Introduction to Corrugated Boxes

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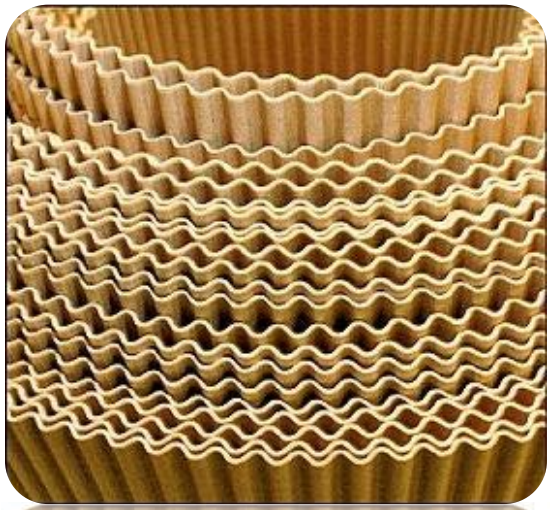
APRIL 23, 2020

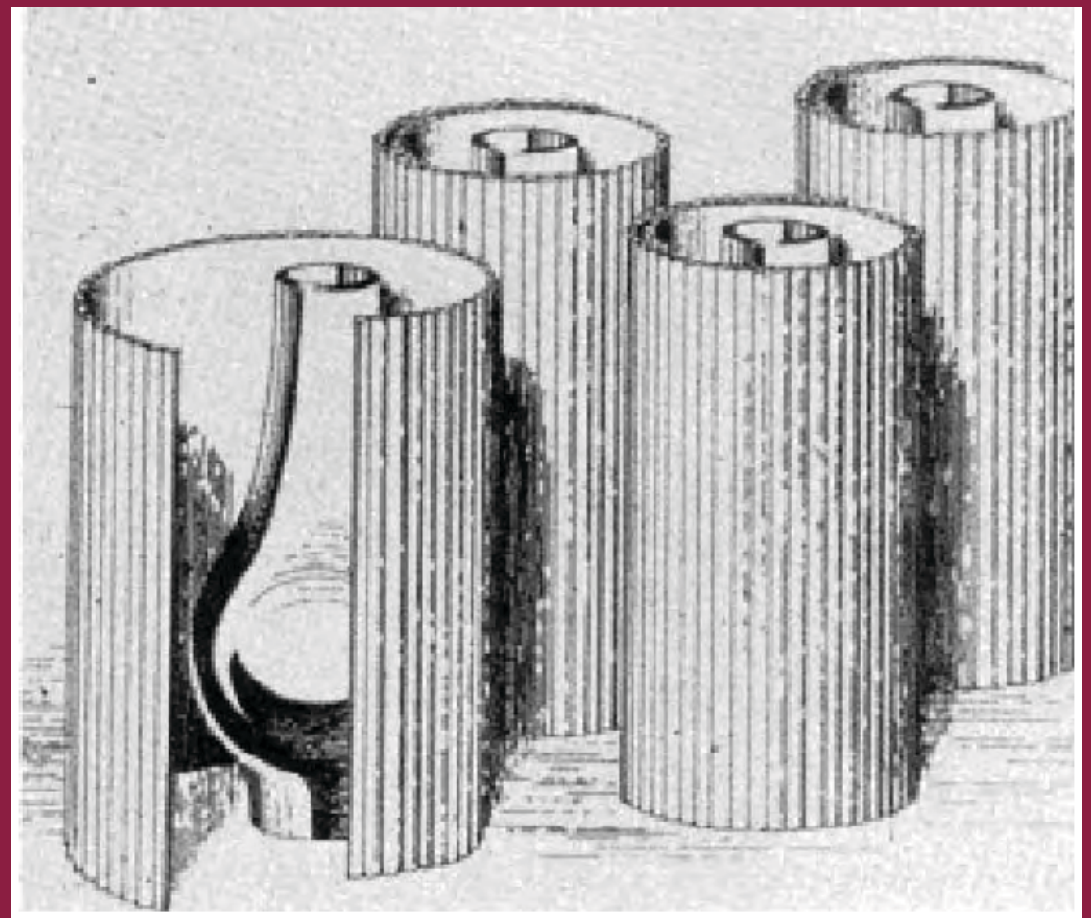
Design Steps for Stacking Strength…



Material

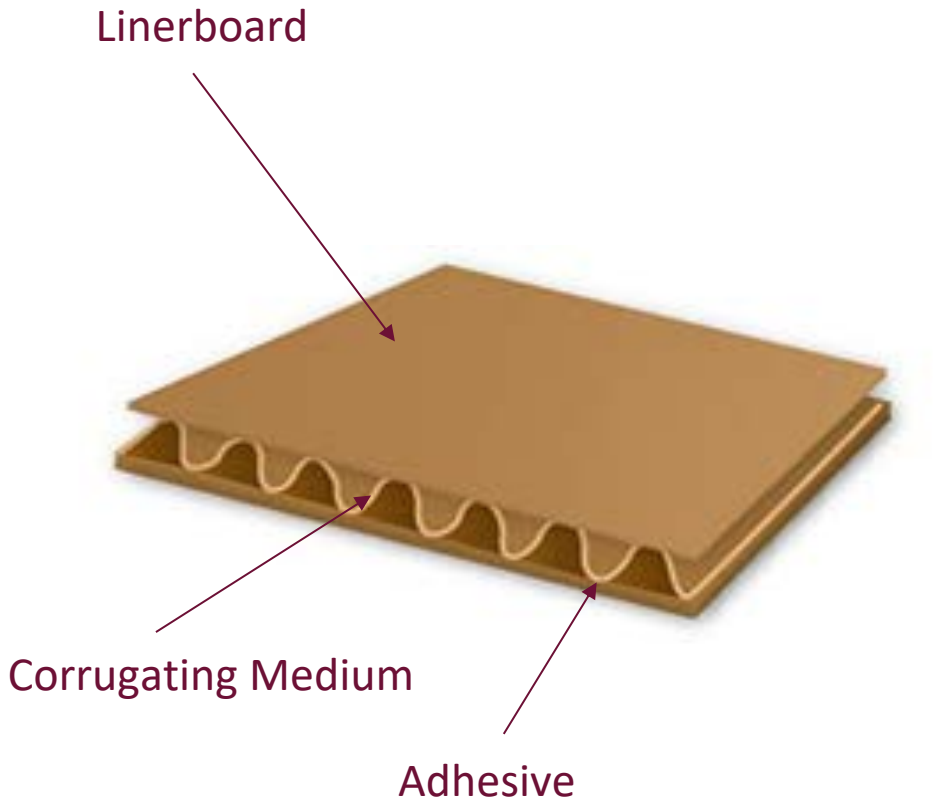
Structure of Single Unit

Structure of Unit Load



History of Corrugated Boards

- 1871 Albert Jones patented the first idea of a fluted paper
- 1874 Oliver Long suggested the creation of the single face board
- Late 1870, Machinery was developed to make corrugated board
- 1890 Another liner was added which resulted the first single wall corrugated board



Corrugated Board Basics

Components:

- Linerboard
- Corrugating Medium
- Adhesive

- Linerboard and medium are characterized using Basis Weight Grades

- **Basis Weight:** Weight of the board in lbs per 1000 sq. ft.

