil and to understand the peaking behavior of the SRHDPE pipe during installation. After the installation, the pipes were exhumed for visual inspection of possible damage to the pipes, especially at the locations of the ribs and liner.

Description of Field Test

Trench, Test Pipes, and Backfill Materials

The test site was located in a KDOT storage yard close to Kansas City in Kansas. This test site was relatively flat, and the groundwater level was below the bottom of the trench when the pipes were installed. A 1.52 m wide, 9.15 m long, and 1.40 m deep trench was excavated on the site. The bottom of the trench was leveled before backfilling. The side walls of the trench were vertical during and after the excavation.

Fig. 1 shows the schematic cross section of the corrugated SRHDPE pipe. This pipe consists of steel spiral ribs for load carrying and stiffness and a high-density polyethylene cover and liner for corrosion resistance. The width of the rib, including the steel reinforcement and the plastic cover, was 2.25 mm and the height was 17.0 mm. Steel reinforcement with a thickness of 1.5 mm was covered by the plastic material to form the rib, and the center to center spacing of the ribs was 25.4 mm. The diameter of the pipe used in the test was 610 mm, and the thickness of the valley liner was 2.0 mm. Khatri et al. (2013) reported the stiffness of the same SRHDPE pipe from parallel plate load tests, which was 294 kPa based on the ASTM D2412 standard (ASTM 2011). This SRHDPE pipe is the same as that used in the laboratory study by Khatri et al. (2015).

Four SRHDPE pipes were tested in the present study. Two of them were buried in the AB3 aggregate (referred to as Section A in this paper) and the other two were buried within the crushed stone (Section B). Soil-tight pipe metal connectors with a dimension of 330 mm wide, 2,096 mm long, and 1.0 mm thick, were used to connect the pipes. Before installing the connector, a rubber band was used to cover the pipe to keep the pipe and the connector tight. Each connector was wrapped around the pipe and two bolts (205 mm long and 10 mm in diameter) attached on the connector were tightened to finish the connection.

Two types of backfill material were used in this study: AB3 aggregate and crushed stone. Fig. 2 presents the particle size

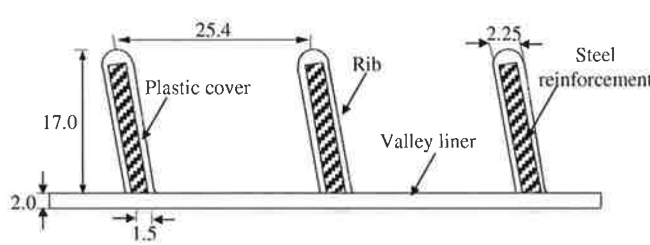

Fig. 1. Schematic of cross section of the corrugated SRHDPE pipe (unit: mm, not to scale)

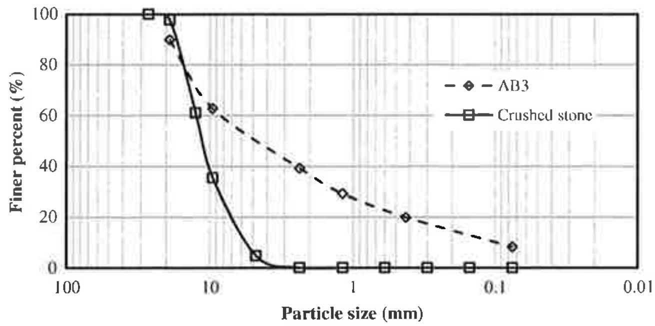

Fig. 2. Particle size distribution curves of AB3 and crushed stone

distribution curves of these two backfill materials. The coefficients of uniformity for the AB3 aggregate and the crushed stone were 15.0 and 1.9, respectively, while the coefficients of curvature for the AB3 aggregate and the crushed stone were 1.03 and 1.32, respectively. The liquid limit and the plasticity index of the particles passing No. 40 sieve size in the AB3 were 20 and 13, respectively; therefore, this portion of soil can be classified as CL-ML based on the Unified Soil Classification System (USCS) plasticity chart. Based on ASTM D2487 (ASTM 2011), the AB3 aggregate can be classified as well-graded gravel (GW-GC) whereas the crushed stone can be classified as poorly graded gravel (GP). Fig. 2 clearly shows that the AB3 aggregate had a much wider range of particle sizes than the crushed stone. The maximum dry density of the AB3 aggregate was determined as 2.25 Mg/m^3 and its optimum moisture content was 7.2% using the modified Proctor test per ASTM D1557 (ASTM 2012). The maximum density of the crushed stone was 1.78 Mg/m^3 following ASTM D4253 (ASTM 2006). Plate loading tests were conducted on the fill material in a wooden box with a dimension of 815 mm long, 810 mm wide, and 460 mm high to determine their moduli of subgrade reaction. Fig. 3 shows the load-settlement curves obtained in the plate loading tests. From Fig. 3, the moduli of subgrade reaction of the AB3 aggregate and the crushed stone can be calculated as 55.0 and 45.8 MPa/m, respectively. In other words, the moduli of the AB3 aggregate was higher than that of the crushed stone because the AB3 aggregate had a wide range of particle sizes, which could form a denser state. The peak friction angle of the AB3 aggregate was 52.4° (Yang 2010) while that of the crushed stone was 53.0° (Khatri 2014). Both friction angles were determined using large direct shear tests with the box size of 300 by 300 mm.

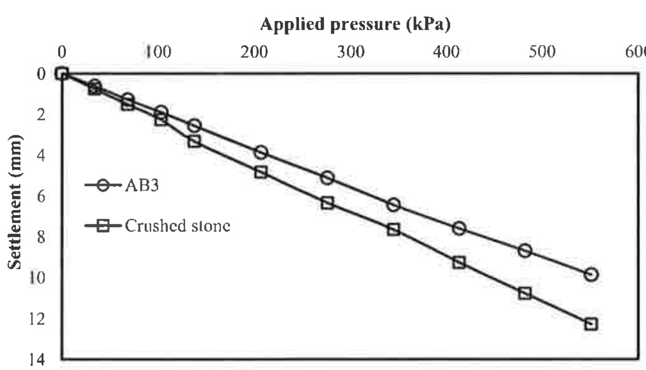

Fig. 3. Plate loading test results of AB3 and crushed stone

Installation and Instrumentation

Fig. 4 shows the schematic of the zones of construction in Sections A and B. A vibratory plate compactor was used to compact the backfill material. Hydraulic rammer plate compactor was used to compact the haunch zones. The following procedure was followed for the construction: (1) before the installation of the pipe in the trench, Zone I was filled and compacted to form a 150 mm thick bedding layer both in Sections A and B; (2) the connected SRHDPE pipes were placed into the trench (Fig. 5), and Zone II was filled and compacted to reach the springline level of the pipe (the thickness of Zone II was 300 mm); (3) Zone III was filled and compacted with a thickness of 300 mm to reach the top of the pipe level; (4) Zone IV was filled and compacted with a lift thickness of 340 mm; and (5) finally, Zone V was filled and compacted with a lift thickness of 300 mm. Section A was filled with the AB3 aggregate whereas Section B was filled with the crushed stone in Zones I to IV. Zone V in both sections was filled with the AB3 aggregate as a base course layer. Sand cone tests were conducted to measure the degree of compaction of the backfills in both sections. To minimize the test error due to sand loss in the crushed stone section, sand cone tests were done in the same place for three times and the average value was calculated as the test result. The average degree of compaction of the backfill in Section A (the AB3 aggregate) was 90.4% whereas that in Section B (the crushed stone) was 89.5%.

Fig. 6 shows the locations of earth pressure cells. The KDE-500KPA pressure cells (Tokyo Sokki Kenkyujo Company, Japan) were used in the field test in this study. Their outside diameter is 50 mm while the sensing surface diameter is 46 mm and the thickness is 11.3 mm. They have a maximum capacity of 500 kPa. Four pressure cells were installed in the instrumented rings in each section as shown in Fig. 4(b), and they are labeled as E1, E2, E3, and E4. Pressure cells E1 and E4 were used to measure the vertical pressures at the springline and the crown of the pipe whereas E2 and E3 were installed to monitor the lateral earth pressures at the springline and 150 mm above the springline of the pipe. The locations of the pressure cells were determined based on the following reasons: (1) E1 and E4 could be used to analyze the soil arching effect during backfilling; (2) E2 and E3 could be used to examine the assumption made by Masada and Sargand (2007) that the pressure induced by compaction of backfill material is constant with the buried depth of the pipe (recognized as the reason for the peaking behavior); and (3) E1 and E2 could be used to calculate the coefficient of lateral earth pressure.

Fig. 7 shows the positions of displacement transducers. Four displacement transducers were installed in the instrumented rings in each section as shown in Fig. 4(b), which are labeled as L1, L2, L3, and L3'. The displacement transducer L1 was used to measure the diameter change in the horizontal direction, and L2 was installed to monitor the deformation of the pipe at 45° from the pipe crown. The displacement transducers L3 and L3' were used to evaluate the vertical deflections of the pipe. Between these two sensors, L3 was positioned at the valley liner profile whereas L3' was positioned at the steel reinforcement profile to investigate a possible deflection difference between the pipe wall and the steel reinforcement ribs.

Test Results and Analysis

Deflection

In this study, the increase of the pipe diameter as compared with that of the undeformed pipe in all three directions (i.e., vertical, 45°, and horizontal) was defined as positive. Fig. 8(a) presents the

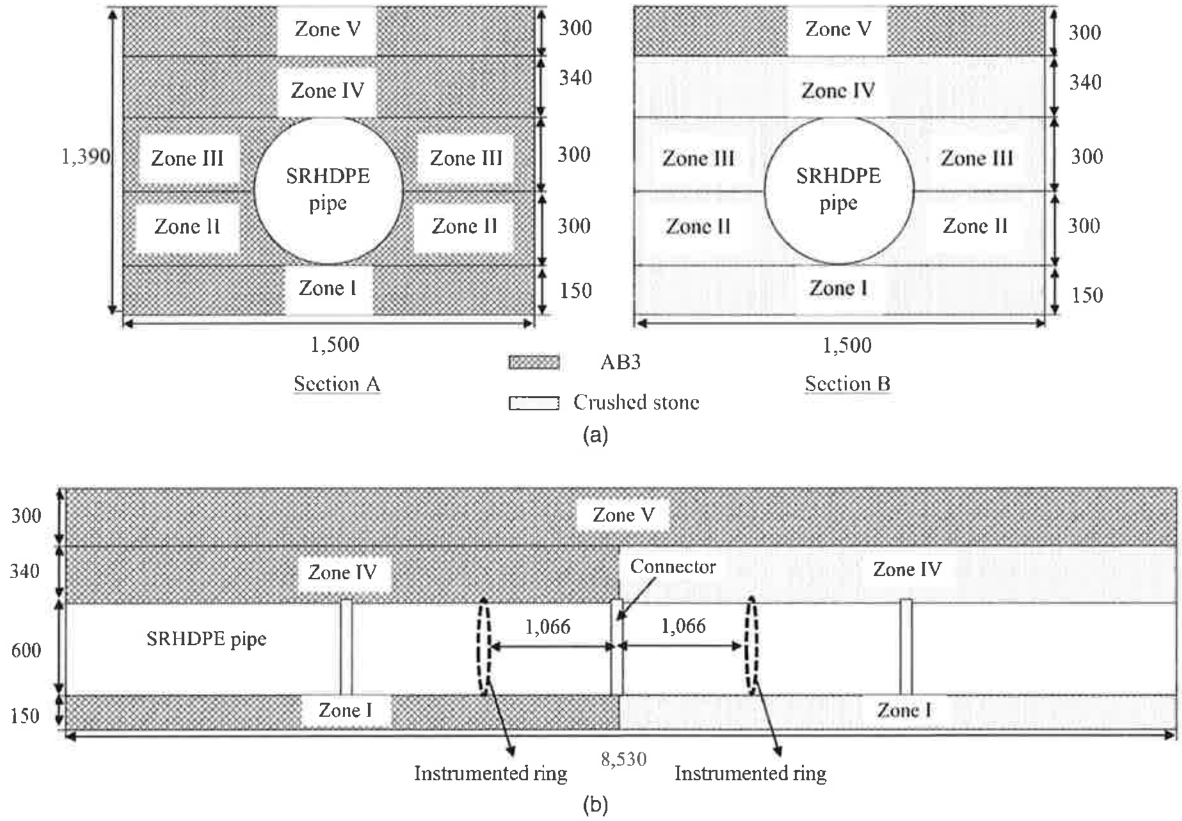

Fig. 4. Schematic of zones of construction (unit: mm, not to scale): (a) cross sections; (b) profile view

Fig. 5. Placement of pipes into the trench (image by Jie Han)

vertical deflections at the valley liner and the steel reinforcement in both sections. It is obvious that the vertical diameter was increased before the backfill reached the top of the pipe, i.e., the peaking behavior, followed by the decrease of the vertical diameter. The peaking deflection of the pipe in Section A (i.e., the AB3 section) was approximately 1.5 mm whereas that in Section B (i.e., the crushed stone section) was 1.0 mm. Masada and Sargand (2007) proposed the following equation to calculate the peaking deflection:

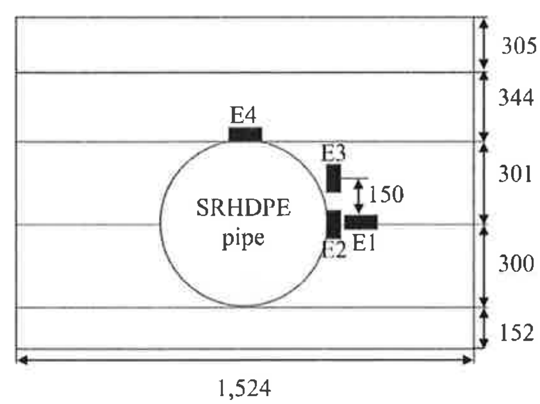

Fig. 6. Locations of earth pressure cells (unit: mm, not to scale)

