Structure Behavior Analysis and Diagnostic

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The paper describes application of developed methodology for analysis and diagnostic of structure behavior. The basement of the analysis represents static, dynamic and thermal estimation by FME. Presented methodology has functions of load, stress and deformation energy distribution in the structure at static and thermal calculation. Kinetic and potential energy distribution on main oscillating modes is determined at dynamic calculation. Own developed software KOMIPS (about 30000 computer lines) installed on PC platform support developed methology. Paper gives brief description of matrix equations and their application in developed methodology.

Keywords: *finite element, structure, diagnostic, behavior, computer*

1. INTRODUCTION

The aim of developed system for analysis and diagnostic of structure behavior is to determine real behavior of the construction in exploitation. Methodology also provides the definition of parameters for recovery, reconstruction or revitalization. Diagnostic parameters obtained through developed software and engineering intuition are used for interactive solving of the above problems.

Structure behavior analysis and its redesign through determination of the parameter sensitivity has been considered in many papers and PhD thesies [4,5,6,7,8]. Presented procedures in analyzed papers are not directly applicable in structures computation using FEM.

2. KOMIPS program

The author of this paper has developed program for computer modeling and structure analysis (KOMIPS) [1,2,3]. Development of the program started in 1978 and it contains about 30,000 lines. The main parts of the program are as follows:

- Preprocessor for interactive computer model generation,
- Processor for static, dynamic and thermal calculation,
- Postprocessor for analysis and diagnostic of structure behavior,
- Users functions,
- Interactive computer graphics, and
- Model conversion.

The basic static equation in matrix form, for the global system of coordinates, can be represented in the form

$$[K]\{\delta\}=\{F\} \tag{1}$$

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

The basic dynamic equation (free nondamping oscilations) is

$$[M]\left\{\ddot{\delta}(t)\right\}+[K]\{\delta(t)\}=\{0\} \tag{2}$$

with the following notation: $[M]$ - cencetrated diagonal mass matrix; $\left\{\ddot{\delta}(t)\right\}$, $\{\delta(t)\}$ - acceleration and deformation.

Algorithm and routines for finite elements definition are taken from relevant literature sources with some modifications. Also algorithm and routines for solution of algebraic equations in static calculation as well as solution of differential equations for free nondamping oscilations (iterative method with subspaces) are taken from relevant literature sources with some modifications.

Damping oscilations are solved only in frequent domain by using Laplace transformation. In this procedure percentage values of damping are given for every main mode.

Theoretical statement of the program and accuracy testing are given in monograph books [1,3]. Analysis of the results shows that errors are in acceptable boundaries.

3. STRUCTURE BEHAVIOR ANALYSIS AND DIAGNOSTIC

Problems raised during equipment exploitation mainly come from insufficiently designed geometry.

In engineering structure analysis the application of explained method is introduced as unavoidability because of very low application costs with very high results level.

Developed system "KOMIPS" has specific calculation for structure behavior. Loading distribution, membrane and bending stress, deformation energy and kinetics and potential energy allow very efficient position analysis and structure performance diagnostic.

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The above mentioned distributions can be presented in the following way:

- By tabular values given in percentage for selected group of finite elements, and
- Graphically by isoclines of selected distribution potential.
- Basement for analysis and programming of distribution function are given in specified literature.

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 on 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.

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 under-standing base for structure performance. In the simplest, the loading travels during the smallest resistance (course-line for the biggest stiffness and the shortest way).

Membrane and bending stress, normal and shear stress distribution

It is here for finite plate element and beam. We find weak (present in high value bending and shear) and good points (present only membrane and normal stress), as well as the points with small stress level. It also shows which modifications should be carried out in order to minimize negative bending and shear influence and better loading distribution.

Deformation energy distribution

Deformation energy distribution according to element groups (structure parts) very effectively shows loading flow and structure parts that transfer and carry loading, respectively. By this is also defined sensitivity to eventual modifications.

