API Ballot id# 6128
SC5 TGOCTG

Work Item	2455—Review of Annex I Geometry Measurement Methods
Type of Distribution [Ballot (vote and comment), Comment-only, Recirculation (comment resolution), Re-ballot, etc.]	Ballot (comment and vote)
Impacted Standard	5C3, 7th Edition
Other Impacts	None
Revision Key	Current/unchanged content in BLACK; Track Changes as: 1) Additions in underlined-BLUE 2) Deletions in stricken-~~RED~~ NOTE The "******" indicates there is un-altered content above / below.

Work Item Charge: To update 5C3 Annex I to allow alternative geometry measurement methods and make appropriate language changes to support 5C3 transition from Technical Report to Recommended Practice and ensure consistency with Work Item 2443. Assessing the impact of measuring alternative methods on the calculated pipe performance should be avoided.

Ballot Rationale: Implementation of changes as discussed and validated with the WG.

NOTE See the ballot email notification for additional information regarding this ballot.

Calculating Performance Properties of Pipe Used as Casing or Tubing

API TECHNICAL REPORT 5C3
SEVENTH EDITION, JUNE 2018

ADDENDUM 1, OCTOBER 2019

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2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM E1928, *Standard Practice for Estimating the Approximate Residual Circumferential Stress in Straight Thin-walled Tubing*

~~This document contains no normative references.~~ For a list of documents and articles associated with API 5C3, see Bibliography.

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3 Terms, Definitions, Symbols, and Abbreviations

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3.2 Symbols

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t_{eff} effective thickness according to ASTM E1928

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Annex I
(~~informative~~normative)

Collapse Test Procedure

I.1 Introduction

~~To be acceptable for API/ISO use, c~~Collapse tests ~~should~~shall be conducted as described below.

Unless otherwise agreed, collapse tests shall be conducted to failure.

I.2 Test Specimen

The minimum length of the collapse test specimen, submitted to pressure, ~~should~~shall be ~~as follows:~~ eight times the specified diameter (*D*). For sizes greater than 9-5/8 in., seven times the specified diameter (*D*) may be used if limited by test apparatus.

~~— eight times the specified diameter (*D*) for specified diameters of 9-5/8 in. and below;~~

~~— seven times the specified diameter (*D*) for specified diameters greater than 9-5/8 in.~~

In addition to the length of the collapse test specimen, additional ~~material~~adjacent samples should be allocated for the residual stress and tensile test specimens (see Figure I.1).

I.3 Test Apparatus

The test apparatus ~~should~~shall apply the test pressure to the full specimen length as defined in I.2. It ~~should~~shall not impose radial or axial restraints on the specimen, either mechanically or hydraulically, and ~~should~~shall not apply pressure to the inside surface of the specimen. ~~For combined collapse and axial load tests, the apparatus should maintain the axial load within ±1 % of the target value during application of external pressure.~~

The test chamber ~~should~~shall be equipped with a maximum reading pressure-measuring device that is open to the test chamber during the test. The device ~~should~~shall be certified ~~by the manufacturer~~ to be accurate within 0.5 % of the full-scale reading.

The pressure-measuring device should be equipped with a damping system to bleed pressure slowly upon specimen collapse. The device should be calibrated at six monthly intervals or more frequently if there is reason to doubt its accuracy. The error within its working range ~~should~~shall not exceed 1 %.

In case of combined loadings i.e., combined collapse and axial load tests, axial restraint is acceptable, and the apparatus should maintain the axial load within ±1 % of the target value during application of external pressure.

