How to choose the resistance to vertical crushing of stacked cardboard box suitable for your trip

Jean-Baptiste Nolot [1*], Philippe Delloque [1], Jean-Charles Candore [1], Victor Huart [2], Jérôme Pellot [2], Alain Copinet [1], Serge Odof [1] and Damien Erre [1]

[1] *ESIReims, University of Reims Champagne Ardenne, FRANCE*
[2] *METROPACK, FRANCE*

[*] *Corresponding author. Email: jb.nolot@univ-reims.fr*

Abstract: In the packaging field, the most widely used material is cellulose: boxboard and corrugated. This material is present in the primary packaging (in a cardboard case) and in grouping case or in pallet boxes. The most common form is the parallelepiped box with contiguous flaps.

The main feature of this case is the resistance to vertical crushing (RVC). Usually, this system is studied with static method. (Constant application speed of stress about 10mm/min). However, during transport, systems are subjected to dynamic loads such as shock or vibration.

The usual procedure consists on the determination of a static RVC where an empirical coefficient is applied to estimate a dynamic RVC linked to the true transport constraints.

This work suggest an alternative approach:

1 Introduction

Usually transport uses corrugated cardboard cases. The boxes are placed on a pallet stacked and wrapped with a stretching film. The load is then cohesive.

Double corrugated EB cardboard cases are used (Basis weight = 654 g/m²). Dimensions are the following: Length = 230 mm, width = 180 mm, Height = 300 mm. Properties of the material samples are in Table 1.

Table 1: Properties of the material samples.

Sample type	Thickness [mm]	Resistance to vertical crushing [N]	Resistance to bending [N]	Edge crush test [N]
Double corrugated EB cardboard Cases	4.3	2344	30.2	829

Resistance to Vertical Compression according to standard NFH 13-001
Edge Crush Test according to standard ISO 3037
All experimentations have been realized in the following conditions: 23°C ï 50% Relative Humidity.
Paper used: type and weight data following manufacturer, Smurfit Kappa, plant of Brignoles (Var, France):

Ref = EB30 K135/C090/C090/HP125/TL120
K = kraft paper
C = recycled paper
HP = High performance paper
TL = test liner paper
Numbers: weight in g/m2

Data collected concern two transports by truck between two plants and a carriage transport inside a plant. Loading and unloading of truck are also recorded. Features of transport are given in the table 2.

Table 2: Trip & Pallet characteristics.

Trip type	Transportation	Distance [km]	Pallet weight [kg]	Road
1- Reims / Epernay	Truck (19 tonnes)	31	245	Secondary road
2- Reims / Recy	Truck (19 tonnes)	43	263	Highway
3- Factory	Forklift (2.5 tonnes)	1.1	236	Internal Factory

3 EURO pallets (800 x 1200 mm) are used.

They are homogeneous. Loading is perfectly cohesive. The masses of pallets are given in table 2.

Two SAVER 3X90 recorders (Lansmont) are screwed to each pallet diagonally at opposite position.

Instruments set-up permits to record shocks after exceeding a trigger of 3G with an acquisition rate of 2500 samples / second. Recordings were filtered at 500 Hz.

Real vertical constraints of shock on current packaging during transportation and manipulations are recorded

2 Constraints recorded on the field

Only vertical shocks are concerned.

10 strongest shocks of each transport are stored and analyzed.

Maximum values of acceleration (Amax, G), shock Time (T, sec) and speed variation (φV, m/s) are measured.

Data are shown in **Figure 1**:

Each point (φV, Am) represents a vertical shock. 3 transports are represented.

