

Modeling, Simulation and Visualization of Static Mechanical Properties of Frame of Elevator Cab

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Abstract— One of the most important methods in current scientific and technological research is the process of modeling and simulation, which is discipline with its own theory and research methodology.

This paper focuses to the process of creation of mathematical and simulation model of static mechanical properties of real technical device. A case study of the process of creation of mathematical model is demonstrated on calculation of deviation of the frame of elevator cab. The mathematical model is established on the basis of *bending theory of the beam*. Validation of the mathematical model is provided by the simulation model created in the program *SolidWorks® Simulation* that is based on the *finite element method*.

Keywords— Bending theory, elevator cab, finite element method, modeling, mathematical model, simulation, simulation model, static mechanical properties, visualization.

I. INTRODUCTION

The terms *system*, *model*, *simulation*, *multidisciplinary approach* are important in current approach to scientific, technological and professional practice. Many universities are realizing that modeling and simulation is becoming an important tool in solving and understanding numerous and diverse problems.

Modeling and simulation, is becoming one of the academic programs of choice for students in all disciplines – see e.g. in [1], [2], [3] or [4]. Modeling and simulation is a discipline with its own body of knowledge, theory, and research methodology.

To engage modeling and simulation the mathematical model of the real system has to be first created. Models are approximations for the *real system*. The model is then followed by *simulation*, which allows for the repeated observation of the model. After the simulation's model is verified, a third step takes place; *visualization* of the model and the real system.

The ability to define a system, to build up a mathematical model and to create a simulation model develops logical thinking skills and imagination and is an inseparable part of a student's study skills for those studying the specialization of

“Applied Informatics”.

In this paper we first briefly introduce the theory of modeling and simulation as a method of multidisciplinary investigation of real technical device.

Secondly the basics of the bending theory of the beam will be presented as well as the basics of the theory of finite element method applied to static mechanics problem.

Finally we introduce a case study illustrating step by step process modeling and simulations of properties of real technical device – *static mechanical properties of frame of elevator cab*.

II. MODELING AND SIMULATION OF THE REAL SYSTEMS

A. Modeling

Modeling is a method that is often used in professional and scientific practice in many fields of human activity.

The main goal of modeling is not only describing the content, structure and behavior of the real system representing a part of the reality but also describing the processes.

The process can be understood as series of transformations that changes the input values to output values. From the *system point of view* the process is dynamic system in which the values of the characteristic of the system elements are changed under the influence of the external elements.

The models are always only approaching of the reality, because the real systems are usually more complex than the models are. The system homomorphism is applied in the process of modeling, which means that each element and interaction between the elements of the model corresponds to one element and interaction of the modeled real system or real process, but the reverse is not true. The model is always to be understood as simplification of the original. If the relation of isomorphism is between the model and real system the original model we could not distinguish between the model and the original, which is discussed e.g. in [5] and [6].

The first step in the process of computer simulation is creation of conceptual/mathematical model of the studied real system. Mathematical model can be represented in different way. The most used representations are:

- Mathematical equitation;
- Static or dynamic 2D or 3D scatter charts.

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Mathematical equitations establishes mathematical model of the studied real system. The model can be obtained either theoretically based on basic physical properties of the system, or numerically by means of the measured values. Determination of parameters of theoretical model developed from empirical data is called system identification. Mathematical equations as basics of the mathematical model adequately describe the dependency system outputs on its inputs. Mathematical models of real system will be shown in the case study of this paper.

Scatter charts (scatter plot) is a type of mathematical diagram using Cartesian coordinates to display values for two variables for a set of data in 2D types of the chart or three variables for a set of data in 3D types of the chart. Three dimensional scatter charts allow for the visualization of multivariate data of up to four dimensions. The scatter plot takes multiple scalar variables and uses them for different axes in phase space. The different variables are combined to form coordinates in the phase space and they are displayed using glyphs and colored using another scalar variable. Visualization of the static mechanical properties of real system via 3D scatter chart created in *SolidWorks*[®] simulation program will be shown in the case study of this paper.

B. Simulation

The process of modeling is closely related to the simulation. Simulation can be understood as process of executing the mathematical model. Simulation enables representation of the modeled real system and its behavior in real time by means of computer. The simulation enables also visualization and editing of the model.

A typical simulation model can be written both through specialized programming languages that were designed specifically for the requirements of simulations, or the simulation model can be created in standard programming languages. In our paper the real system is simulated in the specialized simulation program - *SolidWorks*[®].

