Dr. Ing. Kerstin Kracht
Ingenieurin für Schwingungstechnik &
Strukturdynamik

Markgrafenweg 1
19230 Toddin (Metropolregion Hamburg)
Germany
+40 (0) 176 20 58 41 82
www.vibrationsmanagement.de

COMPARISON OF THE VIBRATION ISOLATION AND SHOCK REDUCTION PERFORMANCE BETWEEN THE DIFFERENT CRATES OF TURTLE

IN GENERAL

The assignment of protective packaging is to achieve a safe environment for works of art during shipment. According to relevant specialist literature the primary threats to heritage objects are summarized as the "Ten Agents of Deterioration". Agent 1 is "Physical Forces".

Static mechanical forces are caused by the gravitational (constant acceleration) dynamic mechanical forces, by variable accelerations.

Shocks and vibrations are characterized by variable accelerations. The variability is expressed by frequencies, the level of accelerations by amplitudes. By reasons of different frequency and amplitude ranges, 4 excitation scenarios during shipment should be considered:

- Truck transport
- Flight
- Handling (harmonic excitation and shock)
- Fall over

Generally, wood is, in comparison to the compound material used for the TURTLE uNLtd, much more elastic. This yields a greater tendency for the wooden crates to vibrate in the frequency range relevant for shipments (from 1 Hz to 300 Hz). Expressed in numbers:

- ✓ First natural frequency of elastic mode of wooden crates (single and double walled) in the same size as a TURTLE uNLtd is 29 Hz (torsion) respectively 40 Hz (drum mode of wall), of the TURTLE uNLtd the elastic modes start at 47 Hz.
- ✓ The transfer factor of the TURTLE uNLtd is 50 % of the wooden crate.
  - ➢ Proof: Continuous Modal Testing of the crates since 07/2018 (ref. reports and emails)

Both supports, the regular corner blocks in the Turtle uNLtd and the support in wooden crates, are made of foam.
The advantages of foam regarding protection against shock and vibrations are:

- Particularly good shock absorption performance

The main disadvantages of foam regarding protection against shock and vibrations are:

- High level of minimum acceleration amplitude is needed to trigger a shock absorption (breakaway acceleration). This means shocks below this level are not reduced.
- Foam with a high stiffness is required to provide good shock absorption performance, however this level of stiffness yields vibration amplification during Truck transport and poor vibration isolation during Flight. It is essential:

  - ➢ The less the weight of the painting the higher the amplification during Truck drive, because: The less the weight of the painting, the vibration isolation during Truck drive becomes worse.
- Material parameters of foam and wood are not stable, they change over time. So, the vibration reduction and shock absorption performance cannot be calculated exactly. Wire rope isolators have a stable performance over 30 years.

Foam and, so far, corner blocks with two different heights of foam, are used for the support of the paintings in the crates. The design of the foam is based on the aim to avoid the creeping effect and an overload of the foam during shock. So, the foam is configured for the maximum weight of paintings which will be transported. In the case of TURTLE uNLtd, the maximum weight of paintings is 40 kg.

In 2018, 2019 and 2020 TURTLE investigated the need for a new generation of corner blocks. In December 2020, TURTLE finished the development of the first generation of TURTLE T+ advanced corner blocks.

Representatives used for testing:
1.) Panel dummy (34.6 kg, W x H = 118 cm x 119 cm), 2.) Canvas painting (8.6 kg, W x H = 120 cm x 90 cm) Results shown in tables 1 - 3.

1. Vibration reduction performance

Crate/support	Value	Truck	Flight
Wooden single-walled crate	Peak-to-Peak	21%	58%
	Mean (RMS)	-15%	26%
Wooden double-walled crate	Peak-to-Peak	23%	47%
	Mean (RMS)	-11%	28%
Foam corner blocks	Peak-to-Peak	Not tested containing the panel painting	
	Mean (RMS)		
TURTLE T+ advanced corner blocks	Peak-to-Peak	55%	70%
	Mean (RMS)	40%	69%

Table 1: Ratio between inside vibrations measured at the left upper corner of the panel frame and outside vibrations measured at the left upper corner of the crate

Crate/support	Value	Truck	Flight
Foam corner blocks	Peak-to-Peak	31%	42%
	Mean (RMS)	21%	35%
TURTLE T+ advanced corner blocks	Peak-to-Peak	63%	69%
	Mean (RMS)	50%	60%

Table 2: Ratio between inside vibrations measured at the left upper corner of the canvas frame and outside vibrations measured at the left upper corner of the crate

2. Shock reduction performance

Crate/support	Value	Shock (Handling)	Fall over
Wooden single-walled crate	Peak-to-Peak	90%	84g
Wooden double-walled crate	Peak-to-Peak	92%	44g
Foam corner blocks	Peak-to-Peak		113g
TURTLE T+ advanced corner blocks	Peak-to-Peak	90%	55g

Table 3: Ratio for shock absorption evaluation like in table 1 and two above and absolute values measured at the left upper corner of the panel dummy's frame for Fall over (on lid) evaluation

Summary

- The shock absorption performances of the tested crates were almost the same.
- The absorption of the Fall impact was best carried out with the double-walled wooden crate, closely followed by the TURTLE uNLtd with T+.
- In contrast to the TURTLE uNLtd solutions, the vibrations during Truck transport were effectively amplified by the wooden crates (effective value). This means, the acceleration amplitudes measured at the dummy in the wooden crate are effectively greater than the acceleration amplitudes measured on the crate.
- The TURTLE uNLtd with T+ performs effectively (RMS value) the vibration reduction during Flight more than 2 times better than the best wooden crate solution.
- The vibration reduction performance of the TURTLE uNLtd with the T+ during Truck transport could be increased by 100% and during the Flight by 60% compared to the performance of TURTLE uNLtd with foam corner blocks.
- During all 4 excitation scenarios, neither an increase in the acceleration amplitudes of vibrations nor a reduced shock absorption performance occur on paintings that are mounted in the TURTLE uNLtd with T+.

Testing results transferred to other paintings

The less the weight of the painting, the worse the vibration reduction performance of foam, which was designed for best shock performance.
The tested wooden crates that contain a painting weighing 34.6 kg already show an amplification of the vibrations during Truck transport. This yields a greater vibration amplification by the wooden crates containing lighter paintings during Truck transport and a worse vibration reduction during Flight.

Overall:
For paintings with a weight > 10 kg, the acceleration amplitudes measured at the frame of a painting contained by a TURTLE uNLtd with T+ are effectively at least 50% less during Truck transport and 2,6 times less during Flight if the same painting is mounted in a wooden crate (same size) bedded in foam.

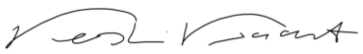
For paintings with a weight < 10 kg, the acceleration amplitudes measured at the frame of a painting contained by a TURTLE uNLtd with T+ are effectively at least 65% less during Truck transport and 3 times less during Flight if the same painting is mounted in a wooden crate (same size) bedded in foam.

Number of cycles

Fatigue fracture is dependent on the force amplitude which is related to the acceleration amplitude and on the number of cycles.

Due to the low tuning frequencies of the vibration isolation carried out by the T+ mounted in the TURTLE uNLtd, the number of cycles during shipping could be greatly reduced. The reduced acceleration amplitudes, together with the reduced number of cycles, represent an optimal vibration reduction.

Toddin, January 27th , 2021



Prof. Dr.-Ing. Kerstin Kracht
Engineer of Vibration Technology &
Structural Dynamics