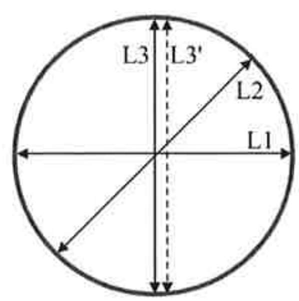

Fig. 7. Positions of displacement transducers (not to scale)

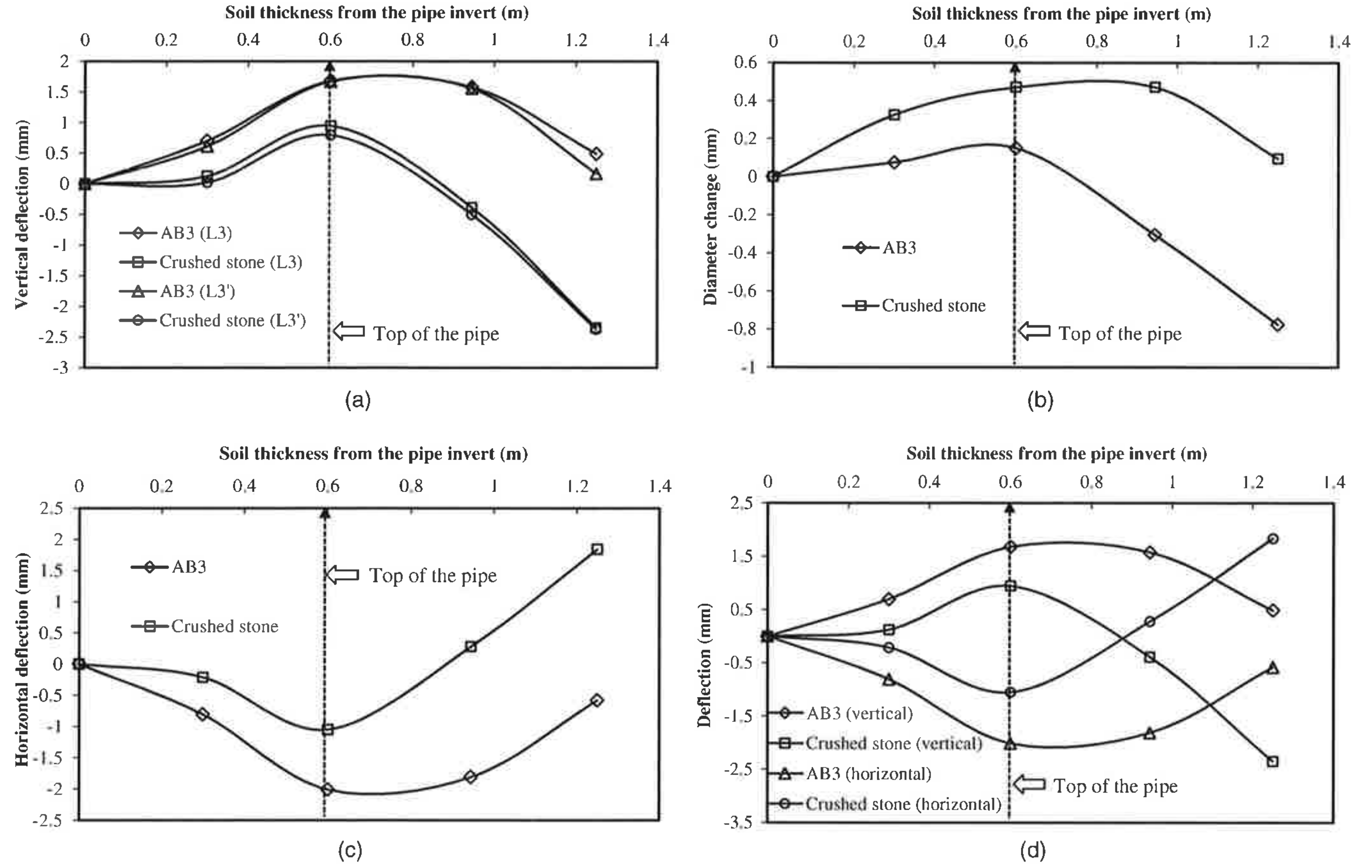

Fig. 8. Development of deflections with soil thickness in three directions during backfilling: (a) vertical deflection; (b) diameter change at 45° from the pipe crown; (c) horizontal deflection; (d) Comparison of vertical and horizontal deflections at the valley liner

$$\frac{\Delta y}{D} = \frac{4.7p_c + K_0 r\gamma}{3.874(PS)} \tag{1}$$

where Δy = peaking deflection; D = diameter of an undeformed pipe; p_c = lateral pressure induced by compaction; K_0 = lateral earth pressure coefficient at rest; r = radius of the undeformed pipe; γ = unit weight of backfill material; and PS = pipe stiffness.

Eq. (1) shows that the vertical deflection increases with the density of the backfill material considering the similar friction angles of AB3 (i.e., 52.4°) and crushed stone (i.e., 53.0°). Since the densities for the AB3 aggregate and the crushed stone were 2.19 and 1.56 Mg/m^3, respectively, the vertical deflection in Section A should be larger than that in Section B. The calculated peaking deflections using Eq. (1) are 1.27 and 1.03 mm, respectively, for Sections A and B using the following parameters: $p_c = 0.207$ kPa as suggested by McGrath et al. (1999) for a vibratory plate compactor; $K_0 = 0.208$ (i.e., $K_0 = 1 - \sin 52.4° = 0.208$) for the AB3 aggregate and 0.201 (i.e., $K_0 = 1 - \sin 53.0° = 0.201$) for the crushed stone; $PS = 294$ kPa; $\gamma = 21.9$ kN/m^3 for the AB3 aggregate and 15.6 kN/m^3 for the crushed stone; and $r = 301$ mm. The measured peaking deflections are close to the calculated ones in both sections.

The vertical deflection at the valley liner was slightly larger than that at the steel reinforcement rib. The vertical diameter was reduced by 1.0 mm from the peaked vertical diameter in Section A at the end of backfilling whereas that in Section B was reduced by 3.5 mm from the peaked vertical diameter. The larger reduction of the vertical deflection in Section B might be attributed to the fact that the crushed stone had a lower modulus of subgrade reaction and stress on the surrounding soil due to soil arching. The soil arching effect will be further discussed in the "Earth Pressure" section. Fig. 8(b) presents the diameter change of the pipe at 45° from the pipe crown. It was observed that the diameter at 45° from the pipe crown first increased with backfilling (i.e., Zones II and III) in both sections and then decreased with the increase of the soil cover thickness (i.e., Zones IV and V). The test results also show that the diameter change in the crushed stone was larger than that in the AB3 aggregate. Fig. 8(c) shows the horizontal deflections of the pipe in both sections. The comparison between Figs. 8(a and c) shows that the horizontal deflection at the valley liner was opposite to the vertical one as shown in Fig. 8(d). In other words, when the vertical deflection increased, the horizontal deflection decreased, and vice versa. In three directions (i.e., vertical, 45° from the pipe crown, and horizontal), the maximum deflections in both sections were 2.5 mm (i.e., 0.4% of the pipe diameter), which was much less than the typical deflection limit of 5% for the steel and HDPE pipes suggested by AASHTO (1998, 2010).

Earth Pressure

Fig. 9(a) shows the vertical earth pressures at the springline and on the top of the pipes in both sections. The measured vertical pressure in Section A was higher than that in Section B. The vertical pressure at the top of the pipe increased with the increase of the soil cover thickness after the backfill reached the top of the pipe. The soil

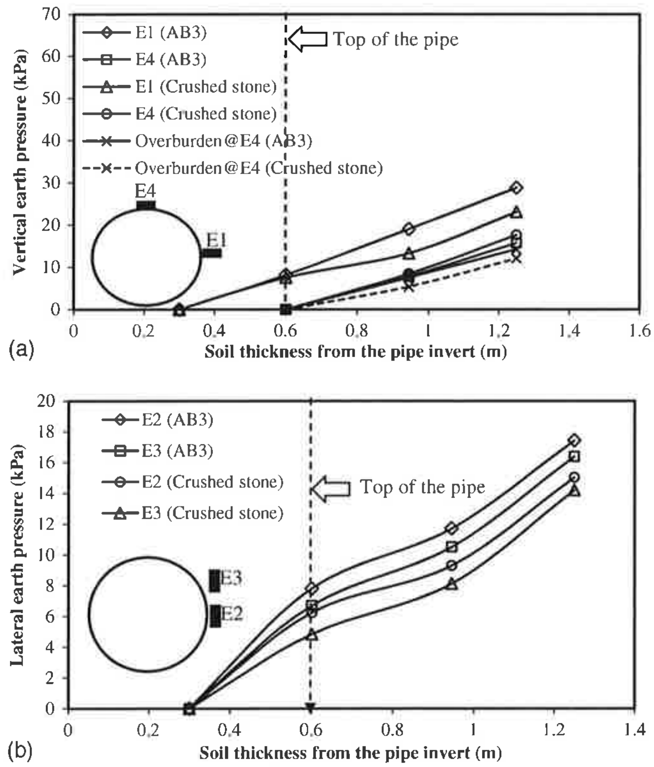

Fig. 9. Development of earth pressures around pipes with soil thickness: (a) vertical earth pressure; (b) lateral earth pressure

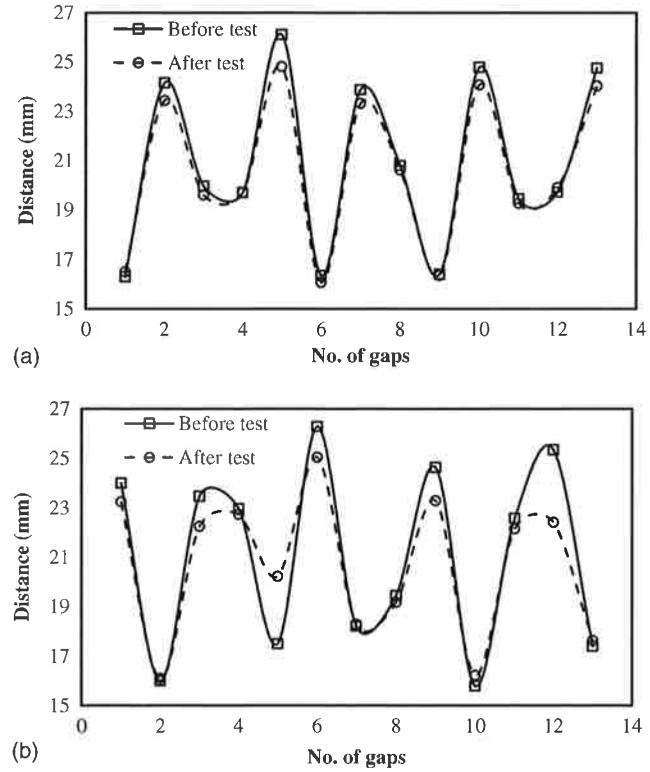

Fig. 11. Displacements of ribs at the springline of pipes in two sections: (a) section A-AB3; (b) section B-crushed stone

arching factors defined as the ratio of the measured vertical pressure (σ_v) at the top of the pipe to the overburden stress (γh) can be calculated as 1.10 and 1.47 for Sections A and B at the end of backfilling, respectively, ($\sigma_v = 15.7$ kPa, $\gamma h = 21.9 \times 0.65 = 14.2$ kPa for Section A and $\sigma_v = 17.6$ kPa, $\gamma h = 15.6 \times 0.35 + 21.9 \times 0.3 = 12.0$ kPa for Section B). The soil arching factors in both sections demonstrated that some overburden stress of the soil cover was transferred from the surrounding soil to the pipe due to the negative soil arching effect (i.e., soil arching factor is greater than one). Fig. 9(b) shows the lateral earth pressure at the springline and 150 mm above the springline of the pipe. From Figs. 9(a and b), the lateral earth pressure coefficient at the springline of the pipe can be calculated and is shown in Fig. 10. Fig. 10 illustrates that the lateral earth pressure coefficient decreased with the increase of the soil thickness. This finding is the same as that

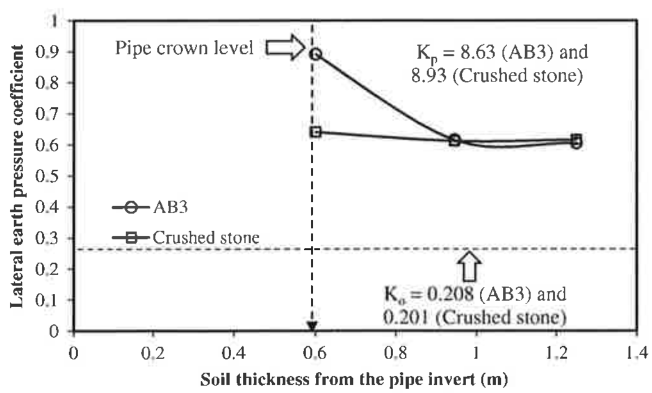

Fig. 10. Lateral earth pressure coefficients at the springline of the pipe with soil thickness

from the laboratory study by Khatri et al. (2015). The lateral earth pressure coefficient for the AB3 aggregate was higher than that for the crushed stone; however, their difference decreased with the increase of the soil thickness, and they were approximately equal at the ending of backfilling. The lateral earth pressure coefficients in both sections were lower than the passive earth pressure coefficients but higher than the earth pressure coefficients at rest. The measured lateral earth pressures at E2 and E3 in Section A with the backfilling at the top of the pipe were 7.80 and 6.68 kPa, respectively; and their difference was 1.12 kPa. The difference induced by the soil overburden stress (i.e., 0.15 m (distance between two pressure cells) $\times 21.9$ kN/m^3 (unit weight of AB3) $\times 0.208$ (lateral earth pressure coefficient at rest) = 0.68 kPa). Therefore, the lateral earth pressures caused by the compaction were approximately equal at the positions of E2 and E3. Similarly, for Section B, the difference between E2 and E3 was 1.0 kPa, which is also close to the difference induced by the soil overburden stress (i.e., $0.15\ \text{m} \times 15.6\ \text{kN/m}^3 \times 0.201 = 0.48$ kPa). This analysis demonstrates that the lateral earth pressure induced by the compactor was constant within the range of 40 to 140° from the pipe crown as suggested by Masada and Sargand (2007).