Corrugated Board Basics

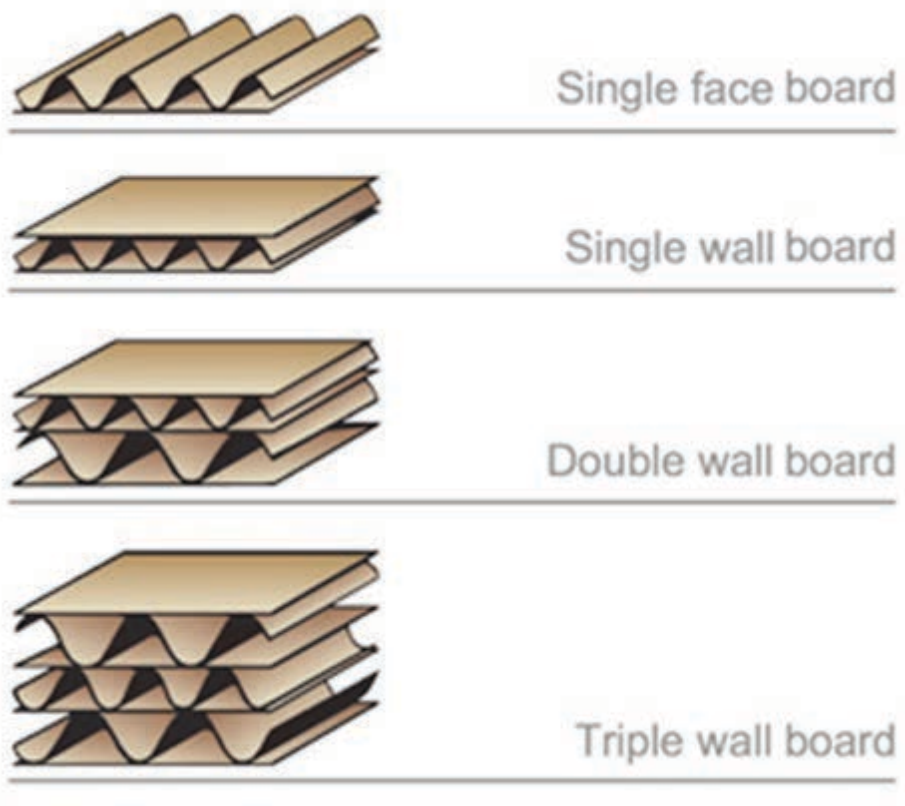
- Most common medium is the 26 lbs / 1000 sq./ft.
- Basis weight grade specified board is characterized by weight and Mullen burst strength.

Corrugating Medium Grades (lbs. /1000ft^2)
23
26 (most common)
30
33
36
40

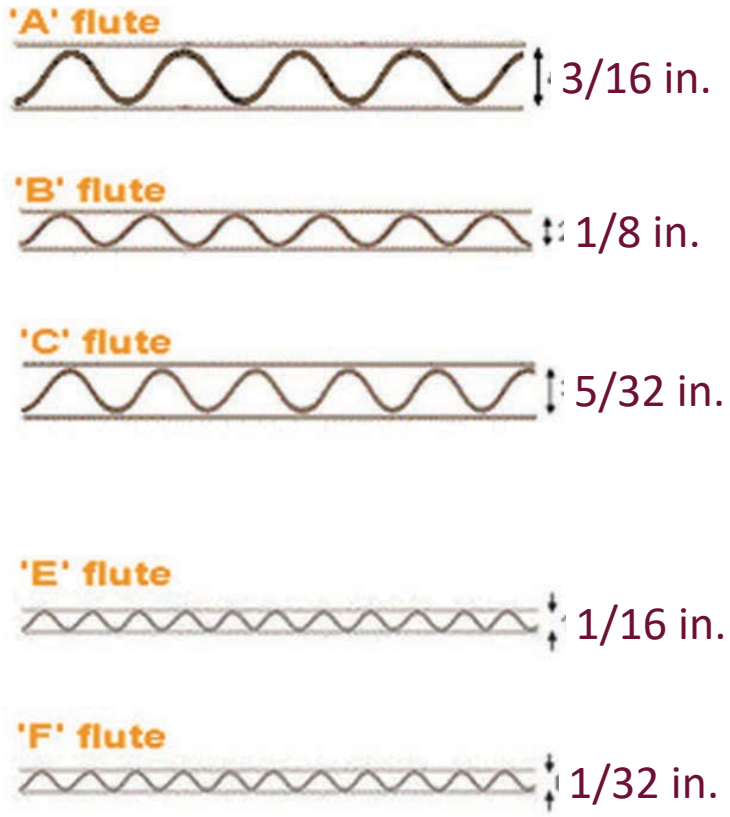
Linerboard Grades (lbs. /1000ft^2)	
Basis Weight Grades	Burst Strength (Psi)
26	70
33	85
38	92
42	100
69	135
90	160

Corrugated Board Basics

- Corrugated Board Types



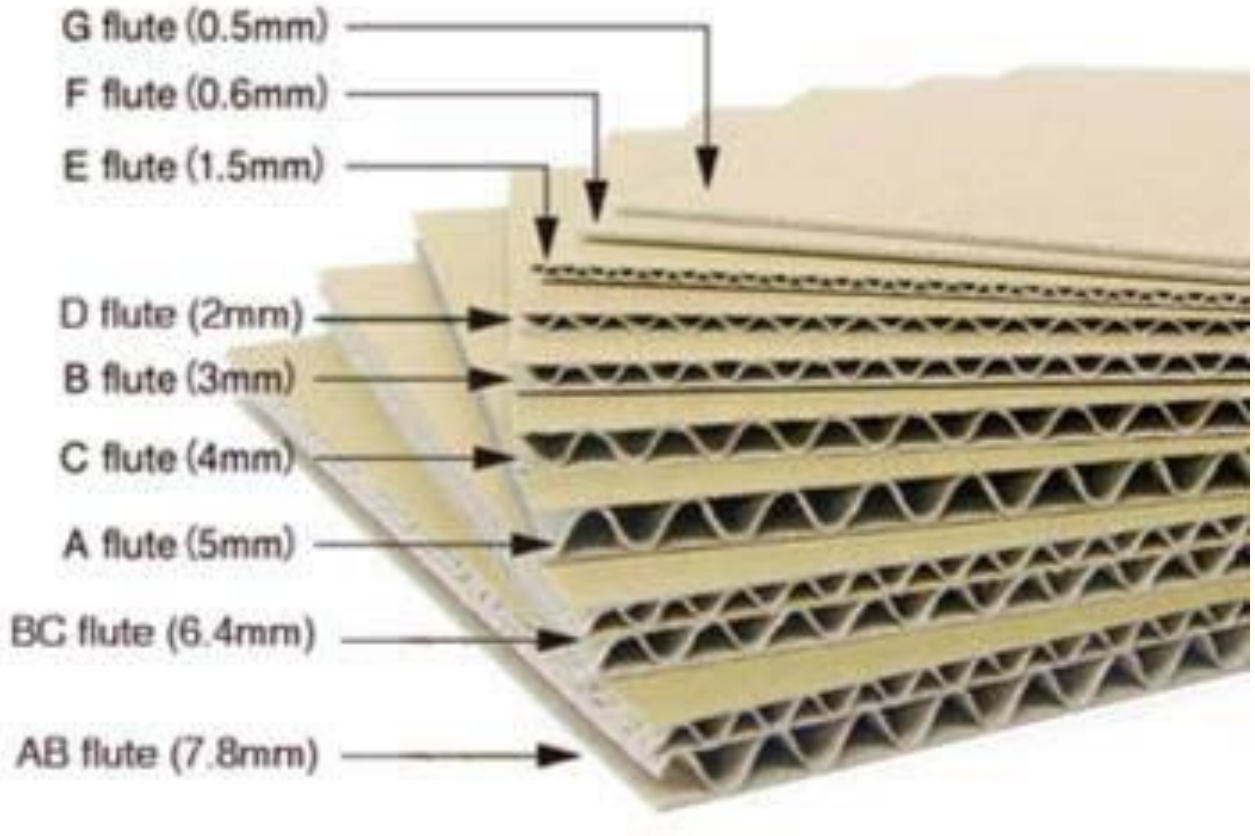
- Corrugated Flute Types



Corrugated Board Basics

Characteristics	A-flute	C-flute	B-flute	E-flute
Stack Strength	Best	Good	Fair	Poor
Printing	Poor	Fair	Good	Best
Die Cutting	Poor	Fair	Good	Best
Puncture	Good	Best	Fair	Poor
Storage Space	Most	Fair	Good	Least
Score/Bend	Poor	Fair	Good	Best
Cushioning	Best	Good	Fair	Poor
Flat Crush	Poor	Fair	Good	Good

Corrugated Board Basics



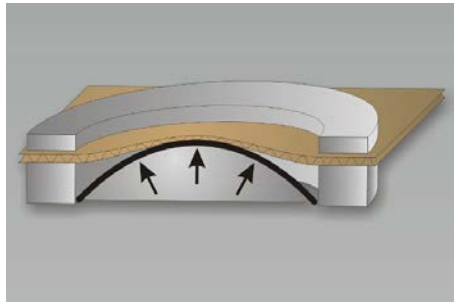
- **Double wall corrugated**
  - Provides extra strength to the box
  - Allows the utilization of the advantages of multiple board types
  - BC or AB-flute board:
    - B-flute side prints better
    - A or C-flute side strengthens

