Is There Any Science for D-bars and Bent Pipes

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What are D-bars?

- They are non-rotating support bars with either straight or curved axes.
- The D may stand for the first letter of "dead bar", which is simply a fixed round bar. Or it may refer to the fact that the bars can take the form of a section of a cylinder that looks like the capital letter D on its side.
- For purposes of this paper, the term D-bar will refer to any non-rotating bar that supports the web and has a circular profile in the contact area.

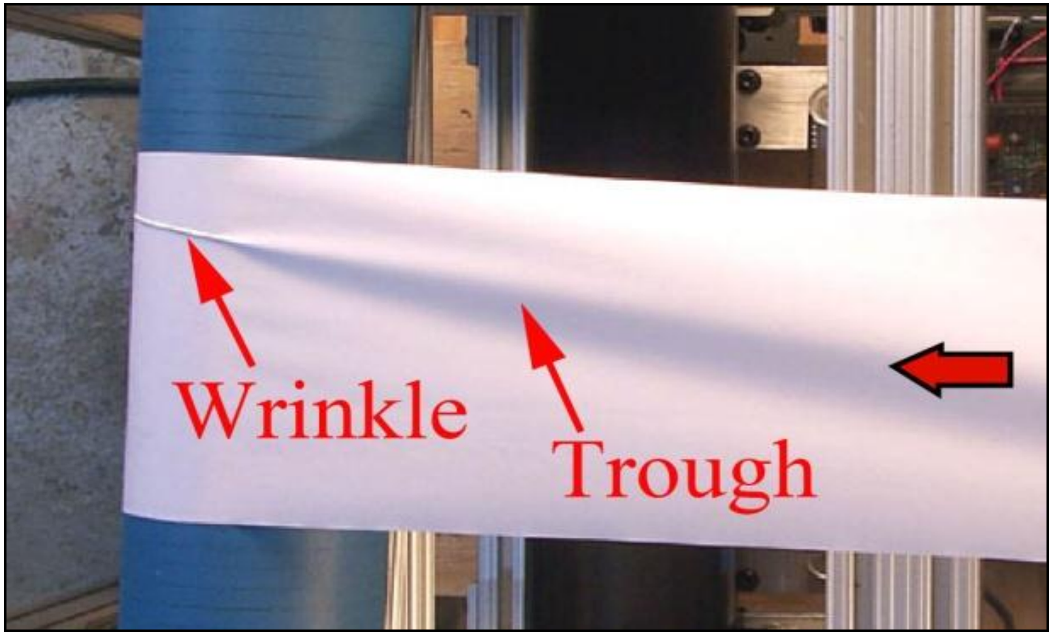
What are Bent Pipes?

- Bent pipe is a term that comes from the paper industry. They can be more complex than the D-bars seen in the converting industry. Some are equipped with multiple jack screws that allow an operator to give the axis a complex shape.
- This paper will discuss only bars that are straight or have a simple circular bow. But, the basic principles can be applied to more complex cases like the bent pipe.

Questions this paper will try to answer

- Do D-bars really spread webs?
  - Do they spread by creating positive spreading stress
  - Do straight D-bars spread webs? If so, how.
  - Are there side effects to be avoided?
- Where should D-bars be located for best results?
- Do their effects persist very far downstream?
- How much bow is needed?

Wrinkle terminology

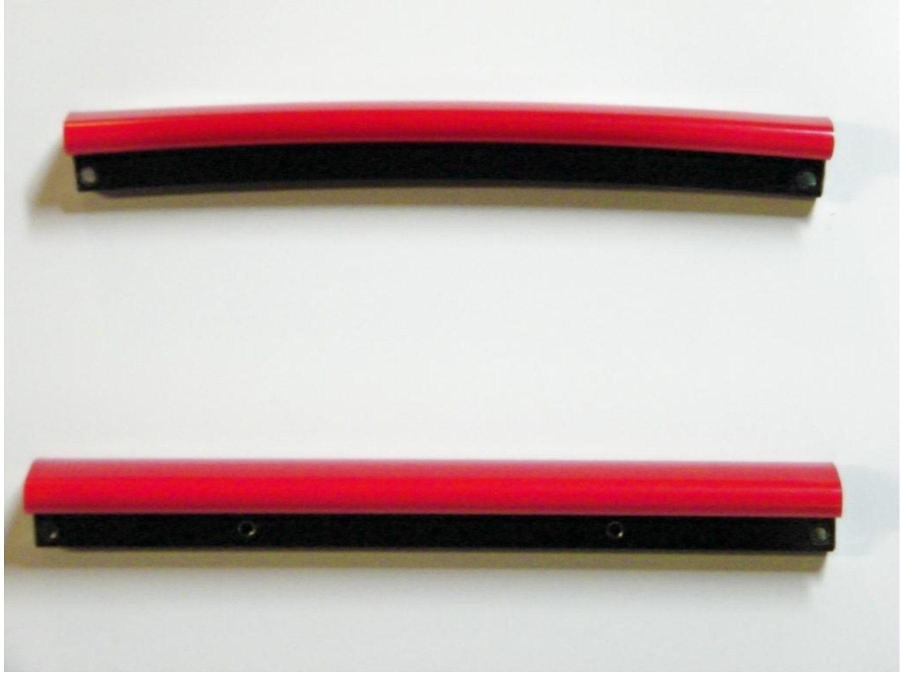


An adjustable D-bar

Cross section

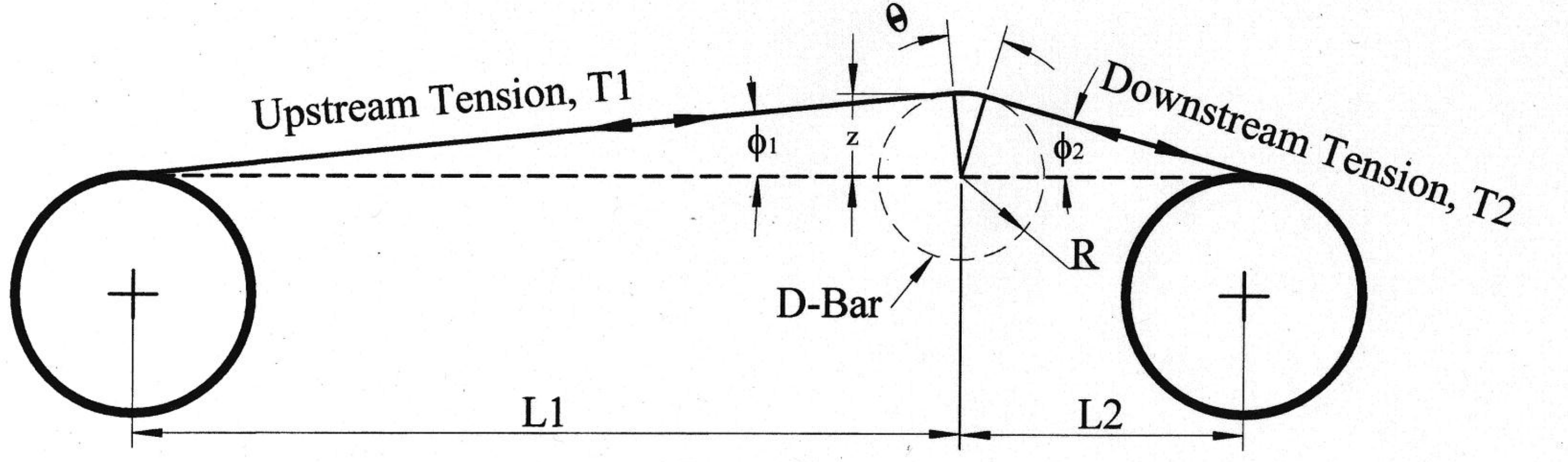
- Maximum wrap angle is ~36 degrees.
- Typical wrap angles in applications are probably much less.

