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Standard Practice for Selection of Corrugated Fiberboard Materials and Box Construction Based on Performance Requirements[1]

This standard is issued under the fixed designation D 5639/D5639M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

ϵ^1 NOTE—Editorial corrections were made in April 2000.

1. Scope

1.1 This practice provides information on corrugated fiberboard for the prospective user who wants guidance in selecting attributes of materials and box construction based on performance requirements. These attributes should be part of specifications which establish levels of the qualities a shipping container must have in order to be acceptable to the purchaser or user. The attributes and qualities should be testable, using standard methods that are recognized by both the buyer and seller. This practice will assist users in developing specifications for corrugated containers through an analysis of performance requirements and subsequent relationships to fiberboard materials and box construction attributes. This practice is intended to provide specific corrugated container performance standards as opposed to packaged product performance evaluation through distribution and handling environments, such as Practice D 4169.

1.2 The attributes and their levels should be based on the intended use of the box, including the handling and environment it will encounter. Many packaging regulations include detailed descriptions of the materials that may be used and style, closure, or other construction details of allowed shipping containers. These regulations are presented as minimum requirements; they may be exceeded for functional reasons, but there is no regulatory reason to do so. Rail and motor freight classifications applicable for surface common carrier transportation have established minimum requirements for certain attributes of corrugated packaging. These may or may not be appropriate for application in the complete distribution system, as they encompass only containerboard or combined corrugated board—not finished boxes—and are not intended to provide for the distribution system beyond the transportation segment.

1.3 Corrugated containers for packaging of hazardous materials for transportation must comply with federal regulations administered by the U.S. Department of Transportation (Code of Federal Regulations—49CFR).

1.4 The values stated in both SI and inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system shall be used independently of the other.

1.5 *Lists and Descriptions of Performance and Material Characteristics and Related Test Procedures*—For further information on the development of performance-based specifications, please refer to the sections on Specifications and Test Procedures of the Fibre Box Handbook.

1.6 *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 *ASTM Standards:*

D 585 Practice for Sampling and Accepting a Single Lot of Paper, Paperboard, Fiberboard, and Related Products[2]

D 642 Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads[2]

D 685 Practice for Conditioning Paper and Paper Products for Testing[2]

D 996 Terminology of Packaging and Distribution Environments[2]

D 4169 Practice for Performance Testing of Shipping Containers and Systems[2]

D 5118 Practice for Fabrication of Fiberboard Shipping Boxes[2]

D 5168 Practice for Fabrication and Closure of Triple Wall Corrugated Fiberboard Containers[2]

D 5276 Test Method of Drop Test for Loaded Containers by Free Fall[2]

E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process[3]

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[1] This practice is under the jurisdiction of ASTM Committee D-10 on Packaging and is the direct responsibility of Subcommittee D10.27 on Paper and Paperboard Products.

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[2] *Annual Book of ASTM Standards*, Vol 15.09.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

2.2 *TAPPI Methods:*

T 411 Thickness of Paper, Paperboard, and Combined Board[4]

T 803 Puncture Test of Corrugated Fiberboard[4]

T 808 Flat Crush Test of Corrugated Fiberboard-Flexible Beam Method[4]

T 810 Burst Test of Corrugated Fiberboard[4]

T 811 Edgewise Crush Test of Corrugated Fiberboard[4]

T 825 Flat Crush Test of Corrugated Fiberboard-Fixed Platen Method[4]

2.3 *Government Documents:*

Code of Federal Regulations, Title 49[5]

2.4 *Other Publications:*

Fibre *Box Handbook*[6]

National Motor Freight Classification Item 222[7]

Uniform Freight Classification Rule 41[8]

3. Terminology

3.1 Definitions—For general definitions of packaging and distribution environments, see Terminology D 996.

4. Significance and Use

4.1 This practice assists users in selecting appropriate performance characteristics of corrugated fiberboard or box construction, or both, commensurate with the user's need for packing and distribution of goods. This practice describes several attributes of fiberboard and boxes which relate to various hazards encountered in distribution and describes test parameters which may be specified by the user to ensure sufficient strength in the box for containment, storage, handling, and protection of contents.

4.2 The user should specify only those attributes and related tests which are required for satisfactory performance in the user's operations and distribution cycle(s). When using packaging regulations as a basis for developing specifications, the reason for the existence of the regulation and its function and importance should be understood. As previously stated, regulations may be exceeded and should be when the minimum specifications are inadequate for the full effects of the distribution cycle.

