original scientific article
approval date 01 04 2011
UDK BROJEVI: 621.798.1:678.5 ID BROJ: 184976396

VALIDATION NUMERICAL MODELING WITH 3D OPTICAL MEASUREMENT OF DEFORMATIONS OF FOLDABLE PLASTIC PACKAGING BUCKLING FAILURE

A B S T R A C T

This paper describes the numerical and experimental methodology for analysis of plastic packaging buckling characteristics that are representative of its strength in the real life. The experiments were executed with ”GOM” equipment and “ARAMIS”software application for modern optical 3D measurement of deformations. Numerical analysis was conducted by the application of finite elements using “KOMIPS” software. The fundamental question to be answered is related to the mechanism of failure of foldable packaging – does the buckling precede plasticity or vice versa? This article will show how experimental results can be predicted by means of finite element analysis; this is found a very strong learning tool that would enable designers to improve the structural strength of the new products in future. Experimental and numerical analysis results to date have shown high degree of correlation.

This paper describes the access that allows real structure behavior diagnostic, reliable prospect for structure in exploitation reacting, elements receiving for different decision making (operating regime, rehabilitation, reconstructions, revitalizations, optimization, confirmation to variable solution selection and so on), poor performance sample defining or structure loosening, structure life time estimation and similar. The described developed diagnosis access is shown in solved examples.

Taško Maneski, Biserka Nestorović
University of Belgrade - Faculty of Mechanical Engineering, Faculty of Forestry

KEY WORDS

FINITE ELEMENT METHOD
3D OPTICAL MEASUREMENT OF DEFORMATIONS
VALIDATION
BUCKLING

INTRODUCTION

The objective was to point out the advantages of applying modern optical 3D measurement of deformations in identifying buckling effects generated due to compressive loads. The equipment typically consisted of two mobile optical digital stereo cameras supported by „ARAMIS“ and „PORTOS“ software applications. Both applications were used for measuring 3D changes of the shape (of an object) and for determining the distribution of deformation due to either static or dynamic loads.

„ARAMIS“ can analyze, calculate and report the deformation of parts of the structure or entire structure. „PORTOS“ can analyze, calculate and report the deformation of a chosen object, rigid body movements and display a dynamic behavior of objects in question.

Mechanical Engineering Faculty in Belgrade is in possession of this equipment including two cameras of 2 Megapixels each, with the ability to measure a volume of 2000mm x 1500mm x 1500 mm.

Measuring equipment must be calibrated as a first step. Calibration is executed by measuring special calibration objects. Any deviation from known dimensions (of the calibration object) is used to actually adjust the measurement equipment.

The following are the fields of application of such measurement equipment:
- 3D deformation, movement and vibration detection;
- Measuring of dynamic behavior for up to 25Hz;
- Linear and non-linear behavior of viscous-elastic materials;
- Testing of homogeneous, non-homogeneous, isotropic and anisotropic materials;
- Creep testing and ageing effects of complex structures;
- NVH testing in car industry and also in an aerodynamic tunnel;
- Calculation, visualization and display of the position of measurement points in different phases of test;
- Verification of the FE results .

Static, dynamic and thermal analysis of the behavior of various constructions is usually performed using Finite Element Method (FEM). The basic static equation in matrix form, for the global system of coordinates, can be represented in the form

$$[K]\,\{\delta\} = \{F\} \qquad (1)$$

where :[K] is the stiffness matrix; $\{\delta\}$ is deformation vector; {F} is loading vector.

The basic dynamic equation (damping oscillations) is

$$[M]\{\ddot{\delta}(t)\} + [B]\{\dot{\delta}(t)\} + [K]\{\delta(t)\} = \{F(t)\} \qquad (2)$$

with the following notation: [M] - mass matrix; [B] - damping intensity factor; $\{\ddot{\delta}(t)\},\{\dot{\delta}(t)\},\{d(t)\}$ - acceleration, speed and deformation; $\{F(t)\}$- dynamic loading vector; t - time.

DETERMINING THE PROPERTIES OF LAMINAS BY OPTICAL 3D MEASUREMENT OF DEFORMATION

Sufficiently accurate measurement of stress and deformations in elements of laminates – wood-based laminas – is an area that is possible to upgrade by modern technological methods of measurement such as optical 3D measurements of deformations and the application of measuring ribbons which contain optical fibers on one or more laminated veneer sheets (Fig. 1).

This method was used to verify the elasticity moduli calculated by experimental research using the test-tubes with uniform veneer stacking, by way of the testing of one lamina made of beech veneer with parallel fiber orientation.