D-bars used in tests



- Both 12 inches long
- Curved bar has ¼ of bow in 12 inches (72 inch radius)

Useful relationships



$$\frac{T_2}{T_1} = e^{\mu\theta}$$

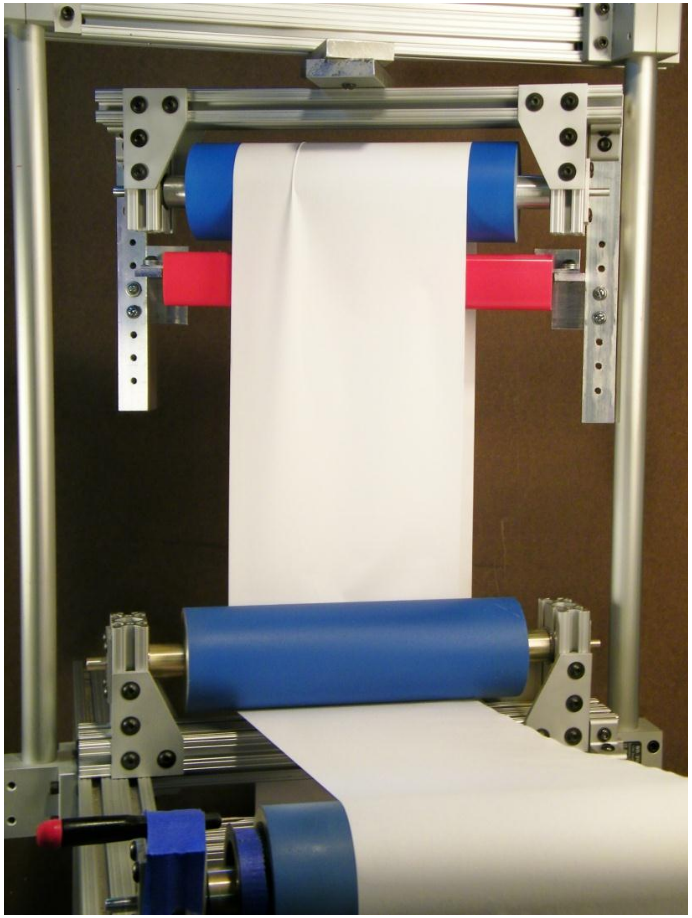
$$\theta = \phi_1 + \phi_2$$

$$P = \frac{T}{R}$$

A few friction coefficients

- A few coefficients of friction for the D-bar covering in the previous slide are.
  - Thermal fax paper (used in experiments) = 0.19
  - Polyester film (pedigree unknown) = 0.28
- Coefficients relative to the anodized aluminum surface under the covering were about the same.

Test setup



- Twist angle = 21°
- Span =13 ¾ in
- Width = 7 in
- Tension = 1 pli
- Modulus = “high” in the neighborhood of 0.5M psi
- Roller radius = 1.5 in
- Bar 3 5/16 below roller centerline
- Bar height = For curved bar, ¾ in on right end and 1 in on left (to get full contact with curve). For straight bar, ¾ in at both ends.