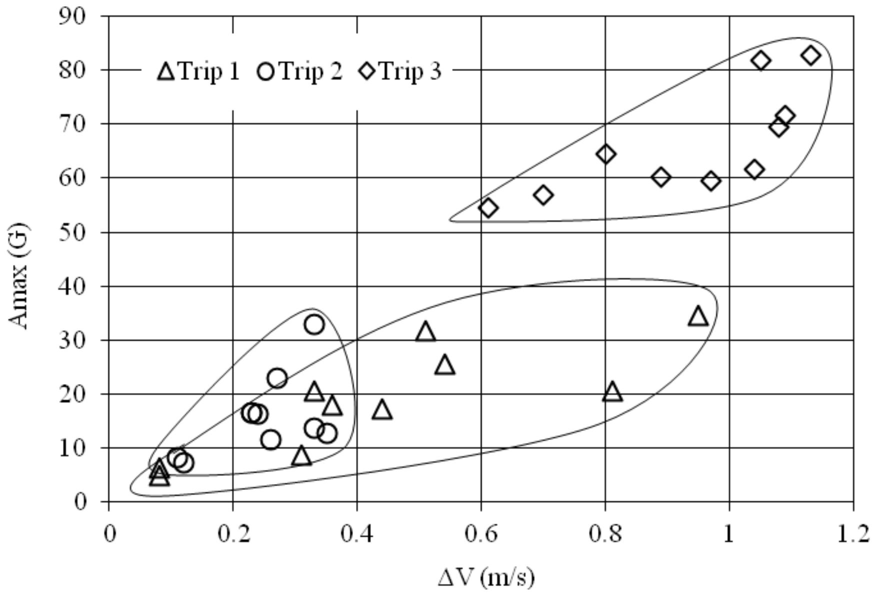

Figure 1: Verticals Shocks on pallets from 3 different trips

3 Fragility Tests of cases

The limit strength of the cardboard case (define Table 1) is define experimentally. ASTM D3332
Different masses (M) are placed on the top of the case. The mass is stuck on the top of box. This is the specimen.
The box (and the masse above) is placed and stuck on the Shock Tester (Lansmont)
TP3 software (Lansmont)
The recording system TP3 (Lansmont) saves shocks generated by the Shock Tester.
The shock is measured on the bottom of specimen. (On the table of the Shock Tester)
Different kinds of shocks are injected.

1/ Short impact: The lab generates a half-sine wave with low impact velocity by the mechanical impact machine, accompanied by a short impulse time, upon the specimen.

On completion of the first impact, a thorough inspection takes place on the appearance and functionality of the product. No deformation and no flexion must be seen on the box. If no anomaly is found, a second impact is performed with a slightly increased impact velocity. The test goes on in this manner with gradually increased impact velocities until the product is damaged (which gives the critical design velocity φVc of the specimen).

2/ Long impact: The specimen is given a low acceleration trapezoid. After one shock, the product is visually inspected and checked for any malfunctions carefully. If there are no defects or malfunctions, then the product is given a slightly higher acceleration shock. This is conducted repeatedly until the product fails to find the product's critical acceleration (Ac). This data will be given to package designers to improve the packaging design for its best protection and will be used for reference during packaged drop test.

Two data are notified:
The specimen's critical velocity (φVc)
The specimen's critical acceleration (Ac)

The damage boundary curves (Figure 2) of cardboard box with mass (M) on the top are established.

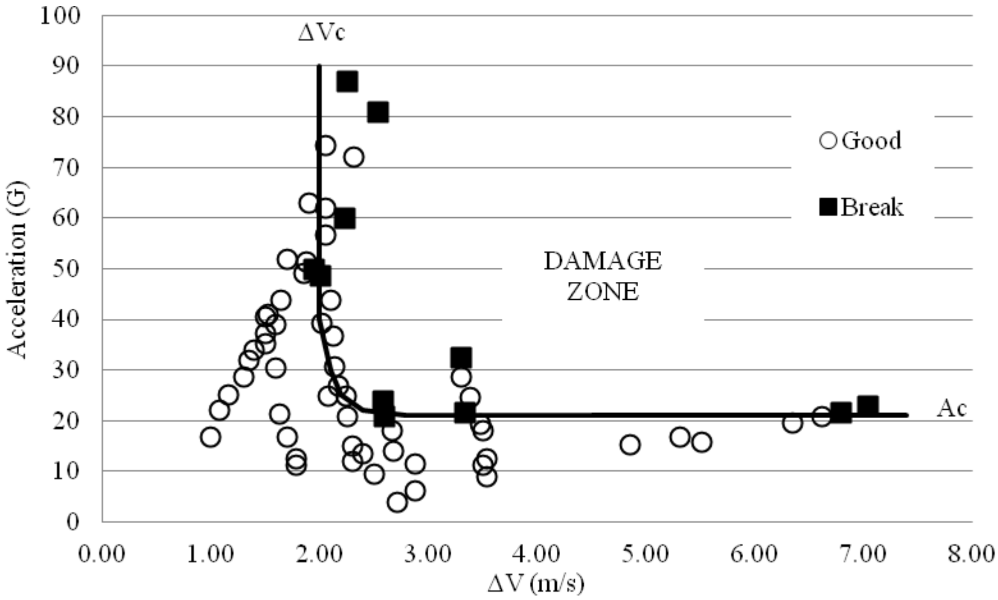

Figure 2: Damage Boundary Curve ï Double corrugated EB cardboard box With Preload M=6.9 kg

For example: With M = 6.9 kg ï Ac = 21.2 G - φVc = 1.98 m/s

3 Fragility versus masse (M) on the top

Several experiments are performed by varying the mass M.