From the above considerations, it is clear that simulation is a process that runs on the computer. In some publications, therefore, can be found the term "computer simulation". It generally is valid that computer simulation is a computer-implemented method used for exploring, testing and analysis of properties of the mathematical models that describe the behavior of the real systems or real process which cannot be solved using standard analytical tools, see e.g. [6].

The simulation models represented by executable computer program have to be isomorphic with the mathematical model that is a representation. It means that the mathematical model and simulation model have to represent the real system, its elements, internal interactions and external interaction with the environment in the same way.

In our paper the real system *Frame of elevator cab* will be presented. We will focus to calculation, simulation and visualization of the static mechanical properties – *bending of the beams of the elevator frame*. This real system is simulated in *SolidWorks*[®] simulation program.

C. Significant function of the simulation

Simulation has from the scientific point of view several functions – see e.g. [6].

We will focus in this paper two of them and they are:

- Replacement of real system;
- Development of educational process.

1) Replacement of the real system

This is an important and indispensable feature of simulations and simulation model because it allows realize a situation that cannot be investigated using conventional real system. The main advantage of simulations is that simulations model allows changing of input parameters, visualization and optimization the behavior of the real system and settings of its mechanical construction parameters. The simulation is usually safety and cheaper.

The case study presented in this paper is based on real system – elevator cab that is used in many elevator systems in buildings in Hradec Kralove. Every data used for the calculation comes from the company producing the elevator systems.

2) Development educational process

The simulation is very useful from educational point of view. Using the simulation model and visualization of simulation results on the screen, students can better understand the basic features of the real systems and develop their intuition. It is also essential that the teaching by means of simulation is much cheaper and faster than the teaching carried by real system. In some cases providing the real system cannot be feasible.

The case study presented in this paper is one example of the seminar work that students of specialization "Applied informatics" have to work out.

D. Model verification and validation

Verification and validation are important aspects of the process modeling and simulation. They are essential prerequisites to the credible and reliable use of a model and its results [5].

1) Verification

In modeling and simulation, verification is typically defined as the process of determining if executable simulation model is consistent with its specification – e.g. mathematical model. Verification is also concerned with whether the model as designed will satisfy the requirements of the intended application. Verification is concerned with transformational accuracy, i.e., it takes into account simplifying assumptions executable simulation model. Typical questions to be answered during verification are:

- Does the program code of the executable simulation model correctly implement the mathematical model?
- Does the simulation model satisfy the intended uses of the model?
- Does the executable model produce results when it

is needed and in the required format?

2) *Validation*

In modeling and simulation, validation is the process of determining the degree to which the model is an accurate representation of the real system. Validation is concerned with representational accuracy, i.e., that of representing the real system in the conceptual model and the results produced by the executable simulation model. The process of validation assesses the accuracy of the models. The accuracy needed should be considered with respect to its intended uses, and differing degrees of required accuracy may be reflected in the methods used for validation. Typical questions to be answered during validation are:

- Is the mathematical model a correct representation of the real system?
- How close are the results produced by the simulation executable model to the behavior of the real system?
- Under what range of inputs are the model's results credible and useful?

Validation and verification are both ultimately activities that compare one thing to another. Validation compares real system and mathematical model. Verification compares conceptual model and executable simulation model. Sometimes validation and verification are done simultaneously in one process.

Validation of the mathematical model as well as verification of the simulation model of our real system – **static bending of the frame beams of elevator cub** – are to be done simultaneously by the comparison of the static bending theoretically calculated from the simulation model with the dependencies of the static bending experimentally measured on elevator frame.

The whole process of transformation from a real system, the simulation model and its visualization is shown in Fig. 1.

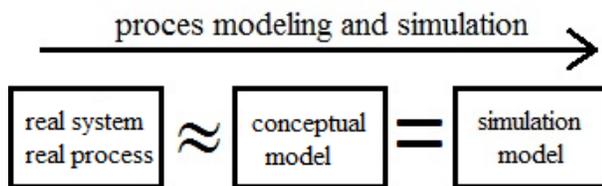


Fig. 1 Process modeling and simulation

Here again let us summarize that the mathematical model that reflects the real system has some limitations and simplifying assumptions (the real system and mathematical model are in homomorphic relation).

In contrast, the simulation model is only the computer expression of the mathematical model (the mathematical model and simulation model are in isomorphic relationship).