4.3 See Appendix X7 for several examples of specification determinations.

5. Sampling

5.1 Selection of a sampling plan depends on the purpose of the testing. The sampling plan from Appendix X2.2.2 of Practice D 585 is recommended for acceptance criteria. An example of acceptance and rejection criteria based on various lot sizes may be found in Appendix X1. For purposes of other than acceptance criteria, use Practice E 122.

6. Conditioning

6.1 All test specimens shall be preconditioned, conditioned, and tested in accordance with Practice D 685.

7. Fiberboard Attributes

7.1 Corrugated fiberboard is commercially available in three wall constructions, and four common flute structures. The user should specify desired wall construction and flute structure based on performance requirements.

7.1.1 *Construction—Singlewall* board is used for lighter contents where some structural rigidity, compression strength, puncture resistance, and cushioning is needed. *Doublewall* board is used for heavier contents requiring a greater degree of structural rigidity, compression strength, and puncture resistance. *Triplewall* is used for the heaviest contents where maximum structural rigidity, compression strength, and puncture resistance are required.

7.1.2 *Flute Structure*—"A" flute offers the highest top-to-bottom compression strength, but low resistance to flat crush. "B" flute has high flat crush resistance but lower top-to-bottom compression than "A" or "C". "C" flute is the most common with average resistance to flat crush and top-to-bottom compression. "E" flute generally replaces solid boxboard, has excellent flat crush resistance, is used mostly for graphics and consumer products, but seldom used for shipping containers. The following typical flute structures are provided as a reference:

	Approximate Number		Approximate Flute Height (not including thickness of facings)	
	Flutes/Meter	Flutes/Foot	mm	[in.]
A-Flute	100 to 120	[30 to 36]	4.67	[0.184]
B-Flute	145 to 165	[44 to 50]	2.46	[0.097]
C-Flute	120 to 140	[36 to 42]	3.61	[0.142]
E-Flute	280 to 310	[86 to 94]	1.19	[0.047]

7.2 *Burst Strength*—This attribute relates to the tensile strength and stretch elongation of the fiberboard. It also provides rupture strength as protection against rough handling.

7.2.1 Burst Strength is measured by the burst (Mullen) test utilizing TAPPI Method T 810.

7.2.2 There is no direct relationship, such as a formula, to relate box handling performance to needed burst strength. However, as a function of box size and weight of the filled package, minimum burst strength requirements for corrugated packaging used in surface common carrier transportation are published in the rail and truck classifications and are shown in Table X2.1. These requirements may or may not be appropriate for the user's applications.

7.3 *Puncture Resistance*—This attribute relates to the ability of the fiberboard to resist both internal and external forces. It also relates to the rough handling integrity of the finished container.

7.3.1 Puncture resistance is measured by the puncture test utilizing TAPPI Method T 803.

7.3.2 There is no direct relationship, such as a formula, to predict rough handling performance of a box based on the puncture resistance of the fiberboard from which it is made.

[4] Available from the Technical Association of the Pulp and Paper Industry, One Dunwoody Park, Atlanta, GA 30341.

[5] Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[6] Available from the Fibre Box Association, 2850 Golf Rd., Rolling Meadows, IL 60008.

[7] Available from American Trucking Association, Inc., 2200 Mill Rd., Alexandria, VA 22314-4677.

[8] Available from National Railroad Freight Committee, Tariff Publishing Officer, 151 Ellis Street, NE, Suite 200, Atlanta, GA 30335.

Shippers and carriers, however, have used various puncture grades successfully for years as noted in Appendix X3. Table X3.1 lists suggested puncture strengths versus maximum gross weights and size. These requirements may or may not be appropriate for the user's application.

7.4 *Edgewise Crush Resistance*—This attribute of fiberboard relates directly to the finished box compression strength through the well-known simplified formula published in 1963 by the Institute of Paper Chemistry (now the Institute of Paper Science and Technology, or IPST) and commonly known as the McKee Formula. Other versions of the McKee Formula utilize the exponent values of box perimeter and board thickness instead of the square root function, or bending stiffness instead of board thickness, and will understate the resultant box compression by about 5 % compared to the simplified square root method.

7.4.1 The simplified McKee Formula is:

$$BCT = (5.87) \times (ECT) \times \sqrt{(BP) \times (T)} \tag{1}$$

where:

BCT = estimated average top to bottom compression test strength of an RSC box, kN [lbf],
ECT = edge crush test, kN/m [lb/in.],
BP = inside box perimeter (sum of twice inside length and twice inside width), m [in.], and
T = combined board thickness, m [in.].

