

Relating bending stiffness measurements across various free span lengths

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ABSTRACT: Bending stiffness should be an intrinsic property of a material, so it is puzzling that the TAPPI Standard Test Method T 836 “Bending stiffness, four point method” specifies span lengths when testing different types of corrugated fiberboard. These specified spans often limit the samples that can be measured with this method. To better understand the relationship between bending stiffness and span length, we performed measurements on a range of materials at different spans. The results provide a practical tool enabling comparison of bending stiffness measurements made at various span lengths. Additionally, this note discusses several areas that could serve as the foundation for more fundamental work exploring the bending behavior of corrugated board.

The compression strength of a corrugated box determines its success in many applications [1]. Box users often focus on the inherent material strength of the combined board, its edge crush test (ECT), but this is just one of the important parameters governing box strength that we understand from the basic mechanics of the failure modes. Another is the bending stiffness or bending resistance of the combined board [2-5]. Typically, boxes fail because one or more of the side panels bulge outward, allowing the box to collapse. The McKee equation [6] for estimation of a box's compressive strength incorporates the root mean square (RMS) bending in the calculation of estimated compression strength to account for the pinning of the panel at the scores forcing panel bending in both directions. Other models use similar forms [7].

Box panel stiffness comes from the fundamental physics of the panel itself. It increases when the liners are heavier and when the board is thicker, putting the masses of the liners farther from the center of the board. Well-formed flutes also significantly contribute; the medium has a critical function both through the structural rigidity of the fluted shape and through its role in maintaining caliber [8]. Crushing of combined corrugated board during the process of making a box can have a significant negative impact on the bending stiffness due to

damage of the flute structure and the related, but separate, reduction in board thickness.

Multiple methods exist to measure the bending stiffness of a material, but many are not suitable for corrugated board. The industry has settled on four-point methods to best assess the effective bending resistance of corrugated materials [3, 9-10]. The advantage of the four-point approach is that flexural stresses, but not shear stresses, act over the central span, and so deflection of the center of the sample can be attributable to pure flexural stiffness.

The initial TAPPI Standard Test Method for measuring flexural stiffness of corrugated board (TAPPI T 820 “Flexural stiffness of corrugated board”) was adopted in 1979 and followed this four-point approach. With an inner support assembly adjustable from 1–12 in. (2.5–30.5 cm) and an outer loading assembly adjustable from 4–18 in. (10.2–45.7 cm), the approach could be used to measure sample specimens greater than about 6 in. (15.2 cm) in length. However, multiple measurements at different loading levels needed to be made to assess the bending stiffness value, with measurements accomplished in a short time span to avoid having board creep due to the loading impact of the stiffness values measured. Additionally, there was concern that the small radius of the support at the loading points may deform or

damage the board. This method, without a precision statement, was redefined as classical in 1985.

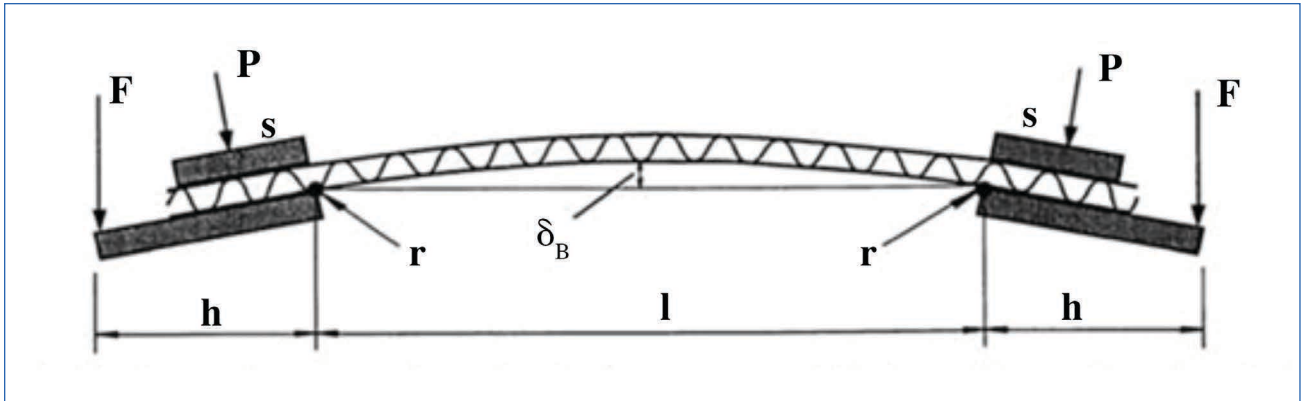
The recommended method to measure bending stiffness has since become TAPPI Standard Test Method T 836 “Bending stiffness, four point method.” Instead of an inner and outer support assembly, this method calls for a clamping mechanism to secure the ends of the specimen (**Fig. 1**). Clamp spacing is adjustable in order to accommodate various specimen span lengths. Conceptually, bending stiffness values should be independent of span (l in the notation of the method). While the strain induced by a given load is impacted by the span of the load application, that impact should be countered by a shift in the deformation of the piece. Using the equations from TAPPI T 836 (notation included in Fig. 1), we find the bending stiffness proportional to the span²/deformation of the center:

$$S^b = \frac{F}{\delta_B} \cdot \frac{hl^2}{8b} \quad (1)$$

However, since the deformation is also proportional to the span squared;

$$\delta_B = \frac{\varepsilon \cdot l^2}{400 \cdot t} \quad (2)$$

the stiffness should be independent of the span. It is thus puzzling that the



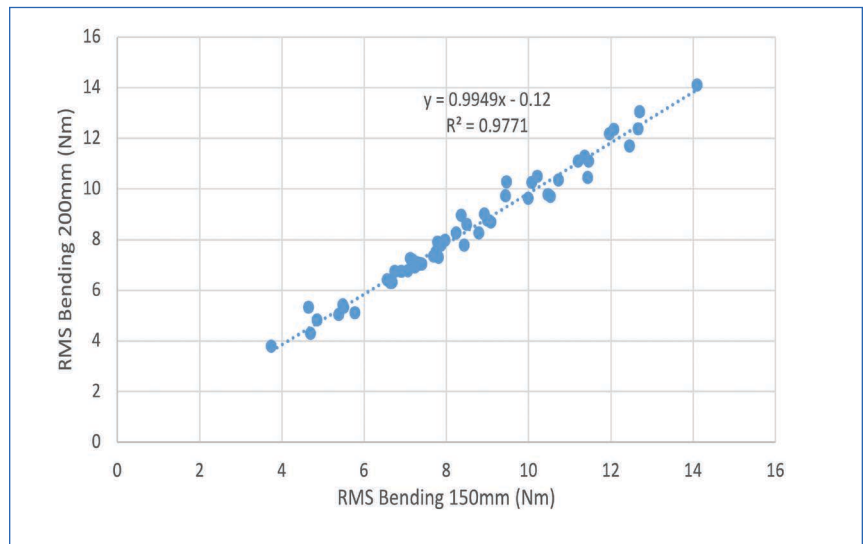
1. The four-point bending stiffness test configuration (testing corrugated fiberboard in machine direction) as described by TAPPI Standard Test Method T 836. (F = force; h = moment arm; l = free span; δ_B = deflection; r = rotation axis; P = clamping pressure; s = clamping length; t = caliper.)

method specifies free spans to be used when testing different types of corrugated fiberboard, because limiting the span length poses particular challenges in practice. For example, the test method recommends a free span of 200 mm for B- and C-flute board. When one accounts for the area required under the clamping mechanism, this means we need >11 in. (~28 cm) of board without scores in order to do the measurement. A very significant fraction of boxes has panels that are smaller than this size, which would thus prohibit testing bending stiffness using this method on short (or even close to “typical”) boxes.

METHODS

To better understand the relationship between bending stiffness and span length, we performed measurements on a range of B- and C-flute boxes at three spans: 200 mm, 150 mm, and 100 mm. The full results are shown in **Table I**.

In this technical brief, we explore the possibility of scaling the results from the narrower spans to those of the “standard” span. While the behavior captured in our dataset may not be representative of the true mechanics for all situations, this work provides a practical tool to ensure that bending stiffness measurements made at various span lengths are comparable. We also briefly discuss several areas that could serve as the foundation for future fundamental work to provide more robust information regarding the bending behavior of a sample at various free spans.



2. Scatterplot depicting linear relationship between root mean square (RMS) bending measurements made at spans of 150 mm and 200 mm.