I.4 Measurements prior to Collapse Testing

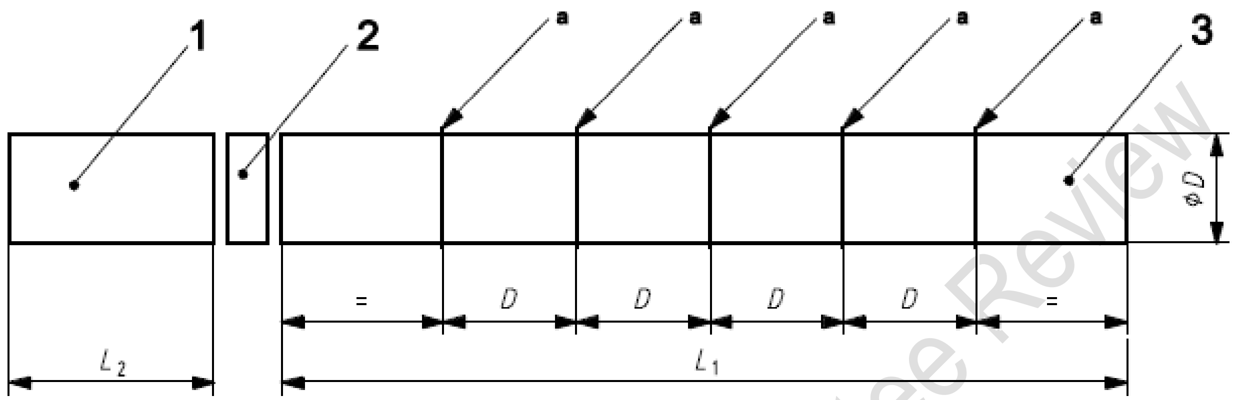
I.4.1 General

Pipe geometry~~, yield stress, and residual stress should~~ shall be ~~accurately~~ measured prior to collapse testing, as described below. Unless otherwise agreed yield stress, and residual stress shall be measured from adjacent samples described in I.2.

I.4.2 Pipe Geometry

I.4.2.1 General

Average outside diameter, average wall thickness, ovality, and eccentricity ~~should~~shall be ~~measured at five equally spaced locations, as shown in Figure I.1. Measurements and calculations for each location should be~~determined as described in I.4.2.2 to I.4.2.5.



Key

1 residual stress test specimen

2 tensile test specimen

3 collapse test specimen

D specified outside diameter

L_1 minimum length of collapse test specimen

L_2 minimum length of residual stress test specimen

[a] five equally spaced locations at which average outside diameter, average wall thickness, and ovality are measured, and eccentricity is calculated from wall thickness measurements

Figure I.1—Measurements prior to Collapse Testing

I.4.2.2 Average Outside Diameter

Average outside diameter ~~should~~shall be measured with a pi tape at five equally spaced locations, as shown in Figure I.1.

Alternative measurement means may be used provided that the measurement resolution along the sample axis is equal to or greater than the one described in Figure I.1. If measurement data from the full pipe length is used, the traceability of the measurements and sample position relative to the full pipe length shall be recorded.

I.4.2.3 Average Wall Thickness

Thicknesses shall be measured and recorded to a minimum accuracy of 0.1 mm.

Wall thickness ~~should~~shall be measured at eight equally spaced positions (that is, at 45° intervals) for the five equally spaced locations, as shown in Figure I.1, and the average ~~taken~~calculated. ~~Thicknesses should be measured and recorded to a minimum accuracy of 0.1 mm.~~

Alternative measurement means may be used provided that the measurement resolution along the sample axis is equal to or greater than the one described in Figure I.1. If measurement data from the full pipe length is used, the traceability of the measurements and sample position relative to the full pipe length shall be recorded.

I.4.2.4 Ovality

Ovality ~~should~~shall be ~~measured~~determined at five equally spaced locations, as shown in Figure I.1, with ~~an API~~a pipe ovality gauge or equivalent. Readings ~~should~~~~shall~~ be taken over the entire circumference;~~ all circumferential positions:~~ measurements at equally spaced intervals (e.g. 45°) are not acceptable. Ovality ~~should~~ at each location is defined, in percent, ~~be calculated~~ as 100 (D_{max} – D_{min})/D_{ave}, where D_{ave} is the average outside diameter from I.4.2.2.

Alternative measurement means may be used provided that the measurement resolution along the sample axis is equal to or greater than the one described in Figure I.1. If measurement data from the full pipe length is used, the traceability of the measurements and sample position relative to the full pipe length shall be recorded.