When solving for ECT using this formula, rearrange as follows:

$$\text{Estimated average } ECT = \frac{\text{Required BCT}}{5.87 \times \sqrt{BP \times T}} \tag{2}$$

See Appendix X4 for example and limitations of formula use.

7.4.2 Edgewise crush resistance is measured by the edgewise crush test (ECT) utilizing TAPPI Method T 811.

7.4.3 Although, as shown in 7.4.1, ECT directly relates to finished box compression strength, the rail and truck classifications have minimum *ECT* requirements as an alternate to minimum burst strength requirements as shown in Table X4.1. These requirements may or may not be appropriate for the user's application.

7.5 *Minimum Uncombined Flute Height*—The overall thickness (caliper) of corrugated fiberboard is an important material attribute relating directly to finished box compression strength. Since thickness consists primarily of the flute structures, *minimum* flute heights may be specified, *not* including any linerboards (facings).

7.5.1 Use as minimum flute heights, the manufacturer's target flute heights, *minus* 4 %.

7.5.2 *Test Method*—First measure the thickness of the combined board structure using TAPPI Test Method T 411. Then measure the thickness of each facing (linerboard), without soaking apart, and subtract the thickness of the facings to obtain flute structure(s) height. All readings must be taken at least 25 mm [1 in.] from any score line, cut edge, or printed area.

7.6 *Flat Crush Resistance*—This attribute is an indication of the rigidity of the flute structure which is in turn directly related to the finished box compression, printing crush resistance, and quality of fabrication practice.

7.6.1 Combined singlewall fiberboard should meet the following minimum flat crush requirements:

Flute	Flexible Beam Method, kPa [lbf/in.^{2}]
A	130 [19]
B	200 [29]
C	165 [24]

7.6.2 Flat crush resistance is measured by the flat crush test (*FCT*). The above values are measured by using the flexible beam test method of TAPPI T808. An alternate method utilizing the fixed beam, TAPPI T825, is also available but will produce values about 20 to 30 % higher.

7.7 *Printing Crush*—Excessive printing crush of fiberboard will reduce compression strength of the finished box and adversely affect automatic packing equipment and warehouse stacking.

7.7.1 The following are suggested *maximum* crush deformations for singlewall boards:

	Oil-Based Inks, mm [in.]	Water-Based Inks, mm [in.]
A-flute	0.38 [0.015]	0.20 [0.008]
B-flute	0.28 [0.011]	0.15 [0.006]
C-flute	0.33 [0.013]	0.18 [0.007]

7.7.2 For doublewall boards used 75 % of the combination of flute structure allowances, for triplewall use 50 % (that is, AAA-flute has maximum allowable crush of 0.30 mm [0.012 in.] for water-based inks).

7.7.3 *Test Method*—Using TAPPI Test Method T 411 measure the board sample at least 25 mm [1 in.] from any score line, cut edge, or printed area. Then measure it in the printed area and subtract from the first reading to determine amount of crush deformation.

8. Finished Container Attributes

8.1 *Box Style*—A wide variety of box styles are available to the user ranging from the most common Regular Slotted Container (*RSC*) to specialized styles configured for particular applications. The more common styles are depicted in Practice D 5118, Figures 1 through 14 and in the Fibre Box Handbook. In addition, rigid boxes formed by automatic in-plant equipment may be appropriate and include the following styles: Bliss, Bliss with tri-fold ends; Bliss with internal flange; Bliss with triangular corner posts; Bliss with integral "H" divider; Tray with side flange sealed flaps; Tray, six corners glued; Tray with triangular corner posts; and Tray split minor. The user should specify the style which is most economical in view of requirements for packing, closure, protection, handling, storage, and transportation.

8.2 *Containment Strength*—The basic purpose of a corrugated box is to contain the product in such a way that the product can be moved safely through the entire distribution cycle. A method of determining containment strength of a box is to conduct drop tests which stress its fibers and structure in a manner similar to that imposed by various environmental hazards. This test is appropriate for common carrier trucking and small parcel shipments, but may not be appropriate for unitized or full truckload or railcar-load shipments.

8.2.1 The test method recommended for measurement of containment strength of corrugated boxes is a free fall drop of loaded containers in accordance with Test Method D 5276. See

Appendix X5 for drop sequence and suggested drop heights.