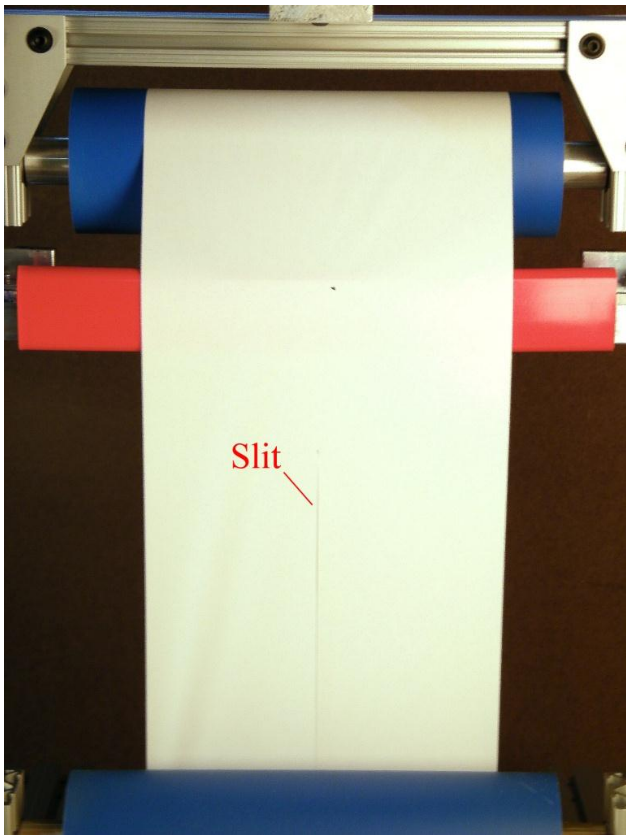
Spreading with the bowed bar

Bowed bar disengaged

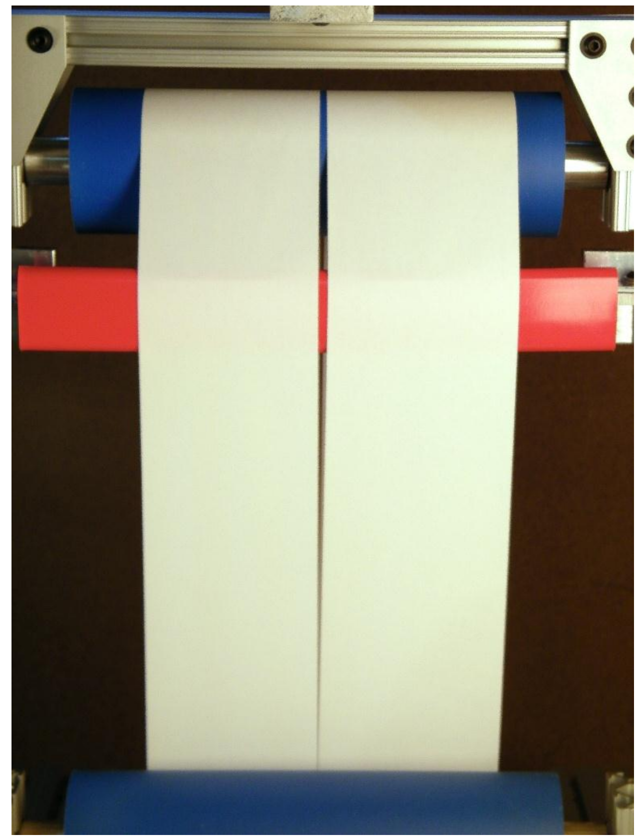
Bowed bar engaged

Is the bar producing positive lateral stress?
The Swanson slit test

Slit approaching bowed bar

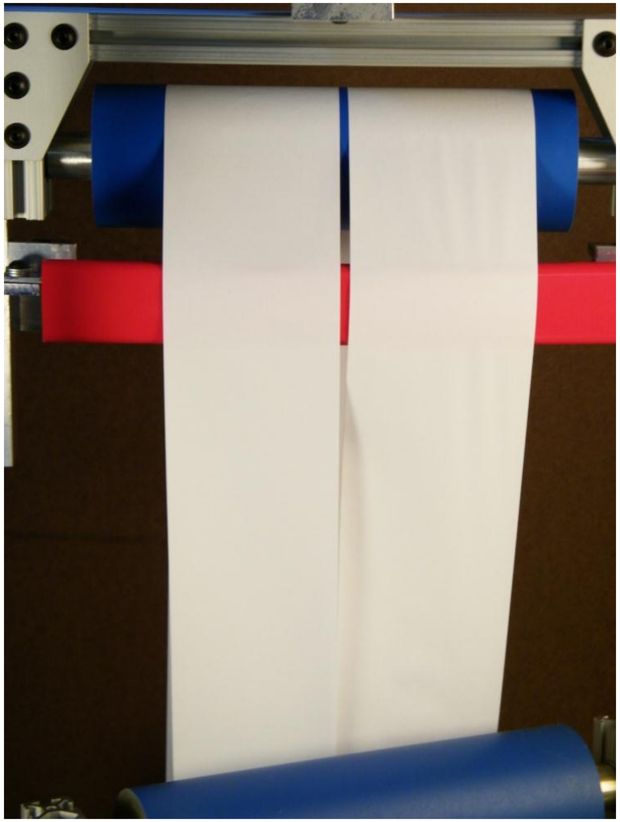


Slit fully opened after running a while



Slit test with web twisted

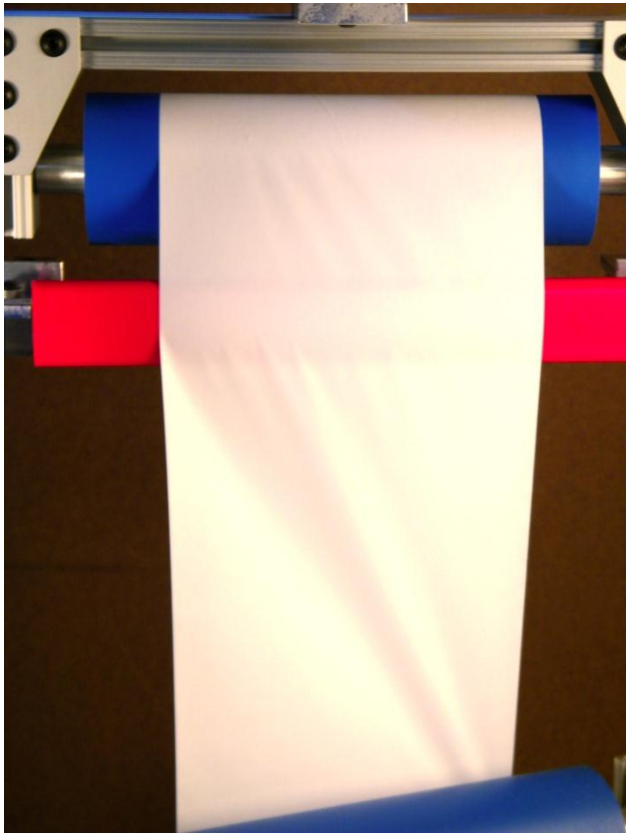
Positive lateral stress of bowed bar overwhelms compressive stress due to twist.



Tests with the straight bar

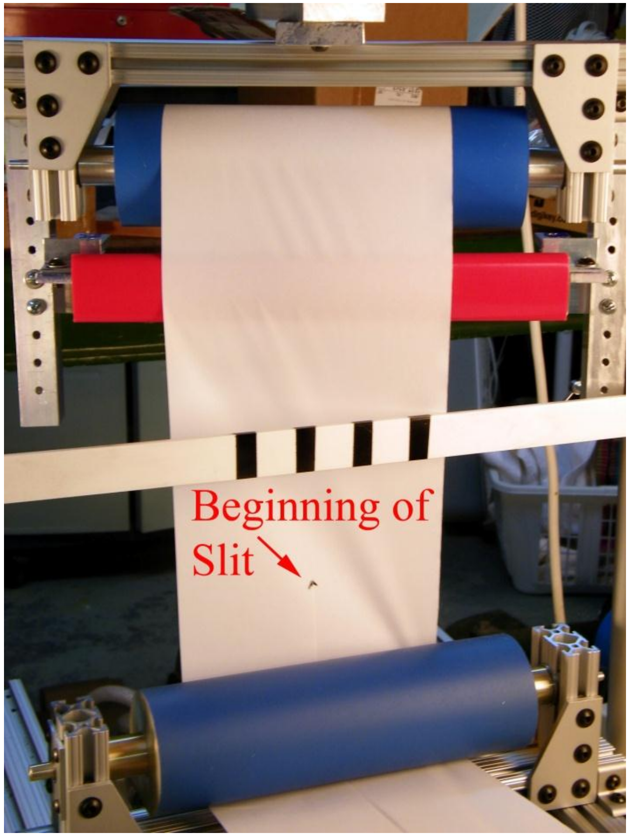
Straight bar disengaged

Straight bar engaged

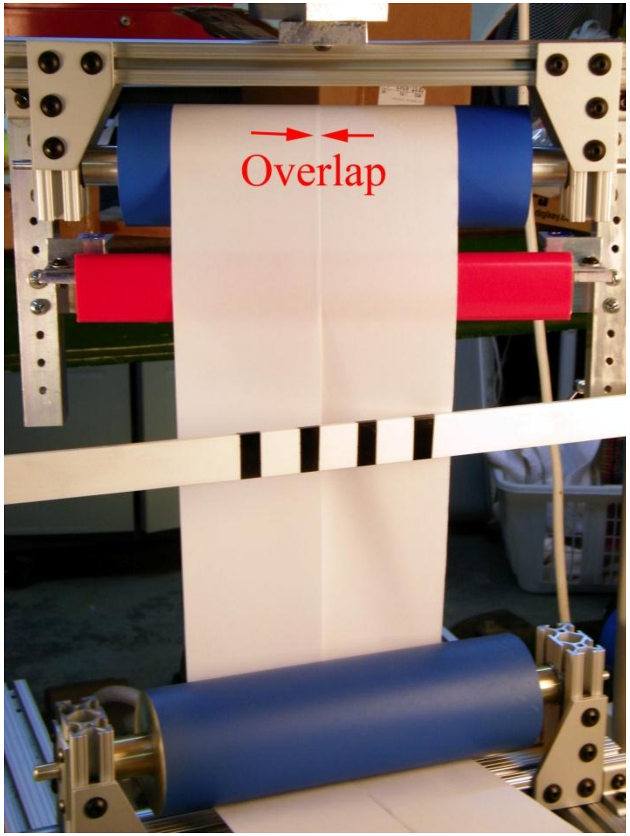


Does a straight bar separate a slit?