We calculate balance equation for potential energy deformation and external forces operation 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: $e_d = \frac{1}{2}\{\delta_{sr}\}_e^T\left[\overline{k_{rs}}\right]_e\{\delta_{sr}\}_e$, where: $\{\delta_{sr}\}_e$ is belonging global deformation vector and $\left[\overline{k_{rs}}\right]_e$ is global element stiffness "*e*".

Kinetic and potential energy distribution on main oscillating modes

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

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

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

$$e_k^r = \omega_r^2\{\mu_{sr}\}_e^T[m]_e\{\mu_{sr}\}_e,$$

$$e_p^r = \{\mu_{sr}\}_e^T\left[\overline{k_{rs}}\right]_e\{\mu_{sr}\}_e,$$

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

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 (reanalize – without additional calculation) words as:

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

where α_e, β_e modification e-element is defined.

4. METHODOLOGY APPLICATION

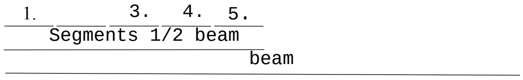
The application of the developed methodology for the analysis and diagnostic of the structure behavior is given on the examples of banding long and short beam. Iron beam has box cross section with dimensions 4x6 cm and with thickness of 1 cm. Length of the long beam is 100 cm, while length of the short beam is 50 cm. Load in the middle of the beam was 2x44 kN. The aim of these examples is to point which strain is dominant (banding or shear), which portion of the cross section is mode strained, which part of the beam geometry has influence on beam behavior etc.

Results of this analysis are given in Table 1 and Figure 1.

5. EXAMPLES APPLICATION

Real problems considered in such way are: support excavator SH400 (FC Beočin) behavior diagnostics; damage fixing for radioaxial bearing on bucket wheel excavator C700 (Kolubara Metal Vreoci); reconstruction for slewing spreader platform ARS 1400/ 22+60+21 O&K (Kolubara Metal Vreoci); operating wheel excavator behavior diagnostics; recovery and reconstruction on operating wheel excavator C700S O&K (Kolubara Metal Vreoci); bucket wheel excavator SchRs 630 support, bucket wheel excavator C700 O&K dumping boom (Kolubara Metal Vreoci); excavator SchRs800 O&K structure recovery and reconstruction (Kostolac Drmno), spreader ARS 1400/ 22+60+21 O&K support recovery and reconstruction; spreader column ARS 1400/ 22+60+21 O&K reconstruction railroad cars rehabilitation and reconstruction; tank truck and half sidecar structure calculation and optimization from manufactured by Gosa and Utva; rotary furnace No.3 FCBeocin (jacket rehabilitation; two side holder reconstruction, operating furnace estimation); limestone mill FC Lafarge Beocin (pin

Table 1. Elements diagnostic behavior

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Banding long beam l/h=8.333
Maximal equivalent stress = 19.2 [kN/cm2]
Distribution [%]: mem/band = 94.5/5.5, σ/τ = 69.4/30.6
Membrane stress
   vertical web  50.0
         flange  44.5
Banding stress
   vertical web   0.0
         flange   5.5
Normal stress
   vertical web  30.0
         flange  39.4
Shear stress
   vertical web  24.0
         flange   6.6
Membrane stress
1. beam segment   9.8
2. beam segment  13.0
3. beam segment  18.2
4. beam segment  23.8
5. beam segment  29.6
Banding stress
1. beam segment   1.2
2. beam segment   0.4
3. beam segment   0.8
4. beam segment   1.0
5. beam segment   2.2
Normal stress
1. beam segment   5.2
2. beam segment   8.0
3. beam segment   3.2
4. beam segment   8.6
5. beam segment   4.4
Shear stress
1. beam segment   6.4
2. beam segment   6.0
3. beam segment   6.0
4. beam segment   6.0
5. beam segment   6.2
Energy: Absolut = 5.16833E+00 [kNcm]
        Relativ = 1.29208E-03 [kN/cm2]
   vertical web  42.0
         flange  58.0
Energy: Absolut = 5.16833E+00 [kNcm]
        Relativ = 1.29208E-03 [kN/cm2]
1. beam segment   5.6
2. beam segment   7.0
3. beam segment  15.2
4. beam segment  27.4
5. beam segment  44.8