8.2.2 For the dropping mass, use the actual product (or a dummy load of similar shape, size, weight, and dynamic characteristics) with the same interior packaging as generally used.

8.2.3 The container fails if it does not meet acceptance criteria previously determined. This criteria should consider the required condition of the container at receipt by the ultimate customer.

8.3 *Top to Bottom Stacking Strength*—A major function of the corrugated container is to provide sufficient stacking strength in storage and transportation for the dual purpose of protecting the contents from damage and maintaining stacks from toppling over due to crushing container walls.

8.3.1 Using Test Method D 642, measure the resistance of corrugated boxes to stacking loads and provide an indication as to the amount of safe load it can withstand in normal stacking situations.

8.3.2 Test Method D 642 permits either fixed or swivel platens. Since fixed platen machines generally cause failure to occur at the specimen's strongest point, while swivel platen machines cause failure at the specimen's weakest point, only one of these two methods should be specified by the user. Failure is considered to occur if the compression strength is less than the specified load.

8.3.3 Specified load will depend on the stacking load expected in storage or transportation. A method of determining compression test requirements based on specified stacking loads is described in Appendix X6. Calculation of specified load includes the use of a design or *F*-factor to account for the loss of strength in a corrugated box due to distribution hazards such as long-term storage, high humidity, stacking and palletizing irregularities, and rough handling. The factor is multiplied by the known stacking load to determine desired machine compression strength.

9. Workmanship

9.1 Corrugated fiberboard should show no continuous visual surface break of the outer component ply nor any facing completely split through at the score line. Commercially accepted fiberboard is normally free of tears, punctures, wrinkles, blisters, washboarding, splices, and scuff marks or any other types of physical damage.

9.2 Edges of fiberboard should be properly aligned so that the distance between the edges of any two components should not exceed 6 mm [¼ in.].

9.3 The amount of warp upon delivery to the customer should not exceed 20 mm/m [¼in./ft].

9.4 Corrugated fiberboard should be free of excessive dirt or oil spots or any other deposit which will detract from the appearance of the fiberboard.

9.5 The edges or ends of the fiberboard sheet should not be delaminated for a distance of more than 6 mm [¼ in.].

10. Precision and Bias

10.1 The precision and bias of this practice are dependent on those of the various test methods used, and cannot be expressly determined.

11. Keywords

11.1 box; containment; corrugated; fiberboard; performance; rough handling; stacking

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF SAMPLING PLAN BASED ON PRACTICE D585

X1.1 Table X2.2 in Practice D 585 lists the acceptance/rejection based on various lot sizes. (Table X1.1 is excerpted from Table X2.2 in Practice D 585.)

X1.2 The following is an example based on an order for 5000 corrugated containers.

X1.2.1 In accordance with Table X1.1, a sample size of 8 is used for the lot size of 5000 (within the range from 1201 to 35 000). Eight test units are selected at random and are tested for each attribute specified. For each attribute, *no* test unit may be below the minimum specified. If not more than one test unit fails, a second series of eight may be retested but no further failures are allowed. In this example the acceptance of the double sample lot is 15 of 16.

TABLE X1.1 Acceptance/Rejection Based on Various Lot Sizes

NOTE 1—n = sample size for first try and n_t = total sample size, that is sum of test units in first and second tries (if a second sample is required), and where Ac_t and Re_t are the acceptance and rejection numbers for double samples.

Lot Size	Sample Size		Acceptance and Rejection Numbers			
	n	n_t	Ac	Re	Ac_t	Re_t
151 to 1200	5	...	0	1	...	...
1201 to 35 000	8	16	0	2	1	2
35 001 and over	13	26	0	3	2	3

X2. BURST STRENGTH

X2.1 Experience of shippers and carriers for many years has shown that the limits in Table X2.1 on gross weights and dimensions of corrugated boxes, as related to minimum burst requirements, will provide sufficient burst strength and containment strength for most products or contents, or both, when shipped by means of less-than-truckload (LTL), as well as air freight, truckload, and railcar. Shipments by small parcel carrier may require lower gross weight limits.