Slit approaching straight bar



Slit overlapped after running several span lengths.



The slit test for the straight bar failed!

- It means that wrinkles can be eliminated without eliminating the compressive stress that causes them.
- We've actually known this for some time, because it's common knowledge that reducing the traction on a roller (making it slippery) can eliminate wrinkles. But, we haven't followed up on the logical consequences.
- The usual explanation is that a slippery roller surface makes it possible for the radial pressure created by MD tension to spread the web out (flatten it).

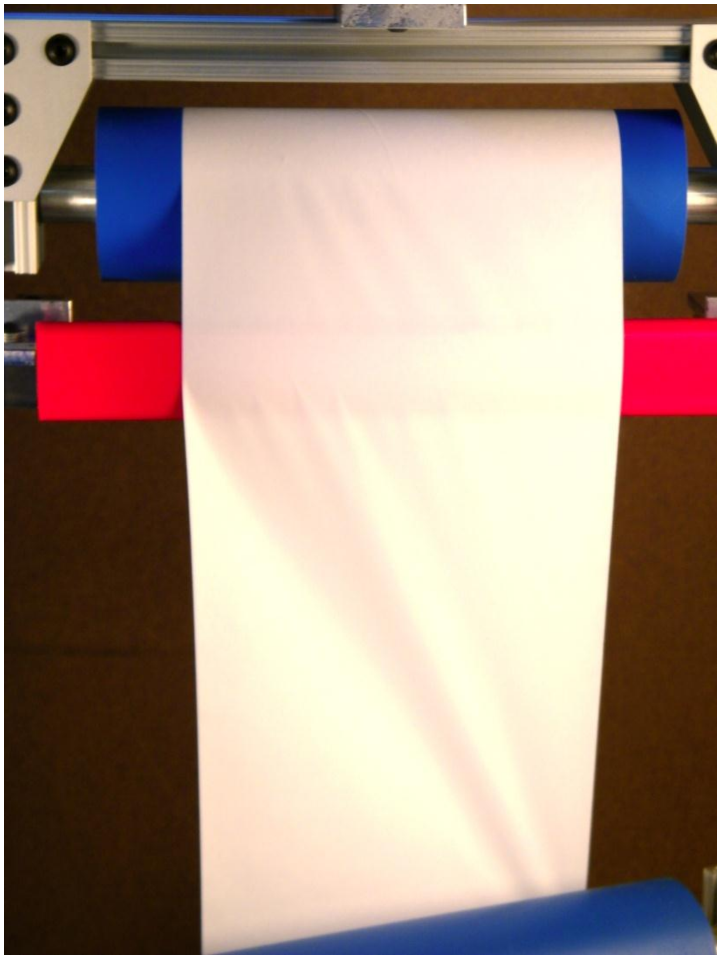
So, what is happening on a slippery roller?

- The lateral compressive stress that forms a wrinkle on a roller can become much higher than the rest of the web and this high stress is confined to a narrow zone at the location of the trough.
- A slippery roller won't allow such non-uniform stress to exist. Without traction, the web flattens, web material is redistributed and the lateral stress falls to a lower average value than the peak values that would exist at troughs on a high-traction roller.
- How this happens is explained in the following slides.

Why the slit test failed for a straight bar?

- In the test of the straight bar the roller traction is good (μ = 0.66), so it can't slip laterally and it's highly unlikely that the bar is generating lateral stress
  - If the bar were producing positive lateral stress to eliminate the wrinkle, the web would separate.
  - If the bar were producing negative lateral stress, the wrinkle ought to get worse.
- Additionally, the MD motion is overcoming the friction on the bar, this will further reduce the chance of the bar generating significant levels of lateral stress.

An important clue



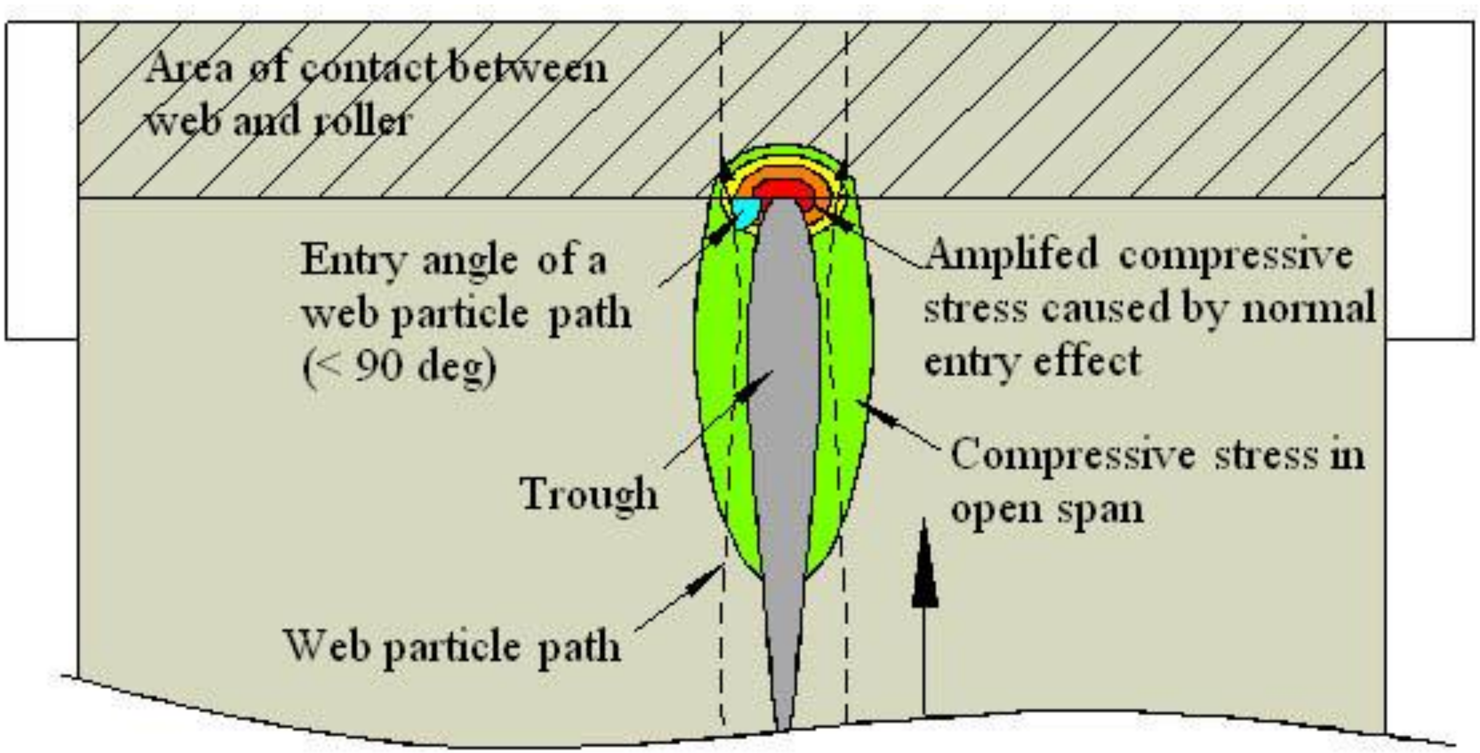
- Notice that there is a trough below the bar that is much deeper than those above it.
- This was also true of the trough that existed before the bar was engaged.
- The bar reduces trough depth.