Main mode    1    Frequency [Hz]    354.391
Energy: Absolut = 2.47886E+03
        Relativ = 6.19774E+05
Potential Energy
   vertical web  42.0
         flange  58.0
Kinetic   Energy
   vertical web  60.0
         flange  40.0
Main mode    1    Frequency [Hz]     354.391
Energy: Absolut = 2.47886E+03
        Relativ = 6.19712E+05
Potential Energy
1. beam segment   9.2
2. beam segment  10.2
3. beam segment  19.0
4. beam segment  28.0
5. beam segment  33.6
Kinetic   Energy
1. beam segment  2.2
2. beam segment  9.4
3. beam segment  20.2
4. beam segment  30.8
5. beam segment  37.4
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Banding short beam l/h=4.167
Maximal equivalent stress = 16.1 [kN/cm2]
Distribution [%]: mem/band = 91.4/8.6, σ/τ = 57.1/42.9
Membrane stress
   vertical web  58.8
         flange  32.6
Banding stress
   vertical web   0.0
         flange   8.6
Normal stress
   vertical web  28.0
         flange  29.1
Shear stress
   vertical web  33.3
         flange   9.6
Membrane stress
1. beam segment  14.6
2. beam segment  13.8
3. beam segment  17.0
4. beam segment  20.8
5. beam segment  25.4
Banding stress
1. beam segment   3.4
2. beam segment   0.4
3. beam segment   0.6
4. beam segment   0.8
5. beam segment   3.6
Normal stress
1. beam segment   8.7
2. beam segment   5.8
3. beam segment   9.4
4. beam segment   3.2
5. beam segment  20.0
Shear stress
1. beam segment   9.6
1. beam segment   8.4
1. beam segment   8.4
1. beam segment   8.2
1. beam segment   8.3
Energy: Absolut = 1.07980E+00 [kNcm]
        Relativ = 5.34890E-04 [kN/cm2]
   vertical web  63.0
         flange  37.0
Energy: Absolut = 1.07980E+00 [kNcm]
        Relativ = 5.34890E-04 [kN/cm2]
1. beam segment  20.0
2. beam segment   8.8
3. beam segment  13.2
4. beam segment  20.6
5. beam segment  37.4

Main mode    1    Frequency [Hz]    1085.390
Energy: Absolut = 2.32589E+04
        Relativ = 1.16294E+07
Potential Energy
   vertical web  59.6
         flange  39.4
Kinetic   Energy
   vertical web  60.0
         flange  40.0
Main mode    1    Frequency [Hz]    1085.390
Energy: Absolut = 2.32589E+04
        Relativ = 1.16294E+07
Potential Energy
1. beam segment  34.6
2. beam segment  12.2
3. beam segment  14.8
4. beam segment  18.0
5. beam segment  20.4
Kinetic  Energy
1. beam segment   5.0
2. beam segment  12.2
3. beam segment  20.8
4. beam segment  28.6
5. beam segment  33.4
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brasses reconstruction); support rotary furnace 1000 t/per day FC Popovac reconstruction; rim of mill wheel (the best variant selection, operating with crack estimation) cement mill face rehabilitation ∅2200x12000 FC Popovac; steam boilers, tanks, high pressure vessels; damage modeling and tank rehabilitation HIP Pančevo; vessel Kolubara Prerada (diagnostic and performance improvement); shaft and fans; pipelines, oil pipelines, reactors (NIS Pančevo); processing and energy equipment.

