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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 healthy environment for works of art during shipment. According to relevant specialist literature the primary threats to heritage objects are summarized to the "Ten agents of deterioration". Agent one is "Physical Forces".
Static mechanical forces are caused by the gravitation (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, four excitation scenarios during shipment should be considered:

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

TURTLE offers crates of wood (mentioned below "wooden crate") and of compound material, for instance the TURTLE uNLtd in two sizes, 125 and 160.
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 TURTLE 160 size is around 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 is 50 % of the wooden crate.
  - ➢ Proof: Continuous Modal Testing of the crates since 07/2018 (ref. reports and emails)

Both supports, the actual Corner Blocks 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.
- A good shock absorption performance of the foam requires a high stiffness of the foam. The great stiffness yields vibration amplification during truck drive 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 vary very much, so the vibration reduction and shock absorption performance cannot be calculated exactly.

Mostly, one type of 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 160, the maximum weight of paintings is 40 kg.

In 2018, 2019 and 2020 TURTLE investigated the need of a new generation of Corner Blocks. In December 2020, TURTLE finished the development of the first generation of TURTLE T+.

Two representatives: 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) have been used for testing, so far. The results are summed up in the tables 1 to 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+	Peak-to-Peak	55 %	70 %
	Mean (RMS)	40 %	69 %

Table 1: Ratio between inside vibrations measured at the left upper corner of the panel dummy's 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+	Peak-to-Peak	63 %	69 %
	Mean (RMS)	50 %	60 %

Table 2: Ratio between inside vibrations measured at the left upper corner of the canvas painting's 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 %	84 g
Wooden double walled crate	Peak-to-Peak	92 %	44 g
Foam corner blocks	Peak-to-Peak		113 g
TURTLE T+	Peak-to-Peak	90 %	55 g

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 have been almost the same.
- The absorption of the fall impact was best carried out with the double-walled wooden crate, closely followed by the TURTLE 160 with T +.
- In contrast to the TURTLE uNLtd solutions, the vibrations during truck drive were effectively amplified by the wooden boxes (effective value). This means, the acceleration amplitudes measured at the dummy are effectively greater than the acceleration amplitudes measured at the crate.
- The TURTLE 160 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 160 with the T+ the during truck drive could be increased by 100 % and during the flight by 60 % compared to the performance of TURTLE 160 with foam corner blocks.
- During all four 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 160 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 drive. This yields a greater vibration amplification by the wooden crates containing lighter paintings during truck drive 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 160 with T+ are effectively at least 50 % less during truck drive and 2,6 times less during flight than 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 160 with T+ are effectively at least 65 % less during truck drive and 3 times less during flight than 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.

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