The answer is in the trough geometry and it’s in two parts

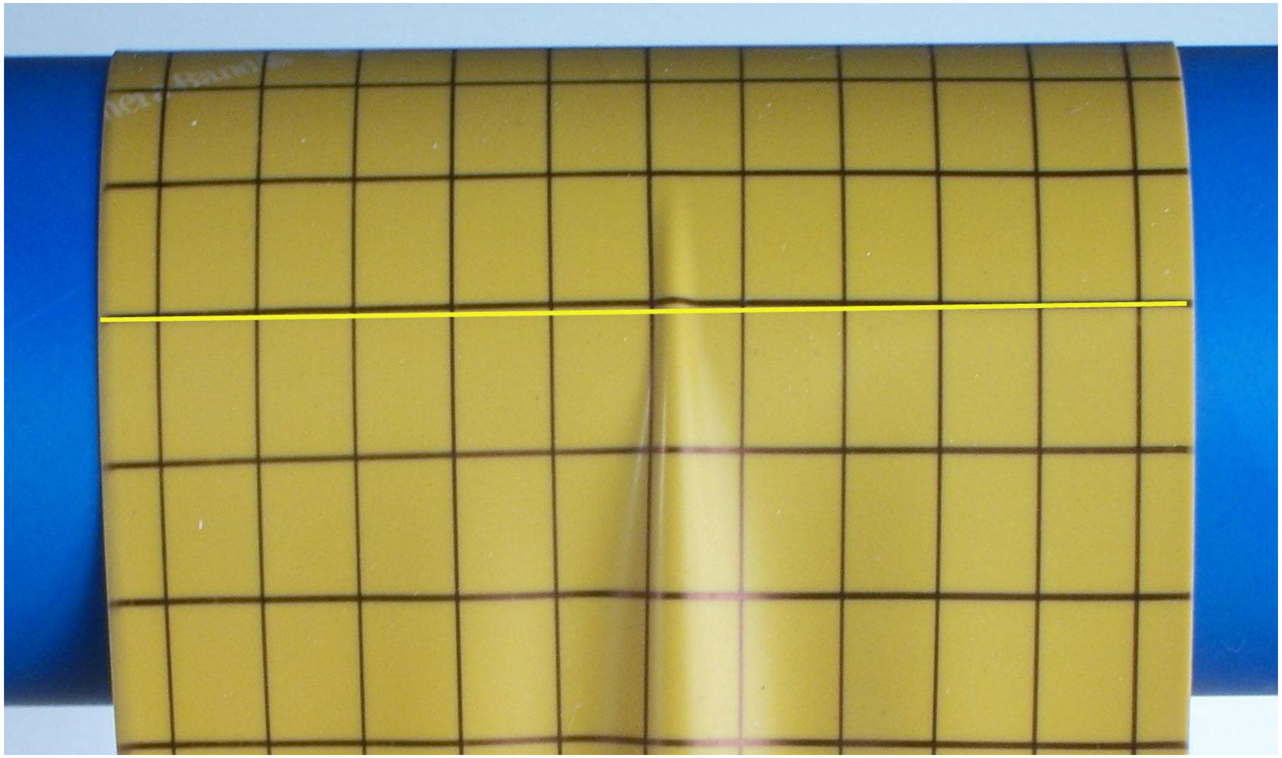
- The first part was mentioned in a 1997 IWEB paper titled “Shear Wrinkling in Isolated Spans” by Good, Kedl and Shelton.
- This idea is still discussed among a few web handling experts. But, it seems to have fallen into the category of “interesting ideas that may or may not be relevant”.

The normal entry effect at troughs

The first part of the explanation

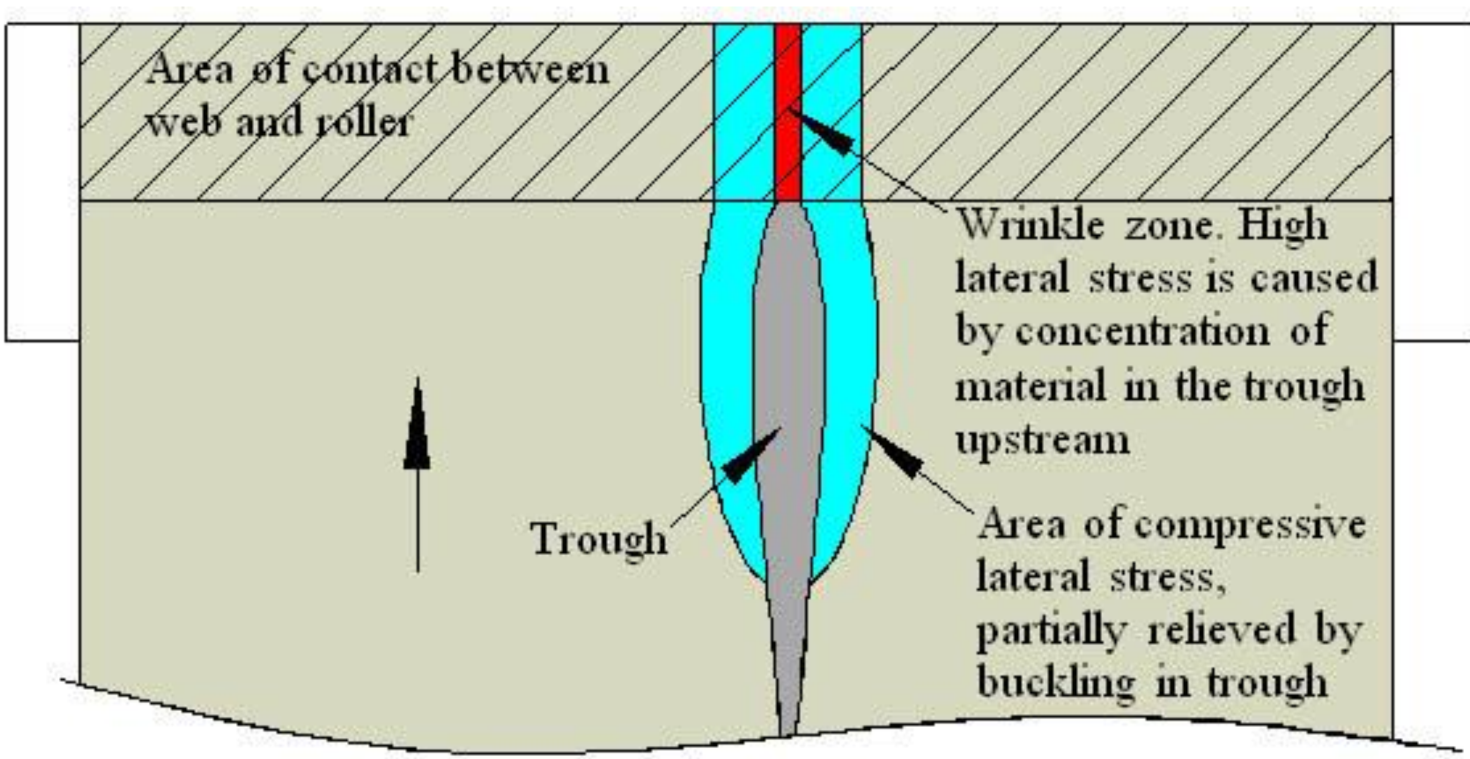


Evidence from an earlier experiment



Material concentration at troughs

The second part of the explanation



Putting it all together

- The 3D contour of a trough causes the amount of material per unit of straight-line lateral distance to be higher than the flat portions.
- If a roller has good traction, there is no way for the extra material in a trough to redistribute itself laterally before it moves onto the roller surface.
- Furthermore, the normal entry effect caused by the trough geometry confines and amplifies the lateral concentration of material.