Displacements of Ribs

To investigate the deformations of ribs during installation, the displacements of ribs at the springline in both sections were monitored. Before the installation, 14 ribs at the springline of each of the middle two pipes were marked and the gap distances (i.e., 13 gaps) between them were measured and recorded. After testing, the gap distances were measured again to evaluate the possible distortions of ribs during installation. Fig. 11 shows the gap distances before and after the installation in both sections. Generally, the gap dis-

tance change for Section B was greater than that in Section A. The possible reason is that more large stone particles were pushed into the gaps in Section B by compaction.

Visual Observation

The buried pipes were exhumed for visual observations after the installation. No obvious damage to the ribs and liners of the pipes was observed. Further research is ongoing to evaluate the possible difference in the structural behavior of the pipes before and after the installation. The results of the further research will be presented in future publications.

Conclusions

A full-scale field test was conducted to investigate the installation effect on the SRHDPE pipes in the AB3 aggregate and the crushed stone with the soil cover thickness of 0.65 m in both sections. The diameter of the pipe was 610 mm. The deflections of the pipes and the earth pressures in the backfills were monitored during backfilling. The following conclusions can be made from the analysis of the test results:

1. The peaking deflection of the pipe in the AB3 aggregate was 1.5 times that in the crushed stone. However, the vertical diameter of the pipe in the crushed stone decreased by 3.5 times that in the AB3 aggregate at the final level of the backfill. The vertical deflection of the pipe at the valley liner was slightly greater than that at the steel reinforcement rib. The diameter change of the pipe at 45° from the pipe crown in the crushed stone was larger than that in the AB3 aggregate. The horizontal deflection of the pipe during backfilling was opposite to the vertical deflection. The maximum deflections in the AB3 aggregate and the crushed stone were both much less than the 5% deflection limit for the steel and HDPE pipes suggested by the AASHTO standards.
2. The soil arching factors at the top of the pipe for Sections A and B were 1.10 and 1.47 at the end of backfilling, respectively, which demonstrated that some overburden stress of the soil cover was transferred from the surrounding soil to the pipe due to the negative soil arching effect. The lateral earth pressure coefficients decreased with the increase of soil thickness in both sections and their values were between the coefficients for the passive and at-rest states. The lateral earth pressure coefficient in the AB3 aggregate was higher than that in the crushed stone. The lateral earth pressure measurements verified that the lateral earth pressure caused by the compaction of the backfill with depth was constant around the pipe.
3. The SRHDPE pipe performed well in the AB3 aggregate and the crushed stone during the installation. The displacements of ribs at the springline of the pipe in the crushed stone section were greater than those in the AB3 section.

Acknowledgments

This study was financially supported by the Kansas Department of Transportation (KDOT). Contech Construction Product Inc. provided the SRHDPE pipes and connectors. The Maintenance Branch of the KDOT provided great assistance in the installation of the pipes in this study. Graduate students, Yan Jiang, Jamal Kakrasul, Madan Neupane, Xiaohui Sun, Ryan Corey, and visiting scholars, Dr. Hongguang Zhang and Mustapha Rahmaninezhad, at the University of Kansas were involved in the field installation. The authors greatly acknowledge all the above support.

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Steel Reinforced Polyethylene (SRPE) Pipe

AASHTO 4b Subcommittee Ballot

Review Comments / Responses

Ballot Results: 13 affirmative, 3 negatives, 4 abstentions

Negatives: Florida, Virginia & Tennessee
Comments: Pennsylvania, New York, Missouri, Georgia, PPI, ACPA & RCP Producer

Primary issues:

1. Provide a better definition of “improved installation methods”

Current verbage:

For installations that utilize improved installation methods (i.e. more restrictive backfill specifications, shape monitoring during installation, etc.), the allowable pipe stiffness can be decreased to the equivalent to a 0.095 flexibility factor. Table X.2 in the Appendix provides pipe stiffness values based on this limit.

Proposed revision:

For installations that utilize improved installation techniques the allowable pipe stiffness can be decreased to the equivalent to a 0.095 flexibility factor. Improved installation techniques shall include the use of structural backfill material meeting an A-1 gradation per M145 or on-site shape control monitoring. Table X.2 in the Appendix provides pipe stiffness values based on this limit.

Primary issues:

2. Treat as a provisional standard

Would M335 become a provisional standard as a whole, or are just diameters > 60” treated as provisional? Is that distinction possible?

CONTECH ENGINEERED SOLUTIONS

Primary issues:

3. Why reduce the test frequency of the stub compression test from 6 months to 24 months?

The test frequency can be reduced for SRPE profiles because there is significantly less potential variation in the production of the profile. Profile wall thermoplastic pipe profiles have considerably more variables that influence the geometry of the profile. Extrusion speed, ambient temperature, rate of cooling, die wear and many other variables can all influence the final geometry of the profile. For SRPE pipes meeting this standard, the only meaningful variables are the steel rib height, rib thickness and yield point of the steel. All of those variables can be more reliably controlled than the variables in the production of a profile wall thermoplastic pipe. Less variability should mean that less frequent testing is required.

Primary issues:

4. What DOT’s are using these larger diameters?

DOT’s that have approved SRPE for diameters > 60”

- Washington
- Colorado
- New Mexico
- Oregon
- Ohio

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ENGINEERED SOLUTIONS

Primary issues:

5. Why the flexibility factor of 0.095?

Lots of experience with corrugated steel pipes. The metal pipe industry has utilized structures with higher flexibility factors in a number of common applications such as arches / pipe-arches, trench installations, installations with more select backfill requirements, long span structures, vertical applications, etc. In these cases, the allowable flexibility factor is increased by a minimum of 50%.

Restricting the select backfill from A-1, A-2 or A-3 to only A-1 greatly reduces the compaction effort required to get the backfill to the required density. All of the pipes produced by Contech that are > 96” have had a FF > 0.065 and used more restrictive backfill materials.

CONTECH ENGINEERED SOLUTIONS

DuroMaxx®

STEEL REINFORCED PE TECHNOLOGY

PROJECT PROFILES

Projects and Applications

- Sanitary Sewers
- CSO & SSO
- RWH & Cisterns
- Watertight Detention
- Large Diameter Storm Sewers
- Irrigation
- Culverts
- Reline / Rehabilitation

DuroMaxx Storm Sewer & Culvert Projects

CONTECH ENGINEERED SOLUTIONS

Fulton Ave Storm Sewer

Canton, OH

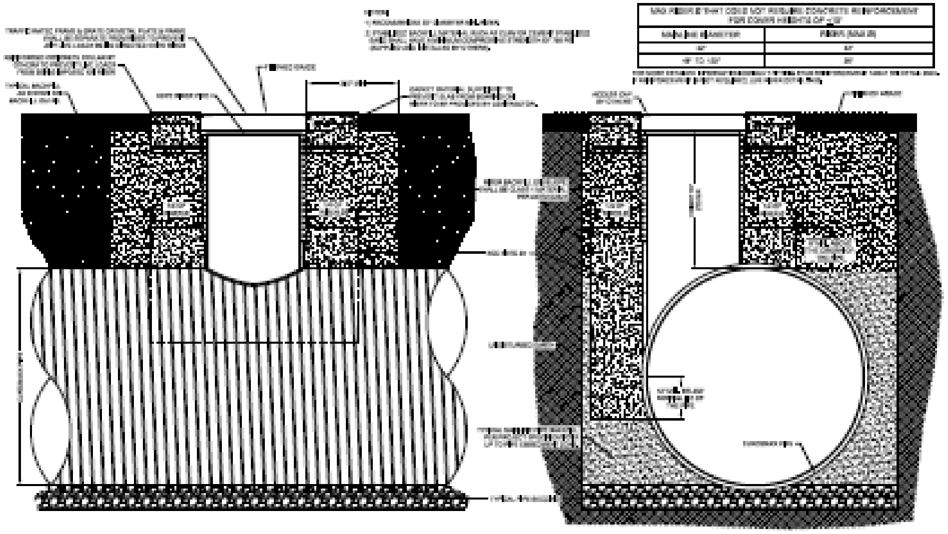
Owner: Stark County Engineer

Engineer: CT Consultants

Contractor: Wenger Excavating

Description: 1575’ 96” Storm Sewer

Installation Date: August 2016



Canal Street Storm Sewer

Carlsbad, NM

Project Team Members:

Owner:
New Mexico DOT

Engineer:
URS Corporation

Contractor:
James Hamilton Construction Co.

Technical Description:
•DuroMaxx HP 15,250 lf of 24" - 72" dia.

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ENGINEERED SOLUTIONS

Northern Avenue

Glendale, Arizona

Knowledge. Solutions. Service.

Storm Sewer

Project Team Members:

Owners:
City of Glendale
Maricopa County Flood Control District

Engineers:
Stantec Inc.
Premier Engineering Corp.

Contractor:
Sundt Construction, Inc.

Technical Description:

- Product: DuroMaxx®
  10,900 ft
  60" and 72" diameters

Installation Date: October 2010

CONTECH ENGINEERED SOLUTIONS

DuroMaxx Detention Projects

University of Louisville
Brook Street Infiltration Basin

Louisville, KY

- Engineer: Qk4
- Contractor: Mack Construction
- 670’ Perforated 120” DuroMaxx
- 393,640 Gallons
- Summer 2014

Wheeler Army Airfield

Wahiawa, Oahu, HI

Project Team Members:

Owner:
US Army Corps of Engineers

Engineer:
R. M. Towill Corporation

Contractor:
Goodfellow Bros., Inc.

Technical Description:

- DuroMaxx LH – 2,442 lf of 84” dia. Storm
- DuroMaxx LH – 2,684 lf of 72” dia. Storm
- 17,250 CF of 60” DuroMaxx Detention Storage

DuroMaxx Rainwater Harvesting & Cistern Projects

Gilardi Ranch Rainwater Harvesting Project

Bodega, CA

Project Team Members:

Owner:
Goldridge Resource Conservation District

Engineer:
Prunuske Chatham Inc.

Contractor:
Prunuske Chatham Inc.

Technical Description:
•DuroMaxx EF **31,500 CF of 84" dia.**

DuroMaxx Sanitary, CSO, SSO, Glycol and Equalization Storage Projects

CONTECH ENGINEERED SOLUTIONS

Project Profile

ODOT Project 133026: I-71 & MLK Intersection, Combined Sewer Replacement

- April 2015
- 1778’ of 30”, 60” & 72”
- 160’ of 60” in 72” casing when depths exceeded 44’
- CANDE Finite Element Analysis checked for 59’
- Engineer: HDR Inc.
- Contractor: Kokosing
- Owners: Cincinnati MSD & ODOT

CONTECH
ENGINEERED SOLUTIONS

Bryan's Lift Station Improvements

Monticello, Indiana

CSO Detention System

Project Team Members:

Owner:
City of Monticello, Indiana

Engineer:
Wessler Engineering

Contractor:
F&K Construction

Technical Description:
- DuroMaxx® CSO detention system with 395,000 gallons of storage

Installation Date: July 2012

84” and 96” Diameter DuroMaxx with fusion welded joints

Upper Lawson Run Combined Sewer Storage

Portsmouth, OH

Owner: City of Portsmouth

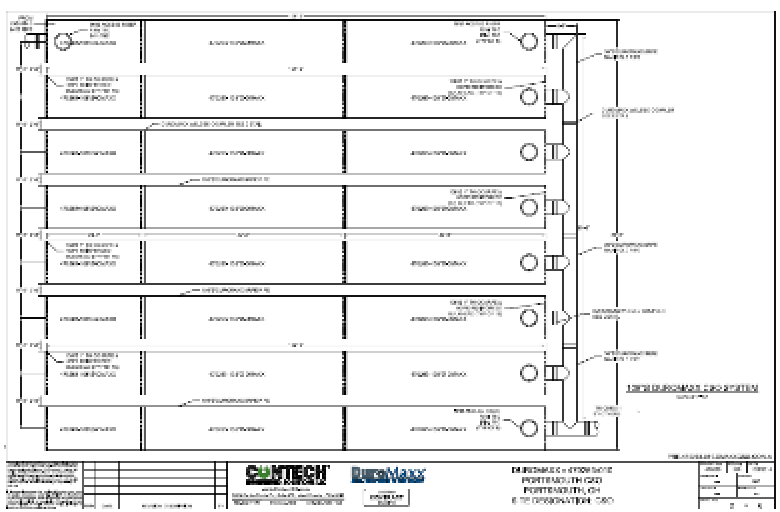
Engineer:
Strand & Associates – Columbus, OH

Contractor: Distel Construction

Description: DuroMaxx CSO Storage

Installation Date: January 2015

832’ 108” diameter; 402,280 gallons



MacArthur Airport
Glycol Pre-Treatment & Collection System
Long Island, NY

Project Team Members:

Owner:
MacArthur Airport

Engineer:
L. K. McLean Associates

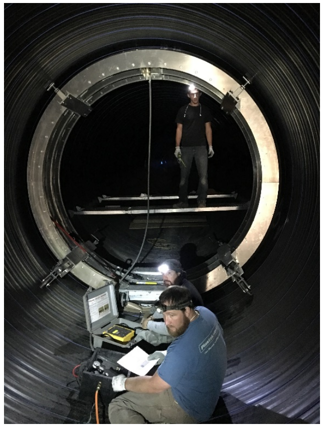
Contractor:
LoDuca Associates, Inc.