E. *Multidisciplinary approach*

Another important benefit associated with the modeling and simulation of real systems is a multidisciplinary approach,

without which the identification of the real systems using mathematical and simulation model cannot be realized. This is also emphasized in this paper.

Multidisciplinary approach generally means that specialized disciplines are applied in a study of real systems. These disciplines provide partial analysis of the systems. These mono-disciplinary analyses are integrated to overall solution by integrating the solver who has basic multi-disciplines knowledge.

In our case study three disciplines are integrated, namely, mechanics, finite element method and mathematics.

III. BENDING THEORY OF THE BEAM

In the first ordering can be *Frame of elevator cab* mathematically modeled as set of four beams connected together to the frame of rectangular shape – see Fig. 2.

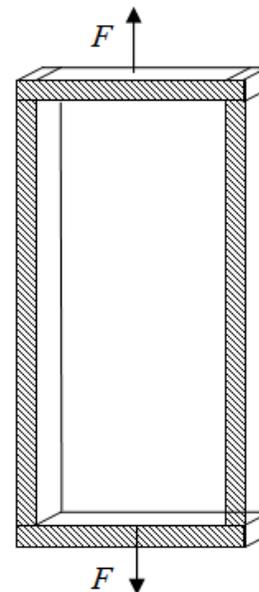


Fig. 2 Frame of elevator cab

A. *Bending of the beam*

Let's have a beam of length l , height h and width w . One end of the beam is fixed to the wall, and second end of the beam is free. The free end is loaded by external force F – see Fig. 3.

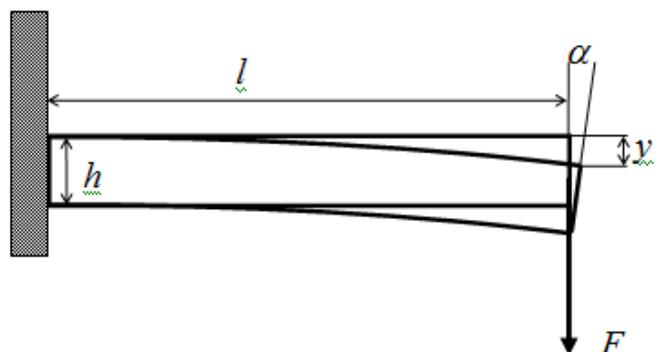


Fig. 3 Beam deflection y loaded by external force

The cross deflection y in the direction of the external force F can be calculated by means of Euler-Bernoulli bending theory (see e.g. [7]). The major assumption of the Euler-Bernoulli bending theory is that “plane sections remain plane”, which means that any deformation due to shear across the section is not accounted for (no shear deformation). Also, this linear distribution is only applicable if the maximum stress is less than the yield stress of the material.

The cross deflection y is:

$$y = \frac{Fl^3}{3EI}, \quad (1)$$

where F is external force at distance l from fixed end of the beam, E is Young's elastic modulus and I is second moment of area. The detailed calculation of the derivation of the cross deflection y can be found e.g. in [7].

The I can be calculated for the beam with perpendicular cross section of height h and width w :

$$I = \frac{hw^3}{12}. \quad (2)$$

Substituting I to equation (1) the cross deflection y of the perpendicular cross section beam is:

$$y = \frac{4Fl^3}{Ewh^3}. \quad (3)$$

The term (3) be also used for calculation of the beam deflection y_d substantiated by two pillars distanced by the length L , which is loaded by lonely middle force F_d – see Fig. 4.

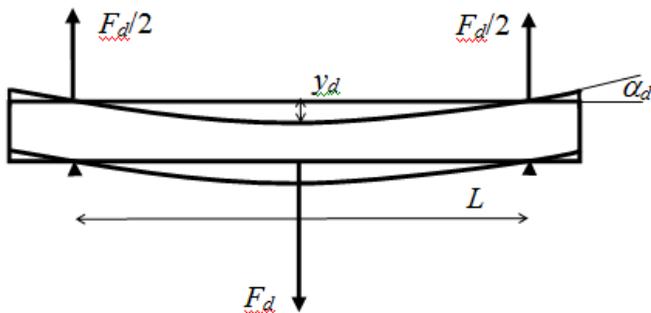


Fig. 4 Beam deflection y_d substantiated by pillars

Due to the symmetry of the problem, the size of the force acting on the pillars is $F_d/2$. For calculation of the deflection d the equation (3) can be used, where l is substituted $L/2$ and F is substituted $F_d/2$, we obtain:

$$y_d = \frac{F_d L^3}{4Ewh^3}. \quad (4)$$

B. Curvature of the beam

The important parameter of the bending of the beam is curvature (i.e. angular deviation) α of the free end of the beam - see Fig. 3:

$$\alpha \approx \text{tg } \alpha = \left(\frac{dy}{dx} \right)_{x=l} = \frac{6Fl^2}{Ewh^3}. \quad (5)$$