Putting it all together (cont.)

- If the trough is shallow, the pressure of the MD tension may be adequate to keep the web pressed against the roller.
- But a deeper trough may channel so much material into the wrinkle zone that it can't be wedged into place and the lateral stress increases to the point where the web can't be held against the roller surface by MD tension.

So, the answer to the straight D-bar mystery is:

A straight D-bar eliminates wrinkles because it reduces the lateral concentration of material in troughs by keeping them shallow.

Full disclosure

- There is an alternative interpretation of the straight bar slit web experiment that should be mentioned.
- It could be argued that the bar interacted with the twisted web geometry to produce non-uniform MD stress that in turn created a positive lateral stress (spreading stress) large enough to prevent wrinkle formation, but not large enough to eliminate all of the compressive stress, leaving some to cause the slit to overlap.
- However, this seems highly improbable because:
  - The logic of the concentration of material by troughs is compelling
  - It does not explain the slippery roller issue
  - There is evidence of the normal entry effect in the latex web experiments.

Where should a straight D-bar be located?

- Since a straight D-bar is used to flatten troughs, it is obvious that it should be in close proximity to the roller where the wrinkles are to be eliminated.
- The only restriction is that it should not be so close that the wrap angle exceeds the design limit of the bar. Even the small radius of the bar illustrated at the beginning of the paper may produce unacceptable pressure levels that will increase bar wear and web scratching.

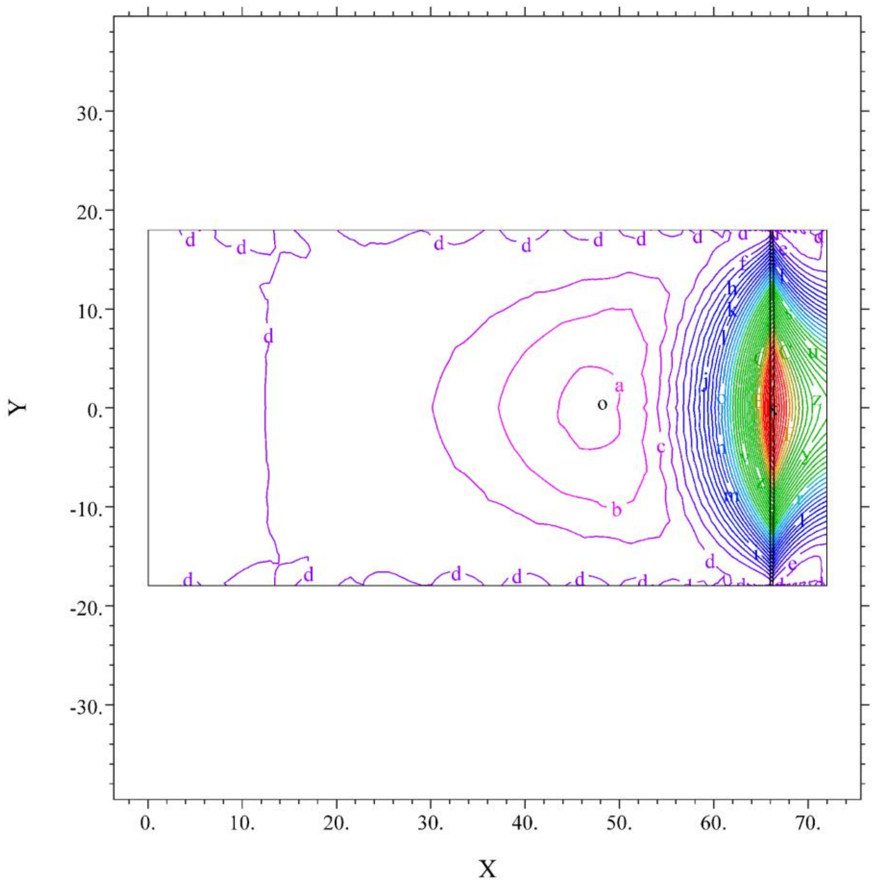
Where should a bowed D-bar be located?

- Since bowed bars produce positive spreading stress, it is less clear where they should be installed.
- This issue was investigated with an FEA model.
- Results indicate that when placed close to a downstream roller it can, as expected, create substantial spreading stress at the roller (this requirement is true of other spreading devices).
- When located half way down the span, the spreading stress dissipates quickly, leaving a slightly negative stress at the downstream roller.
- The upstream lateral stress is also negative and the tangled contours there show signs of trough formation

Model parameters

- The results of some typical FEA runs are shown in the next slides.
- Parameters were:
  - Span length = 72 in
  - Width = 36 in
  - Modulus = 500,000 psi
  - Thickness = 0.001
  - Tension = 1 pli
  - Bar height at ends = 0.5 in
  - Bar height at center = 0.75 in
  - Coefficient of friction = 0.2