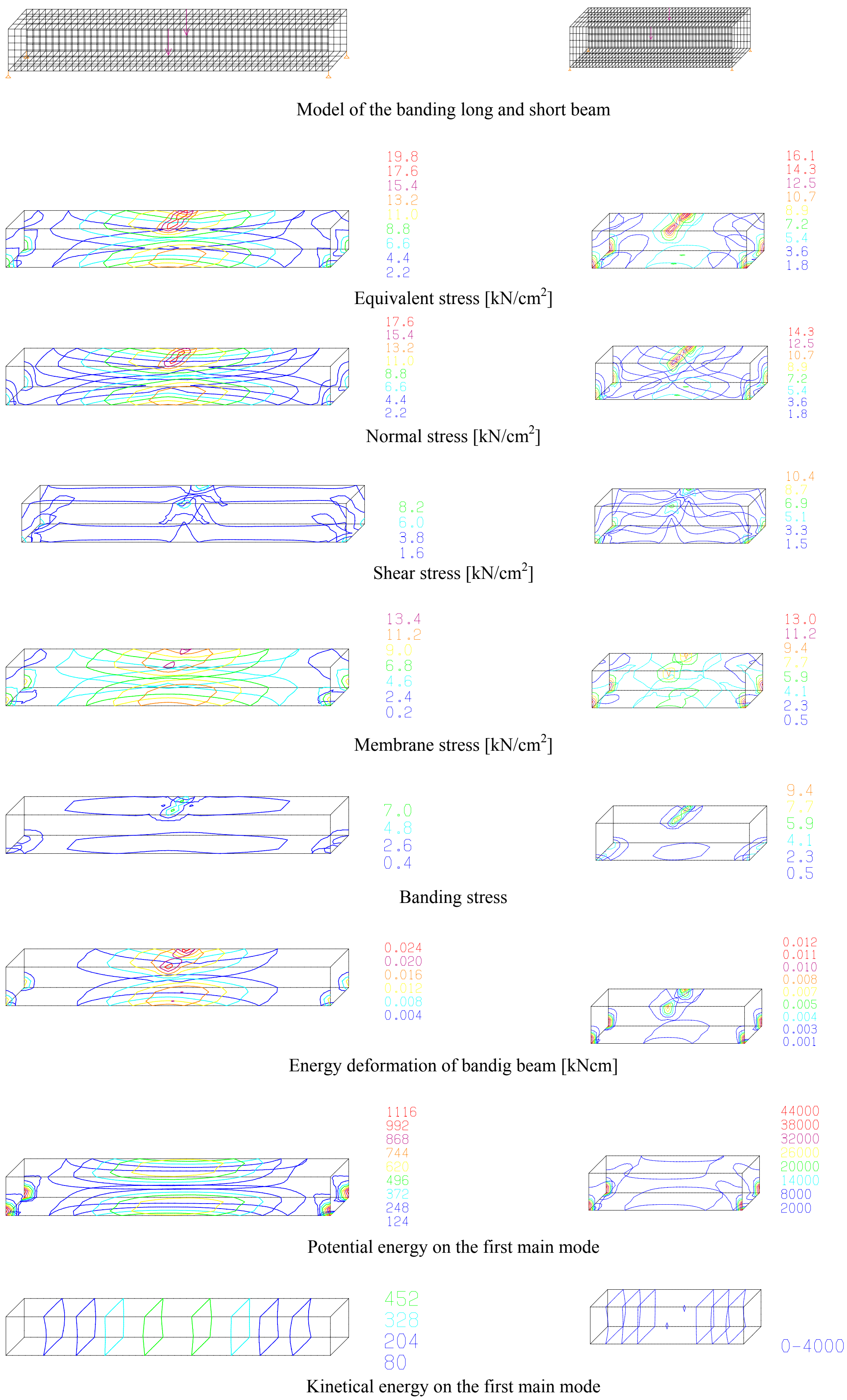
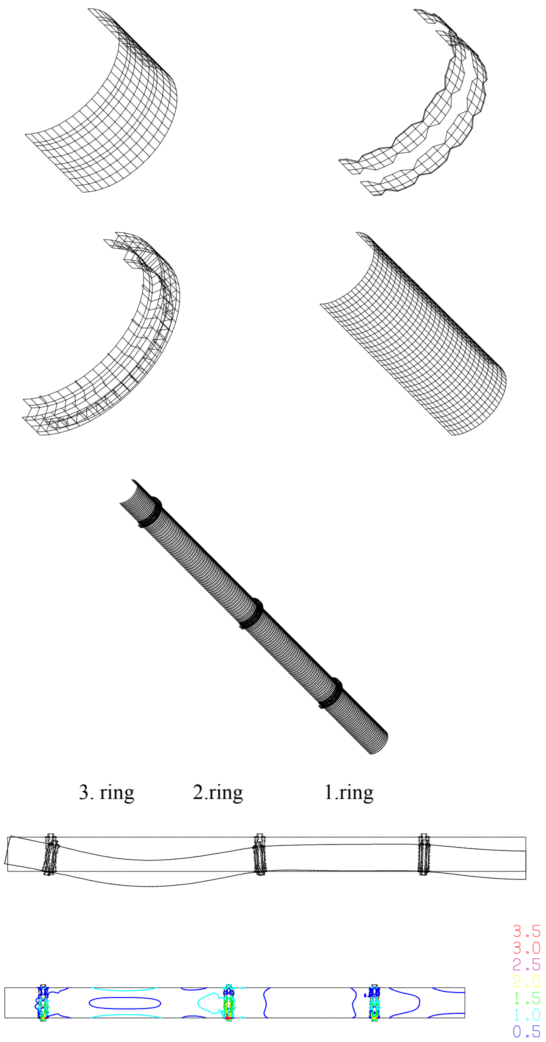


