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Vibration as a hazard during the transportation of canvas paintings

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ABSTRACT

The assessment of vibration levels that cause damage to canvas paintings travelling on loan has been hampered by the lack of direct measurements of the dimensional change of the canvas. The application of triangulation laser displacement sensors in this study has allowed direct continuous in-situ monitoring of the vibration of canvas during packing, handling and transporting by road of three nineteenth-century oil paintings from the collection of the National Museum in Cracow, Poland. The measurements showed varied levels of vibration primarily influenced by packing method: paintings wrapped in a tissue and transported in soft cardboard boxes were better cushioned from the vibration than a painting rigidly fixed in a wooden case. However, increased levels of vibration were always measured during packing the paintings and transferring the cases or boxes to and from the road vehicle, which emphasizes the need to train the staff to handle the paintings with care when they are still in the museum. The strains induced by the vibration levels recorded were much below the critical levels of tolerable strain for the nineteenth-century canvas paintings, quoted in the conservation literature. Therefore the paintings are unlikely to be endangered by fracture or fatigue damage under the transportation conditions monitored.

INTRODUCTION

Vibration has been indicated as a matter of concern to the museum field [1]. It can be generated in museums or historic buildings by visitor circulation or construction works undertaken in the proximity of the exhibition rooms. Vibration and shocks are major hazards to objects during handling, removal, packing and transportation when they are loaned to exhibitions outside the museum. Early vibration tests on framed canvases assessing the packaging systems and protective measures were performed by Green [2]. Broader aspects of the shipping hazards, including shock and vibration inputs to packages, sources of these inputs and their impact on the works of art were overviewed during the *Art in Transit Conference* of 1991 [3-5]. Further work on monitoring shock and vibration during the transportation of paintings was carried out in the National Gallery in London [6].

Vibration can cause damage as it makes objects move or resonate generating stresses in the materials. Larger stresses can cause direct physical changes of fragile objects such as irreversible deformation, fracture or disintegration. Repeated cycles of stress, exceeding a threshold of fatigue level, can lead to progressive, localised, structural failures in the materials due to the accumulation of even small damages at the micro level. The levels of shocks/vibrations that cause damage to museum objects have been analysed by Thickett [7] who carried out an extensive programme of vibration measurements at the British Museum during the re-construction of the Great Court. The measured damaging vibrations levels due to the building work, expressed as acceleration, were between 0.2 and 0.6 g and compared to the background levels between 0.006 g and 0.15 g induced by day-to-day activities.

The maximum acceleration due to shocks and vibration experienced by paintings during transportation can be as high as 8 – 10 g and they occur when the cases are transported to and from the aircraft at the airports [6]. The level of shock/vibration was found to be strongly dependent on the quality of the road, the type of trailer and its speed, which emphasises the need to limit transfers from trailer to aircraft and to specify carefully the transportation conditions at all stages between the lending museum and the receiving institution. In contrast, low vibration was encountered during the flight, and the maximum levels expressed as acceleration, which coincided with take-off or landing of an aircraft, were of the order between 1.0 and 1.3 g. The shock in vertical axis was always greater than in either the lateral or lengthwise axes.

Vibration experienced by objects has been measured so far by attaching accelerometers either directly to the objects, for example to the canvases or frames of mock-up paintings [2,6] or to the vibrating surfaces as close as possible to the affected objects [7]. However, measurements of the acceleration suffer from a serious limitation and can only indirectly be used for assessing risk of damage. Generally, acceleration is a measure of the inertial force acting on an object subjected to vibration or shock. The superposition of all forces present produces deformation in the object which can be characterized by strain - a relative dimensional change. The strain depends, on the one hand, on the magnitude and frequency of the resulting force applied, while, on the other, it depends on the material characteristics of the object, like rigidity and mass. When strain goes beyond a certain critical level, characteristic of a material or object, mechanical damage occurs.

Therefore measuring acceleration allows a relative comparison of input forces acting on one given object in museum galleries or during transportation. By a parallel assessment of ongoing damage of that object, or another, similar in terms of mass, geometry and construction, critical levels of acceleration beyond which risk of damage appear can be determined. In contrast, measurements of strain will allow direct assessment of risk both for infrequent deformations of a large magnitude and for repetitive vibrations leading to cumulative fatigue damage, if only the stress-strain relationships with critical levels of strains at which a given material begins to deform plastically or fails mechanically are available. It should be further noted that information on the input forces provided by the accelerometers is related both to a mode of transportation and a vehicle employed and the object transported. In contrast, monitoring strain provides information on the response of the object itself, reveals its mechanical characteristics related to the vulnerability to damage.