I.4.2.5 Eccentricity

Eccentricity in percent ~~should~~shall be calculated at five equally spaced locations, as shown in Figure I.1, as 100 ($t_{c\ max}$ – $t_{c\ min}$)/$t_{c\ ave}$, where $t_{c\ max}$ and $t_{c\ min}$ are, respectively, the maximum and minimum wall thicknesses ~~from the eight circumferential measurements~~ of I.4.2.3, and $t_{c\ ave}$ is the average wall thickness.

I.4.3 Yield Stress

Unless otherwise agreed, a tensile test ~~should~~shall be conducted for each collapse test sample~~. The~~, the tensile specimen ~~should~~shall be taken from pipe adjacent to the end of the collapse test specimen, as shown in Figure I.1. Tensile testing ~~should~~shall be in accordance with API 5CT or ISO 11960.

If the pipe is flame-cut to obtain material for a tensile test specimen, the specimen ~~should~~shall not be prepared from areas including the heat-affected zone.

I.4.4 Residual Stress

I.4.4.1 Measurement and Calculation

~~Residual~~Unless otherwise agreed, residual stress ~~should~~~~shall~~ be measured for each collapse test sample, using the split ring method. ~~The~~Testing procedure shall be in accordance with ASTM E1928, except as stated herein. Unless otherwise agreed the ring should be taken from pipe adjacent to the end of the collapse test specimen, as shown in Figure I.1. Sample lengths of at least twice the specified outside diameter ~~are required in order to accurately~~ ($L/D \geq 2$) shall be used to measure residual stress [94]. ~~shorter samples give lower predicted residual stresses. Accordingly, two alternative approaches may be used, namely:~~

~~full length ($L/D \geq 2$) specimens;~~

~~shorter specimens ($2 > L/D \geq 0.5$), with the apparent residual stress corrected using a product-specific calibration curve for the effect of sample length. I.4.4.2 gives instructions for the preparation and use of such curves.~~

~~The calibration curve may be used for all subsequent collapse tests for the given manufacturing process. If any relevant part of the process changes (tempering temperature, straightening method, and so forth), testing should be repeated and the curve recalculated.~~

~~Testing should be in accordance with ASTM E1928 [4], except as noted above.~~ Residual stress, σ_{res}, ~~is~~shall be calculated as follows:

$$\sigma_{res} = E\cancel{t_{c\ ave}}\,t_{eff}\,(1/D_{ac} - 1/D_{bc})/(1 - \nu^2) \quad (I.1)$$

where

D_{ac} is the average outside diameter after cutting;

D_{bc} is the average outside diameter before cutting;

E is Young's modulus, 206.9 × 10^9 N/m^2 (30 × 10^6 psi);

~~$t_{c\ ave}$ is the average actual wall thickness;~~

t_{eff} is the effective thickness of the residual stress specimen according to ASTM E1928;

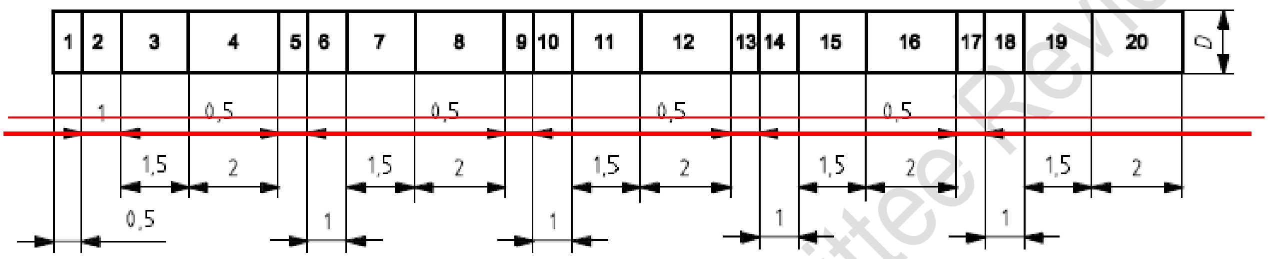
ν is Poisson's ratio, 0.28.