RESULTS

150 mm to 200 mm

The slope of the line correlating the relationship between RMS bending at 200 mm and 150 mm spans is statistically similar to one and the intercept is statistically similar to zero (**Fig. 2**). In line with our expectations from Eq. 1 and Eq. 2, there is no practical difference between the RMS bending measured at either span. We found similar relationships for the machine direction (MD) and the cross direction (CD) bending stiffness measurements individually. Since the intercept is statistically similar to zero across all three forms of bending in the dataset collected, we reanalyzed the data set assuming that the intercept was zero.

Conceptually, the slope should still bound one, as bending stiffness should not be dependent on span length. However, the slope no longer consistently bounds one with its confidence interval for the three 150-mm equations as the theory included in the test method suggests it should (**Table II**). Fortunately, each of the slopes (regardless of orientation) have overlapping confidence intervals and we can use a single general equation to define the relationship between the spans:

$$200\text{mm Bending}_{\text{Estimated}} = (0.982) * (150\text{mm Bending})_{\text{Measured}} \quad (3)$$

Equation 3 represents the linear fit resulting in the minimized sum of the

Bending Stiffness 200mm						Bending Stiffness 150mm						Bending Stiffness 200mm					
CD Bend, Nm (n=10)		MD Bend, Nm (n=10)		RMS Bending, Nm (n=10)		CD Bend, Nm (n=10)		MD Bend, Nm (n=10)		RMS Bending, Nm (n=10)		CD Bend, Nm (n=10)		MD Bend, Nm (n=10)		RMS Bending, Nm (n=10)	
Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD	Avg	STD
7.7	0.3	13.7	0.9	10.2	0.8	7.6	0.3	13.3	0.5	10.1	0.6	9.5	1.1	20.1	2.9	13.8	2.6
5.2	0.2	9.6	0.5	7.1	0.4	5.4	0.4	9.8	0.5	7.3	0.6	5.6	0.3	10.3	0.5	7.6	0.6
5.5	0.3	8.3	0.6	6.7	0.6	5.9	0.5	7.7	0.9	6.7	1.0	6.1	0.7	8.5	0.8	7.2	1.1
6.8	0.2	15.9	1.2	10.4	0.8	8.1	0.6	16.1	1.1	11.4	1.1	8.7	0.8	18.9	1.8	12.8	1.7