TABLE X2.1 Limits of Weight and Size Based on Burst Strength (based on Rule 41 and Item 222 of most recent issue of rail and truck classifications respectively)

NOTE 1—Since heavier doublewall constructions (400 burst and up) may exceed capability of burst (Mullen) testers, one may wish to substitute puncture resistance requirements as follows:

Maximum Gross Weight, kg [lb]	Maximum Outside Dimensions (1 + w + d), m [in.]	Burst Strength, kPa [psi]	Construction SW (Singlewall) DW (Doublewall)	Burst, kPa [psi]	Puncture, joules, in.-oz/in. Tear
9 [20]	1.0 [40]	860 [125]	SW	2760 [400]	13.5 [450]
16 [35]	1.3 [50]	1030 [150]	SW	3440 [500]	16.5 [550]
23 [50]	1.5 [60]	1200 [175]	SW	4140 [600]	19.5 [650]
29 [65]	1.9 [75]	1380 [200]	SW		
36 [80]	2.2 [85]	1380 [200]	DW		
36 [80]	2.2 [85]	1720 [250]	SW		
43 [95]	2.4 [95]	1900 [275]	SW		
45 [100]	2.4 [95]	1900 [275]	DW		
54 [120]	2.7 [105]	2410 [350]	SW, DW		
63 [140]	2.8 [110]	2760 [400]	DW		
72 [160]	2.9 [115]	3440 [500]	DW		
81 [180]	3.0 [120]	4140 [600]	DW		

X3. PUNCTURE STRENGTH

X3.1 Experience of shippers and carriers for many years has shown that the limits in Table X3.1 on gross weights and dimensions of triplewall corrugated boxes, as related to minimum puncture requirements, will provide sufficient puncture resistance, rigidity, and containment strength for most products or contents, or both, when shipped by means of LTL, as well as air freight, truckload, and railcar.

TABLE X3.1 Limits of Weight and Size for Triplewall Boxes Based on Puncture Strength

NOTE 1—Based on most recent issue of carrier classifications, Rule 41 and Item 222.

Maximum Gross Weight, kg [lbs]	Maximum Outside Dimensions (1 + w + d), m [in.]	Puncture Strength, joules [in.-oz. per in. tear]
109 [240]	2.8 [110]	21 [700]
118 [260]	2.9 [115]	27 [900]
127 [280]	3.0 [120]	33 [1100]
136 [300]	3.2 [125]	39 [1300]

X4. EDGEWISE CRUSH TEST (ECT)

X4.1 The average top-to-bottom compression strength (BCT) of a finished RSC-style box can be estimated by using the simplified McKee formula with the ECT in conjunction with box perimeter and thickness of board:

$$BCT = 5.87 \times ECT \times \sqrt{\text{box perimeter} \times \text{thickness of board}} \quad (X4.1)$$

The thickness (caliper) of board in the formula includes linerboards as well as the flute height. Users should contact supplier(s) to obtain expected minimum combined board thickness (caliper).

X4.2 The formula is based only on a regular slotted-style (RSC) box with normal shape where all dimensions (*l*, *w*, *d*) do not vary by extreme amounts from each other. Specifically the depth must not be less than 1⁄7 of the box perimeter and no one dimension more than double any other. When dimensions do vary extremely, the following adjustments are suggested:

Dimension Variations	Alter Calculated Strength
Depth < 2 ⁄ 3 of width	add 5 %
Depth > 1.5 width	subtract 8 %
Length > 2.5 width	subtract 8 %

NOTE X4.1—Extreme variations beyond the dimensions in X4.2 preclude use of the formula. Individual experimentation will be required.

X4.2.1 Following is an example using the shape modifier:

X4.2.1.1 Given container is an RSC style, inside length (*L*) = 0.6 m, inside width (*W*) is 0.4 m, inside depth = 0.15 m, ECT = 6 kN/m, T = 0.004 m, and shape modifier = + 5 % (depth is less than ⅔ width):

Substituting these values in the McKee formula:

$$\begin{aligned} BCT &= 5.87 \times ECT \times \sqrt{\text{perimeter, } 2L + 2W \times (T)} \\ &\quad \times (\text{shape modifier}) \\ &= 5.87 \times 6 \times \sqrt{2.0 \times 0.004} \times (1 + 0.05) \\ &= 3.31 \text{ kN [744 lbf]} \end{aligned} \quad \text{(X4.2)}$$

X4.3 The McKee formula may be realigned to produce the following equation:

$$ECT = \frac{BCT}{5.87 \times \sqrt{BP \times T}} \quad \text{(X4.3)}$$

where:

ECT = estimated average edge crush test,
BCT = required top-to-bottom compression of the box,
BP = box inside perimeter (twice length + twice width), and
T = overall combined board thickness.

This will be of interest in determining a calculated ECT value based on known box compression strength requirement.