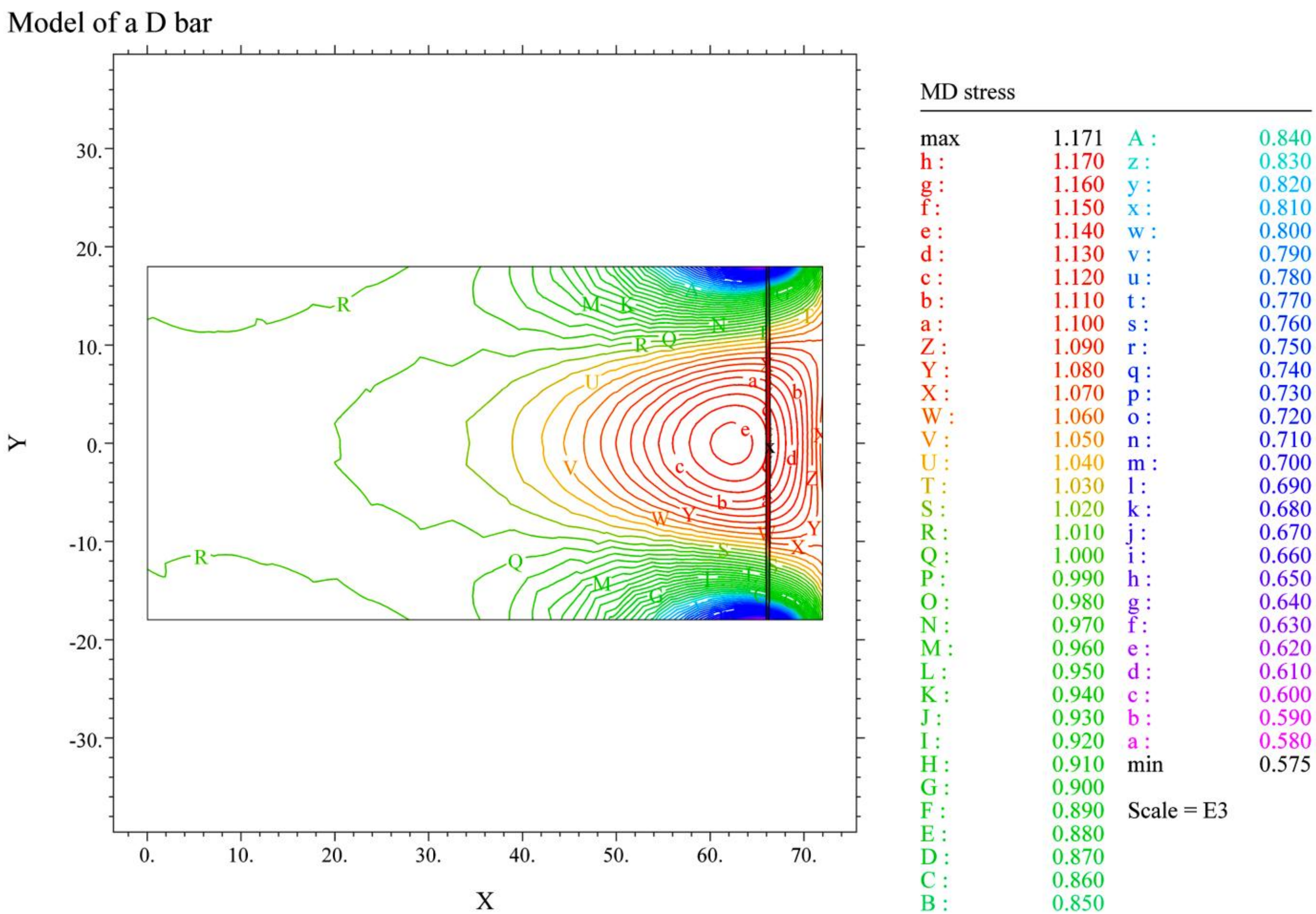
CD stress – bar 6 inches ahead of roller



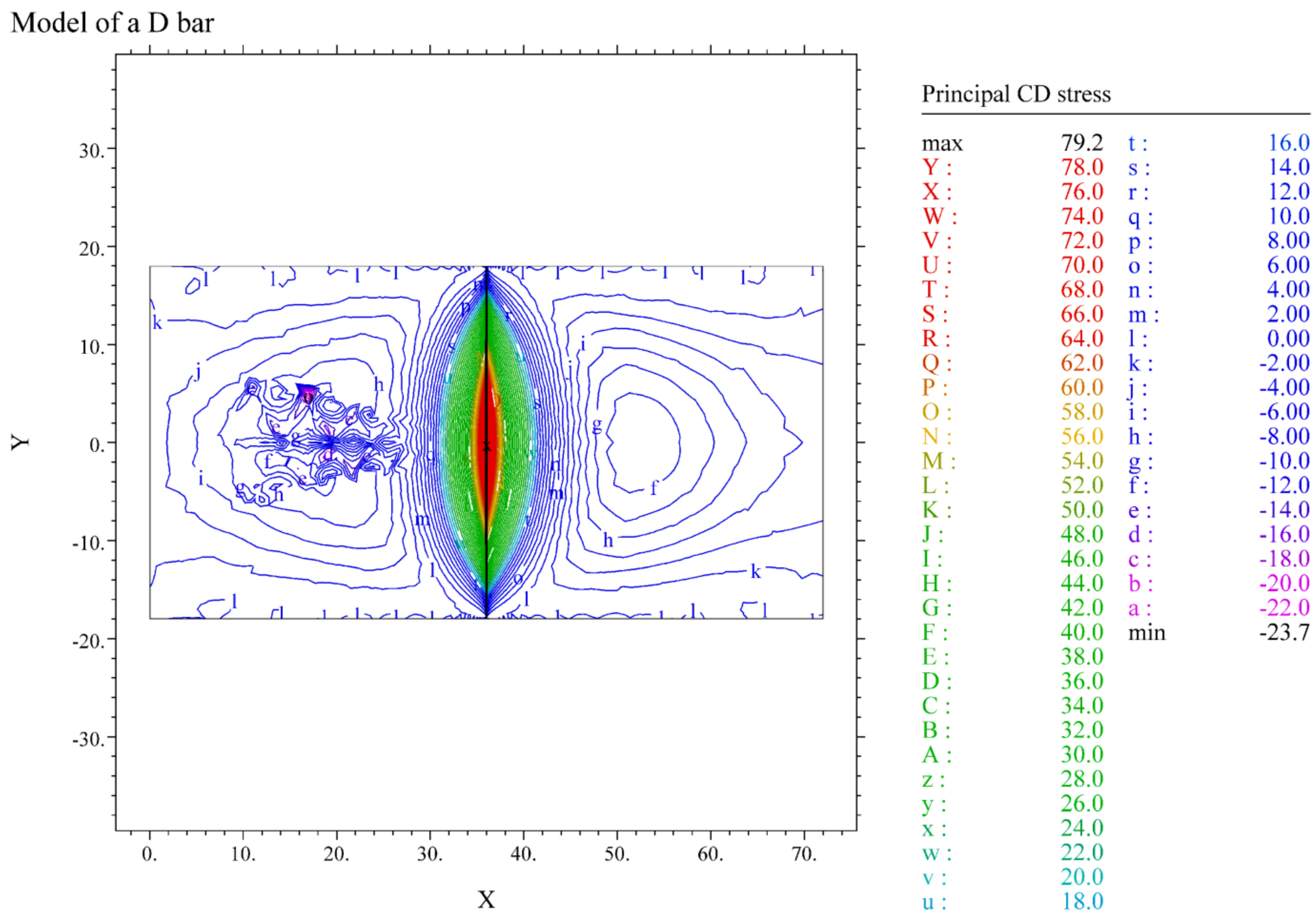
CD stress

max	362.	i :	50.0
N :	360.	h :	40.0
M :	350.	g :	30.0
L :	340.	f :	20.0
K :	330.	e :	10.0
J :	320.	d :	0.00
I :	310.	c :	-10.0
H :	300.	b :	-20.0
G :	290.	a :	-30.0
F :	280.	min	-33.0
E :	270.		
D :	260.		
C :	250.		
B :	240.		
A :	230.		
z :	220.		
y :	210.		
x :	200.		
w :	190.		
v :	180.		
u :	170.		
t :	160.		
s :	150.		
r :	140.		
q :	130.		
p :	120.		
o :	110.		
n :	100.		
m :	90.0		
l :	80.0		
k :	70.0		
j :	60.0		