Figure 1. Elements diagnostic behaviour

5.2 Diagnostic of behavior the rotary furnace 1000 t/day (FC Popovac)

Half model rotary furnace is shown in the Figure 5.

Modeling, model and result of computation are shown in Figure 6 and Table 3 for gravity-thermal ($\Delta T = 100°\text{C}$) loading.



Deformation field ($f_{\max} = 0.353$ cm) and stress (kN/cm^2) furnace of the gravity loading

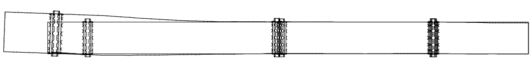


Figure 5. Model, deformation field ($f_{\max} = 6.72$ cm) and stress ($\sigma_{\max}^{\text{equ}} = 15$ kN/cm^2) furnace of the gravity-thermal loading ($\Delta T = 100°\text{C}$)

Table 3. Distribution

[%]	$E_d^{\text{abs}} / E_d^{\text{rel}}$	Mem /Band	σ / τ
Shell	10.2 / 5	27.2 / 19	37.9 / 8.3
3.ring	49.5 / 23.5	6.8 / 9.6	14.6 / 1.7
Tooth 3.ring	32.8 / 40.7	0.7 / 0.1	0.6 / 0.2
Elem. 3.ring	5.3 / 4.9	5.2 / 11.3	13.7 / 2.8
Weld 3.ring.	2.1 / 25.8	2.6 / 5.8	7.1 / 1.3
1+2 ring	0.1 / 0.1	5.6 / 6.1	9.4 / 2.3
$\sum$	100 / 100	48.1 / 51.9	81.6 / 18.4

