Designation: D8409 – 21

Standard Guide for Conducting Stacking Tests on UN Packagings Using Guided or Unguided Loads[1]

This standard is issued under the fixed designation D8409; 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.

1. Scope

1.1 This guide is intended to provide a standardized method and a set of basic instructions for conducting stacking tests on United Nations (UN) non-bulk, intermediate bulk container (IBC), and Large Packagings. Using guided or unguided loads in accordance with the U.S. Department of Transportation Title 49 Code of Federal Regulations (CFR) and the UN Recommendations on the Transport of Dangerous Goods ("The Orange Book"). The combination or interchange of these regulations will be referred to as the Hazardous Material Regulations (HMR).

1.2 The Dangerous Goods Regulations require performance tests to be conducted on packaging designs prior to being authorized for use. The regulations do not include standardized procedures to accomplish this which can result in differences between testing facilities. The purpose of this document is to provide guidance and to establish a set of common practices for conducting stack testing on packagings undergoing UN certification.

1.3 The user of this guide must be trained in accordance with 49 CFR as required by 172.700 and should be familiar with other applicable hazardous materials regulations such as; International Civil Aviation Organization (ICAO) Technical Instructions for the Safe Transport of Dangerous Goods by Air, the International Maritime Dangerous Goods Code (IMDG Code), and carrier rules such as International Air Transport Association (IATA) Dangerous Goods Regulations.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.5 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D642 Test Method for Determining Compressive Resistance of Shipping Containers, Components, and Unit Loads

D685 Practice for Conditioning Paper and Paper Products for Testing

D996 Terminology of Packaging and Distribution Environments

D4332 Practice for Conditioning Containers, Packages, or Packaging Components for Testing

D4577 Test Method for Compression Resistance of a Container Under Constant Load

D4919 Guide for Testing of Hazardous Materials (Dangerous Goods) Packagings

2.2 *ISO Standards:*[3]

ISO 2234 Packaging – Complete, filled transport packages – Stacking tests using static load

ISO 16495 Packaging – Transport packaging for dangerous goods – Test methods

[1] This guide is under the jurisdiction of ASTM Committee D10 on Packaging and is the direct responsibility of Subcommittee D10.22 on Hazardous Materials.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

2.3 *Federal Standard:*[4]

U.S. Department of Transportation Code of Federal Regulations Title 49, Transportation (49 CFR) Parts 100-185

2.4 *UN Standard:*[5]

UN United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations (UN Orange Book)

2.5 *IATA Standard:*[6]

IATA International Air Transport Association (IATA) Dangerous Goods Regulations

2.6 *ICAO Standard:*[7]

ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air

2.7 *IMDG Standard:*[8]

International Maritime Dangerous Goods Code (IMDG Code)

3. Terminology

3.1 *Definitions:*

3.1.1 General definitions for packaging and distribution are found in Terminology D996.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *deflection, n*—amount of vertical deformation in the height of the package under the test load during the test period.

3.2.2 *dynamic compression test, n*—a top loading compression test performed using a machine capable of applying a dynamic top loading on a package. This test is performed in conformance with Test Method D642 and the regulations as applicable.

3.2.3 *guided load, n*—a static top loading test performed with fixed platen compression machines or in a "dead load" stack arrangement where the packaging and weight stack are constrained from tipping due to deformation or collapse of the packaging.

3.2.4 *intermediate bulk container (IBC), n*—a rigid or flexible portable packaging, other than a cylinder or portable tank, which is designed for mechanical handling, has volumetric capacity of not more than 3000 L and includes: flexible, composite, and rigid IBCs.

3.2.5 *large packaging, n*—a packaging that contains articles or inner packagings, which is designed for mechanical handlings, exceeds 400 kg net mass or has a volumetric capacity greater than 450 L but not more than 3000 L.

3.2.6 *load spreader, n*—rigid plate that spreads the stack load across the entire top surface area of the package under the load. The load spreader shall extend to the outside edge of the perimeter or beyond the perimeter of the test specimen.

3.2.7 *packagings, n*—receptacles and any other components or materials necessary for the receptacle to perform its containment function in conformance with the minimum requirements of the HMR; and includes non-bulk, IBC, and Large Packagings.