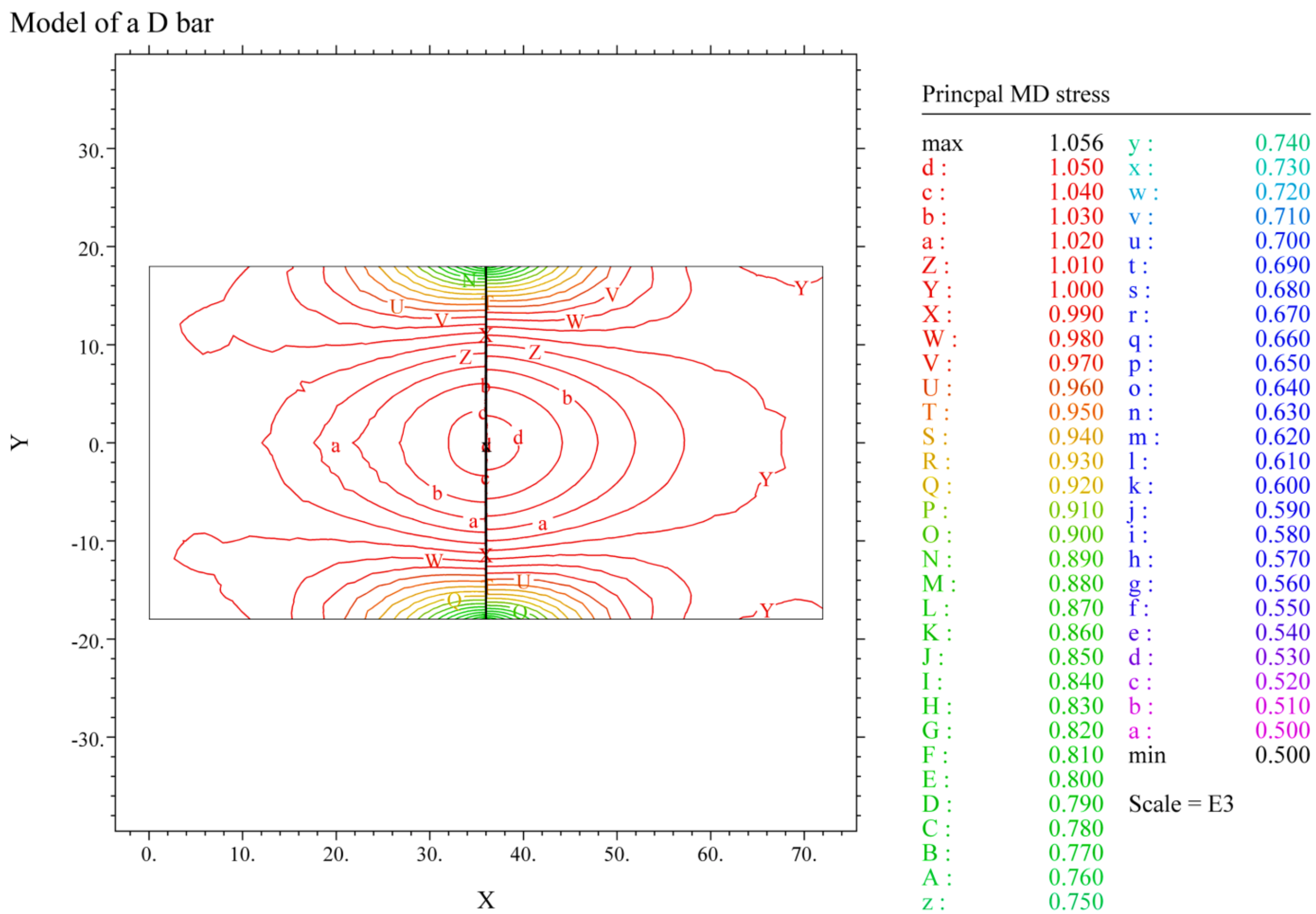
MD stress – bar 6 inches ahead of roller



CD stress – bar half way down span



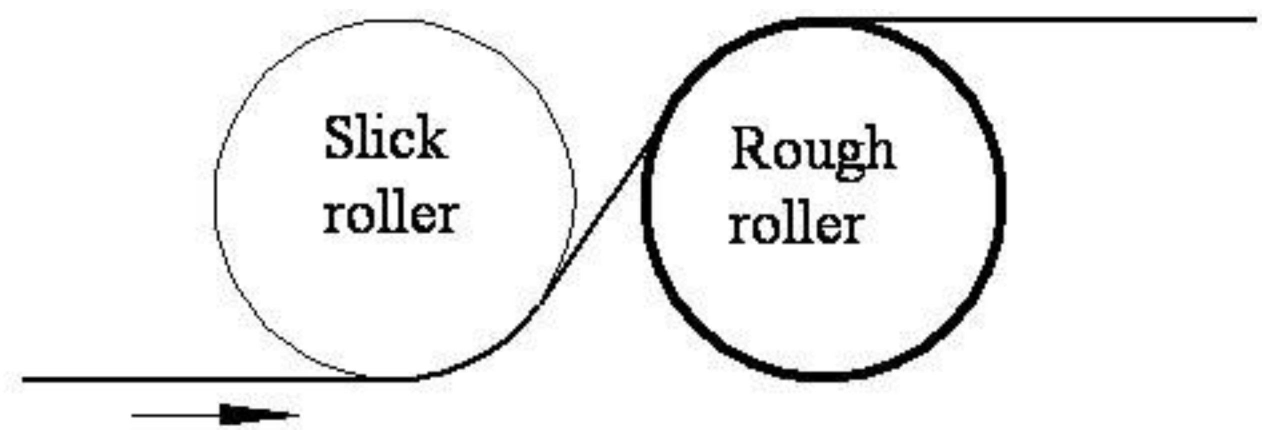
MD stress – bar half way down span



Bowed rollers as D-bars

- It's very common to see bowed rollers installed with the bow oriented so that they cannot be functioning as intended. They may not even be turning.
- An operator may be using it to help solve a baggy web problem.
- But, he may also have discovered that a non-rotating or slipping bowed roller can be used as a D-bar spreader.

Tandem rollers as wrinkle preventers



A situation where two rollers must be installed in close proximity can be exploited to prevent wrinkles by designing the downstream roller for good traction and making its companion slippery. An S-wrap will minimize the amount of span available for trough formation.

Effects of air entrainment

- Air lubrication, up to a point, can improve the wrinkle conditions on a roller by making it possible for the wrinkles to flatten.
- However, if the air film gets very thick (large diameter, high velocity and low tension) the air film may get so thick that troughs can't be flattened.

Effects of air entrainment (cont.)

- Air lubrication could improve a D-bar by reducing scratches and friction.
- However, there are two things to consider.
  - The velocity term in the foil bearing equation will be half that for a roller, so the lubricating effect may be smaller than expected.
  - At very high speed, a thick air film on the bar may prevent effective flattening of the troughs.

Conclusions

- Do D-bars really spread webs? Yes
- Do bowed D-bars produce positive spreading stress? Yes
- Do straight D-bars spread webs and if so, how? Yes, they reduce the depth of troughs.
- Are there side effects to be avoided? Yes, drag and scratching. Vendors should explore better materials and the possibility of controlled air lubrication
- Where should D-bars be located for the best results? Near the roller where the results are desired.

Conclusions (cont.)

- Do their effects persist far downstream? No
- How much bow is needed? Very little. In fact, you may not need any at all to eliminate wrinkles. Adding bow may make it possible to have a smaller wrap angle (smaller height) and thus less drag. Bow is, of course, also useful for helping with a baggy center.

QUESTIONS?

Essex Systems

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