3.1	0.1	4.6	0.2	3.8	0.2	3.1	0.1	4.6	0.3	3.8	0.2	3.4	0.2	5.3	0.4	4.3	0.4
4.9	0.1	5.7	0.4	5.3	0.4	3.7	0.2	5.9	0.5	4.7	0.4	4.1	0.2	6.7	0.8	5.3	0.6
11.1	0.3	17.8	0.6	14.1	0.6	11.2	0.4	17.7	0.5	14.1	0.6	13.6	1.3	20.5	2.5	16.7	2.6
3.5	0.2	6.7	0.8	4.8	0.6	3.6	0.2	6.6	2.1	4.9	1.6	3.8	0.1	6.9	1.9	5.2	1.4
5.7	0.2	9.1	0.4	7.2	0.5	5.6	0.2	9.2	0.4	7.2	0.4	6.3	0.3	10.9	1.8	8.3	1.4
5.8	0.2	12.8	0.9	8.6	0.6	5.5	0.2	13.0	0.9	8.5	0.6	6.3	0.3	14.8	2.8	9.6	1.9
6.0	0.2	9.5	0.3	7.5	0.3	6.2	0.3	9.7	0.4	7.7	0.5	6.2	0.3	9.7	0.5	7.7	0.6
8.6	0.2	12.3	0.7	10.3	0.6	7.3	0.2	12.3	0.6	9.5	0.5	9.1	0.8	13.8	1.9	11.2	1.8
8.0	0.3	11.9	1.4	9.7	1.2	7.7	0.2	11.6	0.4	9.4	0.4	8.9	0.5	12.5	0.9	10.6	1.0
9.8	0.3	15.1	0.7	12.2	0.7	9.5	0.2	15.1	0.7	12.0	0.6	11.3	1.0	18.1	2.5	14.3	2.3
8.7	0.2	12.7	0.8	10.5	0.7	8.6	0.3	12.2	0.7	10.2	0.6	9.3	0.7	12.5	0.8	10.8	1.0
7.2	0.2	8.6	0.5	7.9	0.5	7.0	0.2	8.7	1.2	7.8	1.1	8.8	1.1	9.4	1.4	9.1	1.8
8.0	0.4	10.0	0.4	9.0	0.6	6.9	0.3	10.2	0.4	8.4	0.5	8.4	0.7	11.1	1.4	9.6	1.5
10.3	0.4	14.9	0.2	12.4	0.6	9.7	0.3	15.0	0.3	12.1	0.5	11.4	0.8	19.5	3.2	14.9	2.6
8.3	0.2	9.8	0.6	9.0	0.6	8.1	0.3	9.9	0.3	8.9	0.4	10.3	1.6	10.8	1.3	10.5	2.1
10.6	0.3	16.1	0.8	13.0	0.7	10.4	0.4	15.5	0.5	12.7	0.7	13.1	1.1	21.3	2.0	16.7	2.1
5.9	0.6	10.1	0.6	7.8	0.9	6.0	0.3	10.3	0.5	7.9	0.5	6.4	0.3	11.7	1.8	8.7	1.4
5.5	0.3	13.8	0.5	8.7	0.6	5.6	0.2	14.9	1.7	9.1	1.1	6.1	0.4	15.6	2.1	9.7	1.4
5.6	0.2	10.8	0.8	7.8	0.6	5.8	0.4	10.6	0.7	7.8	0.7	5.8	0.4	11.0	0.8	8.0	0.8
5.6	0.2	11.0	0.8	7.8	0.6	5.6	0.2	11.2	0.9	7.9	0.7	5.7	0.5	13.3	2.0	8.7	1.5
5.9	0.1	10.7	0.8	8.0	0.6	6.1	0.2	10.4	0.4	8.0	0.4	6.3	0.3	11.6	0.9	8.5	0.8
6.2	0.2	11.0	0.9	8.3	0.7	6.1	0.2	11.2	1.0	8.2	0.8	6.5	0.5	12.0	0.8	8.8	0.9
5.5	0.4	12.3	0.8	8.3	0.8	5.9	0.3	13.2	1.3	8.8	1.0	6.7	0.7	14.5	1.6	9.9	1.5
6.0	0.4	15.4	0.8	9.6	0.9	6.3	0.4	16.0	1.1	10.0	0.9	7.4	0.7	17.5	2.6	11.4	2.1
4.9	0.1	8.4	0.7	6.4	0.6	5.0	0.2	8.7	1.2	6.6	0.9	6.2	0.6	10.8	1.4	8.2	1.3
5.6	0.2	8.5	0.6	6.9	0.6	5.9	0.3	8.9	0.6	7.2	0.6	6.5	0.5	10.6	1.3	8.3	1.2