Technical Description:
- DuroMaxx EF
- 819 lf of 84" – 96" dia.

DuroMaxx Irrigation Projects

Klamath Falls Irrigation District C Flume Replacement

- Installed 2016-2017
- Engineer: Anderson Perry & Associates
- Contractor: R & G Excavating
- 3,000’ of 120” DuroMaxx
- Electrofusion and Extrusion Welded joints
- Multiple horizontal and vertical elbows
- Siphon portion under the road



DuroMaxx Rehabilitation Projects

CONTECH® ENGINEERED SOLUTIONS

Project Profile

Mobile Airport, AL
Culvert Rehabilitation

- February 2014
- Engineer: Volkert & Assoc.
- Contractor: Indiana Reline
- Host 132” Multi-Plate
- 35’ of cover
- 1742’ of 120” DMX 40’ sections
- First pull 542’, Second 1200’
- Light Weight Cellular Grout

Bradford County Reline

Starke, FL

Project Team Members:

Owner:
Bradford County, FL

Contractor:
WW Engineering

Technical Description:
•DuroMaxx EF 80' 120" dia.

DuroMaxx®
A STEEL REINFORCED POLYETHYLENE PIPE

DuroMaxx® Specification Sheet

Scope
This specification describes DuroMaxx® pipe for use such as storm sewers, sanitary sewers, industrial waste applications, drainage pipes, underground detention, infiltration, cistern or rainwater harvesting systems in 30" (750 mm) through 120” (3000 mm) nominal diameters.

Description
DuroMaxx is a reinforced polyethylene pipe with a smooth waterway wall and exterior profile that is reinforced with high strength galvanized steel ribs. The continuous reinforcing ribs are completely encased within the polyethylene profile. DuroMaxx is manufactured using a helical winding process that results in a continuously fusion welded lap seam. The pipe profile is manufactured using a high quality stress-rated thermoplastic meeting the requirements of ASTM F2562 “Standard Specification for Steel Reinforced Thermoplastic Ribbed Pipe and Fittings for Non-Pressure Drainage and Sewerage” or AASHTO Designation MP-20. For the purpose of hydraulic design, the recommended Manning's "n" value shall be 0.012 for pipe diameters included within this specification.

Material Properties
Virgin high density polyethylene stress-rated resins are used to manufacture DuroMaxx pipe and complimentary fabricated fittings. Resins shall conform to the minimum requirements of cell classification 345464C as defined and described in the latest version of ASTM D3350 “Standard Specification for Polyethylene Plastics Pipe and Fittings Materials”.

Joint Performance
Pipe lengths shall be joined on site using coupling bands, bell & spigots or ElectroFusion couplers especially designed for DuroMaxx pipe. Joints shall meet one of the performance levels as required and specified:

- **Soil Tight Joints** (30” – 120””) shall be plain ended DuroMaxx pipe with Aluminized Type 2 (or optional Polymeric coated) CMP coupling bands and elastomeric gaskets (see Standard Drawings 1012802).

- **Low Head (LH) Joints** (30” – 84”) shall be gasketed, stress-rated high density polyethylene bell and spigot joints (meeting the requirements set forth in the above Material Properties paragraph) that have been laboratory tested to 3 psi when tested in accordance with ASTM D3212 “Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals” (see Standard Drawing 1012803).

- **High Performance (HP) Joints** (30” – 84”) shall be gasketed, bell and spigot joints where both the bell and spigot are reinforced with steel that is fully encased in stress-rated high density polyethylene (meeting the requirements set forth in the above Material Properties paragraph) and that have been laboratory tested to 15 psi when tested in accordance with ASTM D3212 “Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals” (see Standard Drawing 1012804).

- **Welded Joints** (36” – 120”) shall utilize plain ended DuroMaxx pipe welded together utilizing exclusive pressure testable ElectroFusion (EF) couplers or extrusion welded (WC) couplers. The welded connections provide a true in-field watertight system assured by the pressure testable welded sleeves at each welded connection. The field installed welded joints shall remain watertight up to a test pressure of 30 psi (see Standard Drawing 1012805).

Fittings
All fabricated fittings and couplings supplied by the manufacturer shall be constructed to ensure no loss of structural integrity or joint tightness at welded seams and joints. Only those fittings supplied by or recommended by the manufacturer shall be used.

Installation
Installation shall be in accordance with ASTM D2321 "Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications" along with product-specific recommendations contained in Contech Installation Guidelines for DuroMaxx pipe, available from local Contech representatives or from www.conteches.com.

Pipe Dimensions and Cover Limits

Nominal Pipe Size	Outside Diameter	Unit Weight*	Minimum Waterway Wall Thickness (t_1)		Minimum Cover***		Maximum Cover	
inch	in. [mm]	lbs./ft	in.	[mm]	ft.	[m]	ft.	[m]
30	30.9 [785]	15.5	.082	[2.08]	1	[.305]	50	[15.2]
36	37.1 [942]	20.8	.082	[2.08]	1	[.305]	50	[15.2]
42	43.2 [1097]	26.5	.082	[2.08]	1	[.305]	50	[15.2]
48	49.5 [1257]	29.1	.130	[3.30]	1	[.305]	30	[9.1]
54	55.5 [1410]	34.7	.130	[3.30]	1	[.305]	30	[9.1]
60	61.4 [1560]	41.6	.130	[3.30]	1	[.305]	30	[9.1]
66	67.8 [1722]	56.9	.220	[5.58]	1.5	{.457]	30	[9.1}
72	74.1[1882]	65.6	.220	[5.58]	1.5	[.457]	30	[9.1]
84	85.9 [2182]	76.3	.220	[5.58]	2	[.610]	30	[9.1]
96	98.3 [2497]	87.0	.220	[5.58]	2	[.610]	30	[9.1]
108	111.3 [2827]	99.7	.220	[5.58]	2.5	[.762]	25	[7.6]
120	121.9 [3097]	109.0	.220	[5.58]	3	[.914]	25	[7.6]

* Approximate weights. Actual weight will vary with length and joint type.
** Minimum and maximum cover limits are for H20/H25 loading.

The Contech Environmental Commitment

Contech is an environmentally conscious company committed to shaping the future of green building and design. DuroMaxx is Contech's newest contribution to our ecofriendly portfolio of civil engineering solutions. Starting with the manufacturing process, DuroMaxx consumes less than 35% of natural resources to produce AASHTO M294 HDPE pipe. The green design continues with DuroMaxx's steel reinforced ribs which are made of recycled steel in content levels ranging from 55-80%. Plus, when utilized appropriately, it can contribute to a variety of the U.S. Green Building Council's LEED credits in the categories for sustainable sites, water efficiency and landscaping, and materials and resources.

Attachment #8

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

AASHTO Designation: M 335-18[1]

Technical Section: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

AASHTO

American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Standard Specification for

Steel-Reinforced Polyethylene (PE) Ribbed Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

AASHTO Designation: M 335-18[1]

Technical Section: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

1. SCOPE

1.1. This specification covers the requirements and methods of tests for steel-reinforced polyethylene (PE) ribbed pipe, couplings, and fittings for use in surface and subsurface drainage applications.

1.1.1. Nominal sizes of 300 to 1500 mm (12 to 60 in.) are included.

1.1.2. Materials, workmanship, dimensions, perforation, pipe stiffness, impact resistance, tensile strength of seams, shape stability, joining systems, and form of markings are specified.

1.2. Steel-reinforced PE ribbed pipe is intended for surface and subsurface drainage applications where soil provides support to its flexible walls. Its major use is to collect or convey drainage water by open gravity flow as culverts, storm drains, etc.

Note 1—When PE pipe is to be used in locations where the ends may be exposed, consideration should be given to protection of the exposed portions due to combustibility of the PE and the effects of prolonged exposure to ultraviolet radiation.

1.3. This specification only deals with this pipe's materials requirements. The structural design of steel reinforced thermoplastic culverts and the proper installation procedures are given in the *AASHTO LRFD Bridge Design Specifications*, Section 12, and *AASHTO LRFD Bridge Construction Specifications*, Section 26, respectively. Upon request of the user or engineer, the manufacturer shall provide profile wall section detail required for a full engineering evaluation.

1.4. *Units*—The values stated in SI units are to be regarded as standard. Within the text, the U.S. Customary units are shown in parentheses and may not be exact equivalents.

1.5. The following precautionary caveat pertains only to the test method portion, Section 9, of this specification. *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards*:

- M 288, Geosynthetic Specification for Highway Applications

- T 341, Determination of Compression Capacity for Profile Wall Plastic Pipe by Stub Compression Loading
- *AASHTO LRFD Bridge Design Specifications*, Section 12
- *AASHTO LRFD Bridge Construction Specifications*, Section 26

2.2. *ASTM Standards*:

- A653/A653M, Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
- D618, Standard Practice for Conditioning Plastics for Testing
- D638, Standard Test Method for Tensile Properties of Plastics
- D883, Standard Terminology Relating to Plastics
- D2122, Standard Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings
- D2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
- D2444, Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
- D3212, Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals
- D3350, Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
- F412, Standard Terminology Relating to Plastic Piping Systems
- F477, Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
- F2136, Standard Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe

3. TERMINOLOGY

3.1. The terminology used in this standard is in accordance with the definitions given in ASTM D883 and ASTM F412 unless otherwise specified.

3.2. *Definitions*:

3.2.1. *crack*—any break or split that extends through the wall.

3.2.2. *crease*—a visible irrecoverable indentation, generally associated with a loss in shape stability.

3.2.3. *delamination*—a gap extending through the weld seam between two adjacent wrap widths.

3.2.4. *encapsulation thicknesses*—the thicknesses of the high-density polyethylene (HDPE) covering on both sides of the steel reinforcement as well as the thickness of the closure at the top (outside) of the rib and the thickness of the profile directly under (inside) the reinforcement (see Figure 2).

3.2.5. *gravity flow*—a condition in which liquid flow through a piping system results from a downward pipeline slope, but flow is less than full, except during conditions when the system may become temporarily surcharged, in which case the system is subject to temporary internal hydrostatic pressure that is limited to 74 kPa (10.8 psi).

3.2.6. *polyethylene (PE) plastics*—plastics based on polymers made with ethylene as essentially the sole monomer (ASTM D883).

3.2.7. *reworked plastic*—a plastic from a processor's own production that has been reground, pelletized, or solvated after having been previously processed by molding, extrusion, etc. (ASTM D883).

3.2.8. *weld seam*—the portion of the helically wrapped strip that overlaps and is fused to adjacent helically wrapped strips (see Figure 1).

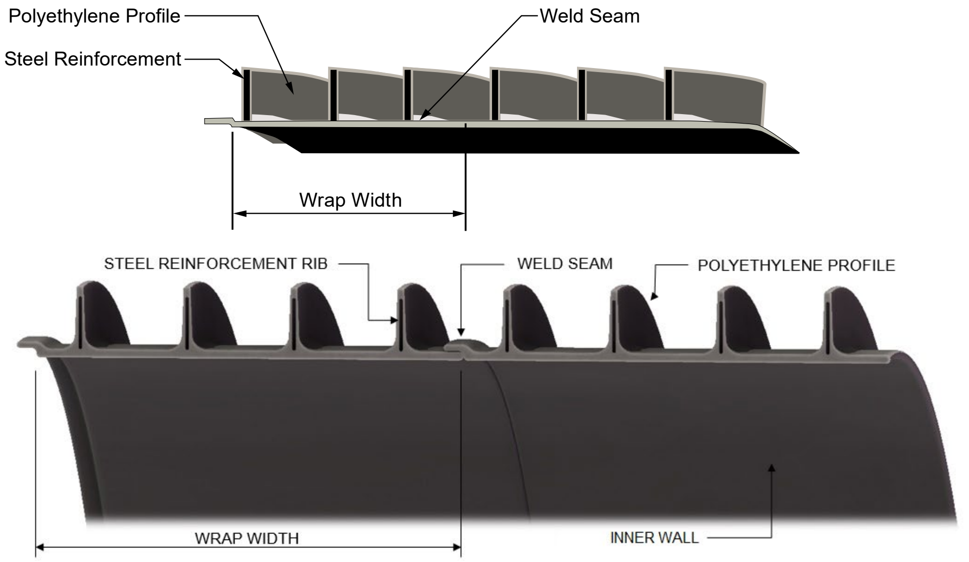


Figure 1—Cross Section of Profile

3.2.9. *shape stability*—a general measure of the pipe's ability to maintain geometric and structural stability while deflected and carrying a load equal to or greater than 75 percent of its peak load-carrying capability. Peak load-carrying capability is identified as the maximum load in the load/deflection curve as measured during the flattening test as described in Section 9.2.

3.2.10. *steel-reinforced ~~thermoplastic~~ polyethylene pipe*—ribbed thermoplastic pipe with steel reinforcing encapsulated within the ribs (see Figure 1 and Figure 2).

3.2.11. *slow crack growth*—a phenomenon by which a stress crack may form. A stress crack is an external or internal crack in plastic caused by tensile stresses less than its short-term mechanical strength.

3.2.12. *virgin polyethylene material*—PE plastic material in the form of pellets, granules, powder, floc, or liquid that has not been subject to use or processing other than required for initial manufacture.