This experiment is currently the most advanced type of determining the properties of test materials in a relatively simple manner, and replaces complex experiments which use measuring ribbons.

NUMERICAL FEM ANALYSIS OF PLASTIC FOLDABLE PACKAGING IN BUCKLING

Long Side FE Models

- Bottom face simply supported (surface support);
- Load continually applied to each node of the top face pointing downwards.

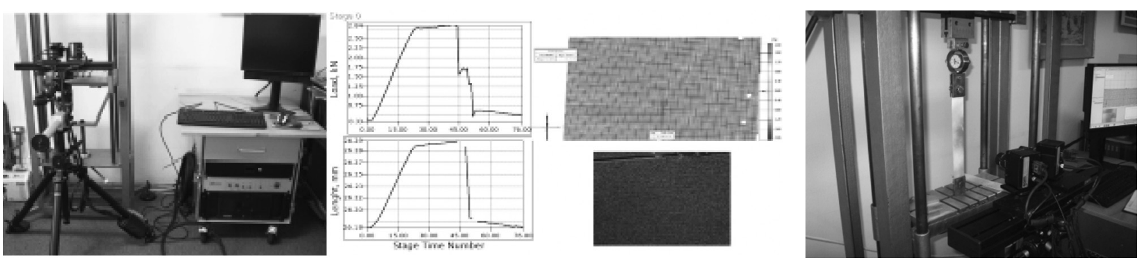

Figure 1
The experiments were executed with “GOM” equipment and “ARAMIS” software application for modern optical 3D measurement of deformations

Modulus of elasticity was E=1200MPa. Total compressive load pointing downwards, equally distributed along the side was 4023N (400kg). This equated to $2\times4023 + 2\times2/3\times4023 = 13410$N of linear force acting upon entire length of the top face of the crate (Fig. 2, 3 and 4).

Long Side Compression Strength

Figure 3. Maximum total spatial deformation was 3.7 mm. Vertical deformation of top edge was 1 mm. Lateral deformation in horizontal plane of the top edge middle point was 0.92 mm

Buckling Analysis for the Long Side

Please see the following page for the natural frequencies analysis where the modes shapes for the first three modes were shown (Fig. 5, 6 and 7).

Buckling Force Estimate Based On Static and Dynamic Analysis

- Static calculation: linear elastic limit to stress is 27MPa / 5.4MPa = 5;
- Dynamic calculation: amplitude in the first mode to deformation due to static force is 3.3mm / 0.92mm = 3.59.

As 3,59 < 5 it is concluded that buckling would precede the plastic deformation. Estimated buckling force would be F_{buck}= 13410N×5×3.59/5 = 48142N. This determined the load carrying capacity of the crate in compression.

The presented analysis of the buckling force and the load carrying capacity was not a function of the modulus of elasticity.

Experimental Analysis of Plastic Foldable Packaging in Buckling

Experimental verification of the previous numerical analysis was executed with the described equipment for 3D optical deformation measurements. Results are shown in the following picture. The measured vertical deformation was 1.79mm (Fig. 8).

These are the two examples of experimental analysis of buckling effects which occurred much earlier than the plastic deformation. Buckling was determined by the means of 3D optical measurement equipment.

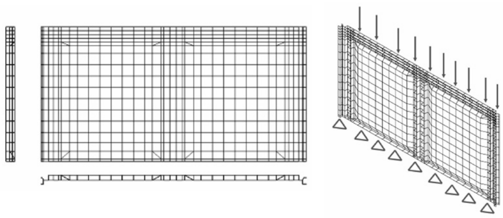

Figure 2
FE Models

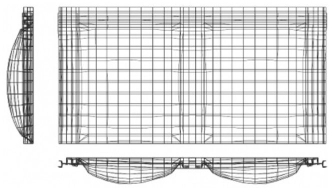

Figure 3
Maximum total spatial deformation was 3.7 mm.
Vertical deformation of the top edge was 1 mm. Lateral deformation in horizontal plane of the top edge middle point was 0.92 mm

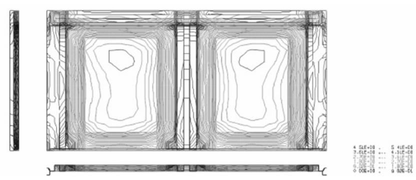

Figure 4
Von Misses Stress [MPa] (Max 5.41 MPa)