Similarly the curvature α_d of the beam substantiated by two pillars (see Fig. 4) is:

$$\alpha_d \approx \text{tg } \alpha_d = \left(\frac{dy_d}{dx} \right)_{x=l} = \frac{3Fl^2}{4Ewh^3}. \quad (6)$$

IV. FINITE ELEMENT METHOD

The *Finite element method* - FEM (or its practical application often known as finite element analysis (FEA)) is from mathematical point of view a numerical, variational method for finding approximated solutions of partial differential equations and their systems - integral equations.

Solution procedure is based on the complete elimination of differential equations, or the transfer of linear differential equations into an equivalent ordinary differential equation, which can be solved by standard procedures. Essential step when solving partial differential equations is assembly equation that approximates the solution of equations and is numerically stable in the sense that errors in input data and auxiliary calculations do not accumulate and do not lead to such absurd results.

In simple terms, FEM is a method for dividing up a very complicated problem into small elements that can be solved in relation to each other. The FEM is a reasonable choice for solving partial differential equations in complex real systems.

A. FEM as application engineering discipline

From the application point of view can be FEM understand us the mechanical engineering discipline commonly used in design and development of the real technical systems and products.

In a structural simulation, FEM helps tremendously in producing stiffness and strength visualizations and also in minimizing weight, materials, and costs.

FEM allows detailed visualization of where structures bend or twist, and indicates the distribution of stresses and displacements.

FEM software, such as *SolidWorks* (see next paragraph), provides a wide range of simulation options for controlling the complexity of both modeling and analysis of simulated real systems.

Similarly, the desired level of accuracy required and associated computational time requirements can be managed simultaneously to address most engineering applications. FEM allows entire designs to be constructed, refined, and optimized

before the design is manufactured.

Benefits of FEM include increased accuracy, enhanced design and better insight into critical design parameters, virtual prototyping, fewer hardware prototypes, a faster and less expensive design cycle, increased productivity, and increased revenue.

B. The principle of FEM

The solution of FEM is based on the Lagrange's principle: *The body is in equilibrium if the total potential energy of deformation of the system is minimal* – see e.g. [8].

The steps of process of use of the FEM method are as follows:

1. Creation of 3D mechanical model;
2. Elementarization of the model - replacing the infinite volume of model by finite number of elements, and nodes. This step can be understand as real system identification;
3. Reaching the set of equations for each discrete element:
 - three equations – array of displacements in all directions (x, y, z);
 - six equations – array of deformations;
 - six equation – array of stress field;
4. Replacement of array of displacement by polynomial function and expression of displacement function;
5. Introduction of boundary conditions;
6. Calculation of systems of linear algebraic equations;
7. Calculation of strain and stress for the individual nodes;
8. Creation of graphical view of the model with a list of important values.

The basic idea of FEM is decomposition the body into smaller elements - finite elements, whose behavior can be simply described.

In the mathematical description of the steps FEM is usual to use matrix notation.

1) Discretization of shifts

Continuously distributed element displacements $\{\mathbf{u}\}$ are expressed using matrix of shape functions $[\mathbf{A}]$. The matrix $[\mathbf{A}]$ is function of positional coordinates $\{\mathbf{r}\} = \{x_1, x_2, x_3\}$.

$$\{\mathbf{u}\} = [\mathbf{A}]\{\mathbf{q}\}, \quad (7)$$

where $\{\mathbf{q}\} = \{q_1, q_2, q_3\}$ are generalized shifts in three dimensions.

2) Discretization of transformations

Continuously distributed *element* transformation $\{\boldsymbol{\varepsilon}\}$ are expressed using matrix $[\mathbf{B}]$ and finite number of generalized shifts $\{\mathbf{q}\} = \{q_1, q_2, q_3\}$.

$$\{\boldsymbol{\varepsilon}\} = [\mathbf{B}]\{\mathbf{q}\}. \quad (8)$$

The stress can be based on Hooke's law expressed:

$$\{\boldsymbol{\sigma}\} = [\mathbf{C}]\{\boldsymbol{\varepsilon}\}, \quad (9)$$

where matrix $[\mathbf{C}]$ is constant.