3.2.8 *stacking test (top load compression test), n*—a test designed to ascertain the performance capability of a packaging under top load compressive forces in storage or transportation. It is a required design type test for all non-bulk packagings except bags, and all IBCs intended to be stacked.

3.2.9 *unguided load, n*—a constant top loading test performed with floating (swivel) platen compression machines or a "dead load" (constant load) mass applied in manner that would allow the stack load to tip over in the event of excess deformation or collapse of the packaging. Floating platens swivel to maintain constant load on parts of the packaging that are deforming under pressure.

3.2.9.1 *Discussion*—Additional packaging terms and definitions specific to the regulations are located in 49 CFR, Section 171.8, and the Orange Book, Section 1.2.1.

4. Significance and Use

4.1 This guide is intended to provide a standardized method and a set of basic instructions for performing stack testing on UN packaging designs using either guided or unguided top loads. This guide provides the suggested minimum information that should be documented when conducting stacking test and provides information for recommended equipment.

4.2 All packaging design types other than bags must be subjected to a stacking test. Packagings subject to the stacking test must be capable of withstanding a superimposed top load of a specified minimum mass for a specified period of time without failure as these parameters are defined in the regulations. The test is not intended to determine the absolute top load capability of a packaging.

NOTE 1—When quantification of box compression strength is desired for determining stacking strength or for design purposes use Test Method D642 and conditioning as recommended in 4.5.

4.3 Design qualification testing procedures are intended, as explicitly stated in the HMR, to be the minimum performance capability levels for packaging manufactured to transport Hazardous Materials under conditions normally incident to transportation.

4.4 The HMR tests are designed to be gross package capability evaluations that can be performed in a similar manner in all parts of the world, but under circumstances with some variance in test facility capabilities. This is an intentional feature of the test designs and protocols. The focus of HMR testing is not the determination of quantifiable, comparison data to allow for analytical evaluation.

4.5 It is recommended that facilities performing the HMR tests consult the guidance on conditioning in the relevant ASTM documents for any particular packaging material as

[4] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402-9371 (website: https://www.phmsa.dot.gov/phmsa-regulations).

[5] Available from the UN Economic Commission for Europe, Information Service, Palais des Nations, CH-1211 Geneva 10 Switzerland (website: http://www.unece.org/trans/danger/danger.htm).

[6] Available from the International Air Transport Association (IATA), 800 Place Victoria PO Box 113 Montreal - H4Z 1M1 Quebec - Canada (website: http://www.iata.org).

[7] Available from the International Civil Aviation Organization, (ICAO) 999 University Street, Montréal, Quebec H3C 5H7, Canada (website: http://www.icao.org).

[8] Available from the International Marine Organization (IMO, 4 Albert Embankment, London, SE1 7SR United Kingdom (website: http://www.imo.org).

applicable. The following conditioning documents, Practices D4332 and D685, are commonly used.

5. Apparatus

5.1 *Closing equipment* such as; torque wrenches, torque meters, lid presses, cover/closure crimping tools, etc., to close the container as for transport.

5.2 *Top Load Equipment*—Constant (dead) load weights or mechanical compression system (machine), such as those described in Test Method D4577 or Test Method D642.

5.3 *Stacking fixture (optional)* may be used to aid in applying force load, aligning weights, or improve safety if stack load weights should topple

5.4 *Load spreader* used as necessary to ensure even distribution of the top load.

5.5 *Measuring device* appropriate to the task if needed.

5.6 Closing equipment, top load equipment, and measuring devices shall be calibrated as necessary.

6. Sampling, Test Specimens, and Test Units

6.1 Visually inspect packaging(s) to be tested for consistency with closing instructions and any defects. Verify all closures, plugs, gaskets, accessories, etc. match the closing instructions. Determine if the container has a properly formed sealing surface (record any blemishes or defects). Examine for and record any damage which might invalidate the test.

6.2 Number of specimens as required by current regulations being used for testing. These must be randomly selected specimens.

6.2.1 *Packagings (Non-Bulk)*—Three specimens is the minimum required.