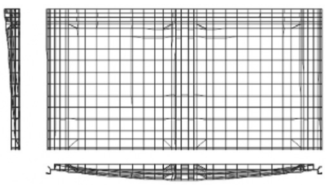

Figure 5
The first mode. Natural frequency: 32.4 Hz
Maximum horizontal lateral deformation of the top edge middle point is 3.3 mm

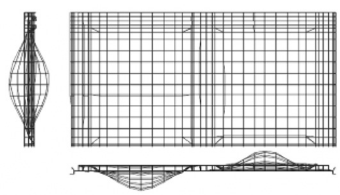

Figure 6
The second mode. Natural frequency: 61.7 Hz
Maximum horizontal lateral deformation of the top edge middle point is 6.3 mm

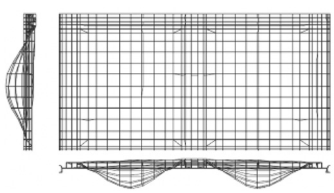

Figure 7
The third mode. Natural frequency: 65.9 Hz
Maximum horizontal lateral deformation of the top edge middle point is 6.5 mm

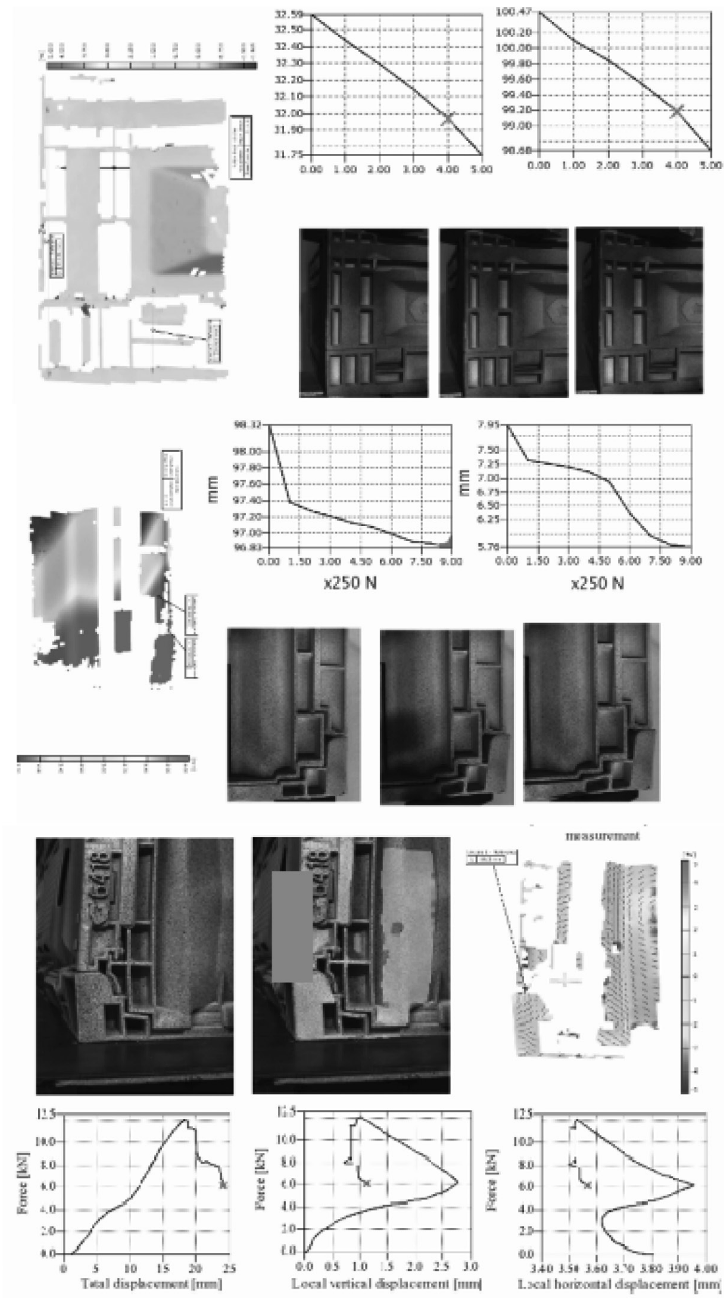

Figure 8
Experimental verification of the previous numerical analysis was executed with the described equipment for 3D optical deformation measurements

ANALYSIS AND STRUCTURE BEHAVIOR DIAGNOSTIC

The main aim of numerical and experimental diagnostics of structural behavior was finding out the actual behavior of their production structures. Appearance of basic numerical algorithms and experimental diagnostics of structural behavior has the following comparative display (Fig. 9).