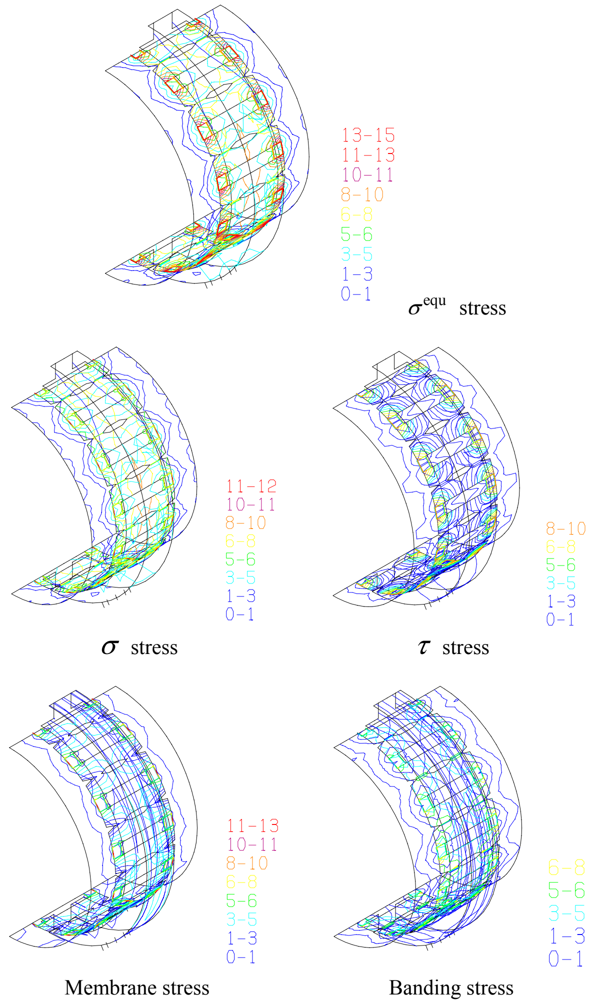


Figure 6. Equivalent stress field [kN/cm^2]

The 3rd ring has the most significant influence on the rotary furnace behavior.

5.3. Diagnostic behavior of the pressure vessel (Kolubara Prerada Vreoci)

Computing model and deformation of the pressure vessel are shown in Figure 7. Load is represented by pressure 26 bars, temperature of 220^{0}C and own weight. The dimensions of the vessel are ∅2200x4600x24 mm. The elements of behavior diagnostic are given in Figure 8. It can be concluded that shear stress and deformation energy are located on the welded joints. This is very unfavorable for the vessel behavior.

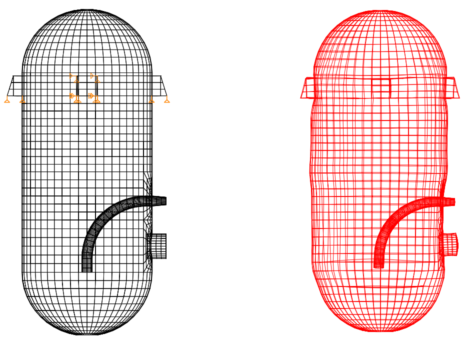


Figure 7. Model and deformation ($f_{\max} = 0.24$ cm)