6.2.2 *IBCs and Large Packagings*—One specimen is the minimum required.

6.3 Prepare the packaging for testing, as specified by the current regulations being utilized for the specific design type. When the specimen is required to be filled for testing, it shall be closed and secured in the same manner as for transport.

6.3.1 The fill capacity for single or inner packagings of non-bulk and inner packagings of Large Packagings is:

6.3.1.1 Solids must be filled to not less than 95 % of maximum capacity.

6.3.1.2 Liquids must be filled to not less than 98 % of maximum capacity.

6.3.1.3 Non-bulk combination packagings prepared for the stacking test may also be prepared without their inner packagings, unless it would invalidate the test. Packagings may be tested empty.

6.3.2 IBCs and Large Packagings, except flexible design types, must be filled to their maximum permissible gross mass.

6.3.2.1 Flexible IBCs or flexible Large Packagings must be filled to not less than 95 % of its capacity with the fill being evenly distributed and to the maximum net mass.

6.4 49 CFR permits the use of dynamic compression testing in place of the 24 hour or 28 day stacking test for periodic retests of non-bulk, IBCs, and Large Packagings. The test specimens must be empty and unsealed. The dynamic compression test should be conducted in accordance with Test Method D642.

7. Conditioning

7.1 For design qualification testing, the minimum conditioning duration for paper or fiberboard packagings is 24 hours prior to testing. Unless testing is conducted in the conditioning atmosphere, it is recommended the test start as soon as possible, but no more than 15 minutes after removing the packaging test specimen from the conditioning atmosphere.

NOTE 2—When quantification of box compression strength is desired for determining stacking strength or for design purposes, more fully defined conditioning is advisable. For quantifying box stacking strength, it is recommended using conditioning as specified in Practices D4332 and D685 (see 4.4 and 4.5).

7.2 It is recommended to condition fiberboard packagings prior to testing in accordance with the conditioning atmosphere specified in Practices D4332 and D685. These ASTM procedures recommend conditioning fiberboard and paper for a minimum of 72 hours.

7.3 Conditioning of specific packaging design types in accordance with the applicable regulation as outlined in 49 CFR is identified in Table 1.

8. Calculating Load

8.1 All calculations for minimum top load should be performed using SI units, where the results are stated in kilograms before conversion to other units of measure is made.

8.2 When no rounding requirements are provided, it is recommended to round up to the nearest tenth at each step when calculating the minimum load.

8.2.1 The steps to calculating the minimum load would include:

8.2.1.1 *Step 1*—The calculation of the number of containers,

8.2.1.2 *Step 2*—The calculation of the mass of the container, and

8.2.1.3 *Step 3*—The calculation of the minimum load.

NOTE 3—To calculate the absolute minimum, do not round until all calculations are complete. Accuracy should be reflected in the capability of the equipment used.

8.3 For non-bulk, the load is the mass of filled like-packagings that could be stacked on top of the test specimen during transport to the equivalent height of 3 m.

8.3.1 Calculation of top load for a non-bulk packaging tested with solids or liquids is:

$$\text{Minimum Top Load} = (n - 1) \times w \quad (1)$$

where:

n = minimum number of containers that when stacked, reach a height of 3 m. The number of packages is calculated using Eq 2 and this number may not be an integer.

w = maximum total mass in kilograms (kg) of the subject package as it would be filled and prepared for testing in accordance with the regulations. This would be maximum gross mass of the package for transport.

TABLE 1 Stack Test Conditioning Requirements for Packaging Design Types

NOTE 1—Refer to 6.4 for usage requirements for the dynamic compression test method.