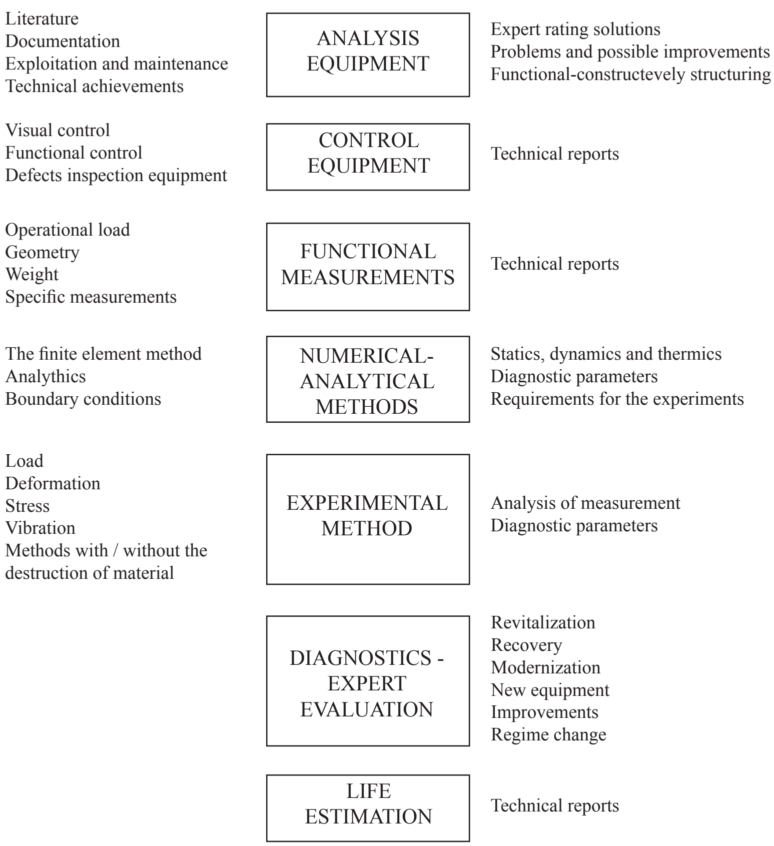

Figure 9 Algorithm for analysis and structure behavior diagnostic

Finding and solving the problem causes is achieved by numerical and experimental diagnostic methods. This approach should enable the determination of the actual behavior of structures, reliable prediction of structural response in service, obtaining the parameters of choice and decision, determining the cause of poor behavior or structural deterioration, assessment of service life time of reliable operation and construction.

Experimental methods include:
- Measurement of deformation and stress,
- Vibro-diagnostics,
- Non destructive testing,
- Determining the thickness and sheet double-plate,
- Destructive tests,
- Welded joint,
- Bolted connections,
- Measuring the gap,
- Hardness,
- Anti-corrosion protection,
- Control of geometry.

Part of the equipment for the experimental measurements is provided in the following figure (Fig. 10)

Diagnostic base for structure behavior represent computer modeling and structure analysis of construction by "KOMIPS" with numerical method for finite elements application throughout static, dynamic and thermal calculation of its construction.

KOMIPS allows modeling and structure and problems complex calculation, real deformation and stress defining, structure and its elements real behavior discovery, reliable construction in exploitation reacting forecast, receiving of elements for decision making (operating regime, rehabilitation, reconstructions, revitalizations, optimizations, confirmation for selected construction type solution), poor performance sample defining or structure loosening, exploitation life time estimation and structure reliable operation efficiency. Every structure performance improvement that can be achieved by such access allows extension for structure exploitation life and its reliability increase.

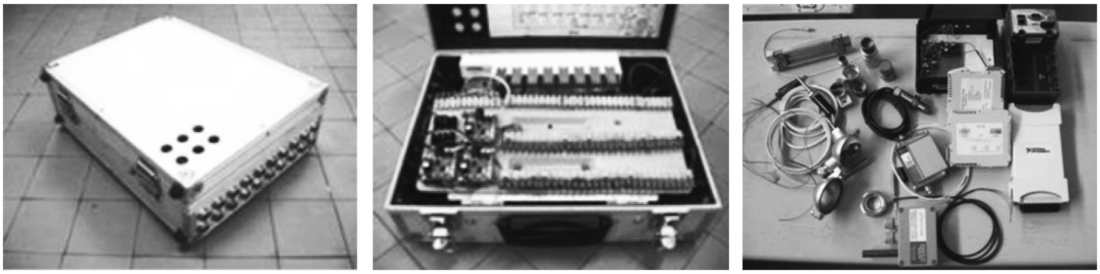

Figure 10 Equipment for experimental measurements

The problems raised during equipment exploitation mainly come from insufficiently well-designed geometry. Besides, it very often results from insufficient material resistance and especially of welded joints.