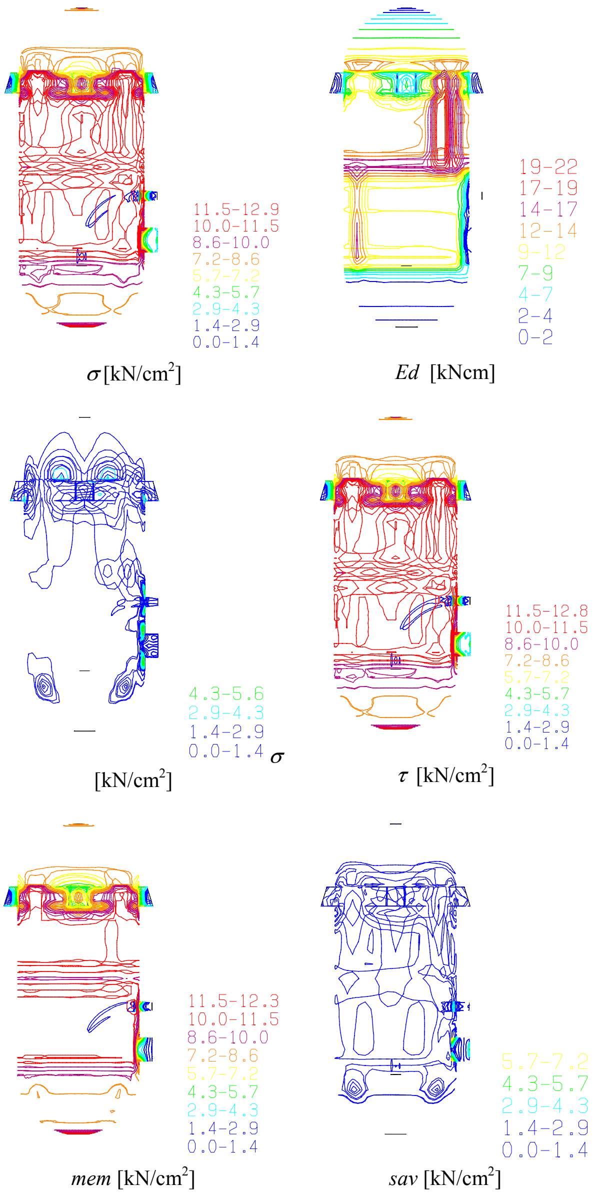


Figure 8. The elements of behavior diagnostic

5.4. Behavior diagnostic of cantilever b/w excavator C700O&K (open-cast mine Kolubara)

Figure 9 shows the cantilever plane model. Strain energy is distributed as follows: beam (72.2%); tie (16.8%); cylinder (10.5%); yoke (0.5%). Static calculation has concluded: too large tilting of the beam in the support joint; the axial force in tie and cylinder is too large, but rather low in the yoke; the bending moment of the beam is large in yoke link; and dominant strain energy in beam.

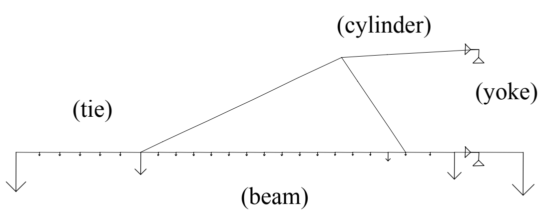


Figure 9. Planar model of the cantilever

Dynamic calculations conclude: the first two frequencies are very low, nearly equal, and coincide with static deformation and energy which are dominant in the beam (potential) and in external masses (kinetic) (Figure 10, Table 4).

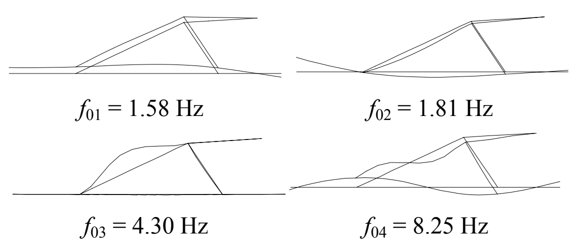


Figure 10. First four main modes and distribution

Table 4.. First four main modes and distribution

Distribution [%] structural elements	Potential/Kinetic energy f_{01} = 1.58 Hz	Potential/Kinetic energy f_{02} = 1.81 Hz
Beam	80/35	90/16
Tie	12/3	6/1
Cylinder	8/0	4/0
Yoke	0/0	0/0
External mass	0/62	0/73

5.5. Bucket wheel behavior diagnostic of excavator SRs2000 (open-cast mine Kostolac)

Bucket wheel substructures are as follows: body, stiffness, flange big membrane, little membrane, shaft, spindle and big gear. The following operating wheel loads are approved: circumferential force 310 kN and lateral force 80 kN per one bucket .

Computation model and parameters of diagnostics structure behavior are given in Figure 11.

The operating wheel behavior is very postive.

The distribution of stress and energy deformation per wheel substructures is also very positive.

6. CONCLUSION

This approach enables the determination of real structural behaviour, reliable forecasting of structural response in exploitation, determination of choice and decisions parameters and the cause of poor behaviour or structural deterioration.