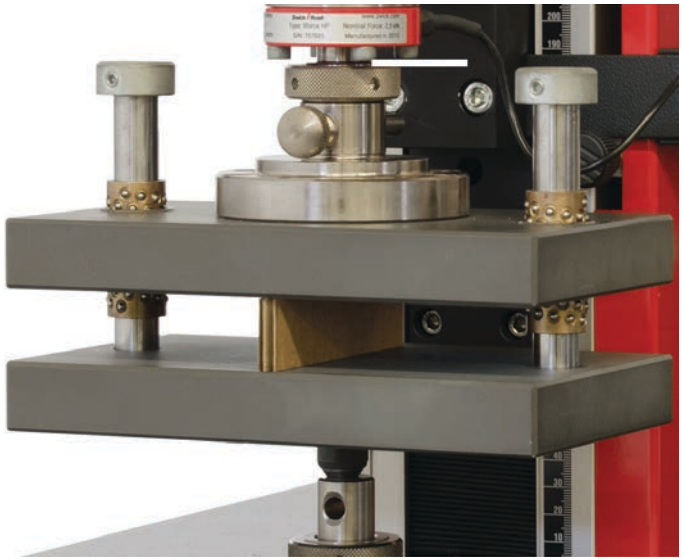
Corrugated Board Basics

- The Corrugated Board Grade identifies the liner and medium combination.

- Outside liner - Medium(Flute type)- Inside liner
  - Example
    - 42-26C-42
    - 56-33C-56
    - 33-26B-33-26C-33

- Board grade identifies specific performance attributes of combined board

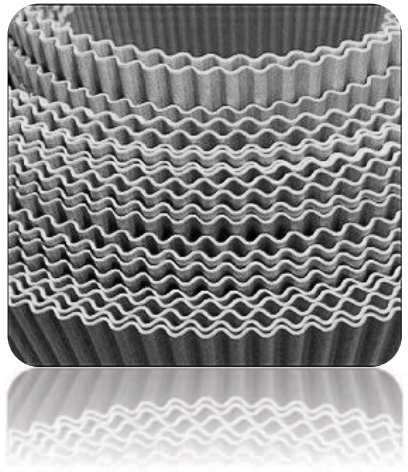




Corrugated Board Mechanical Properties

- **Burst Strength test (TAPPI 810)**
  - Measure the resistance of the corrugated board against rupture
  - Measures the strength of the liners
- **Edge crush test (TAPPI T811)**
  - Measures the strength in the flute direction
  - Used to determine box stacking strength