X4.3.1 *Example*—Referring to the example in X6.1.3, required box compression is 6.62 kN [1458 lbf]. If box perimeter is 1.5 m [60 in.] and thickness is 6.4 mm [0.20 in.], then the required average ECT can be estimated:

$$ECT = (6.62) / [(5.87) \times \sqrt{(1.5) \times (.0064)}] = 11 \text{ kN/m} \quad \text{(X4.4)}$$

$$ECT = (1458) / [(5.87) \times \sqrt{(60) \times (0.250)}] = 64 \text{ lb/in.} \quad \text{(X4.5)}$$

X4.4 Table X4.1 shows minimum requirements of fiberboard ECT strengths listed in carrier regulations (Rule 41 and Item 222). **Caution:** The user should determine maximum gross weights to be shipped in the box based primarily on the user's performance requirements, and secondarily on the carrier regulation maximum gross weight listings. Usually, if the user's performance requirements are met, the ECT values will be in compliance with carrier regulations. In general, carrier maximum weights and dimensions should never be exceeded unless the regulations do not apply for the shipment(s) and the user's performance requirements so indicate.

NOTE X4.2—The highest ECT grade of triple wall (27 kN/m [155 lb/in.] is based on Practice D 5168.

TABLE X4.1 Edgewise Crush (ECT) Values

NOTE 1—Values for pounds/inch are extracted from most recent issues of carrier classifications, Rule 41 and Item 222. The SI units are not exact equivalents of the inch-pound units.

kN/m (lb/in.)	Construction
4.0 [23]	Singlewall
4.5 [26]	
5.1 [29]	
5.6 [32]	
7.0 [40]	
7.7 [44]	
9.6 [55]	
7.4 [42]	Doublewall
8.4 [48]	
8.9 [51]	
10.7 [61]	
12.4 [71]	
14.4 [82]	
11.7 [67]	Triplewall
14.0 [80]	
15.8 [90]	
19.6 [112]	
27.1 [155]	

X5. DROP TESTS TO MEASURE CONTAINMENT STRENGTH

X5.1 Utilizing Test Method D 5276, drop the test specimen from the drop heights listed in Table X5.1 in the following sequence: a bottom corner, the three edges radiating from that corner, and six flat sides for a total of ten drops.

TABLE X5.1 Suggested Drop Heights Based on Contents Weights

Contents Weight,		kg[lb]	Drop Height, m [in.]
0	to 9.5	[0to20.9]	0.75 [30]
9.6	to18.6	[21to40.9]	0.60 [24]
18.7	to27.6	[41to60.9]	0.45 [18]
27.7	to45.4	[61to100.9]	0.30 [12]
45.4	to90.8	[101to200]	0.15 [6]

X6. COMPRESSION TEST REQUIREMENTS BASED ON STACKING LOADS

X6.1 Practice D 4169, Section 11, covers how to calculate required compression test levels for warehouse stacking (Element C) and carrier vehicle stacking (Element D).

X6.1.1 A similar procedure may be used to determine the minimum compression strength to be specified for a corrugated box.

NOTE X6.1—The specification for a new box, untested in previous elements of a distribution cycle, should be somewhat higher than those of a sequential performance test procedure. Test shipments and storage trials should also be performed as a further check on calculated strengths.

X6.1.2 An example of a higher requirement for a new box is the following for a shipping unit construction Type 1, (see 11.2 of Practice D 4169) where the design or F factor (see 8.3.3) for Assurance Level II is 4.5. A box specification based on the same method of calculation should utilize a design or F factor of 5 or 5.5. Otherwise the box may fail during a compression test element of a lengthy performance test sequence. Since Assurance Level II reflects an average distribution environment, the F factor for a box specification may be adjusted up or down depending on relative severity of the actual expected environment.

X6.1.3 Following is an example showing calculation of required box compression strength. The box construction is a CB-flute RSC style, normal shape, with exposure to an expected maximum warehouse stack height of 3 m for up to one year. The box and contents weigh 15 kg, and contents are non-load bearing so the box must carry the entire stacking load. Box height is 0.3 m. Using the formula in Practice D 4169:

$$L = M \times J \times [(H - h)/h] \times F \quad \text{(X6.1)}$$

where:
L = minimum required load, N [lbf],
M = mass of one package, kg [lb],
J = 9.8 m/s/s [1 lbf/lb] for gravity constant,
H = maximum height of stack, m [in.],
h = height of individual package, m [in.] and,
F = 5.0, as noted in X6.1.2 example.