5.7	0.2	8.1	0.8	6.8	0.7	6.0	0.2	8.3	0.8	7.1	0.7	6.6	0.5	9.5	0.9	7.9	1.0
5.3	0.1	7.6	0.6	6.3	0.5	5.6	0.2	7.9	0.6	6.6	0.6	5.9	0.6	9.5	1.6	7.5	1.4
5.9	0.2	7.7	1.2	6.7	1.1	5.9	0.1	8.1	0.5	6.9	0.4	6.4	0.6	9.0	0.9	7.6	1.0
5.7	0.1	9.2	0.4	7.2	0.4	5.8	0.2	8.8	0.4	7.1	0.4	6.5	0.4	10.6	1.4	8.3	1.2
5.9	0.2	8.3	1.1	7.0	0.9	6.1	0.2	9.1	0.7	7.4	0.6	6.9	0.9	10.8	1.4	8.6	1.5
5.9	0.2	8.4	0.6	7.0	0.6	6.1	0.2	8.9	0.9	7.4	0.8	7.1	0.7	10.4	1.1	8.6	1.2
5.8	0.3	8.5	0.6	7.0	0.6	6.1	0.4	8.9	0.8	7.4	0.8	6.6	0.7	10.9	1.7	8.5	1.6
8.3	0.4	18.4	0.4	12.4	0.6	8.7	0.5	18.5	0.7	12.7	0.9	9.9	1.0	21.7	2.1	14.6	2.0
8.5	0.2	14.5	0.6	11.1	0.5	8.7	0.2	14.5	0.7	11.2	0.6	10.2	0.9	18.0	1.1	13.5	1.4
7.5	0.3	17.0	0.4	11.3	0.5	7.5	0.2	17.3	0.7	11.4	0.6	8.3	0.8	20.2	1.6	12.9	1.6
2.9	0.3	6.4	0.4	4.3	0.5	3.2	0.3	6.9	0.6	4.7	0.7	3.4	0.5	7.4	1.2	5.0	1.1
4.9	0.5	8.1	0.7	6.3	0.9	5.0	0.6	8.9	0.5	6.7	0.9	6.1	0.9	10.7	1.4	8.1	1.6
5.5	0.2	9.8	0.8	7.3	0.6	5.8	0.2	10.3	0.7	7.7	0.6	6.4	0.4	12.2	1.2	8.9	1.0
5.4	0.3	9.3	0.2	7.1	0.4	5.4	0.2	9.9	0.3	7.3	0.3	6.1	0.3	11.4	0.6	8.4	0.6
6.2	0.1	8.6	0.7	7.3	0.6	6.5	0.2	9.4	0.3	7.8	0.4	7.3	0.6	10.8	1.1	8.9	1.2
6.8	0.3	13.8	0.7	9.7	0.6	7.2	0.4	15.4	0.7	10.5	0.7	7.9	0.7	19.5	1.7	12.4	1.6
7.5	0.2	12.7	0.5	9.8	0.5	8.4	0.4	13.0	0.9	10.5	0.8	10.7	0.6	16.9	1.4	13.4	1.3
6.1	0.3	12.6	1.1	8.8	0.9	6.6	0.3	12.3	0.8	9.0	0.7	8.0	0.9	14.7	0.9	10.9	1.3
3.1	0.3	8.0	0.4	5.0	0.5	3.3	0.3	8.7	0.3	5.4	0.5	4.2	0.5	9.6	1.0	6.3	1.0
3.5	0.1	8.3	0.5	5.4	0.4	3.6	0.1	8.5	0.5	5.5	0.4	4.4	0.4	12.8	1.3	7.5	1.0
3.4	0.1	8.4	0.5	5.3	0.4	3.4	0.1	8.9	0.3	5.5	0.2	4.6	0.3	12.6	1.6	7.6	1.1
8.4	0.2	14.6	0.4	11.1	0.4	9.1	0.4	14.5	0.5	11.5	0.6	11.7	0.7	16.8	1.1	14.0	1.2
8.9	0.3	15.4	0.6	11.7	0.6	9.2	0.4	16.9	0.7	12.5	0.8	11.6	0.8	17.3	1.0	14.2	1.3
7.8	0.4	13.7	0.6	10.4	0.7	8.2	0.3	14.0	0.8	10.7	0.7	9.5	0.8	14.4	0.8	11.7	1.1
3.5	0.1	7.3	0.2	5.1	0.2	4.0	0.1	8.4	0.5	5.8	0.4	4.7	0.4	9.1	0.6	6.5	0.7
6.0	0.2	10.0	0.3	7.8	0.3	6.5	0.3	11.0	0.6	8.4	0.5	6.6	0.4	12.8	1.1	9.2	1.0