The purpose of this paper is to illustrate the usefulness of measuring directly the deformation in application to canvas paintings during transportation. The opportunity to monitor several oil paintings on canvas was presented by a temporary transfer of the collection of the nineteenth-century Polish art of the National Museum in Cracow from its traditional location in the Cloth Hall in central Cracow to a historic castle in Niepołomice, 25 km away. Altogether 1500 works of art were re-located, of which three paintings were monitored at all stages of handling, packing, transporting by road and exhibiting or storing them in the new location. Triangulation laser displacement sensors were used as our earlier research proved their capability of providing fast, precise, non-contact, continuous measurements in the field [8].

MEASUREMENTS

All three paintings selected for monitoring were oils on canvas dating to the second half of the nineteenth century. They differed considerably in dimensions: Painting A (1859) was 78 x 63 cm, painting B (1886) 113 x 88 cm and painting C (1883) 212 x 370 cm. The paintings were packed according to a standard practice at the National Museum: the relatively small painting A was fixed in a wooden case with no padding to decouple the painting from its box. The two remaining larger paintings were wrapped in a thin nylon tissue and packed into cardboard boxes. The paintings were transported by a MAN 14.224 truck, designed for transportation of fragile cargo, with two air cushions per wheel and temperature and relative humidity stabilized at 18 ^{o}C and 55% levels respectively.

To measure the vibration experienced by each painting, a laser displacement sensor (Micro-epsilon ILD 1401-100) was attached to a light metal mounting-system from Bosch clamped to a stretcher and positioned at the centre of the rear face of the painting (Fig. 1). The laser-to-canvas distance was about 10 cm. The sensor performed the non-contact measurements of the out-of-plane displacement of canvas with a resolution of 50 μm and a measuring rate of 1 kHz. The signal from the sensor was sampled at a frequency of 1 kHz. The data was recorded on a portable computer. The system allowed the recording of data during packing, handling and transporting the painting without any interference with typical shipment procedures.

DATA ANALYSIS

The raw data for paintings A and C are shown in Figs. 2 and 3 respectively - results for painting B were qualitatively identical with those for painting A. Therefore, only the final outcome of their analysis is presented below. The graphs, even without any further analysis, allow us to compare the relative amplitudes of vibration of the canvas during different stages of transportation. It is clear that the influence of a packing method is of major importance. In the case of painting A, which was rigidly fixed in a wooden case, the amplitude of the vibration induced by packing the painting and transferring the case to the vehicle was less than that observed during its transportation by road. In contrast, the vibration of painting C during road transportation was dampened to a great extent due to it being wrapped in tissue and packed into a soft cardboard box. The observations show that, though soft packing of painting C significantly reduced vibration levels during road transportation, the handling of the painting and the transferring of the box to and from the car produced vibrations of considerable amplitude. The vibration of the canvas during packing and transfer was further aggravated by static strains that occurred when the position of the painting was shifted from a vertical to a horizontal position and vice versa as indicated in Figs. 2 and 3. Our observations parallel those of Saunders [6] that highest shocks and vibration were registered during the stopovers and transfers of the pallet with paintings between the aircraft and the storage area rather than during the flight with the conclusion that handling staff should be trained to take special care of such shipments.

Wavelet transformation was used to derive characteristic frequencies of the canvas vibration from the recorded data. Wavelets are mathematical functions that look like small waves which are non-zero on a finite interval. They are short-term, multi-frequency functions similar in character to the irregular vibration observed; therefore they are able to trace accurately characteristic frequencies present in each time window of the vibration signal. The outcome is a three-dimensional analysis of the signal in the frequency-time domain. The wavelet transformations of the raw signal illustrated in Figs. 4a and 5a for paintings A and C respectively are shown in the same figures in parts b. The frequency spectrum is visualised using a scale of grey: light tones indicate the predominant characteristic frequencies whereas dark tones point to a lack of frequency components in the relevant area.