This results in a negative residual stress if the pipe springs open, and a positive stress if it springs shut. This is consistent with the sign convention used in Annex F (compression at ID face is negative).

~~I.4.4.2 Correction for Specimen Length~~

~~I.4.4.2.1 General~~

~~Correction curves should be based on test results for a total of twenty specimens of lengths from 0.5*D* to 2.0*D*. The slit ring method should be used, and residual stress should be calculated as described in I.4.4.1. The specimen lengths and cutting sequence should be as shown in Figure I.2. All specimens should be cut from a single pipe, as residual stress is approximately constant along each pipe but varies between pipes.~~



~~**Key**~~

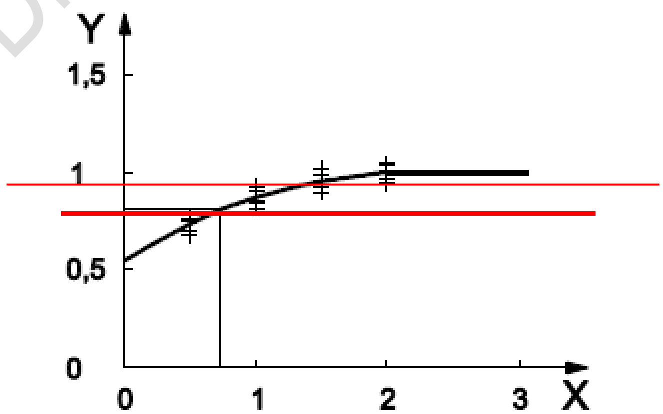
~~*L* length of test specimen~~ ~~*D* outside diameter~~ ~~1 to 20 order of cutting specimens~~

~~**Figure I.2—Order of Cutting Specimens from Test Pipe**~~

~~The mean apparent residual stress should be calculated for each *L*/*D* and divided by the mean residual stress for *L*/*D* = 2 to determine predicted/actual stress versus specimen length, a plot of which is the correction curve. The line can be assumed to become horizontal at *L*/*D* = 2. Figure I.3 gives an example of curve preparation. Separate curves should be prepared for each grade and heat treatment type (e.g. normalized N80 and quenched and tempered N80 are separate cases).~~

~~I.4.4.2.2 Example of Use~~

~~A slit ring specimen of length 0.75*D* gives an apparent residual stress of −23.56 ksi. Reference to a correction curve previously prepared for the relevant grade and heat treatment (Figure I.3) gives a correction factor of 0.804. The actual residual stress is therefore −23.56/0.804 = −29.3 ksi. Figure I.3 is for illustration only, and should not be used for any other purpose.~~



~~**Key**~~

~~X specimen length/outside diameter~~

~~Y predicted residual stress/actual residual stress~~

~~For a given grade and heat treatment, slit ring testing of a single pipe gives predicted residual stresses as follows:~~

	~~*L/D*~~			
	~~**0.5**~~	~~**1.0**~~	~~**1.5**~~	~~**2.0**~~
~~Predicted residual stress~~	~~–27.60~~ ~~–27.97~~ ~~–24.66~~ ~~–25.76~~ ~~–28.70~~	~~–31.28~~ ~~–33.49~~ ~~–34.22~~ ~~–30.91~~ ~~–29.81~~	~~–36.43~~ ~~–37.54~~ ~~–35.14~~ ~~–34.22~~ ~~–33.12~~	~~–37.35~~ ~~–38.64~~ ~~–35.33~~ ~~–34.78~~ ~~–37.90~~
~~Mean~~	~~–26.94~~	~~–31.94~~	~~–35.29~~	~~–36.80~~
~~Predicted/ actual stress~~	~~–26.94/ –36.80~~	~~–31.94/ –36.80~~	~~–35.29/ –36.80~~	~~–36.80/ –36.80~~
~~Ratio~~	~~0.732~~	~~0.868~~	~~0.959~~	~~1~~

~~**Figure I.3—Example of Preparation of Residual Stress Correction Curve**~~

I.5 Test Procedure

The exterior surface of the specimen ~~should~~shall be hydraulically loaded at a rate sufficiently slow as to permit reading of the ~~collapse~~ pressure within the specified accuracy. Tests may be conducted either with or without axial stress. If the former, the axial load ~~should~~shall be applied first~~,~~ and held constant during pressure loading.