Substituting:

$$L = (15) \times (9.8) \times [(3.0–0.3)/0.3] \times (5.0) = 6615 \text{ N or } 6.62 \text{ kN} \quad \text{(X6.2)}$$

The minimum required compression strength of the box is equal to the minimum required load for stacking, or 6.62 kN [1458 lbf].

X6.1.4 An alternate method for calculating compression strength can be found in X4, providing an ECT value is specified for the fiberboard and box shape is within the formula parameters.

X7. EXAMPLES OF USING PRACTICE D5639 FOR SPECIFICATION DETERMINATIONS

X7.1 The first example is for a distribution environment that is similar to distribution cycle (DC) 6 of Practice D 4169, unitized loads shipped by means of truckload, and with warehouse stacking as the first element of the cycle (DC 14 added). For this situation stacking strength is most important and rough handling potential is minimal.

X7.1.1 The attributes which should be considered for this example are as follows: Fiberboard-edgewise crush resistance, minimum flute height, printing crush limit; finished box-top to bottom compression strength.

X7.1.2 Parameters of the example are as follows: A shipper requires a corrugated container for a non-load bearing product and interior packaging. An RSC-style box is selected based on the product characteristics and method of packing. The weight of the packaged product is 15 kg [33 lb] and its dimensions are 0.5 × 0.3 × 0.25 m [20 × 12 × 10 in.]. The packages will be unitized 5 tiers per unit load and stored 2 unit loads high in warehouses for an average of one month and a maximum of one year. The handling and transportation environment is normal. The unit load base is a lightweight slipsheet, a flat sheet of material with a tab on one or more sides, used as a base for assembling, handling, storing, and transporting goods in unit load form.

X7.1.3 Calculate the box specifications as follows:

X7.1.3.1 *Minimum Top to Bottom Box Compression (BCT) Strength*—Before calculating BCT, the design or Ffactor must be selected (see 8.3.3). A factor of 5.0 is chosen, based on the distribution environment and the discussion in X6.1.2. The BCT is then calculated using the formula from Practice D 4169 as follows:

$$BCT = M \times J \times [(H - \mathrm{h})/(\mathrm{h})] \times F \quad \text{(X7.1)}$$

where:
M = 15 kg,

J = 9.8 m/m/s, gravity constant,
H = 5 tiers/unit load and 2 unit loads high or $(5) \times (0.25) \times 2 = 2.5$ m,
h = 0.25 m, and
F = 5.0.

Substituting:

$$BCT = 15 \times 9.8 \times [(2.5 - 0.25) / (0.25)] \times 5.0$$
$$= 6615 \text{ N or } 6.62 \text{ kN} \qquad (X7.2)$$

The minimum BCT to be specified therefore is 6.62 kN [1458 lbf].

X7.1.3.2 *Minimum Edgewise Crush (ECT)*—Using the formula in X4.3:

$$ECT = \frac{BCT}{5.87 \times \sqrt{\text{box perimeter} \times \text{board thickness}}} \qquad (X7.3)$$

Assuming the box manufacturer has both C flute singlewall and CB doublewall available, calculate the minimum ECT needed based on both wall constructions to determine if both are feasible. For C flute, assuming the manufacturer supplies a minimum of 4.1-mm overall caliper (thickness) for the heaviest fiberboards, calculate the ECT as follows:

$$ECT = \frac{6.62}{5.87 \times \sqrt{1.6 \times 0.0041}} = 13.9 \text{ kN/m [80 lb/in.]} \qquad (X7.4)$$

This ECT minimum value is higher than generally available in singlewall and therefore C flute singlewall is not applicable. For CB flute doublewall the manufacturer supplies a minimum of 6.9-mm caliper thickness for medium-strength boards and ECT is calculated as follows:

$$ECT = \frac{6.62}{5.87 \times \sqrt{1.6 \times 0.0069}} = 10.7 \text{ kN/m [61 lb/in.]} \qquad (X7.5)$$

This is in the medium range of doublewall strengths offered by the industry and therefore minimum specified ECT is 10.7 kN/m [61 lb/in.].

X7.1.3.3 *Minimum Flute Height* (see 7.5)—For CB flute doublewall, the manufacturer's target flute height (not including linerboards) is 5.7 mm. The minimum flute height to be specified is 4 % less, or 5.5 mm [0.217 in.].

X7.1.3.4 *Maximum Printing Crush for Water Based Inks* (see 7.7)—CB-Flute − 0.25 mm (0.010 in.).