It is apparent from the plot, that the first harmonic of the resonant frequency, is between 4 and 15 Hz. The values fall within a broader range of 1-50 Hz indicated as the natural frequency band for canvas paintings under normal tension [3].

Marcon [2] indicated that vibration frequencies of 2.5 – 100 Hz were typically observed for trucks traveling over a variety of road surfaces. Stolov [9] in contrast indicated 70 – 200 Hz as a typical range for the highway travel. Vibration induced at the resonant frequencies can cause a dramatic increase of the vibration amplitude and consequently badly damage the painting. Generally, the resonant frequencies cannot be avoided during transportation or in day-to-day museum practice. However, they can be increased by stiffening paintings through wrapping, backing boards, stretcher linings and crating [3]. For a given input vibration level, or in response to constant conditions, amplitudes are beneficially reduced as the resonant frequencies increase.

The computation of strains of the canvas surface induced by the vibration recorded was the next step of analysis. The strain was calculated along the intersection of the canvas surface by the plane perpendicular to the two longer sides of the stretcher that goes through the central point of the canvas (Fig.6). The canvas was assumed to oscillate with the fundamental frequency (M_{11} mode of vibration) and the deformation along that intersection was approximated to a parabola. As the maximum strain in the entire canvas is thus calculated - maximum deformation in the central point related to the shortest distance - further discussion will be limited just to this parameter as representing the worst case. Fig. 7 shows the number of instances at which increasing strain levels were appearing in the three paintings during packing and transfer. As one can see the plots follow the same pattern. The largest strain levels appear in painting C, which probably reflects its considerable size and imperfect tensioning. Fig.8 provides the same information for the road transportation. The results confirm that much larger strains are experienced by painting A, rigidly mounted in the case, when compared to paintings B and C wrapped in tissue. Dimensions of paintings also play a role; smaller painting B properly tensioned and easy to handle during packing and transfer showed the least vibration of the three paintings studied.

DISCUSSION

An important question appears as to whether the obtained patterns of strain resulting from the vibration experienced by the paintings during the transportation were endangering the paint layer by physical degradation like cracking or delamination from the canvas. The failure mechanism of paintings on canvas supports has received a considerable attention in the conservation literature [5,10]. Uniaxial tensile mechanical properties of such systems were analysed in detail, also for the authentic, naturally-aged nineteenth-century material [11]. The typical load-extension curves indicated that at low-strain levels, a high-stiffness, near-linear response was observed, the end of which coincided with the failure of the ground/paint layer. The failure was characterized by developments of cracks perpendicular to the loading direction, which joined with longitudinal cracks, leading to ground delamination. The initiation of the paint-layer failure occurred at an applied strain of approximately 1%.

The quoted value of 1% represents the critical strain leading to damage in one cycle. However, fatigue fracture of paint layers can be caused by a cumulative effect of vibrations of lower amplitude. In high-cycle fatigue situations, materials performance is commonly characterised by a sigmoid S-N curve, also known as a Wöhler curve, where S – is critical strain leading to damage and N – number of cycles necessary to cause damage at that strain. The curves start at the critical strain leading to damage in one cycle, and decrease to a plateau where strains occurring cyclically can be endured by the object indefinitely. S-N curves are derived from tests on samples of the material to be characterised where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. The conservation literature provides very limited information on the S-N curves for materials building up a ground/paint layer. Michalski [12] assumed that the plateau begins in the range between 1 million to 10 million cycles at a strain between 1/4 and 1/10 of the single cycle strain. His proposition is supported by the fatigue literature, mainly concerning the modern construction materials. For polymers, which are the closest category to painting materials used historically, the fatigue limit of about 20-30% of the initial strength is generally quoted.

The largest strains recorded in this study during road transportation did not exceed 0.015% so the paintings are unlikely to suffer from the fatigue damage especially because they are not subjected to the vibration for prolonged periods of time. Such risk estimates should, however, be used only as approximate indices of the objects safety as the number of cycles the objects have already experienced in the past remains unknown.