3.2.13. *wrap width*—the width the helically wrapped strip covers when measured across the strip, perpendicular to the ribs (see Figure 1).

3.2.14. *~~waterway~~ inner wall*—the minimum wall thickness separating the inner and outer surfaces of the which is measured between pipe ribs (see Figure 2).

4. CLASSIFICATION

4.1. *The steel-reinforced PE ribbed pipe covered by this specification is classified as follows*:

4.1.1. *Type S*—This pipe shall have a full circular cross section with an essentially smooth inner wall.

4.1.2. *Type SP*—This pipe shall be Type S with perforations.

4.2. Perforations are described in Section 7.5.

5. ORDERING INFORMATION

5.1. *Orders using this specification shall include the following information as necessary to adequately describe the desired product*:

5.1.1. AASHTO designation and year of issue;

5.1.2. Perforation, if applicable (Section 7.5);

5.1.3. Diameter and length required, either total length or length of each piece and number of pieces;

5.1.4. Certification, if desired (Section 12.1); and

5.1.5. Type of pipe joint (Section 7.12.1).

6. MATERIALS

6.1. *Polyethylene Materials*:

6.1.1. *Pipe and Fittings*—Pipe and fittings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 334452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided the product requirements are met.

6.1.2. *Rotational Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 213320 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met. For slow crack resistance, acceptance of resins shall be determined by using the notched, constant ligament-stress (NCLS) test according to the procedure described in Section 9.6. The average failure time of the five test specimens must exceed 24 h with no single test specimen's failure time less than 17 h.

6.1.3. *Injection Molded Fittings and Couplings*—Fittings and couplings shall be made of virgin PE, conforming to the requirements of ASTM D3350 and having a cell classification of 324452 C or E. Resins that have higher cell classifications in one or more properties are acceptable provided product requirements are met.

6.1.4. *Carbon Black Content*—The carbon black content shall not exceed 4 percent of the total PE compound weight.

6.1.5. *Other Materials*—It is permissible to use materials other than the cell classification in Section 6.1.1 as part of the welding processes, provided these materials have higher cell classifications in one or more properties and in no way compromise the performance of the pipe products in the intended use.

6.1.6. *Rework Plastics*—In lieu of virgin PE, it is permissible to use clean reworked plastic generated from the manufacturer's own pipe production, provided that it meets the cell class requirements as described in Section 6.1.1.

6.2. *Steel Materials*:

6.2.1. *Steel Material*—The steel material shall be cold- or hot-rolled, formable steel meeting the requirements of ASTM A653/A653M and the mechanical requirements for strength in Table 4 of ASTM A653/A653M for the grade defined by the manufacturer as required for their pipe's design. The steel shall have a galvanized coating. All steel materials shall be galvanized per the requirements of ASTM A653/A653M with a G60 minimum coating weight.

Note 2—The actual strength of the steel and the rib dimensions are dependent on the manufacturer's design. If requested by the purchaser, the manufacturer shall provide before purchase and delivery their pipe design and certify with delivery that the grade of steel and rib dimensions in the pipe supplied conform to their design.

6.2.2. *Gaskets*—Elastomeric gaskets shall meet the requirements of ASTM F477.

6.2.3. *Industrial Sealant*—Sealants, such as moisture cure urethane or asphalt-based sealant materials used for repairs or assembly of the internal coupling joint, as recommended by the manufacturer, may be used.

7. REQUIREMENTS

7.1. *Workmanship*—The pipe and fittings shall be free of foreign inclusions and visible defects as defined herein. Visible defects shall not affect the wall integrity or the encapsulation of the steel reinforcement. The steel reinforcing materials shall not be exposed.

7.2. *Visible Defects*—Cracks, creases, delamination, and unpigmented or nonuniformly pigmented pipe that are visible by the unaided eye are not permissible in the pipe or fittings.

7.3. There shall be no evidence of cracking or delamination when tested in accordance with Section 9.2.

7.4. *Pipe Dimensions and Tolerances*:

7.4.1. *Inside Diameter*—The tolerance on the inside diameter shall be ±2.0 percent, when measured in accordance with Section 9.8.1. Pipe dimensions (for both perforated and nonperforated pipe) shall comply with Table 1.

7.4.1.1. Other diameters that are within the range of pipe sizes shown in Table 1 are permissible. The minimum wall thickness and other properties shall be interpolated from the adjacent values given in Table 1.

Table 1—Nominal Pipe Sizes, Inside Diameters, and Minimum ~~Waterway~~ Inner Wall Thicknesses

Nominal Pipe Size, mm (in.)	Inside Diameter, mm [in.] [a]	Minimum ~~Waterway~~ Inner Wall Thickness, t_1, mm [in.]	Minimum Encapsulation Thickness (Bottom), t_2, mm [in.]
300 (12)	300 [11.81]	1.1 [0.043]	0.9 [0.035]
375 (15)	375 [14.76]	1.2 [0.047]	1.0 [0.039]
450 (18)	450 [17.72]	1.3 [0.051]	1.3 [0.051]
600 (24)	600 [23.62]	1.5 [0.059]	1.5 [0.059]
750 (30)	750 [29.53]	2.0 [0.079~~1.5 [0.059]~~	2.0 [0.079~~1.5 [0.059]~~

900 (36)	900 [35.43]	2.0 [0.079~~1.7 [0.067]~~	2.0 [0.079~~1.7 [0.067]~~
1050 (42)	1050 [41.34]	2.0 [0.079~~1.8 [0.071]~~	2.0 [0.079~~1.8 [0.071]~~
1200 (48)	1200 [47.24]	3.3 [0.130~~1.8 [0.071]~~	3.3 [0.130~~1.8 [0.071]~~
1350 (54)	1350 [53.15]	3.3 [0.130~~2.0 [0.079]~~	3.3 [0.130~~2.0 [0.079]~~
1500 (60)	1500 [59.06]	3.3 [0.130~~2.0 [0.079]~~	3.3 [0.130~~2.0 [0.079]~~

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

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7.4.2. *~~Waterway~~ Inner Wall*—Minimum ~~waterway~~ inner wall thickness shall be as required in Table 1 when measured in accordance with Section 9.8.2.

7.4.3. *Length*—The pipe shall be sold in any length agreeable to the user. Length shall not be less than 99 percent of the specified length, when measured in accordance with Section 9.8.3.

7.4.4. *Encapsulation Thickness*—The minimum thickness of the HDPE encapsulation at the sides, top (outside), and bottom (inside) of the reinforcement shall be as shown in Figure 2. Factory cut pipe ends shall have the cut rib ends encapsulated to meet the requirements of Figure 2 for the top (outside) of the ribs. Encapsulation thicknesses shall be measured in accordance with Section 9.8.4.

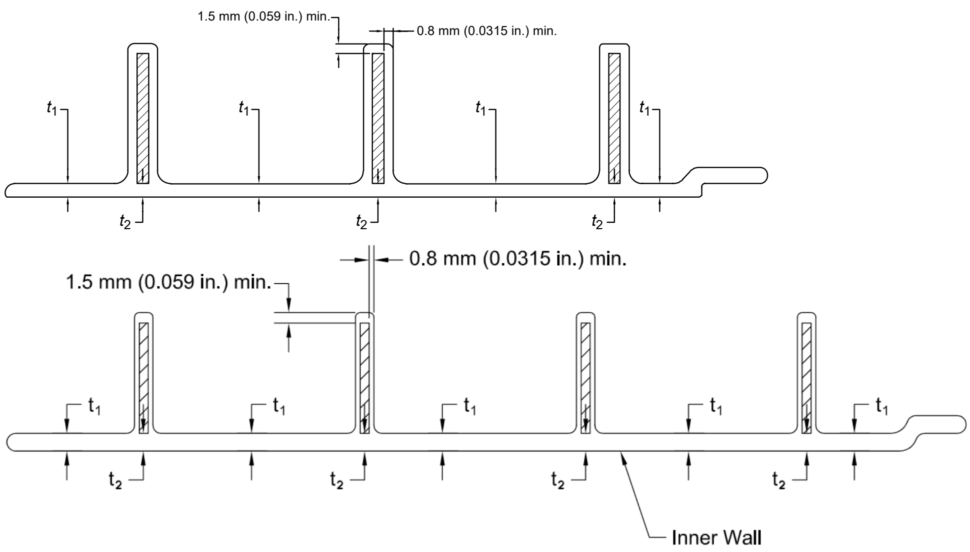

Figure 2—Schematic Representation of Steel-Reinforced Thermoplastic Pipe Profile

7.5. *Perforations*—When perforated pipe is specified, the perforations shall be cleanly cut and uniformly spaced along the length and circumference of the pipe. Circular perforations shall be a minimum of 5 mm (0.2 in.) and shall not exceed 10 mm (0.4 in.) in diameter. The water inlet area shall be a minimum of 30 cm^2/m (1.5 in.^{2}/ft) for pipe sizes 300 to 450 mm (12 to 18 in.) and 40 cm^2/m (2.0 in.^{2}/ft) for pipe sizes larger than 450 mm (18 in.). All measurements shall be made in accordance with Section 9.8.5. The perforations shall be cleanly cut so as not to restrict the inflow of water. Pipe connected by bell and spigot joints may not be perforated in the area of the bells and spigots. Perforations shall be located in the ~~waterway~~ inner wall portion of the pipe

between the ribs and shall not cut into encapsulation of the reinforcement, the radius between this encapsulation and the ~~waterway~~ inner wall, or the fused seam. The reinforcing steel material shall exposed by these perforations.

7.6. *Pipe Stiffness*—The pipe shall have minimum pipe stiffness at 5 percent deflection as listed in Table 2. Pipe stiffness shall be tested in accordance with Section 9.1.

Table 2—Pipe Stiffness and Shape Stability Limits

Nominal Pipe Size, mm (in.)	Pipe Stiffness, kPa [psi] [a]	Shape Stability Limit, %
300 (12)	345 [50]	20
375 (15)	290 [42]	20
450 (18)	276 [40]	20
600 (24)	234 [34]	20
750 (30)	193 [28]	20
900 (36)	152 [22]	20
1050 (42)	140 [20]	20
1200 (48)	125 [18]	15
1350 (54)	110 [16]	15
1500 (60)	97 [14]	15

[a] Conversions of SI units to U.S. Customary units in this table are "soft" conversions; i.e., the metric measurement is mathematically converted to its exact (or nearly exact) equivalent in inch-pound measurement.

Note 3—The 5 percent deflection criterion was selected for testing convenience and should not be considered as a limitation with respect to in-use deflection.

7.7. *Pipe Flattening*—There shall be no visual evidence of splitting or cracking when tested in accordance with Section 9.2. Additionally, there shall be no separation or delamination of the spiral seam or the rib at the top of its junction with the ~~waterway~~ inner wall of the pipe when tested in accordance with Section 9.7.

7.8. *Shape Stability*—In the flattening test described in Section 9.2, the load shall not decrease with increasing deflection until after the percentage shape stability limit tabulated for the relevant diameter (in Table 2) has been exceeded. Additionally, if the peak load is reached before 20 percent deflection, the load at 20 percent deflection shall be a minimum of 75 percent of the peak load. Shape stability limit is calculated as follows:

$$SSL = \frac{\Delta Y}{ID} \times 100\% \quad (1)$$

where:

SSL = shape stability limit

ΔY = change in vertical deflection

ID = inside diameter of pipe

7.9. *Impact*—There shall be no evidence of splitting, cracking, or breaking when tested in accordance with Section 9.3. Additionally, there shall be no separation of the spiral seam or the rib at its junction with the ~~waterway~~ inner wall when tested in accordance with Section 9.7.

7.10. *Tensile Strength of Seam*—There shall be no breaking or separation of the weldment material in the lap seam~~weld~~ when tested in accordance with Section 9.4. Excess weldment material located outside of the lapped seam is not considered as part of the test.

7.11. *Fitting Requirements*:

7.11.1. Only fittings supplied or recommended by the manufacturer shall be used. Fabricated fittings shall be supplied with joints compatible with the overall system requirements. A bell-and-spigot joint is an example of a typical design.

7.11.2. All fittings shall be within an overall length dimensional tolerance ±12 mm (0.5 in.) of the manufacturer's specified dimensions when measured in accordance with Section 9.8.3.

7.11.3. The fittings shall not impair the overall integrity or function of the pipe.

7.11.4. Common fittings include in-line joint fittings, reducers, and branch or complementary assembly fittings such as tees and wyes. These fittings shall be installed or coupled to the pipe by various methods.

7.11.5. Fittings shall not reduce the inside diameter of the pipe being joined by more than 12 mm (0.5 in.). Reducer fittings shall not reduce the cross-sectional area of the small size diameter by more than 3 percent.

7.12. *Jointing Requirements*:

7.12.1. Pipe joints and couplings shall be bell and spigot or screw-on collar. Only couplings supplied or recommended by the manufacturer shall be used. Couplings shall be supplied with joints compatible with the overall system requirements.

7.12.1.1. Other types of couplings or fastening devices that are equally effective as those described in Section 7.12.2.1 and that comply with the soiltight joint performance criteria of the *AASHTO LRFD Bridge Construction Specifications*, Article 26.4.2.4, may be used when approved by the purchaser. An example of another type of coupler is a split-collar coupling, which shall match the pipe profile and shall provide sufficient longitudinal strength to preserve pipe alignment and prevent separation at the joints. Split-collar couplings shall engage at least three full ribs on each pipe section.

7.12.1.2. *Internal Coupling, Sealant Type*—Joint seal is affected by applying an industrial sealant between the external surface of the coupling and the internal surface of the pipe. This jointing system may be used when approved by the purchaser.