Described access allows real structure behavior diagnostic. In engineering supporting structure analysis the application of explained method is introduced as unavoidability because of very low application costs with very high results level.

The presented approach in solving the cause for poor structural performance and the large number of solved cases point out the necessity for its application.

Reconstruction and revitalization mainly means geometry change and interventions on material (particularly with welded) are often necessary. Structure revitalization means reconstruction with the aim for its lifetime extension.

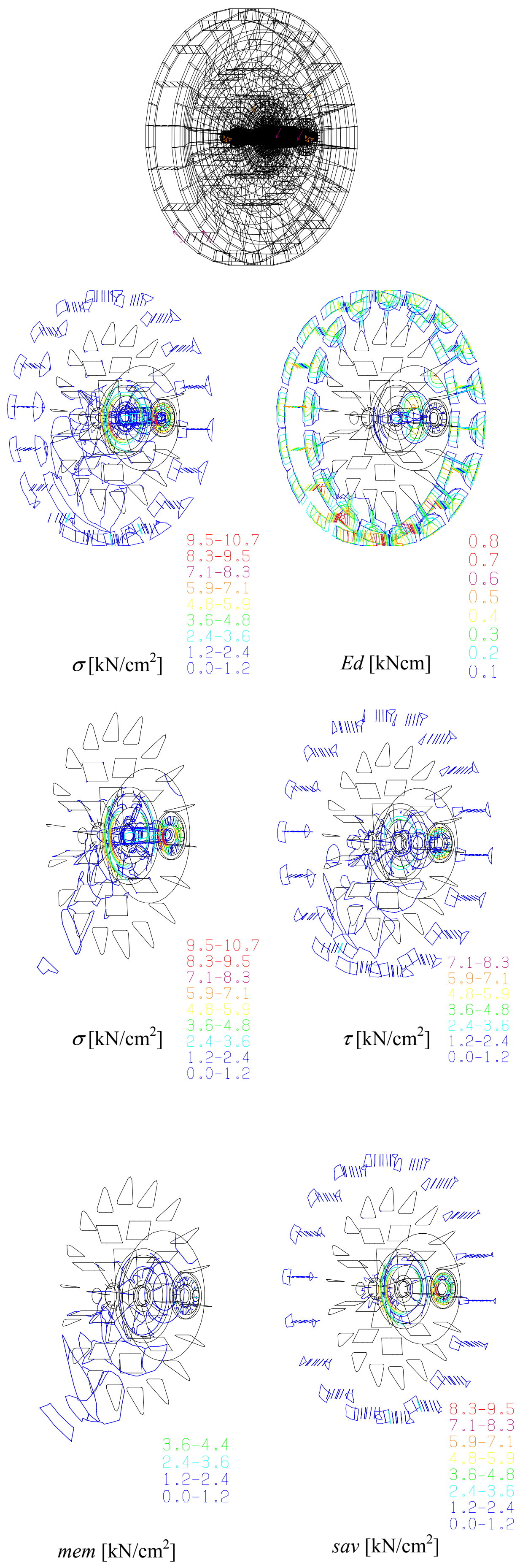


Figure 11. Computation model and diagnostic parameters

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АНАЛИЗА И ДИЈАГНОСТИКА ПОНАШАЊА СТРУКТУРА

Ташко Манески

У раду је дат опис примене развијене методологије анализе и дијагностике понашања структуре. Основа анализе представља статички, динамички и термички прорачун применом методе коначних елемената. Наведена методологија обухвата функције расподеле оптерећења, напона и енергије деформисања при статичком и термичком прорачуну. При динамичком прорачун присутна је расподела потенцијалне и кинетичке енергије по главним облицима осциловања. Развијени сопствени софтвер КОМИПС (око 30000 инструкција) на ПЦ платформи има наведене прорачуне и фукнкције. У раду је дат кратак опис матричних једначина наведених анализа, као и њихова примена.