I.6 Data Reporting

The information provided in Table I.1. shall be reported, unless otherwise agreed. Data include all results from I.4.2 to I.4.4 and test result. In the event that a specimen did not collapse, the maximum pressure reached during testing shall be reported and denoted as “Proof” by opposition to “Collapse”.

~~The data reported should be as shown in Table I.1. The~~For I.4.2 results, the pipe geometry properties (average outside diameter, average wall thickness, ovality, and eccentricity) ~~should~~shall be the average of the values ~~for~~of, determined according to I.4.2.2 to I.4.2.5, the five circumference locations taken over 4 times the specified diameter. Data should be provided in electronic format~~ if at all possible~~.

Table I.1—Format for Reporting Collapse Test Data

Nominal OD in.	Nominal Weight lb/ft	Grade	Nominal Wall Thickness in.	Forming Process [a]	Heat Treat-ment [b]	Yield Stress ksi	Average OD [c] in.	Ovality [c, d] %	Average Wall Thickness [a] in.	Eccent-ricity [c, e] %	Straight-ening [f]	Residual Stress [g] ksi	L/D [h]	Axial Stress [i] ksi	Collapse Pressure ksi	Test Result [j]
7.000	26.0	P110	0.362	SR	QT	117.9	7.047	0.085	0.364	12.4	CG	–27.9	11.2	12.1	8.17	Collapse
7.000	26.0	P110	0.362	SR	QT	120.6	7.044	0.241	0.366	6.8	CG	–25.6	11.2	11.4	7.74	Proof
7.000	26.0	P110	0.362	SR	QT	118.2	7.046	0.185	0.363	9.0	CG	–28.1	11.2	0	7.57	Proof
7.000	26.0	P110	0.362	SR	QT	115.1	7.046	0.170	0.366	22.5	CG	–24.2	11.2	0	7.65	Collapse
7.000	26.0	P110	0.362	SR	QT	113.4	7.043	0.071	0.363	9.9	CG	–34.7	11.2	0	8.31	Proof

NOTE Data may be entered in metric units if desired.

a Forming process:

—SP = seamless, pilger mill; SM = seamless, plug mill; SR = seamless, retained or floating mandrel mill; SS = seamless, stretch reduced; SE = seamless, hot expanded.

—WE = welded, electric weld; WL = welded, laser weld; WS = welded, submerged arc weld.

b Type of heat treatment/cold working:

—AR = as rolled; CR = control rolled; NR = normalized; NT = normalized and tempered; QT = quenched and tempered; CP = cold worked, pilgered; CD = cold worked, drawn.

c Average of values for the circumferences.

d Ovality = 100 (maximum OD – minimum OD)/average OD.

e Eccentricity = 100 (maximum WT – minimum WT)/average WT.

f Type of straightening:

—NS = not straightened; CG = cold gag straightened; CX = cold cross-rolled straightened; CS = cold straightened and stress-relieved; HR = hot rotary straightened.

g Compression at ID face is negative. Hence enter residual stress as negative if the pipe springs open after cutting, and positive if it springs shut.

h L = specimen length; D = nominal diameter.

i Tension is positive.

j Test result: Proof = specimen did not collapse; Collapse = specimen collapsed.

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Bibliography

General

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~~[4] ASTM E1928-99, *Standard Practice for Estimating the Approximate Residual Circumferential Stress in Straight Thin-walled Tubing*, 1999~~

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API Note: The figures and bibliography references will be renumbered accordingly upon publication.