7.12.1.3. Other types of jointing methods such as flanging, internal coupling (gasket type), extrusion welding, electro-fusion, butt fusion, and others may be used when approved by the purchaser.

7.12.2. *Joint Tightness*—The pipe or fitting joint shall meet the requirements defined as one of the following types:

7.12.2.1. *Soiltight Joints*—Soiltight joints are specified as a function of opening size (maximum dimension normal to the direction that soil may infiltrate), channel length (length of the path along which the soil may infiltrate), and backfill particle size. If the size of the opening exceeds 3 mm ($^1/_8$ in.), the length of the channel must be at least four times the size of the opening. No opening may exceed 25 mm (1 in.). Backfill material containing a high percentage of fine-graded soils requires investigation for the specific type of joint to be used to guard against soil infiltration.

7.12.2.2. *Silt-Tight Joints*—A silt-tight joint is resistant to infiltration of particles that pass the No. 200 sieve. Silt-tight joints are specified to provide protection against infiltration of backfill material containing a high percentage of fines, and typically utilize some type of filtering or sealing component, such as an elastomeric rubber seal or geotextile wrap. Geotextile wraps are manufactured to tolerances that assure silt will not pass through them. The successful performance of these wraps in the field is dependent on their installation. If a geotextile wrap is specified for

use, the material specified should meet the requirements of M 288, with an Apparent Opening Size (AOS) > 70.

For joints that utilize an elastomeric rubber seal, silt-tight performance shall have been demonstrated in a laboratory test to meet the hydrostatic requirements of ASTM D3212, with the exception that the hydrostatic test pressure shall be a minimum of 14 kPa (2 psi).

7.12.2.3. *Leak-Resistant Joints*—Leak-resistant joints shall be bell and spigot and utilize an elastomeric rubber seal meeting the requirements of ASTM F477. Alternative methods of joining (e.g., external joint wraps) shall be allowed provided the requirements of Section 7.12.2.3.1 are achieved.

7.12.2.3.1. Leak resistance shall be verified in the lab by meeting all of the requirements of ASTM D3212. The hydrostatic test pressure and vacuum specified in the test method shall be 74 kPa (10.8 psi).

7.12.3. *Special Design Joints*—Special design joints shall include joints requiring special strength in bending or shear, pull-apart capabilities, or unusual features such as restrained joints placed on severe slopes, welded joints, flanged and bolted joints for high pressures, high heads, or velocities. Watertight joints that provide zero leakage for a specified head or pressure application are included in this type of joint.

7.13. *Stub Compression Test*—Profile compression capacity in any specimen in the stub compression test shall not be less than 50 percent of the gross cross section of the steel reinforcing area times the minimum specified yield strength of the steel when tested in accordance with Section 9.9. The stub compression test, T 341, shall be a material and wall design qualification test conducted twice a year or whenever there are changes in wall design or material distribution. Computing the minimum capacity requires determining the cross-sectional area of the pipe wall. This can be accomplished conveniently by optically scanning the profile and determining the section properties using a computer drafting program.

8. CONDITIONING

8.1. *Conditioning*—Condition the specimen prior to test at 21 to 25°C (70 to 77°F) for not less than 24 h in accordance with Procedure A in ASTM D618 for those tests where conditioning is required, and unless otherwise specified.

8.2. *Conditions*—Conduct all tests at a laboratory temperature of 21 to 25°C (70 to 77°F) unless otherwise specified herein.

9. TEST METHODS

9.1. *Pipe Stiffness*—Select a minimum of two pipe specimens and test for pipe stiffness $F/\Delta y$, as described in ASTM D2412, except for the following conditions:

1. The length of the test specimen shall be a whole number of wraps, with a minimum length of four wrap widths or half the pipe diameter, whichever is greater.
2. Randomly orient each specimen in the loading machine.
3. Testing speed of the specimens shall be 12.5 mm/min (0.5 in./min) for testing up to 5 percent deflection. For flattening beyond 5 percent deflection (see Section 9.2), it is permissible to increase test speeds up to 125 mm/min (5 in./min).
4. The deflection indicator shall be readable and accurate to ±0.02 mm (0.001 in.).
5. The beginning point for deflection measurement shall be at a load of 20 ± 5 N (4.5 ± 1.1 lbf). The point shall be considered as the origin of the load deflection curve.

9.2. *Flattening*—Flatten the two pipe samples from Section 9.1 until the vertical inside diameter is reduced by 20 percent. The length of the test specimen and the rate of loading shall be the same as in Section 9.1. Examine the specimen with the unaided eye for cracking, splitting, or delamination. It is permissible for the ribs to lean during this test only to the extent that neither the above requirements nor the shape stability requirements (Section 7.8) are failed.

9.3. *Impact*—Test pipe specimens in accordance with ASTM D2444 except that six specimens shall be tested. Specimens shall be at least four wrap widths in length and impact points shall be at least 152 mm (6 in.) from the end of the specimen. Impact resistance shall not be less than 136 J. Tup B and a flat plate specimen holder shall be used. Condition the specimens for 24 h at a temperature of 0 ± 1°C (32 ± 2°F), and conduct all tests within 60 s of removal from this atmosphere.

9.4. *Tensile Strength of Seam*—Test in accordance with ASTM D638, with the following conditions:

1. The sample shall be prepared according to the dimensions for Type I specimens, with the weld seam arranged centrally and perpendicular to the tensile test axis.
2. All steel reinforcement shall be removed from the profile.
3. It is permissible to reduce the height of the HDPE ribs to no less than 2.5 mm (0.1 in.) if required to facilitate testing.

9.5. *Joint Integrity*—Assemble each fitting or coupling to the appropriate pipe in accordance with the manufacturer's recommendations. Use pipe samples at least 300 mm (12 in.) in length. Assemble a specimen at least 600 mm (24 in.) in length with the connection at the center. Load the connected pipe and fitting between parallel plates at the rate of 12.5 mm/min (0.5 in./min) until the vertical inside diameter is reduced by at least 20 percent of the nominal diameter of the pipe. Inspect for splitting, cracking, delamination, or other damage while at the specified deflection and after load removal.

9.6. *Slow-Crack-Growth Resistance of Resin Compounds*—Test basic resin compounds for stress-crack resistance in accordance with the ASTM F2136, the NCLS test, except for the following modifications:

9.6.1. The applied stress for the NCLS test shall be 4100 kPa (600 psi).

9.6.2. Resin test specimens shall be plaques molded from the reground resin from the rotomolded or injection-molded parts.

Note 4—The notched depth of 20 percent of the nominal thickness of the specimen is critical to this procedure.

9.7. *Delamination*—Test the fusion of the weld between the inner and outer wall of the wrap width with a probe or knife point. It shall not be possible to separate cleanly the two walls at the lap seam weld. Test samples at eight equally spaced points around its circumference.

9.8. *Dimensions*:

9.8.1. *Inside Diameter*—Measure the inside diameter of three specimens, each a minimum of 300 mm (12 in.) long with any suitable device accurate to 0.8 mm (0.03 in.), at two positions, namely, any point in the circumferential direction and 90 degrees from this point, and average the six measurements. Inside diameter shall meet the requirements of Section 7.4.1.

9.8.2. ~~*Waterway*~~ *Inner Wall*—Locate and measure the wall thickness between the ribs at four equally locations around the circumference of the pipe, in accordance with ASTM D2122.

9.8.3. *Length*—Measure pipe with any suitable device accurate to ±6.0 mm in 3 m (±0.25 in. in 10 ft). Make all measurements on the pipe while it is resting on a relatively flat surface, in a straight line,

with no external tensile or compressive forces exerted on the pipe. These measurements may be taken at ambient temperatures.

9.8.4. *Encapsulation Thickness*—Locate and measure the encapsulation thickness by cutting a cross section and measuring in accordance with ASTM D2122.

9.8.5. *Perforations*—Measure dimensions of perforations on a straight profile specimen with no external forces applied. Make linear measurements with instruments accurate to 0.2 mm (0.08 in.).

9.9. *Stub Compression Capacity*:

9.9.1. Determine the stub compression capacity of the pipe section in accordance with T 341. Conduct four tests on specimens cut from the same ring of pipe at 90-degree intervals around the circumference.

10. INSPECTION AND RETEST

10.1. *Inspection*—Inspection of the material shall be made as agreed on by the purchaser and the seller as part of the purchase contract.

10.2. *Retest and Rejection*—Retesting in the event of a test failure shall be conducted on samples from the failed lot only under an agreement between purchaser and seller. There shall be no changes to the test procedures or the requirements.

11. MARKING

11.1. *All pipe shall be clearly marked at intervals of no more than 3.5 m (11.5 ft) as follows*:

11.1.1. Manufacturer's name or trademark;

11.1.2. AASHTO M 335;

11.1.3. Nominal inside diameter;

11.1.4. The plant designation code; and

11.1.5. The date of manufacture or an appropriate production code. If a date code is used, a durable manufacturer sticker that identifies the actual date of manufacture shall be adhered to the inside of each length of pipe.

Note 5—A durable sticker is one that is substantial enough to remain in place and be legible through installation of the pipe.

11.2. Fittings shall be marked with the designation number of this specification, AASHTO M 335, and with the manufacturer's identification symbol.

12. QUALITY ASSURANCE

12.1. A manufacturer's certificate that the product was manufactured, tested, and supplied in accordance with this specification, together with a report of the test results and the date each test was completed shall be furnished on request. Each certification so furnished shall be signed by a person authorized by the manufacturer.

13. KEYWORDS

13.1. Crack; crease; delamination; gravity flow; polyethylene; pipe; steel reinforced.

APPENDIX

(Nonmandatory Information)

X1. QUALITY CONTROL/QUALITY ASSURANCE PROGRAM

X1.1. *Scope*:

X1.1.1. As required in Sections 10 and 12, the acceptance of these products relies on the adequate inspection and certification agreed to between the buyer and the seller/manufacturer. This appendix should serve as a guide for both the manufacturer and the user. It places the responsibility on the manufacturer to control the quality of the material they produce and to provide the quality control.

X1.2. *Program Requirements*:

X1.2.1. The manufacturing company must have a quality control plan approved by the specifying agency.

X1.2.2. The manufacturing plant must have an approved quality control plan.

X1.2.3. The plant must have an approved laboratory, either within the company or an independent laboratory.

X1.2.4. The manufacturing plant(s) must have a designated quality control technician.

X1.3. *Quality Control Plan*:

X1.3.1. The manufacturer must supply to the specifying agency a written quality control plan that shows how the producer will control the equipment, materials, and production methods to ensure that the specified products are supplied. The following information must be included in the plan:

X1.3.1.1. Titles of the personnel responsible for production quality at the plant(s).

X1.3.1.2. The physical location of the plant(s).

X1.3.1.3. The methods of identification of each lot of material during manufacturing, testing, storage, and shipment. The method of identification shall allow the specifying agency to trace the finished product to the material provider.

X1.3.1.4. The method of sampling and testing of raw materials and of finished product, including lot sizes and types of tests performed.

X1.3.1.5. A plan for dealing with nonconforming product, including how the manufacturer plans to initiate immediate investigation and how corrective action will be implemented to remedy the cause of the problem.

X1.4. *Approved Laboratory*:

X1.4.1. All tests must be conducted at laboratories approved by the specifier. Each manufacturer may establish and maintain its own laboratory for performance of quality control testing or may utilize an approved independent laboratory. Records of instrument calibration and maintenance and sample collection and analysis must be maintained at the laboratory.

X1.5. *Quality Control Technician*:

X1.5.1. All samples must be taken and tested by quality control technicians designated by the manufacturer. The designated quality control technicians will be responsible for overall Quality Control at the manufacturing plant.

X1.6. *Annual Update*:

X1.6.1. An annual update may be required. The annual update may be submitted by the manufacturer to the specifying agency by December 31st of each calendar year.

X1.7. *Plant Approval*:

X1.7.1. The plant approval process requires the manufacturer to submit an annual update to the specifying agency. The update must identify the specific product manufactured at the plant.

X1.7.2. The specifying agency will review the manufacturer's written quality control plan, and a plant inspection may be scheduled. This inspection will verify that the quality control plan has been implemented and is being followed and that at least one designated quality control technician is on-site and will be present when material is being produced under this program. The laboratory will be inspected and approved if it meets the requirements.

X1.8. *Sampling and Testing*:

X1.8.1. The quality assurance plan approved for each manufacturer, or manufacturer's location, or both, shall detail the methods and frequency of sampling and testing for all raw materials and products purchased or manufactured at that location. All testing shall be in accordance with current specifications and procedures referenced in M 335.

X1.8.2. Samples of materials and pipe may be taken by the specifying agency.

X1.8.3. The specifying agency may require an annual third-party independent assurance test.

X1.9. *Sample Identification and Record Keeping*:

X1.9.1. Manufacturer's quality control samples are to be uniquely identified by the producing plant.

X1.9.2. Quality control and quality assurance data are to be retained by the manufacturer for 2 years and made available to the specifying agency on request.

X1.9.3. Quality control test reports shall include the lot identification.

X1.9.4. Unless requested at the time of ordering, test reports do not have to be filed for specific projects.

X1.9.5. Reports shall indicate the action taken to resolve nonconforming product.

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[1] Formerly AASHTO Provisional Standard MP 20. First published as a full standard in 2018.