Packaging Design Type	Test Condition	49 CFR Reference	UN Reference[A]
Non-bulk plastic single or composite packagings for liquids	40°C (104°F)[B]	§178.606(c)1	6.1.5.6.2
Rigid plastic IBC and composite IBCs with plastic outer packagings		§178.815(c)(3)	6.5.6.6.3 (ii)
Rigid plastic Large Packagings		§178.980(c)(3)	N/A
Non-bulk single composite or combination packaging with fiberboard outer	20°C ± 2°C (68°F ± 4°F) and 65 % ± 2 % RH, or	§178.602(d)	6.1.5.2.3
Fiberboard and composite IBCs with fiberboard outer	23°C ± 2°C (73°F ± 4°F) and 50 % ± 2 % RH, or	§178.802(a)	6.5.6.3.1
Fiberboard Large Packagings	27°C ± 2°C (81°F ± 4°F) and 65 % ± 2 % RH	§178.960(d)	6.6.5.2.4
All other non-bulk packagings	Ambient		
All other IBCs			
All other Large Packagings			
For periodic retests:	Ambient		
Dynamic compression tests of non-bulk, IBCs, and Large Packagings		§178.602(d)(3) §178.802(c) §178.815(d)(2)	Dynamic Compression: N/A for UN 6.1.5.1.3
Fiberboard packaging design types		§178.980(d)(2)	N/A for FB IBCs 6.6.5.1.3

[A] Reference from UN Recommendations on the Transport of Dangerous Goods ("The Orange Book"), Volume II.
[B] Testing for non-bulk plastic single or composite packagings for liquids maybe greater than 40°C.

8.3.1.1 The number of packages is calculated as:

$$n = \left(\frac{300}{h}\right) \quad (2)$$

where:

h = height, in centimetres, of the subject packaging, adjusted to account for any interlocking features.

(1) The number of packages in the stack must account for any interlocking (nesting) stack features of the packaging. The effective height of the packages for the stack test may be less than the total height of the specimen packaging if these interlock features are part of the design type. The nested height of the stack must be used to calculate the required number of packages in the load calculation.

8.3.1.2 For a packaging tested with water in place of hazardous materials, w is replaced by w' in the equation above. w' is calculated using the equation:

$$w' = (\mathrm{SG} \times m) + W_{\mathrm{tare}} \quad (3)$$

where:

SG = specific gravity marked on the packaging,
m = mass in kilograms (kg) of the net liquid contents of the package as filled with water in accordance with the regulations, and
W_{tare} = tare mass in kilograms (kg) of the entire design type packaging including closures.

8.3.2 For combination packaging the net liquid contents would be summed from all the inner packagings; and the tare mass of all inner packaging (including inner packagings used as receptacles and their closures) would be added as part of the tare mass of the total packaging.

8.4 For all IBCs and Large Packagings, the load to be placed on the testing specimen must be 1.8 times the combined maximum permissible gross mass of the number of similar packagings that may be stacked on top of the packaging during transportation.

8.4.1 Calculation of top load for IBCs and Large Packagings tested with solids or liquids is:

$$\text{Minimum Top Load} = 1.8 \times \mathrm{MPGM} \times n \quad (4)$$

where:

MPGM = maximum permissible gross mass in kilograms (kg) as marked on the package, and
n = the number of similar packagings that may be stacked during transport.

NOTE 4—Typically, Large Packagings and IBCs are not stacked with more than one other packaging during transport due to limitation of interior cargo spaces.

8.5 The above methods and examples are designed to calculate minimum test loads. Other packaging test protocols, methods or transport conditions may require additional top loads to be used in testing as safety, environmental or design factors or additional minimum requirements are specified by users or other standards. For example: A contract specifying a packaging be tested at a higher level than required by the stack test load calculations in 49 CFR. When testing to a higher level, it may be requested that the minimum test load be rounded up to include the next whole number of packages as calculated in 8.3.1.1.

8.6 If using dynamic compression test, IAW Test Method D642 for periodic retests for non-bulk, IBCs, and Large Packagings, the top load must be calculated using the appropriate equation in Table 2.

9. Procedure

9.1 The stack test should be conducted on a level, hard surface.

9.2 Center the load over the packaging using a load spreader when necessary.

9.2.1 The load spreader used must be sufficient rigidity to distribute weight evenly across the test specimen.

TABLE 2 Minimum Top Load Equations Using Dynamic Compression Testing for Periodic Retesting

NOTE 1—When replacing liquid hazards with water, substitute as in 8.2.1.2.