Design Steps for Stacking Strength…

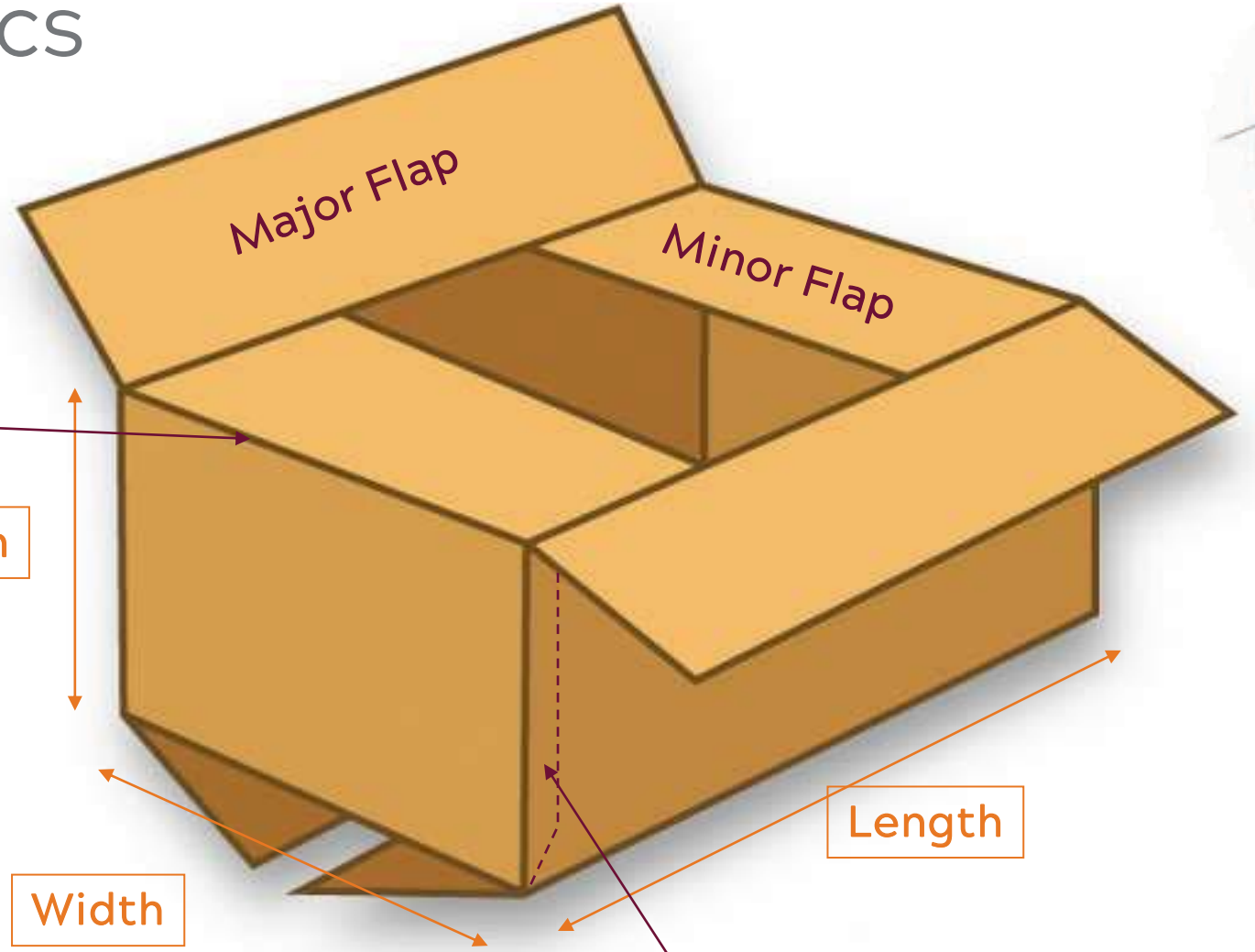


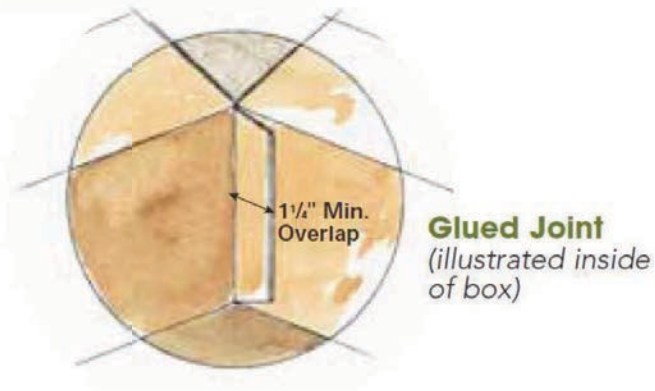
Material

Structure of Single Unit

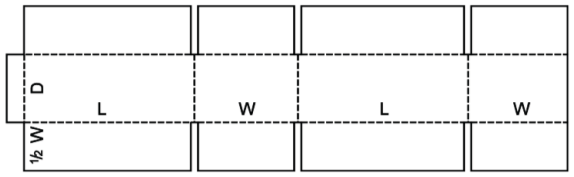
Structure of Unit Load

Box Basics





Manufacturer's Joint



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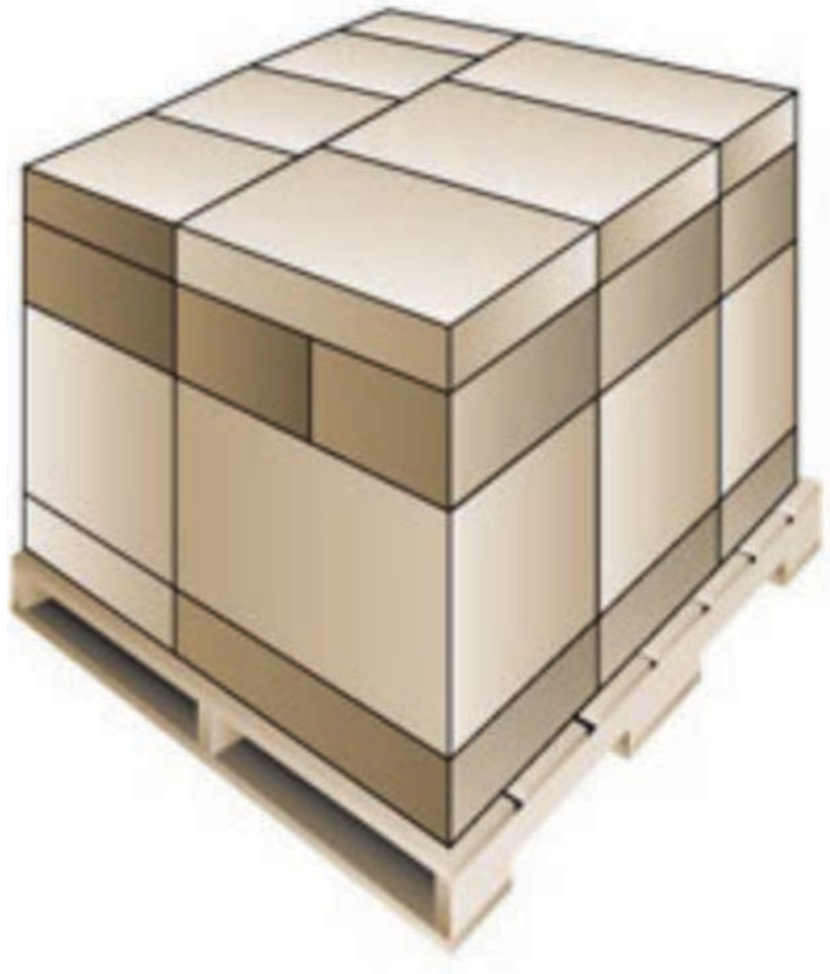
Corrugated Box -Sizes

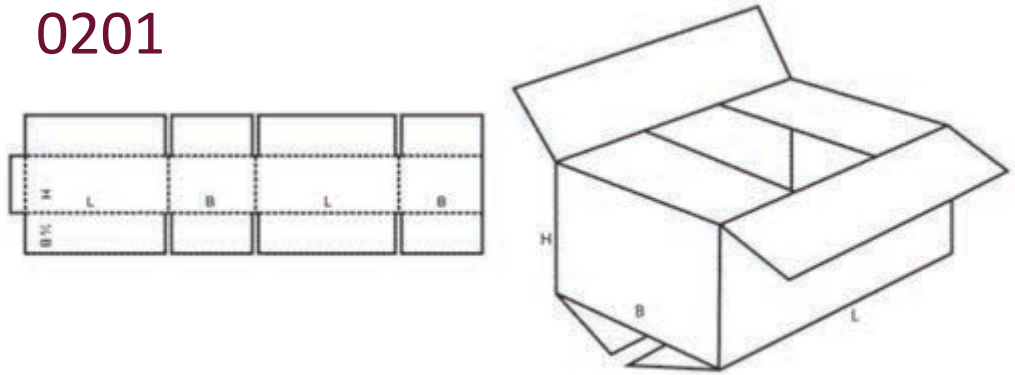
- **Common footprint** was developed to create standard footprint in the retail sector
- Most popular: **600mm x 400mm**
- Fit 5 boxes on a 1,200mmx1,000mm pallet
- Fractions:
  - 300mmx400mm
  - 300mmx200mm
  - Etc.



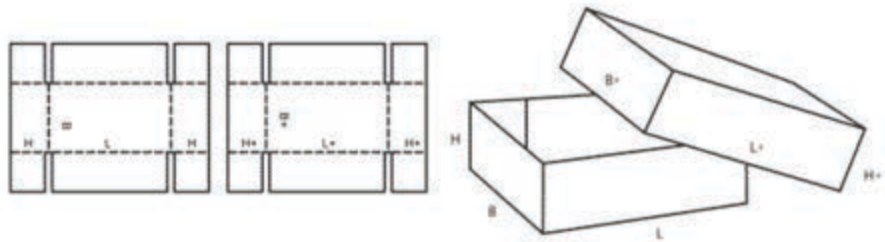
Corrugated Shipper - Styles

- FEFCO Corrugated Box Standard
- Styles:
  - 01 - commercial rolls and sheets
  - 02 - slotted- type boxes
  - 03 - telescope- type boxes
  - 04 - folder- type boxes and trays
  - 05 - slide- type boxes
  - 06 - rigid- type boxes
  - 07 - ready- glued cases
  - 09 - interior fitments