Substituting $\{\boldsymbol{\varepsilon}\}$ from equation (7) to (8) the final result can be reached:

$$\{\boldsymbol{\sigma}\} = [\mathbf{C}][\mathbf{B}]\{\mathbf{q}\}. \quad (10)$$

3) Virtualization of shifts and transformations

Virtual shift can be expressed:

$$\{\delta\mathbf{u}\} = [\mathbf{A}]\{\delta\mathbf{q}\}, \quad (11)$$

virtual transformation can be expressed:

$$\{\delta\boldsymbol{\varepsilon}\} = [\mathbf{B}]\{\delta\mathbf{q}\} \quad (12)$$

and acceleration of the element:

$$\{\ddot{\mathbf{u}}\} = [\mathbf{A}]\{\ddot{\mathbf{q}}\} \quad (13)$$

Applying relations expressing the principle of virtual work and using the previous equations the final term for each element is:

$$\begin{aligned} \{\delta\mathbf{q}\} \int_V [\mathbf{B}]\{\boldsymbol{\sigma}\} dV = \{\delta\mathbf{q}\} \int_V \rho[\mathbf{A}]\{\boldsymbol{\sigma}\} \{\ddot{\mathbf{q}}\} dV + \\ + \{\delta\mathbf{q}\} \int_V [\mathbf{A}]\{\mathbf{p}\} dS + \{\delta\mathbf{q}\} \{\mathbf{F}\} \end{aligned}, \quad (14)$$

where

$$\{\mathbf{f}_i\} = \int_V [\mathbf{B}]\{\boldsymbol{\sigma}\} dV. \quad (15)$$

is internal force at the node,

$$\{\mathbf{f}_v\} = \int_V \rho[\mathbf{A}]\{\boldsymbol{\sigma}\} \{\ddot{\mathbf{q}}\} dV = [\mathbf{m}]\{\ddot{\mathbf{q}}\}. \quad (16)$$

is volume force at the node,

$$\{\mathbf{f}_s\} = \int_V [\mathbf{A}]\{\mathbf{p}\} dS. \quad (17)$$

is surface force at the node,

and $\{\mathbf{F}\} = \{F_1, F_2, F_3\}$ is matrix of external force acting to element.

Motion equation for each element is:

$$[\mathbf{m}]\{\ddot{\mathbf{q}}\} + [\mathbf{k}]\{\mathbf{q}\} = \{\mathbf{f}_s\} + \{\mathbf{F}\} = \{\mathbf{f}\}. \quad (18)$$

4) Composition of the elements

The next step in FEM is the composition of the elements back together. From the model, we know how the elements are placed against each other - it is possible the stiffness matrixes

of individual elements and mass matrixes of individual elements assembled into the resulting global stiffness matrix and mass matrices.

In the case of linear problems of elastic body small displacements, small deformation and linear behavior of the material are assumed. The final term of the finite set of element is:

$$[M]\{\ddot{Q}\} + [K]\{Q\} = \{F\} \quad (19)$$

and in the case of stationary solution:

$$[K]\{Q\} = \{F\} \quad (20)$$

V. CASE STUDY – MODEL AND SIMULATION OF STATIC MECHANICAL PROPERTIES OF ELEVATOR FRAME

One of the research programs of the University of Hradec Kralove is the development of simulation models of real devices. It is not only the work of students in resolving their theses, but also the researchers, whose results were published in professional journals [9].

We established a computer simulation model of static mechanical properties of elevator cab.

Static properties will be demonstrated on modeled real frame of elevator cab.

- A. Position of the maximal deflection of vertical frame beam will be calculated by mathematical model and compared with the simulation model created in simulation program;
- B. The tension of the construction will be simulated in simulation program

The simulation model will be created in simulation software *SolidWorks*[®].

The result of these simulation models can be used in practice, for example in determining the design parameters of elevators, establishing a timetable and technical plan of the regular revisions etc.

A. Construction parameters of the elevator frame

The elevator frame can be in the first order modeled by set of four beams connected together to the frame of rectangular shape – see Fig. 2.

Cross section dimensions of the beams:

In our case study the vertical beams and upper beam are made from the same type of the beams with the cross section dimensions $h_1 \times w_1 = 50 \times 35$ mm, while bottom beam has cross section dimension $h_2 \times w_2 = 75 \times 45$ mm.

Length of the beams:

Vertical beams have length $l_1 = 2100$ mm, horizontal beams have length $l_2 = 1200$ mm.