Industry updates regarding AASHTO M 294 revision incorporating Recycled Materials

COMP - Technical Subcommittee 4b

August 7, 2018

Research Overview

- **NCHRP Project 4-32 – *Performance of Corrugated Pipe Manufactured with Recycled Content***
  - $350,000 project, TRI was prime contractor
  - Completed in 2011 and published in **NCHRP Report 696**
- **NCHRP Project 4-39 – *Field Performance of Corrugated HDPE Pipes Manufactured with Recycled Materials***
  - $600,000 3-year project built on Project 4-32; TRI and Crossroads Engineering Services were Principal Investigators
  - Completed in 2016 and will be published in **NCHRP Report 870**
- ***Evaluation of Corrugated HDPE Pipes Manufactured with Recycled Materials in Commuter Railroad Applications***
  - PhD Dissertation, published by Michael Pluimer, PhD in 2016

NCHRP
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

TRI ENVIRONMENTAL, INC.

CROSSROADS ENGINEERING SERVICES

Research Background

- Evaluated **28 different recycled resins** (25 PCR, 3 PIR), **75 different blends** of virgin and recycled materials, and **24 full-scale pipes** (4 different manufacturers) manufactured with various blends of recycled materials
- Service life model validated on 9 full-scale pipes containing a range of recycled material blends
- Over 1000 different tests conducted
- 11 years of research (contract started in Feb. 2006), project budget of $950,000 ($350K for NCHRP 4-32, $600K for NCHRP 4-39)

Background - Past Research

- Both post-consumer (PCR) and post-industrial (PIR) recycled materials evaluated, but focus on post-consumer
- Included both field and lab testing, as well as the development and validation of a service life prediction model

Overview of Recycled Materials for Corrugated HDPE Pipe

- Post-consumer recycled (PCR) PE materials
  - PE materials from products that have served a previous consumer purpose
  - Flake or reprocessed pellets
  - More readily available than PIR materials and more consistent in performance, though may have lower stress crack resistance
  - Approx. 5.5 billion pounds of these materials in agricultural and land drainage pipes over past 20 years!

Overview of M 294 Changes

First true performance-based specification for plastic pipes

- Pipes can be manufactured with either virgin or recycled (PCR and/or PIR)
- All finished product performance requirements remain unchanged – pipe stiffness, flattening, brittleness, NCLS, stub compression, etc.
- All material performance requirements equal to or greater than current standard – same 435400 cell classification (density, MI, tensile strength, flexural modulus), same NCLS (24 hours for plaque; 18 for liner), same carbon black (2 – 4%)
- Pipes manufactured with recycled materials have additional requirements: UCLS test, 150% elongation at break, and 20 minute OIT

Note: None of the pipes made with recycled materials and evaluated in NCHRP 4-39 met the final requirements specified in the standard

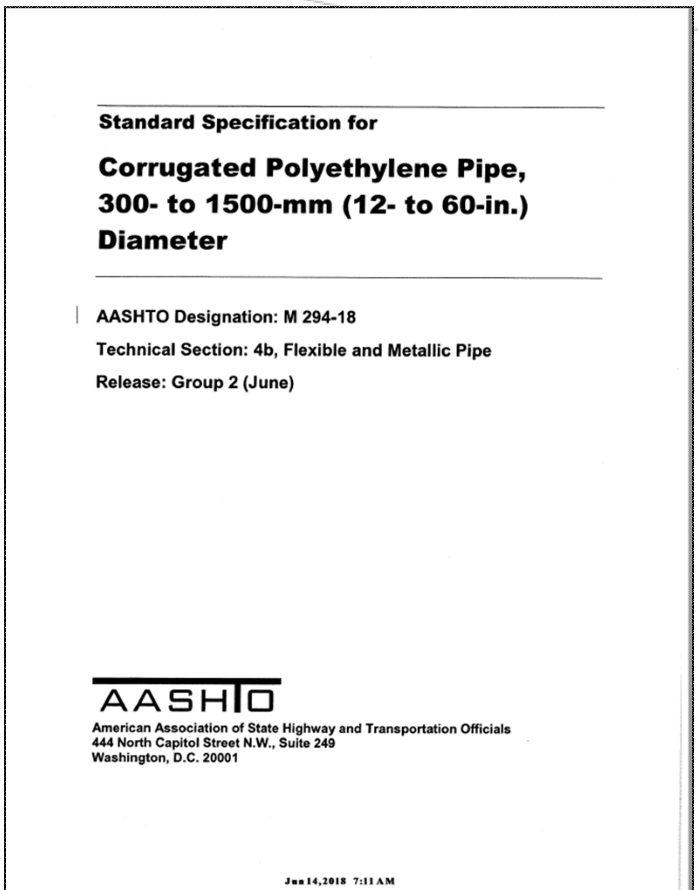
NCHRP Report 870 Validated Service Life Prediction Method

- Every pipe that was predicted to crack developed cracks within the predicted timeframe, both for the parallel plate test and the simulated field test
- None of the pipes that were not predicted to crack developed cracks
- The UCLS test provides the basis for a true performance-based specification for pipes manufactured with recycled materials
- The percent recycled content isn't as important as the final blend properties
  - NCLS, UCLS & OIT test properties that govern service life

ASTM F17 Standards

- Revision ASTM F2306 - change incorporating recycled resins in final phase of process
- New ASTM F3308 - “Standard Practice for Determining Sampling and Testing Frequency for Recycled Materials in Polyethylene Pipe for Non-Pressure Applications”

AASHTO M294 Revisions



Standard Specification for

Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

AASHTO Designation: M 294-18

Technical Section: 4b, Flexible and Metallic Pipe

Release: Group 2 (June)

AASHTO

American Association of State Highway and Transportation Officials
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Jun 14,2018 7:11 AM

- ***<u>All material properties and performance expectations specified in M294 are identical for pipe made with virgin or recycled resins</u>***
  - pipe stiffness
  - impact strength
  - flattening
  - stub compression
  - dimensions
  - workmanship
  - same cell classification 435400C
  - same NCLS criteria

Additional requirements for M294 Pipe made with Recycled Resins

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Corrugated Polyethylene Pipe, 300- to 1500-mm (12- to 60-in.) Diameter

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- ***Pipes manufactured with recycled materials must also meet the following criteria***:
  - Average UCLS failure time must exceed a minimum calculated value to ensure that service life exceeds 100 years
  - Minimum OIT of 20 minutes (ensures resistance to Stage III chemical failure)
  - Elongation at break must exceed 150% (redundant contaminant test)
- ***None of the test pipes made with recycled materials and evaluated in NCHRP 4-39 met the final requirements specified in the standard***

M294 Revision Implementation

- Published by AASHTO June 13, 2018
- No guidance for implementation or “grandfathering”
  - No pipe marked M294R prior to 6/13/18
  - Pipe marked M294 (only) is made with virgin only if manufactured prior to 6/13/18
  - State-by-state implementation is assumed
- NTPEP – setting implementation of August 1, 2018
  - Pipe produced after 8/1 must either be marked M294V or M294R
  - Pipe produced between 6/13/18 and 8/1/18:
    - Either M294 or M294V (for virgin only).
    - Pipe produced with recycled resin content must be marked M294R and “contains recycled resins”

NTPEP Audits for M294 Pipe Production

AASHTO's National Transportation Product Evaluation Program

Section 3: Standard Specifications

Auditor Note - Indicate if current versions of the following AASHTO & ASTM standards are available at the plant.		
	AASHTO	ASTM
Specification for Corrugated Polyethylene Drainage Pipe	M 252-09 ☒	
Specification for Corrugated Polyethylene Pipe, 300- to 1500-mm Diameter	M 294-10 ☒	
Test Method for Tensile Properties of Plastics		D 638-10 ☒
Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials		D 790-10 ☒
Test Method for Melt Flow Rates of Thermoplastics by Extrusion Plastometer		D 1238-10 ☒
Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement OR Test Method for Density of Plastics by the Density-Gradient Technique		D 792-08 ☒ D 1505-10 ☒
Standard Test Method for Determination of Carbon Black Content in Polyethlyene Compounds By the Muffle Furnace Technique		D 4218-96 (08) ☒
Test Method for Determining Dimensions of Thermoplastic Pipe and Fittings		D 2122-98 (10) ☒
Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading		D 2412-11 ☒
Test Method for Determination of Impact Resistance of Thermoplastic Pipe and Fittings by Means of a TUP (Falling Weight)		D 2444-99 (10) ☒
Specification for Polyethylene Plastics Pipe and Fittings Materials		D 3350-10a ☒
Test Method for Notched, Constant Ligament-Stress (NCLS) Test to Determine Slow-Crack-Growth Resistance of HDPE Resins or HDPE Corrugated Pipe		F 2136-08 ☒
Comments:	**The plant had current versions of all applicable AASHTO and ASTM standards. These standards were located and accessed through the corporate Share Point System.**	

Key proposed changes to HDPE Work Plan

Finished Product Material Testing - One finished product sample shall be collected for every 45,000lb [20,412 kg] of product produced or every 24 hours, or whenever the material blend ratios are changed by more than 5% or the blend constituents are changed, whichever comes first. Material samples from the finished product shall be tested for the properties in Table 4.

Table 4: Test Requirements for Finished Product Containing Recycled HDPE

Test Property	Test Designation
Density	ASTM D4883
Melt Index	ASTM D1238
Un-notched Constant Ligament Stress (UCLS)	ASTM F3181
Oxidation Induction Time (OIT)	ASTM D3895
*Notched Constant Ligament-Stress (NCLS)	ASTM F2136
Break Strain	ASTM D638

Proposed Revisions to the Work Plan for HDPE Pipe Audits is under review

- Task Group completed proposed revisions
- Revised Work Plan issued for ballot August 3, 2018
- Expect opportunity for first audits of plants producing HDPE pipe made with recycled resins in September

AASHTO's
National Transportation
Product Evaluation
Program

Industry Implementation of NTPEP HDPE Work Plan Revisions

If plant audit scheduled to occur in late 2018:

- Manufacturer can request to add audit of HDPE made with recycled resins

If plant audit has already occurred for 2018:

- Manufacturer can request for an additional audit to be scheduled later in 2018, for an additional fee

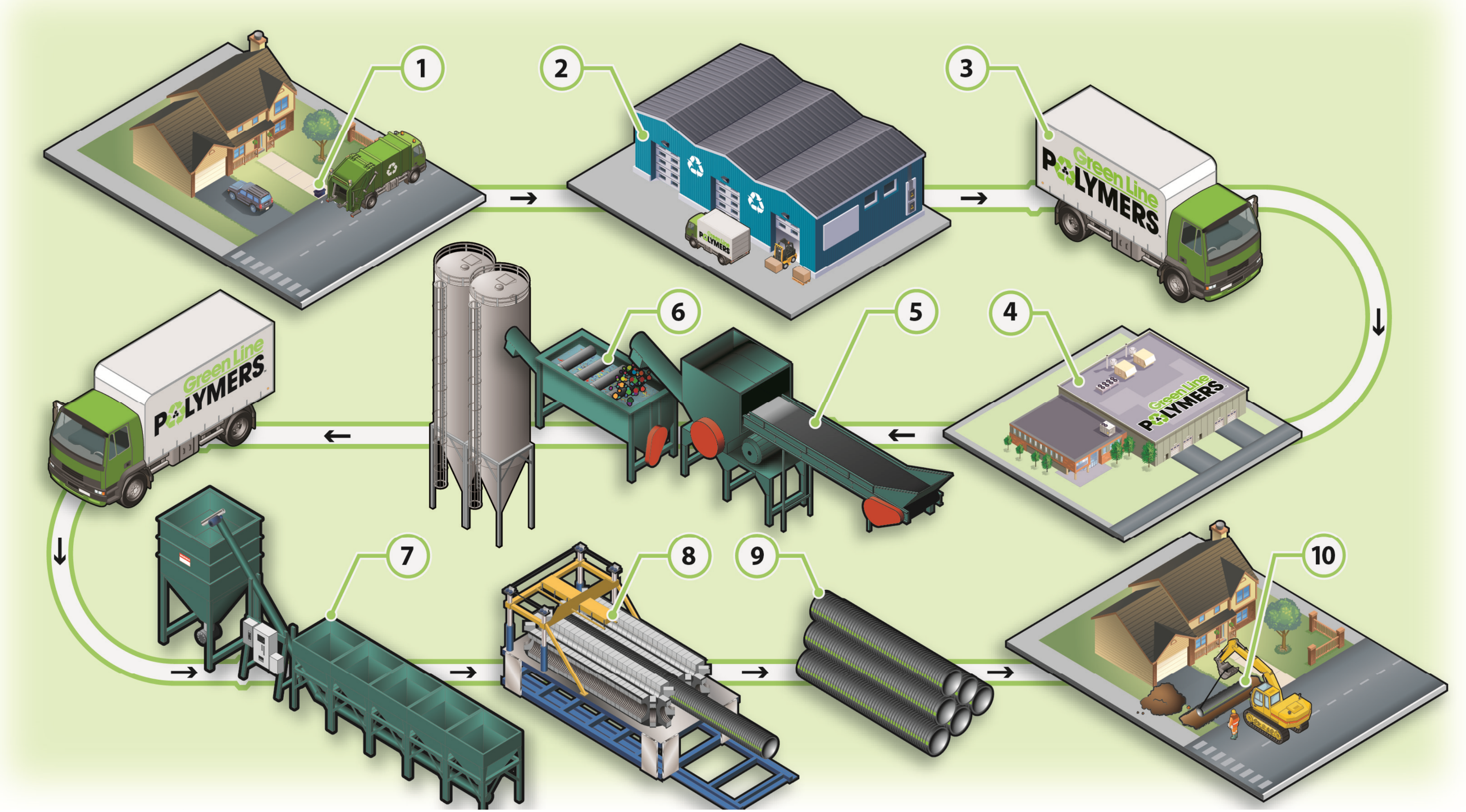
Some manufacturers may wait choosing to schedule audits for HDPE with recycled resins in 2019