CD = cross direction; MD = machine direction; RMS = root mean square; Avg = Average; STD = standard deviation.

I. Each row reports the results for one of the 56 distinct samples tested. The entire set consists of production run regular slotted containers (RSCs) in a range of commercial single wall board combinations.

squared residuals, across all three orientations.

When calculating this general equation, the increased sample count confirmed that the intercept was still statistically similar to zero. Since the RMS orientation is a calculated value based on the CD and MD results, we were curious if a distinct RMS scaling equation was appropriate or if the RMS should be calculated based on the CD and MD estimates calculated from those two respective equations. Since the confidence interval for the slope of the RMS equation contains the result of $\sqrt{\text{Slope}_{CD} \cdot \text{Slope}_{MD}}$, either approach appears appropriate.

100 mm to 200 mm

Our observations are qualitatively different when comparing the RMS bending values measured at the specified span of 200 mm to those measured at a span of 100 mm. While there still appears to be a linear relationship (with evenly distributed deviation plots), the slope is not close to one and the intercept is not similar to zero. There is also notably more scatter of the data around the best fit line (**Fig. 3** and **Table III**).

Similar to the 150 mm equations, each of the three slope and intercept averages have overlapping confidence intervals. This supports the idea that the difference arises from the mechanics of the test and not the materials, and again allows us to reduce the three relationships to a single scaling equation:

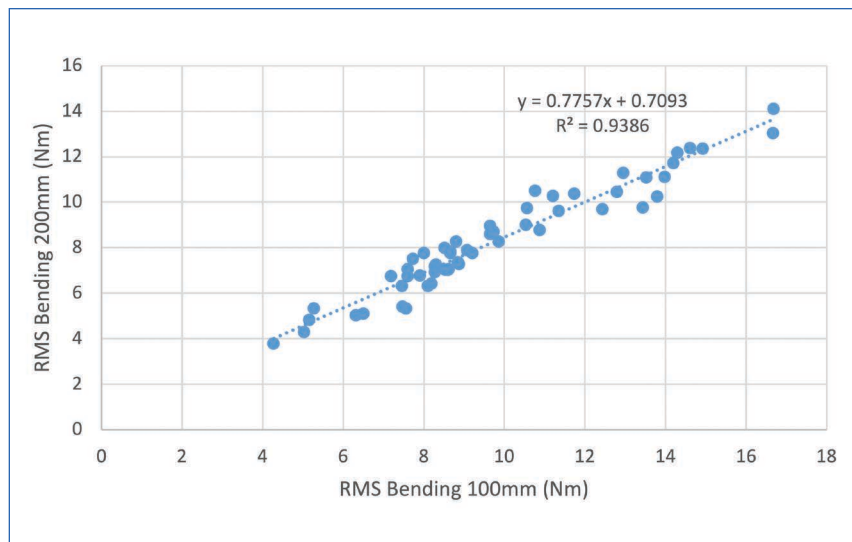
$$200\text{mm Bending}_{\text{Estimated}} = (0.776) \cdot (100\text{mm Bending})_{\text{Measured}} + 0.706 \quad (4)$$

Again, Eq. 4 represents the linear fit resulting in the minimized sum of the

Orientation	Slope		Model R ²
	Average	Standard Error	
CD	0.987	0.009	0.996
MD	0.977	0.005	0.998
RMS	0.982	0.005	0.998

CD = cross direction; MD = machine direction; RMS = root mean square.

II. Regression equations assuming a zero intercept, relating bending measurements made at a span of 150 mm to measurements made at a span of 200 mm.



3. Scatterplot depicting linear relationship between RMS bending measurements made at spans of 100 mm and 200 mm.

squared residuals across all three orientations. When calculating this general equation, the increased sample count confirmed that the intercept was statistically significant, and thus that the two values are not simply proportional.

The “noise” in an individual measurement, as indicated by the coefficient of variation (COV)—standard deviation divided by the mean, grows as the span decreases (**Table IV**). The significantly larger average error for each set tested at 100 mm helps explain why the average intercepts for the MD, CD, and RMS

equations have overlapping confidence intervals. Since the confidence intervals for each of the equations’ slope and intercept terms bound the reported general slope and intercept terms, results from use of the general equations should not lead to a systematic bias larger than the natural variation of the testing.

The increase in variation serves as a reminder that measurements should only be made at smaller spans for samples that cannot physically be tested at a larger span. Even by increasing the span by 50 mm (~2 in.), we find a sig-

Orientation	Slope		Constant, Nm		Model R ²
	Average	Standard Error	Average	Standard Error	
CD	0.762	0.029	0.700	0.275	0.926
MD	0.759	0.034	1.033	0.462	0.903
RMS	0.776	0.027	0.709	0.275	0.939

CD = cross direction; MD = machine direction; RMS = root mean square.

III. Regression equations relating bending measurements made at a span of 100 mm to measurements made at a span of 200 mm.

nificant decrease in the measurement variation. This improvement extends to the scaling equation's accuracy, as shown by the difference in the R^2 values for the 150 mm and 100 mm equations (compare Table II and Table III).

FUTURE WORK

Despite these general equations defining the observed relationship between the measurements made at different span lengths, this work does not answer the question as to why measured stiffness is not independent of span to begin with. The difference in measurements may involve the geometry and mechanics of the specified instrument, specifically the impact of using clamps to secure the ends of the samples (Fig. 1).