CONLUSIONS

The use of triangulation laser displacement sensors has allowed precise in-situ measurements of the vibration of canvas paintings at all stages of their transit between the two locations. The measurements showed varied levels of vibration primarily influenced by the packing method: wrapping a painting in a tissue and placing it in a soft cardboard box considerably reduced the vibration when compared to a painting rigidly fixed in a wooden case. In addition, high levels of vibration were always measured during packing the paintings and transferring them to and from the vehicle. They were further aggravated by the static strains that occurred when a painting was turned from a vertical to a horizontal position and vice versa. The finding emphasizes the need to carefully analyse the handling and transportation conditions at all stages from the time a painting is taken off the wall to the time it is displayed in the receiving institution.

The analysis of strains induced by vibration levels recorded has shown that they were much below the critical level of tolerable strains quoted in the literature. Therefore the paintings were unlikely to be endangered under the transportation conditions monitored though their vulnerability to damage depends also on the fatigue accumulated already in the past.

SUPPLIERS

Laser displacement sensors: Micro-Epsilon Messtechnik GmbH & Co., Koenigbacher Strasse 15, D-94496 Ortenburg, Germany.

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FIGURES

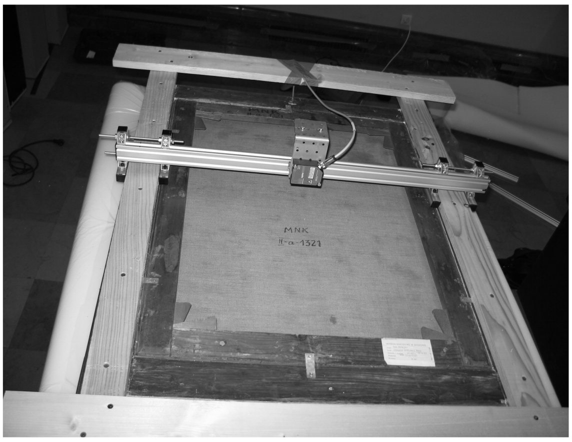

Fig. 1. Laser displacement sensor mounted on painting A

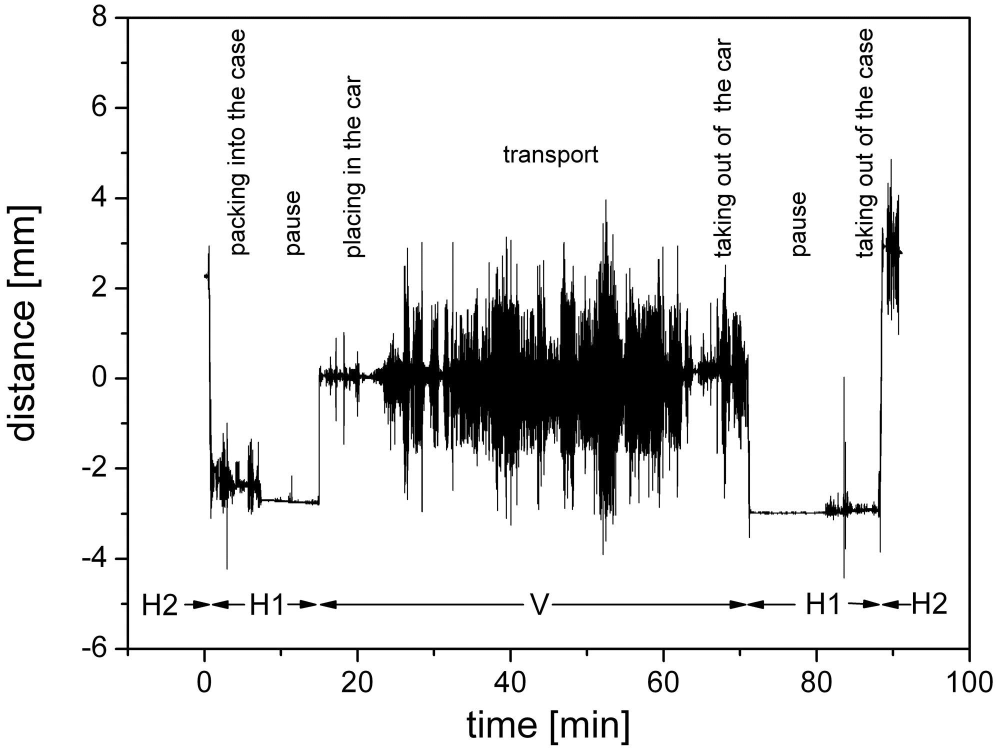

Fig. 2. The vibration of the canvas of painting A, measured as a displacement between the laser sensor and the canvas surface, during packing and transportation by road. V – vertical position, H1 and H2 – horizontal positions with the rear face of the painting up or down respectively.