X7.1.3.5 Carrier regulations should always be considered and calculated specifications checked against regulations to ensure compliance. In this example, the calculated specification of 61 lb/in. ECT far exceeds the minimum carrier requirements of 26 lb/in. ECT in Rule 41 and Item 222.

X7.2 The second example is for a distribution environment similar to distribution cycle (DC) 3 of Practice D 4169, single package up to 45.4 kg [100 lb] by LTL truck shipment or small parcel carrier. For this situation, containment and protection in rough handling are most important with a secondary concern for stacking strength in carrier vehicles.

X7.2.1 The attributes which should be considered for this example are as follows: fiberboard—burst or puncture resistance; finished box—containment strength, top to bottom compression strength.

X7.2.2 Parameters of the example are: The shipper requires a corrugated container for a non-load-bearing product and interior packaging. An RSC-style box is selected based on manual method of packing and product characteristics. The weight of the packaged product is 30 kg [66 lb] and dimensions are $0.5 \times 0.3 \times 0.25$ m ($20 \times 12 \times 10$ in.). Although the packages are palletized, all storage is in racks, one pallet high, four tiers per pallet. The handling and transportation environment is normal.

X7.2.3 Calculate the box specifications as follows:

X7.2.3.1 *Minimum Fiberboard Burst Strength*—Using the carrier classification for burst strength (see Table X2.1), for a 30-kg [66-lb] weight of box and contents, the minimum burst strength value to be specified is 1720 kPa [250 psi] for singlewall construction.

X7.2.3.2 *Minimum Box Containment Strength* (see X5)—Conduct ten drop tests from 0.3-m [12-in.] height with results to meet acceptance criteria. The dropping mass may be a dummy load weighing 30 kg.

X7.2.3.3 *Minimum Top to Bottom Compression (BCT) Strength* (see Practice D 4169)—The maximum stack height one might encounter is in LTL trucks or small parcel vehicles. Assuming a maximum height of carrier vehicles is 2.7 m [106 in.], an average density of miscellaneous freight is 160 kg/m [10 lb/ft] and a design factor of 5.0 for corrugated without loadbearing contents, calculate the required compression strength as follows using the formula of Practice D 4169:

$$BCT = M \times J \times ((L \times W \times D)/K) \times ((H - h)/(h)) \times F \qquad (X7.6)$$

where:
BCT = minimum required load, N [lbf],
M = average shipping density factor, kg/m[lb/ft],
J = constant for gravity, m/s/s,
L = inside length of the box, m [in.],
W = inside width of the box, m [in.],
D = inside depth of the box, m [in.],
K = 1 m^3/m^3[1728 $in.^3/ft^3$],
H = height of the stack in the trailer, m [in.],
h = outside height of the box, m [in.], and
F = 5.0.

Substituting:

$$BCT = 160 \times 9.8 \times ((0.5 \times 0.3 \times 0.25)/1]$$
$$\times ((2.7 - 0.27)/(0.27)) \times 5$$
$$= 2646 \text{ N or } 2.65 \text{ kN} \qquad (X7.7)$$

The minimum BCT to be specified is 2.65 kN [595 lbf].

X7.2.3.4 *Determination of Flute Configuration*—Checking the compression strength when using the alternate ECT to 250-psi burst in the Carrier Classifications, it can be determined from the following calculations that this alternate grade of board should be sufficient using C flute singlewall.

Average box compression (BCT) using McKee formula =

$$5.87 \times ECT \times \sqrt{\text{perimeter} \times \text{thickness}} \quad (X7.8)$$

where:

ECT = 7.0 kN/m [40 lb/in.] as alternate to 1720-kPa[250-psi] burst strength calculated in X7.2.3.1,
perimeter = 1.6 m (twice length + twice width), and
thickness = supplied by the box manufacturer at 4.1 mm minimum for C flute.

Substituting,

$$BCT = 5.87 \times 7.0 \times \sqrt{1.6 \times 0.0041} = 3.33 \text{ kN } [748 \text{ lb}]$$

Since the calculated BCT of 3.33 kN is 26 % higher than the required BCT of 2.65 kN calculated in X7.2.3.3, C flute singlewall should be more than sufficient.

X7.2.4 Carrier regulations should be considered where applicable and calculated specifications checked against regulations to ensure compliance. Since the burst strength, maximum gross weight and maximum outside dimensions for this example are taken from carrier regulations in the listing of Table X2.1, they will be in compliance.