0201

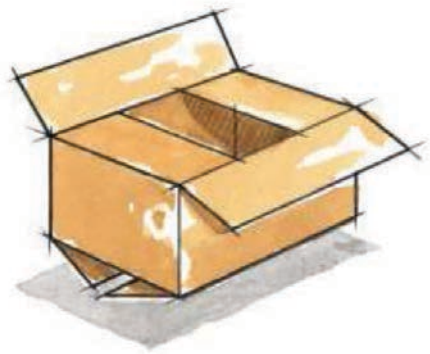


0300

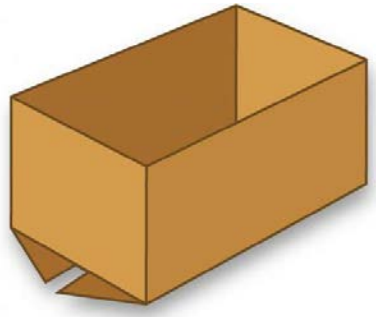


https://www.gwp.co.uk/packaging/packaging-products/fefco-styles/#codes

Corrugated Shipper - Styles

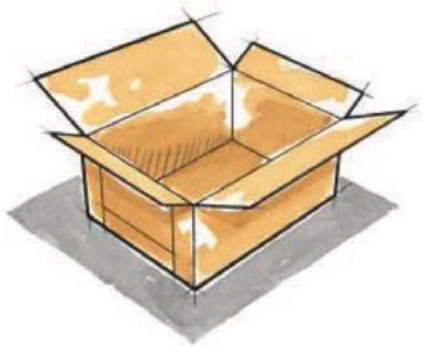


0201 Regular Slotted Container (RSC)

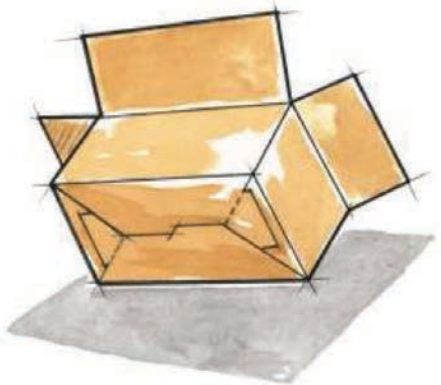


0200 Half Slotted Container (HSC)

0427 Roll End Tray with locking Cover



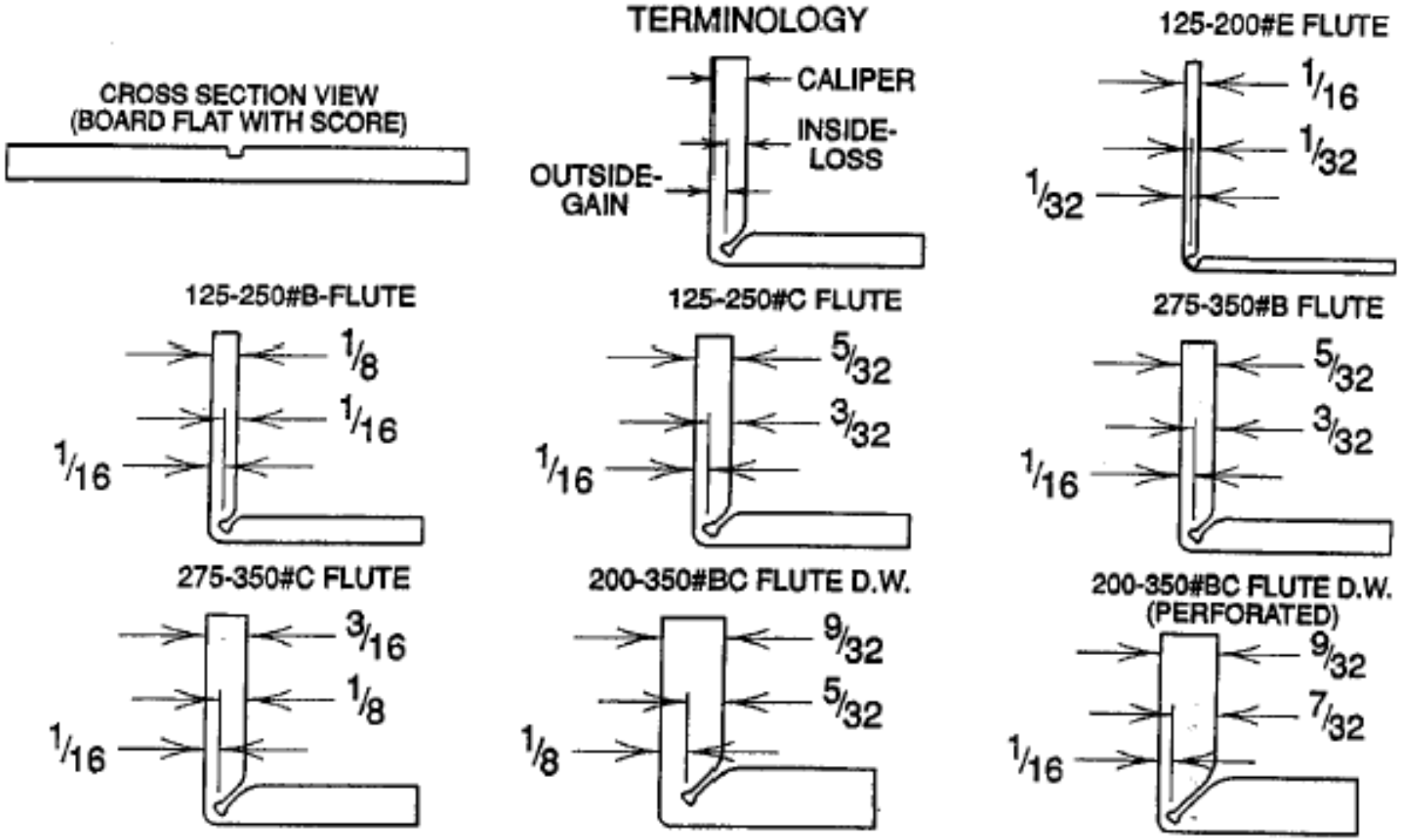
06 Bliss Style



0711 Pre-glued Auto Bottom with RSC Top Flaps

https://www.iopp.org/files/Fibrebox_Association_Box-Styles_Basics.pdf

How Corrugated Folds:



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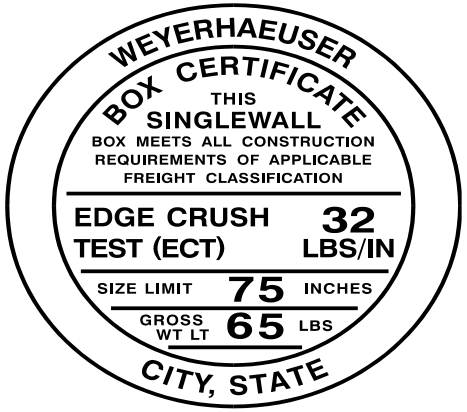
Maximum Weight of Box and Contents (lbs.)	Maximum Outside Dimensions, (Length + Width + Depth) (in.)	Minimum Bursting Test (lbs. per sq in.)	Minimum Edge Crush Test (lbs. per sq in.)
Single Wall			
20	40	125	23
35	50	150	26
50	60	175	29
65	75	200	32
80	85	250	40
95	95	275	44
120	105	350	55
Double Wall			
80	85	200	42
100	95	275	48
120	105	350	51
140	110	400	61
160	115	500	71
180	120	600	82

Carrier Rules

- Truck: National Motor Freight Classification (NMFC)
- Rail: Uniform Freight Classification (UFC)
- Requires all box to comply with the requirements and have the Box Certificate.



Weyerhaeuser

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Basics of Mechanics of Corrugated Box

Compression

- **Definition:** compression load resulting from static (warehouse stacking) or dynamic (clamping) load on a container or other package

Dynamic Lateral Compression

Static Vertical Compression

Compression

What is box compression strength?

Definition: Resistance of the box against compression forces applied perpendicularly to one or more of its faces.

Box Compression Strength

- Box Compression Strength can be determined in two ways:
  - Calculated using simplified McKee equation
  - Measured using a short term box compression test

Calculation of Box Compression Strength

- Box Compression Test (BCT):

$$BCT = 5.87\ ECT\sqrt{P\ Z}$$

- Where:
  ECT - edge crush test (lbf/in)
  P - box perimeter (2L + 2W) (in)
  Z - caliper of combined corrugated board (in)

- Calculation is not applicable for all size and construction
- Mainly applies to RSC, HSC, or Telescopic Boxes

Measurement of Box Compression Strength

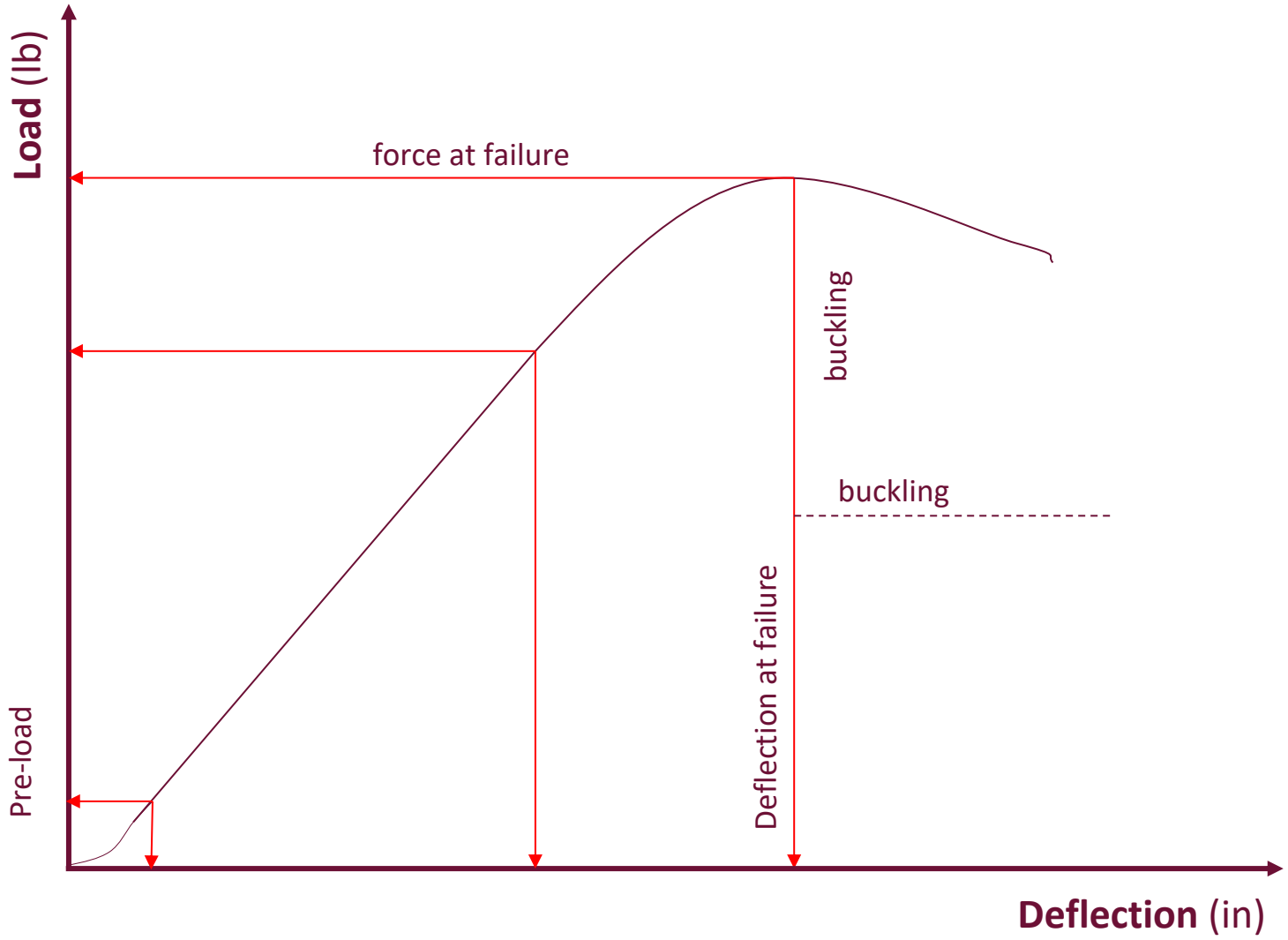
Short-Term Compression

- **ASTM D642** - Compression Test for Shipping Containers (https://www.astm.org/Standards/D642.htm)