Packaging Design Type	Equation	49 CFR Reference
Non-bulk	Minimum Top Load$=(n-1)\times w\times 1.5$	§178.606(c)(2)(ii)
IBCs and	Minimum Top Load$=1.8\times(n-1)\times w\times 1.5$	§178.815(d)(2)
Large Packagings		§178.980(d)(2)

where:
n = maximum number of packagings being stacked during transportation[A]
w = maximum total mass in kilograms (kg) of the subject package as it would be filled and prepared for testing in accordance with the regulations. This would be maximum gross mass of the package for transport.

[A] For non-bulk the minimum number of packagings stacked to reach a height of 3 m.

9.3 For manual application loading should be level and carefully applied in a steady, even rate that will not allow the weights to drop onto the packaging.

9.4 When using a mechanical compression system, the load should be applied at a rate not to exceed 12.7 mm/min ± 6.4 mm/min (0.5 in/min ± 0.25 in/min). An initial preload of 23 kg (50 lbs.) should be applied to ensure contact between the test specimen and the platen.

9.5 *Unguided Load on a Packaging*—Packagings are free to topple due to deformation or collapse at the weakest spot. Safety devices, such as chain supports can be used to prevent an unsafe failure, but they should not be designed to support any of the top load. Examples are shown in Fig. 1 and Fig. 2.

9.6 *Guided Load on Packaging(s)*—Load is supported on two or more sides or corners so that the specimen may not deflect and the load may not be distributed equally across the entire surface area of the package under the load. This method requires the performance of a stability test as outlined in 49 CFR 178.606(c) after the initial stack test is completed. Example is shown in Fig. 3.

9.7 The test duration must be conducted at the minimum times as required by the applicable regulations. Time does not begin until the entire load has been applied. See Table 3 for test durations.

9.8 When using dynamic compression testing to perform 49 CFR periodic retesting IAW Test Method D642, the package may be tested to failure and the graph provided to show the load at the maximum allowed deflection of 1 in.

9.9 Another option for periodic retesting using a dynamic compression test machine may be to hold the minimum test load for not more than a minute to evaluate the packaging for deflection and any permanent deformation which may be unsafe for transport.

10. Evaluation

10.1 Each packaging shall be periodically inspected for any leakage of filling substance.

10.2 Refer to the current regulations to determine the criteria for passing the test.

10.3 For guided load test protocols used on non-bulk packagings, the stability evaluation must be performed.

10.3.1 The stability evaluation includes placing two filled similar packages onto the tested specimen for 1 hour. The stacked packages must maintain their position without toppling. Plastic packagings must be cooled to ambient before evaluation.

11. Report

11.1 Record container information:

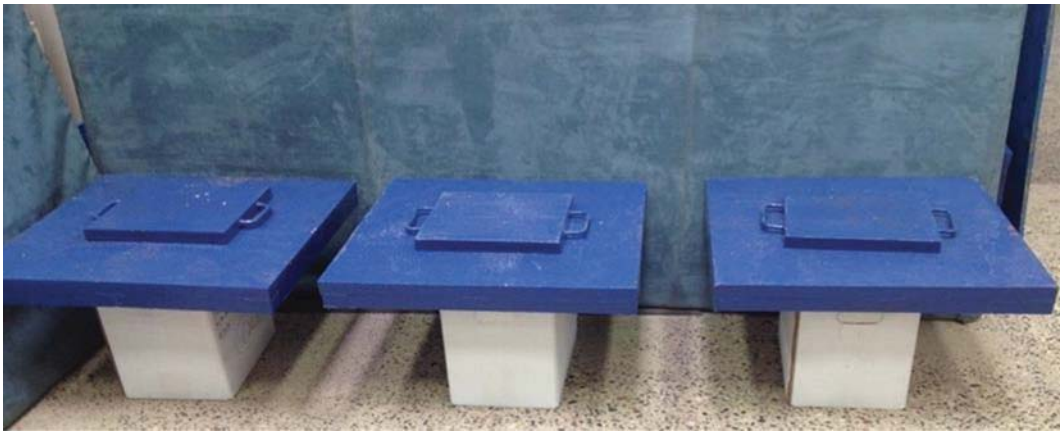

FIG. 1 Unguided Load, Each Package With Individual Top Loading