The table 3 below presents the results:

Table 3: Properties of the material samples.

Masse M [kg]	Critical Acceleration Ac [G]	Critical Velocity φVc [m/s]
2.4	110.1	3.62
3.9	58.7	3.04
6.9	21.2	1.98
11.9	15.0	1.4
16.9	10.2	0.92
21.9	7.4	0.80

The different damage boundary curves (Figure 3) of cardboard box with different mass (M) on the top are established.

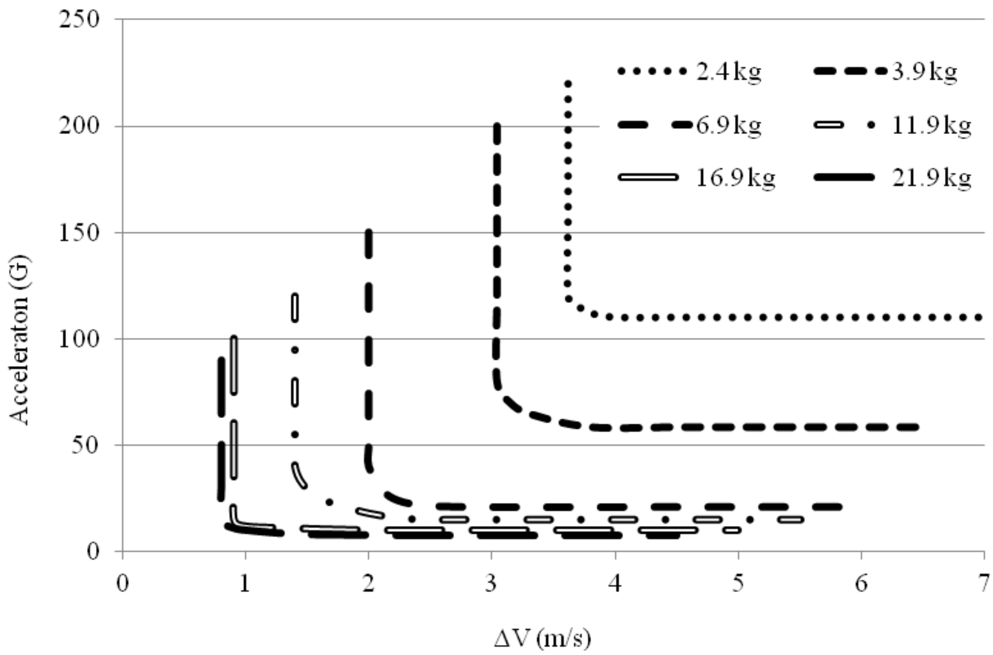

Figure 3: different damage boundary curves versus masse M

These measures permit to determine the position of critical points (φVc ï Ac) depending on the mass M.

The following equation defined the critical acceleration depending on the mass M:

$$Ac = 286.85\ M^{-1.202} \quad \text{with } R^2 = 0.982$$

The equation of the variation of speed depending on the mass M is the following:

$$\varphi Vc = 7.4444\ M^{-0.711} \quad \text{with } R^2 = 0.982$$

Position of critical points is shown on Figure 4:

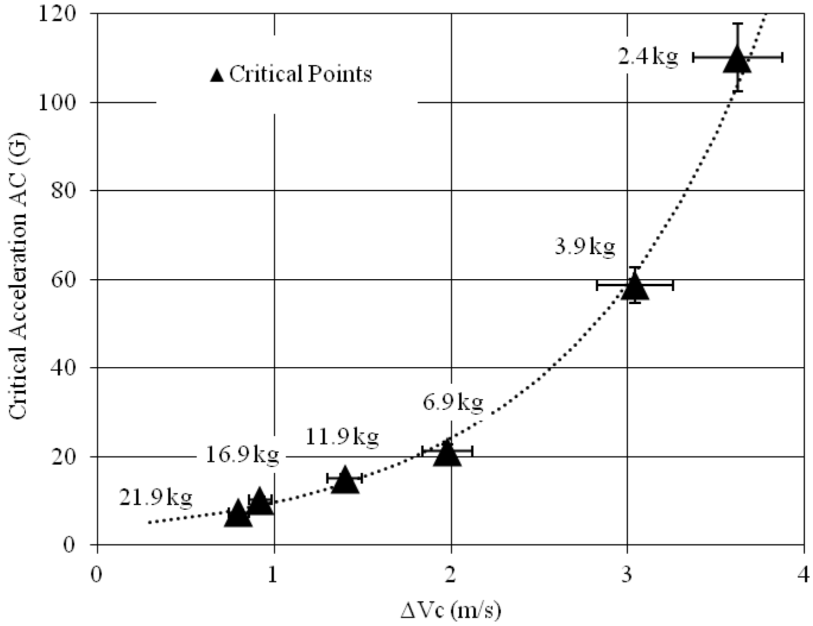

Figure 4: Position of critical points versus masse M

4 Comparison between damage and trip

Following these results, it can be possible to choose the maximum acceptable mass of stacking for this Double corrugated EB cardboard box and its transport.

Shocks encountered in transport are critical values that it will be not exceeded.

By projecting extreme points of each transport on the curve of critical points, the maximum acceptable weight (M) is calculated.

Figure 5 below shows the reading.

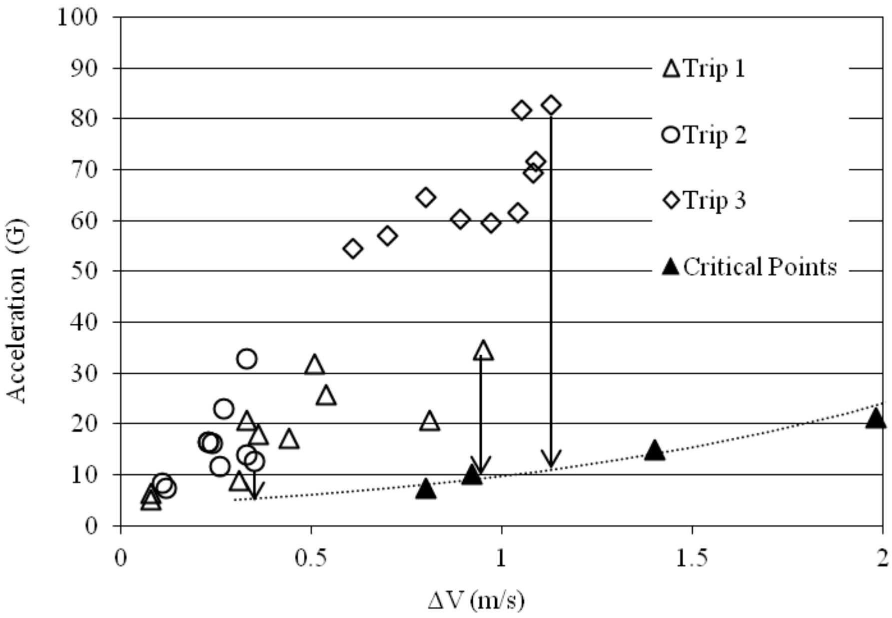

Figure 5: Comparison between damage and trip

Maximal acceptable masses (M) on the top of Double corrugated EB cardboard box are the following:

Table 4: Mass supported by trip

Trip type	Acceleration Maxi Amax [G]	Velocity Variation φV [m/s]	Masse Maximum [kg]
Trip 1	37.4	0.95	18.1 +/- 0.5
Trip 2	32.9	0.35	73.7 +/- 0.5
Trip 3	82.8	1.13	14.2 +/- 0.5

5 Conclusion

This method allows-us to choose the acceptable mass which can be stacked during transport.

The physical factor limiting the compressive strength of a cardboard box in the dynamic phenomena such as shock is the variation in maximum critical speed (φVc) that preloaded box can accept. This study shows that the acceleration measurement is not sufficient to develop a protective packaging.

Therefore, it is necessary to bring greater attention to the measurement of speed variation of shocks.

This method requires the position sensor on the pallet.