- **Procedure**
  - Apply preload
    - 50lb for single wall box
    - 100lb or 500lb for double or triple wall box

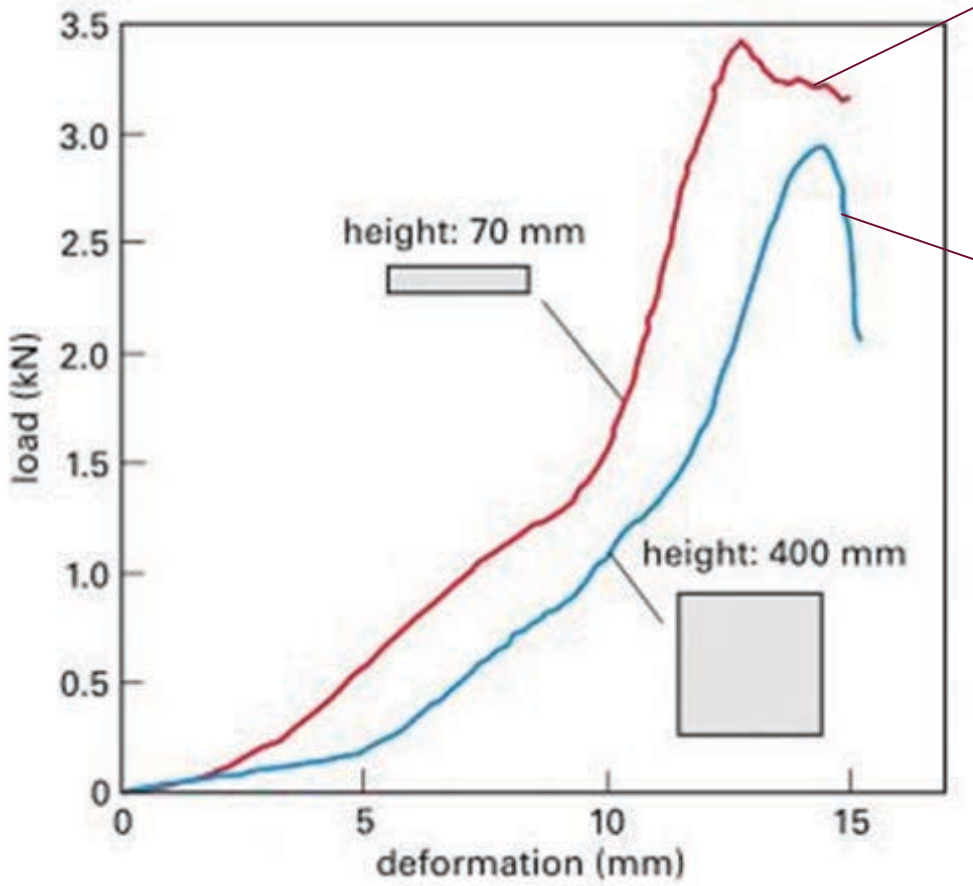
  - Recommended: 5 samples
  - Record load and deflection (500lb @ 0.5” or 1000psi)
  - Test until visual failure
  - Failure of the box does not mean that the package failed

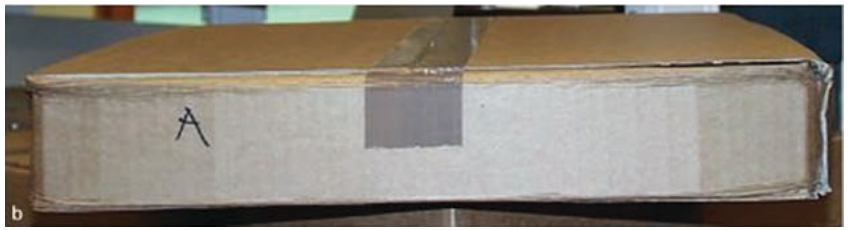
Load-Deflection Curve



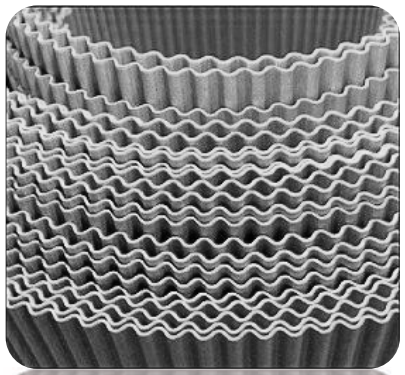
Failure Modes Based on Aspect Ratio

- Always run the tests until visible failure occurs!





Design Steps for Stacking Strength…



Material

Structure of
Single Unit

Structure of
Unit Load

Determining Stacking Strength

- **Stacking Strength**- the amount of load that the box can safely hold.

$$Stacking\ Strength = \frac{BCT}{Safety\ Factor}$$

Determining Stacking Strength

- Influencing factors:
  - Product and package interaction
  - Humidity
  - Time
  - Stacking misalignment
  - Pallet overhang
  - Transportation
- Fix safety factors or Retention Analysis are used to account for these influencing factors

Determining Stacking Strength

- **Fixed safety factor:** often used when the exact conditions that the package will be subjected to are not known.

- Range of safety factors can be found in ASTM D4169

- **Depends on:**
  - Assurance level
  - Package type
  - Transportation mode
    - Warehouse (static)
    - Vehicle (dynamic)

	F Factors Assurance Level					
	Schedule B—Warehouse			Schedule C—Vehicle		
Shipping Unit Construction	I	II	III	I	II	III
1. Corrugated, fiberboard, or plastic container that may or may not have stress–bearing interior packaging using these materials, and where the product does not support any of the load.	8.0	4.5	3.0	10.0	7.0	5.0
2. Corrugated, fiberboard, or plastic container that has stress-bearing interior packaging with rigid inserts such as wood.	4.5	3.0	2.0	6.0	4.5	3.0
3. Containers constructed of materials other than corrugated, fiberboard, or plastic that are not temperature or humidity sensitive or where the product supports the load directly, for example, compression package.	3.0	2.0	1.5	4.0	3.0	2.0

Determining Stacking Strength

- **Assurance Levels:**
  - The levels are determined based on
    - the product value,
    - the desired level of anticipated damage that can be tolerated,
    - the number of units shipped,
    - the knowledge of the shipping environment, or
    - other criteria

- **ASTM Assurance Levels:**
  - Level 1 - Low probability, High intensity events (more severe than Level 2)
  - Level 2 - (Commonly used)
  - Level 3 - High probability, low intensity events (less severe than level 2)

Example 1

Safe Stacking Strength using Fixed Safety Factor method:

- Suppose you compression test a package in the lab under standard conditions and get a compression strength of 800 lbs. The package is made out of corrugated box without any rigid internal supports. The client want to use Assurance Level II.