In a pure four-point bending situation, we would have load applied at the **F** arrows and the support points at the **r** arrows, allowing the entire piece to have a constant curvature over the whole length from the left **F** to the right **F**. However, for the current equipment, the plates apply clamping force **P**, which restricts the board, forcing it to be linear under the clamp. This causes the sample to only have true curvature along the length **L** and not along the full length (**L**+2**h**). By impacting the support points, we could be influencing the shape of curvature across the **L** span.

Since the calculation for bending is derived assuming curvature along the full length, these deviations from a pure four-point bending could be causing the difference across span lengths. Deflection may be linear with load but the calculated bending stiffness would not be constant, because we are not considering the correct span and we have changed the boundary conditions. This

ABOUT THIS TECHNICAL BRIEF

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impact would become more prominent at shorter spans as the relative fraction of material forced to be linear (under the clamp) increases.

We measured bending stiffness at a span of 300 mm for the few samples in our data set large enough to accommodate. Under the guiding assumption that as the span decreases, we more drastically change the bending shape, we would expect that as the span *increases*, the need for an intercept would decrease. When we did not fix the intercept to zero, we found, as with the correlation of 200 mm with 150 mm, that the intercept scaling from 200 mm to 300 mm was not statistically significant. Because the sample size is small,

the resulting relationships are insufficiently robust to present. However, they are supportive of the hypothesis described here.

It is also possible that the differences in measurements relate to the viscoelastic nature of the material. While the time for all these tests was constant (the instrument makes the deflection measurement after a fixed interval following load), a heavier load applied to the ends would potentially lead to a larger stretch or creep component during this time interval. If shorter spans significantly change the geometry, then they may also impact the load inducing this creep.

Our dataset and method of analysis is not able to address these fundamental questions about the mechanics of the test. Instead, this may be more appropriate to work on at a university, where this clamping approach can be compared to the more traditional/classical approach (TAPPI T 820) where the full specimen is free to curve. Such a comparison over a large data set would provide an interesting starting point for future discussions, as well as fill a clear

	COV		
	200 mm	150 mm	100 mm
Average	7.7%	8.1%	14.0%
Confidence Interval	0.7%	1.2%	1.1%

IV. Coefficient of variation (COV) for measurement of a given span length across all three bending stiffness orientations.

gap in the literature verifying whether or not the two approaches to measuring bending stiffness actually produce the same results.

CONCLUSION

To accurately assess the bending stiffness of combined board and successfully use it in estimation equations for box performance, measurements need to assess the intrinsic physical property. By measuring a set of samples at various span lengths, we have shown that the bending stiffness as measured using the standard industry test method is span dependent. The scaling equations generated from the presented data take on different forms depending on the spans compared, raising questions about the mechanics of the instrument. Though this highlights the need for continued research, the general equations presented provide a practical tool that can be used by current practitioners to help evaluate the performance of boxes too

small to be amenable to testing at the current standard 200 mm span. **TJ**

LITERATURE CITED

1. Frank, B., *Packag. Technol. Sci.* 27(2): 105(2013). <https://doi.org/10.1002/pts.2019>.
2. Kellicutt, K.Q., "Note No. 11: Compressive Strength of Boxes Part 1," *Package Eng.*, 1959, December.
3. Koning Jr., J.W. and Moody, R.C., *Tappi* 54(11): 1879(1971).
4. McKee, R.C., Gander, J.W., and Wachuta, J.R., *Paperboard Packag.* 47(12): 111(1962).
5. Lee, M.H. and Park, J.M., *Packag. Technol. Sci.* 17(5): 275(2004). <https://doi.org/10.1002/pts.663>.
6. McKee, R.C., Gander, J.W., and Wachuta, J.R., *Paperboard Packag.* 48(8): 149(1963).
7. Urbanik, T.J. and Frank, B., *Wood Fiber Sci.* 38(3): 399(2006).
8. Chalmers, I., *Appita J.* 59(5): 357(2006).
9. McKee, R.C., Gander, J.W., and Wachuta, J.R., *Paperboard Packag.* 47(12): 111(1962).
10. Luo, S., Suhling, J.C., and Laufenberg, T.L., "Bending and twisting tests for measurement of the stiffnesses of corrugated board," in *Mechanics of Cellulosic Materials*, 1995 (R.W. Perkins, Ed.), American Society of Mechanical Engineers, New York, 1995, AMD Vol. 209/MD-Vol. 60, pp. 91-109.



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