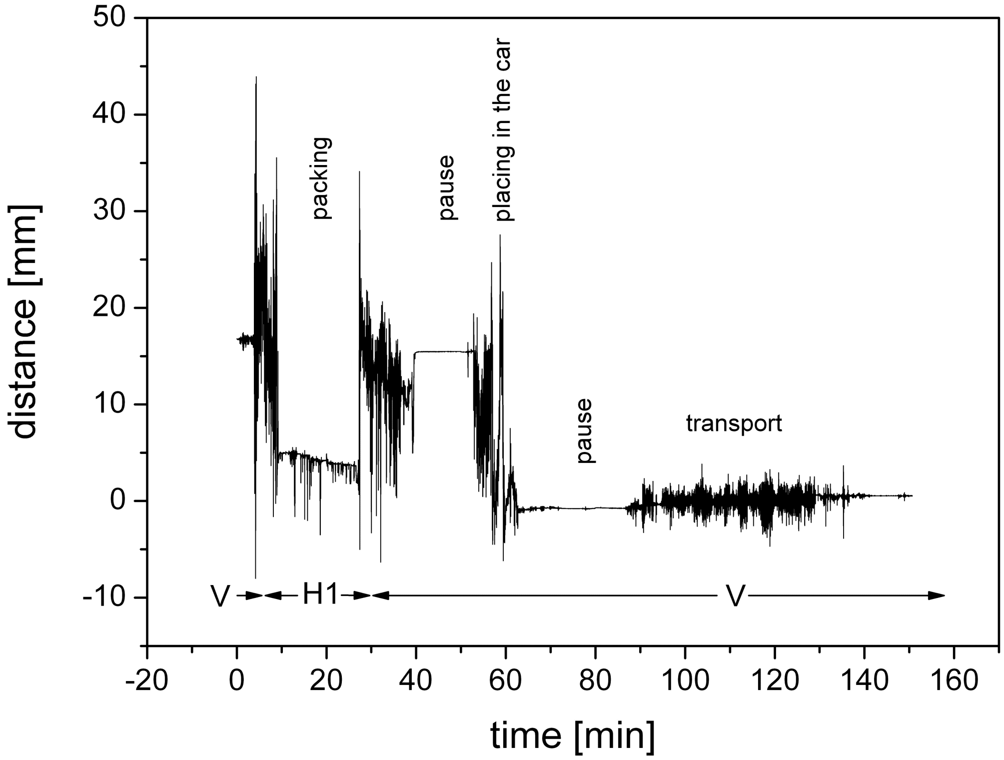

Fig. 3. The vibration of the canvas of painting B. For description see Fig.1.