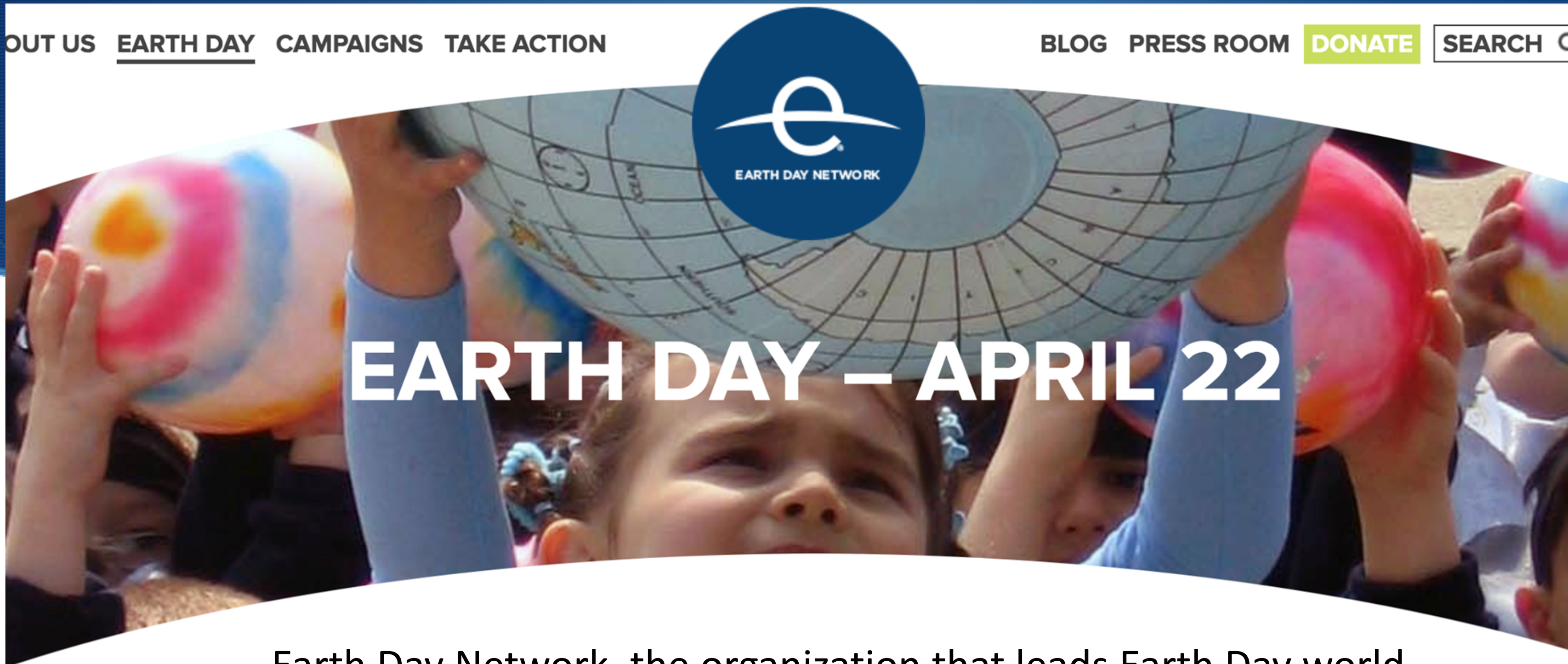
Some manufacturers may wait to see if enough DOT interest in their area to justify NTPEP audit and inventorying 2 M294 products

Summary & Conclusions

- The research resulted in the development of the first true performance-based specification for plastic pipes
- If recycled materials are used, the final blend must meet the current cell class and NCLS requirements; In addition, it must meet minimum UCLS, OIT and break strain requirements, and the pipe must be properly marked
- The incorporation of recycled materials into M 294 offers both economic and environmental benefits to state DOT’s, and the proposed requirements will ensure these pipes have a service life equal to or greater than pipes manufactured with virgin materials

Plastic Recycling Opportunity





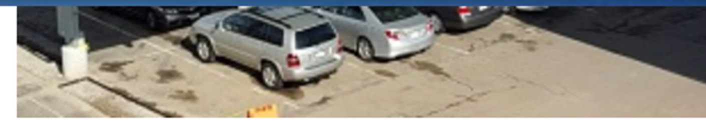
Earth Day Network, the organization that leads Earth Day world-wide, has chosen as the theme for 2018 to End Plastic Pollution

EDN has built a multi-year campaign to End Plastic Pollution. Our goals include ending single-use plastics, promoting alternatives to fossil fuel-based materials, promoting 100 percent recycling of plastics, corporate and government accountability and changing human behavior concerning plastics.

Plastic Waste Changes & Data
University of Georgia Study - Jenna Jambeck

- China has stopped importing nearly half of the worlds' plastic waste as of January 2018 (mainly from wealthiest nations)
- Approximately 72% of the world's plastic waste went to China & Hong Kong since 1992 w/HK passing on 63% to China.
- Waste management facilities are struggling to process the excess waste. Some states are now allowing recyclable materials into landfills
- 2016: California exported 500K tons of low grade plastic to China
- An estimated 111 million metric tons could pile up by 2030

Our Sustainability Efforts



DOT will incorporate sustainability principles into our policies, operations, investments and research through innovative initiatives and actions such as:

- Infrastructure investments and other grant programs,
- Innovative financial tools and credit programs,
- Rule- and policy- making,
- Research, technology development and application,
- Public information, and
- Enforcement and monitoring

DOT has incorporated sustainable practices into the Department's mission and operations. DOT will continue to pursue opportunities for the national transportation system which:

- Promote energy and natural resource conservation,
- Decrease emissions of greenhouse gases (GHGs) and other pollutants,
- Enhance our operations by minimizing use of hazardous materials and chemicals,
- Advance our national interest in increasing energy efficiency,
- Reduce our dependence on fossil fuels,
- Ensure transportation infrastructure resiliency and
- Build livable communities.

Buy Clean California Act

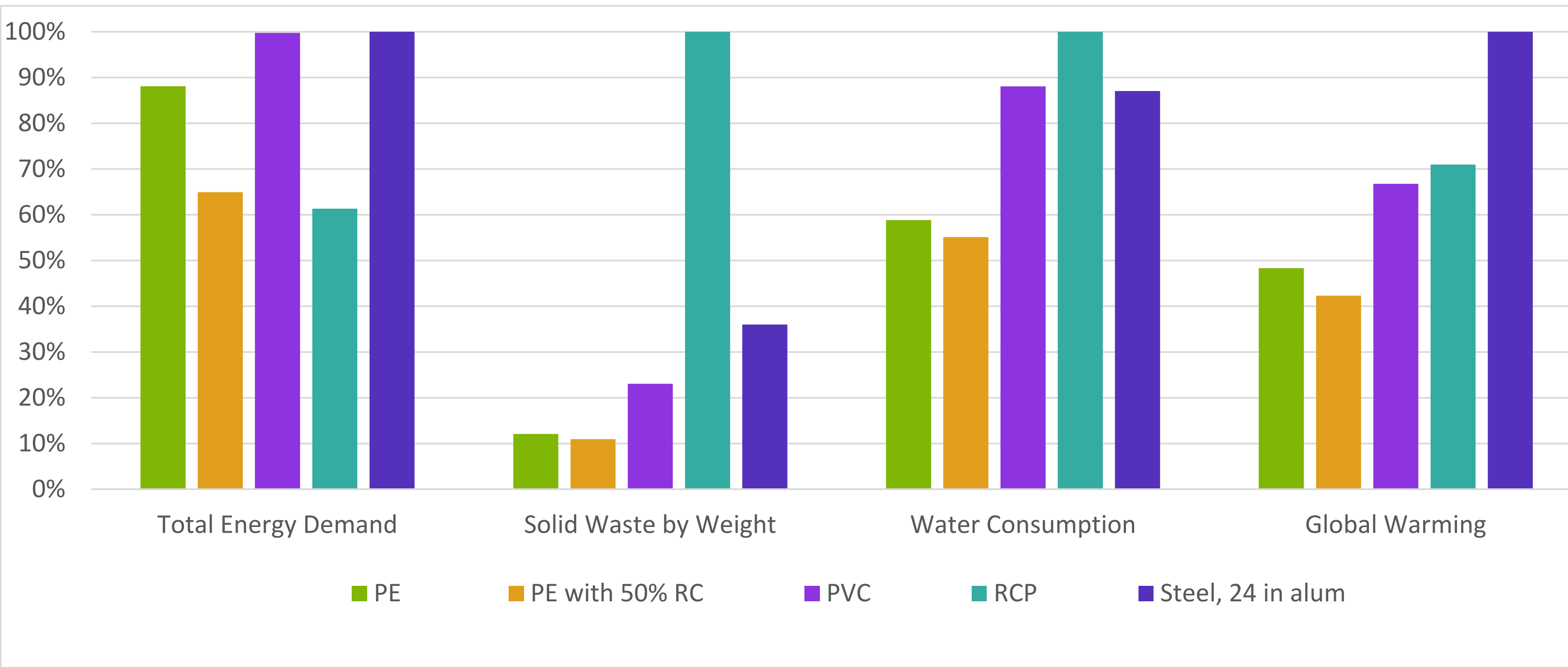
Executive Order B-30-15 issued by Governor Brown stipulates that “State agencies shall take climate change into account in their planning and investment decisions and employ full life-cycle cost accounting to evaluate and compare infrastructure investments and alternatives.”

BCCA 3504. In carrying out its duties under this article, an awarding authority shall strive to achieve a continuous reduction of emissions over time.

Preliminary LCA Data

(to be presented at Plastic Pipe XIX – September 2018)

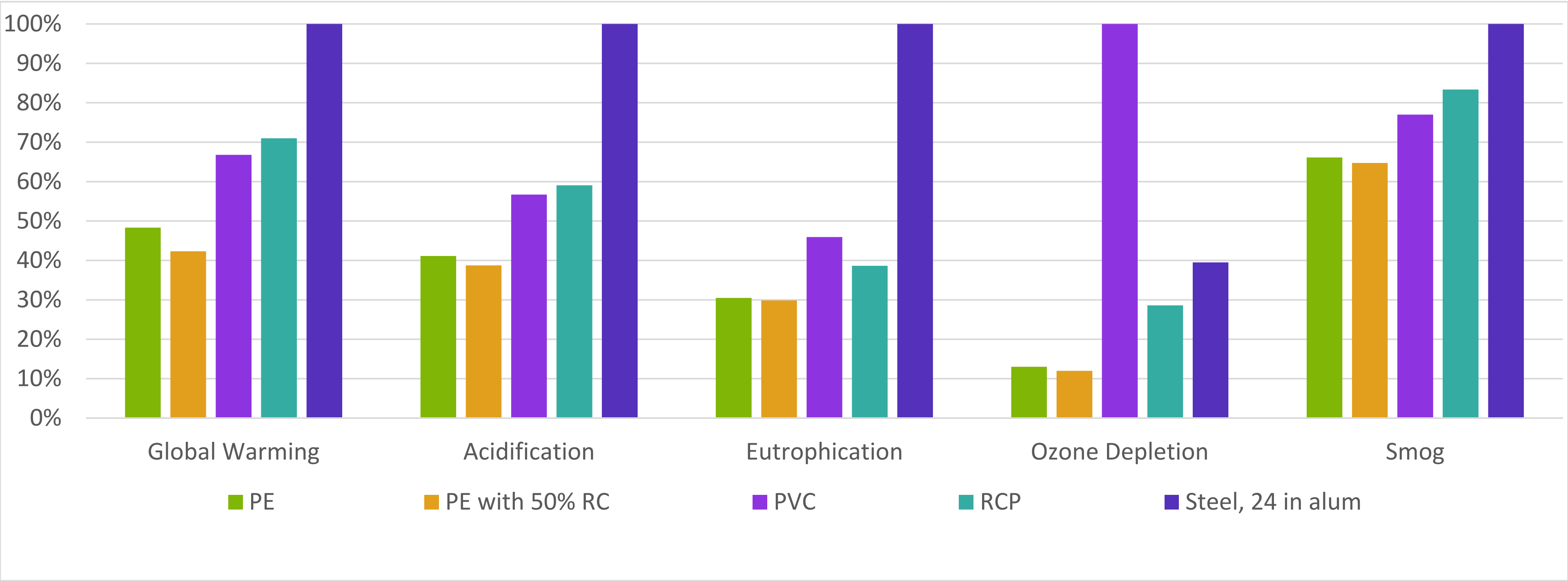
Indexed comparison of key LCA Categories by Pipe Type



Preliminary LCA Data

(to be presented at Plastic Pipe XIX – September 2018)

Indexed comparison of LCA Emissions Categories by Pipe Type



Questions?

Standard Assignments

TECHNICAL SECTION 4B, FLEXIBLE AND METALLIC PIPE		
Group No.	**Standard No.**	**Volunteer Name**
1	M 36	Washington, Michigan
	M 218	New York, Pennsylvania
	T 241	Missouri, Louisiana
2	M 196	Kansas, AASHTO
	M 197	Florida, Tennessee
	T 249	Missouri, Georgia
3	M 252	Alabama, Delaware
	M 294	Virginia, North Carolina
4	M 264	Maine, New York
	M278	Connecticut, Washington
	M304	Maine, Tennessee
5	M190	Michigan, Pennsylvania
	M 245	Florida, Illinois
	M 246	Connecticut, Louisiana
6	M 274	Ontario, Maine
	M 289	Louisiana, Pennsylvania
7	M 167	Georgia, Alabama
	M 219	Washington, Tennessee
	M 243	New York, Maine
8	M 326	Delaware, Virginia
	M 330	Florida, Missouri
	M 335	Michigan, North Carolina
	R 82	Virginia, Alabama
	R63	Louisiana, Tennessee
	T 341	South Carolina, Kansas