- **How much is the safe stacking strength of the package in a warehouse?**

Example 1

Safe Stacking Height using Fixed Safety Factor Method:

- BCT= 800 lbs.
- **Safe Stacking Strength=?**

Shipping Unit Construction	F Factors Assurance Level Schedule B—Warehouse I	II	III	Schedule C—Vehicle I	II	III
1. Corrugated, fiberboard, or plastic container that may or may not have stress–bearing interior packaging using these materials, and where the product does not support any of the load.	8.0	4.5	3.0	10.0	7.0	5.0
2. Corrugated, fiberboard, or plastic container that has stress-bearing interior packaging with rigid inserts such as wood.	4.5	3.0	2.0	6.0	4.5	3.0
3. Containers constructed of materials other than corrugated, fiberboard, or plastic that are not temperature or humidity sensitive or where the product supports the load directly, for example, compression package.	3.0	2.0	1.5	4.0	3.0	2.0

F factor

$$Safe\ Stacking\ Strength = 800/4.5 = 177.78\ lb$$

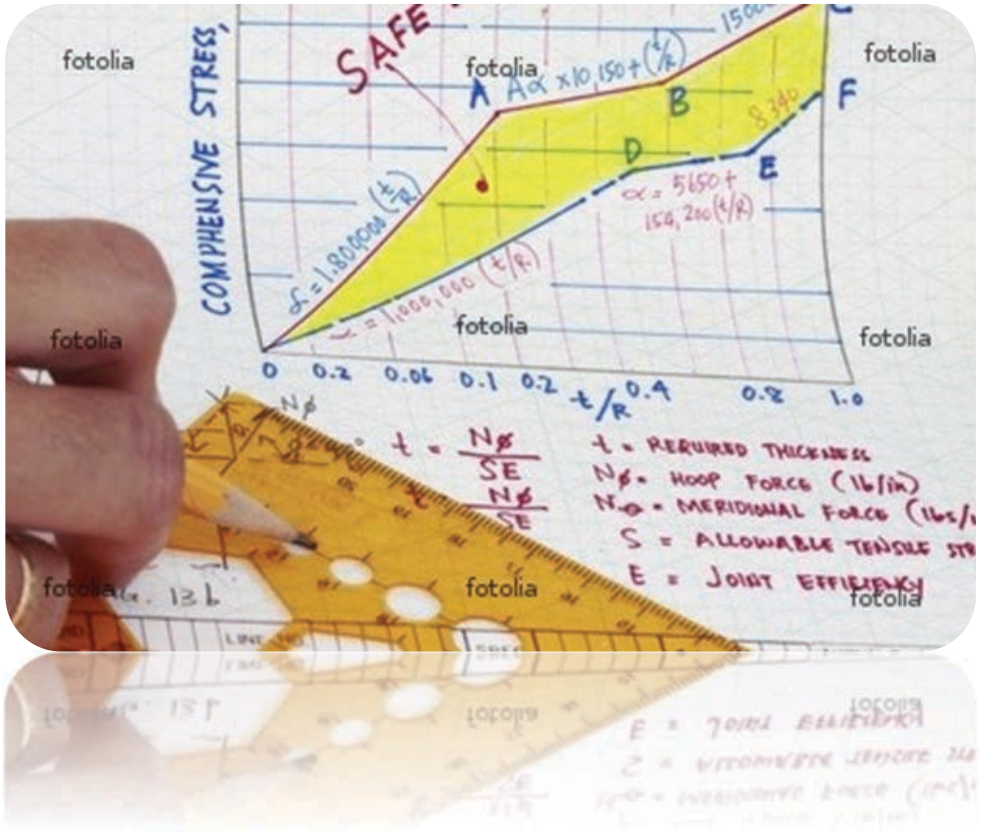
Determining Stacking Strength

Retention Analysis:

- Aimed at evaluating the compression strength retained by the package in the presence of the debilitating influences

$$\textbf{\textit{Safety Factor}}: \left(\frac{1}{H \cdot T \cdot PP}\right)$$

H – Humidity
T – Storage Time
PP – Pallet Pattern



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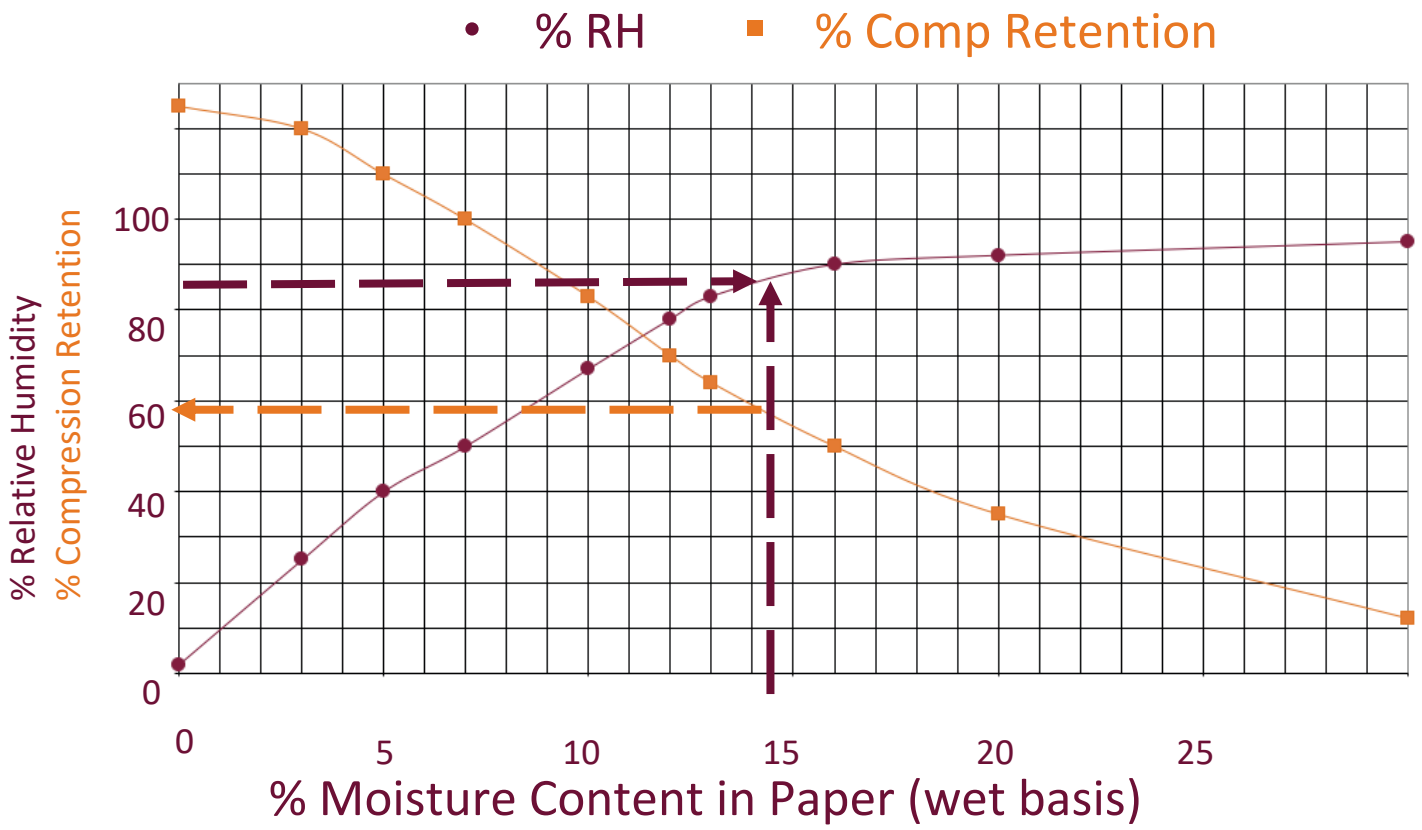
Determining Stacking Strength

Retention Analysis:

- **Humidity Factor (H)**
  - Humidity weakens the box because of absorption
  - 85% Relative Humidity (RH) is common in warehouse across the U.S.