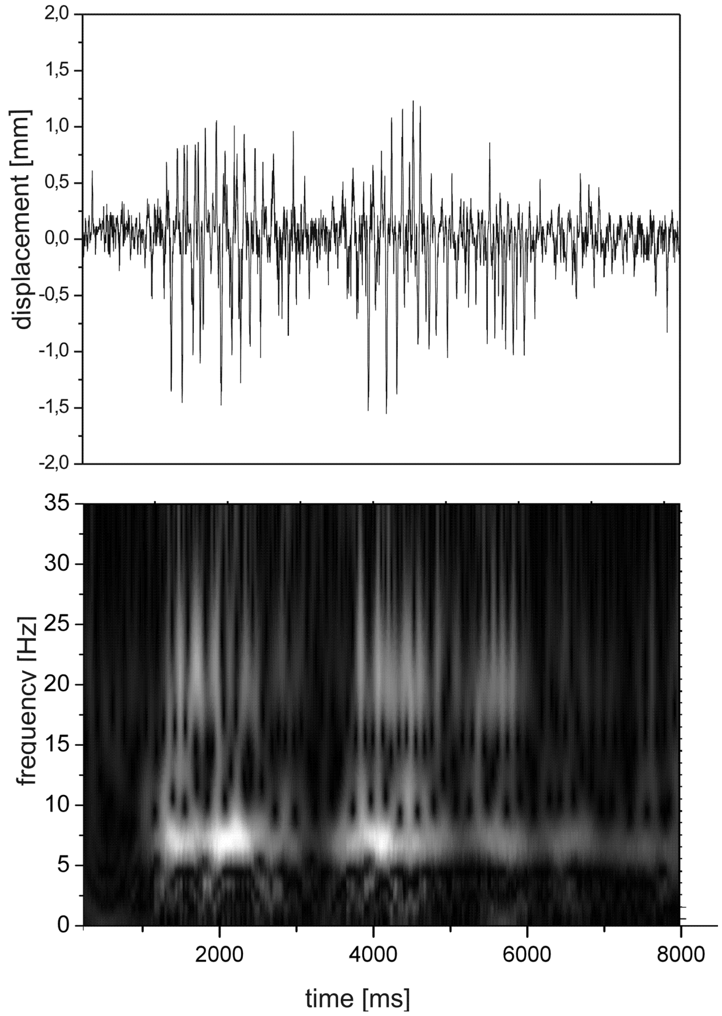

Fig. 4. A vibration event in painting A: raw signal (a) and wavelet transform in the time-frequency domain (b), the predominant characteristic frequencies are shown as a pale region.

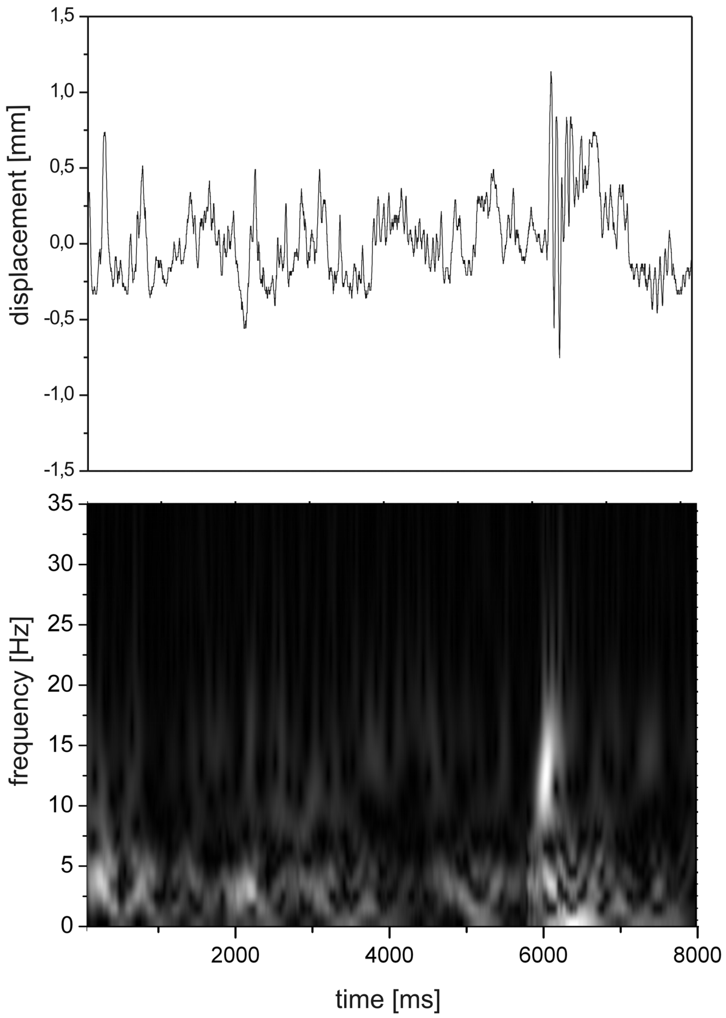

Fig. 5. A vibration event in painting C. For description see Fig. 3.