In engineering structure analysis the application of the explained method has been introduced as unavoidable because of a very low application costs with very high results level achieved.

The developed system "KOMIPS" has specific calculation for closer structure behavior defining. Loading distribution, membrane and bending stress, deformation energy and kinetics and potential energy allows for very efficient position analyis and structure performance diagnostic for designed or executed structure.

The aspirations for good structure performances in exploitation are as follows: as higher difference between the highest operating and yield point, as even deformation and tension and energy distribution, as smaller stress concentration presence, as larger material resistance to origin and cracks growth, as far dynamic response from eventual impulse, as higher first frequency and as larger distance between frequencies, as smaller dynamic reinforcement factor, as possible.

Loading distribution

Movement course determination and loading distribution on structure from the point of its entrance to its bottom (from source to abyss) represents the base of understanding of the structure performance. As simplified, the loading travels during the smallest resistance (course-line for the biggest stiffness and the shortest way).

Membrane and bending stress, normal and tangential stress distribution

It regards here the finite plate element and beam. Weak (they are present in high measure bending and removing) and good points (present only membrane and normal stress) have been found, as well as the points with small stress level. It also shows which modifications should be carried out in order to minimize negative bending influence and better loading distribution.

Deformation energy distribution

Deformation energy distribution according to element groups (structure parts) very effectively shows loading course and structure parts that transfer, carry loading, respectively. The sensitivity to eventual modifications has also been defined by this.

Balance equation for potential energy deformation and external forces operation is calculated by multiplication of basic static equation from left transported deformation vector $\{\delta\}^T [K]\{\delta\} = \{\delta\}^T [F] \equiv 2E_d$. Deformation energy for finite element e_d words: $e_d = 0,5\{\delta_{sr}\}^T_e [\overline{k_{rs}}]_e \{\delta_{sr}\}_e$, where: $\{\delta_{sr}\}_e$ is the belonging global deformation vector and $[\overline{k_{rs}}]_e$ global element stiffness "e".

Kinetic and potential energy distribution on main oscillating forms

Kinetic and potential energy distribution on main oscillating forms even precisely defines performance. By dynamic equation multiplying from left side with conveying matrix of main vectors one achieves balance equalities of potential and kinetic energy:

$$[\mu]^T [K][\mu] = [\mu]^T [M][\mu]\{\lambda\} \qquad (3)$$

Kinetic (e_k^r) and potential (e_p^r) finite element energy "e" and whole structure E^r on r- main form words as:

$$e_k^r = \omega_r^2 \{\mu_{sr}\}_e^T[m]_e\{\mu_{sr}\}_e,\ e^r_p = \{\mu_{sr}\}_e^T [\overline{k_{rs}}]_e\{\mu_{sr}\}_e,$$

$$E^r = E^r_k = E^r_p = \omega_r^2\{\mu_r\}^T[M]\{\mu_r\} = \{\mu_r\}^T[K]\{\mu_r\}, \qquad (4)$$

where are ω_r– r-main frequency, $\{\mu_r\}$– r - main vector and $\{\mu_{sr}\}_e$– belonging r-main vector element. Square change of main r - frequency (reanalyze – without additional calculation) words as:

$$\frac{\Delta\omega_r^2}{\omega_r^2} = \frac{\alpha_e e_p^r - \beta_e e_k^r}{E^r}, \qquad (5)$$

where α_e and β_e modification e-element is defined.

CONCLUSION

The methodology described in this paper has shown satisfying results regarding the buckling effects on plastic packaging. The conclusions have been reached about the root-causes of the buckling. The analysis was consistent with all previously conducted observations of container behavior due to compressive loads. The difference is that the previous conventional observations of deformations could only detect the consequence of buckling (structural failure) where the 3D optical equipment enabled us also to understand the root-cause.

This type of analysis is applicable to a wide range of structural problems with diverse loading patterns.

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5 Software ARAMIS, GOM, Germany

6 Software KOMIPS, Faculty of Mechanical Engineering

NOTES

N.B. Authors is suppored by the project TP 36008 of the Serbian Ministry of Science and Technological Development