RH	0%	25%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
H	125%	110%	100%	96%	91%	86%	81%	75%	68%	60%	48%	29%



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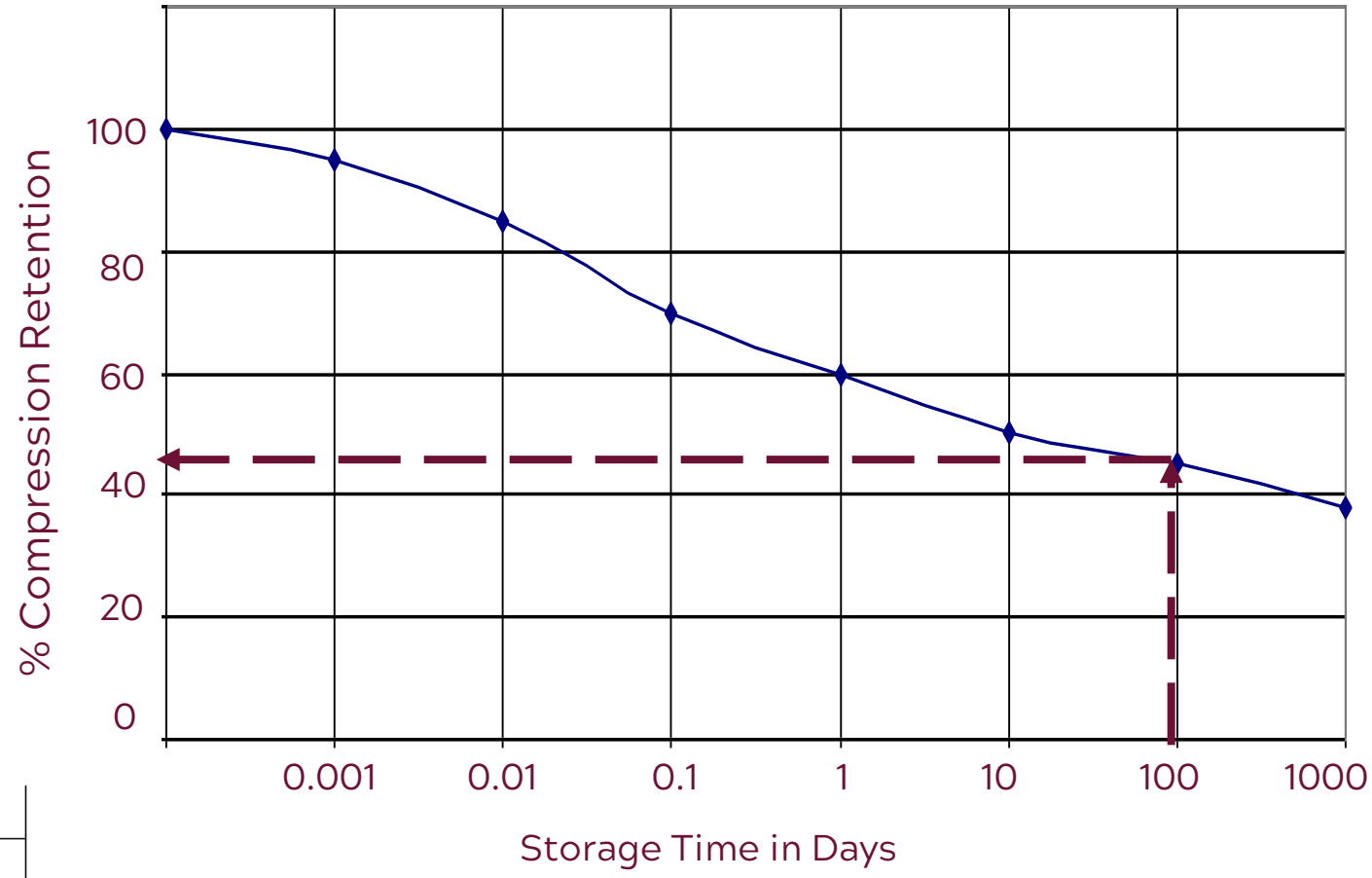
Determining Stacking Strength

Retention Analysis:

- **Storage Time Factor (T)**
  - Box weakened due to fatigue
  - Common to store loads up to 90 days.

Time	0	1	6	12 hrs	1	2	3	4	5	10	30	60	90	180 days	1	2 yrs
T	100%	87	79	76	73	70	68	67	66	64	60	57	55	52	50	46



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Determining Stacking Strength

Retention Analysis:

- **Pallet Pattern Factor (PP):**
  - Column stacked and aligned: 8% loss
  - Column stacked and misaligned: 10-15% loss
  - Interlocked: 40-60% loss
  - Overhang: 20-40%
  - Deck board gap: 10-25% loss
  - Excessive handling: 10-40% loss

Example 2

Corrugated box strength: 800 lb

H (85%)= 0.60

T (90 days)= 0.55

PP (Column stacking, misaligned) = 0.85

PP (Deckboard gap)= 0.75

$$Stacking\ Strength = \frac{800\ lb}{\left(\frac{1}{0.60 \cdot 0.55 \cdot 0.85 \cdot 0.75}\right)} = \frac{800}{4.76} = 168\ lb$$

Example 3

Corrugated box strength: 800 lb

H (85%)= 0.60

T (90 days)= 0.55

PP (interlock stacking) = 0.40

PP (Deckboard gap)= 0.75

PP (Overhang)= 0.80

62% Reduction

$$Stacking\ Strength = \frac{800\ lb}{\left(\frac{1}{0.60 \cdot 0.55 \cdot 0.40 \cdot 0.75 \cdot 0.80}\right)} = \frac{800}{12.6} = 63.4\ lb$$

Box Analysis in PDS 6.1

Container Type: Corrugated Box

Box Style: Regular Slotted Container (RSC) #0201
Combined Board Type: Singlewall
Flute Profile: C-Flute
Caliper: *0.156 in.*
ECT (lb/in): 32
Simplified Mckee Box Crush Capacity: 555 lbs.
Stacked 1 Unit Load High:
Max Uniform Box Loading: 60 lbs.
Rigid Surface Safety Factor: 9.3

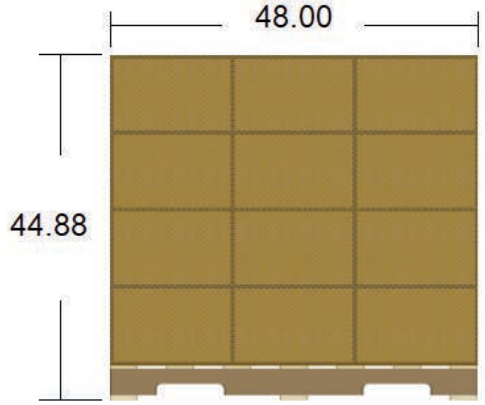
Box Outside Dimensions: 16.000 X 12.000 X 10.000 in.
Weight per Box: 20.0 lbs.
Total Weight of Load: 720 lbs.
Weight of Complete Unit Load: 762 lbs.

Number of Boxes per Layer: 9
Number of Layers per Unit Load: 4, Column Stacked
Number of Boxes per Unit Load: 36

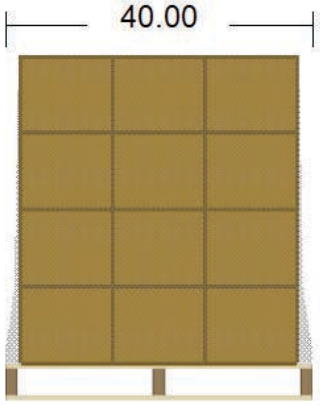
Load Stabilizers

Wrap: Stretch Wrap

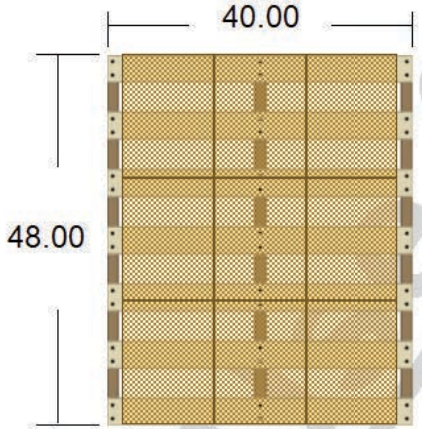
Side View

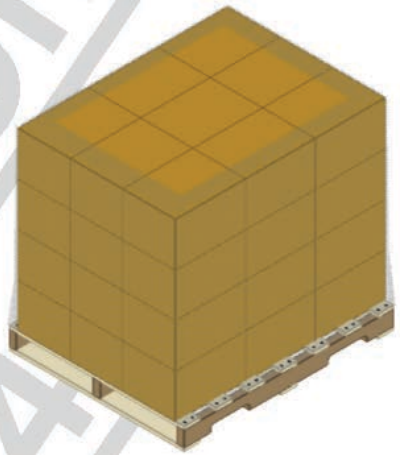


End View



Top View





THANK YOU FOR YOUR ATTENTION

LASZLO HORVATH
ASSOCIATE PROFESSOR
DIRECTOR, CENTER FOR PACKAGING AND UNIT LOAD DESIGN

APRIL 23, 2020