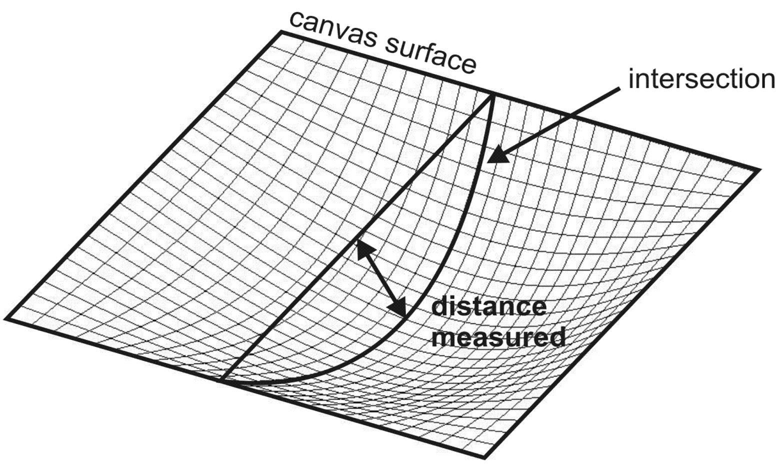

Fig. 6. Diagrammatic scheme of the canvas deformation and the line for which the maximum strain was calculated.

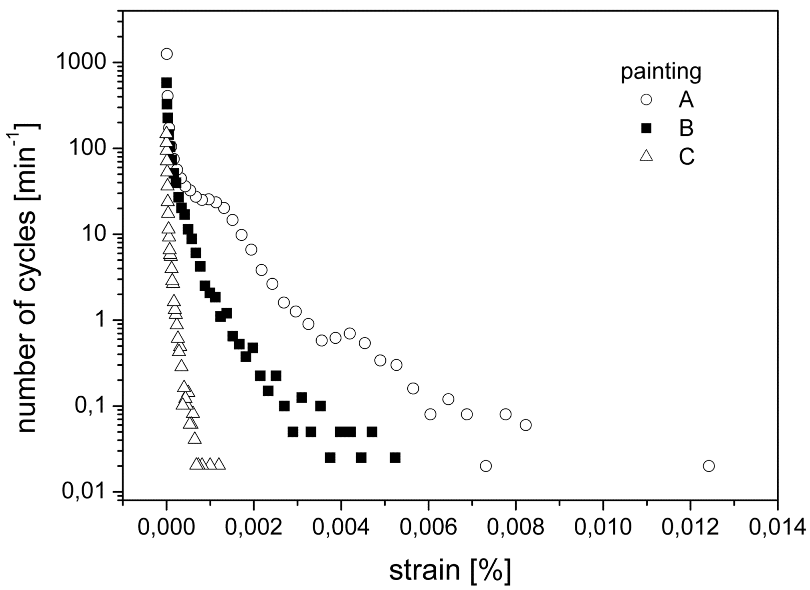

Fig. 7. Number of cycles as a function of strain levels appearing during packing and transfer of the paintings to the car.

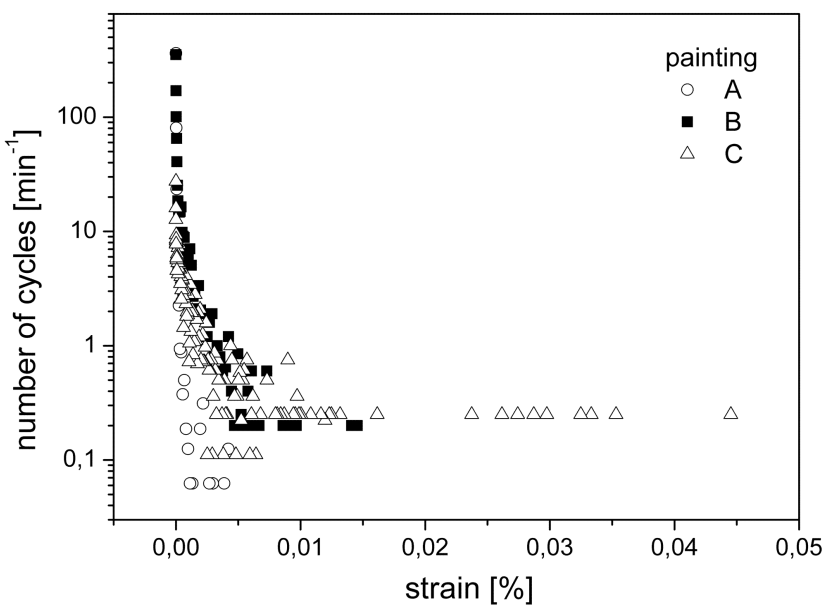

Fig. 8. Number of cycles as a function of strain levels appearing during the transportation of the paintings by road