B. Mathematical model

Position of the maximal deflection of vertical frame beam

The elevator frame is loaded by external forces shown on the Fig. 2. Deformation of the frame due to these external forces is schematically shown on the Fig. 5.

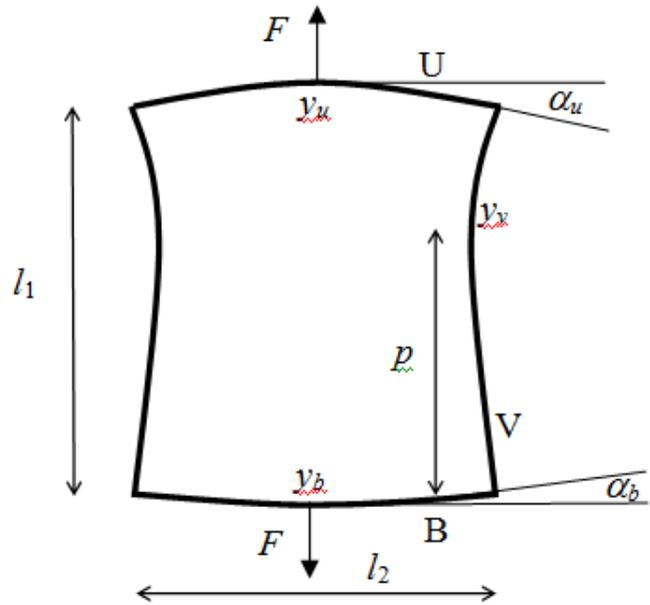


Fig. 5 Deflection of the frame beams

Upper blade has less cross section dimensions than bottom blade, so the deviation of upper blade y_u is different (higher) than deviation of the bottom blade y_b . The result is that deviation of the vertical blade is not symmetrical.

The task is calculated position p of the maximal deviation of vertical beam.

1) Calculation of the deflection and curvature of the horizontal beams

The deviation of the horizontal beams can be calculated based on formula (4):

$$y_b = \frac{Fl_2^3}{4Ew_2h_2^3} \quad (21)$$

$$y_u = \frac{Fl_2^3}{4Ew_1h_1^3} \quad (22)$$

and curvature based on formula (6).

$$\alpha_b = \frac{3Fl_2^2}{4Ew_2h_2^3} \quad (23)$$

$$\alpha_u = \frac{3Fl_2^2}{4Ew_1h_1^3} \quad (24)$$

2) Calculation of the position of of the maximal deviation of vertical beam

The calculation of deviation of vertical beam has to be calculated so that the vertical beam is divided to two beams:

- lower part of the vertical beam with length p ;
- upper part of the vertical beam with length $l_1 - p$.

The deviation will be calculated using formulas (3) and (5) for one side fixed beam.

Under the consideration that horizontal and vertical beams are absolutely fixed, i.e. the curvatures of the horizontal is 100% transferred to vertical beams (the curvatures of the horizontal and vertical beams have the same value), the forces acting to the upper F_{vu} and lower F_{vb} part of the vertical beams can be derivated from the Fig. 6.

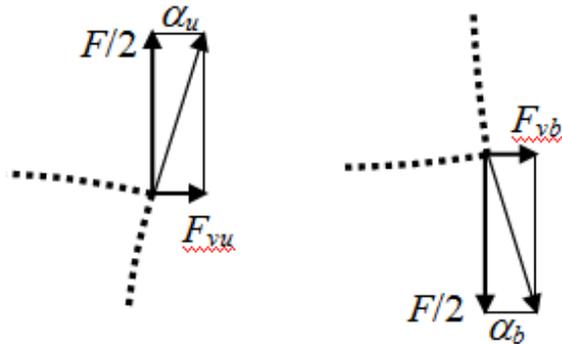


Fig. 6 Forces acting to the upper and lower part of the vertical beams

Forces F_{vu} and F_{vb} can be calculated based on consideration that α_u and α_b are rather small:

$$F_{vb} = \frac{F}{2} \operatorname{tg} \alpha_b = \frac{F}{2} \alpha_b. \quad (25)$$

$$F_{vu} = \frac{F}{2} \operatorname{tg} \alpha_u = \frac{F}{2} \alpha_u. \quad (26)$$

Angles α_b and α_u can be taken from equation (23) and (24). The result is:

$$F_{vb} = \frac{3F^2 l_2^2}{8E w_2 h_2^3}. \quad (27)$$

$$F_{vu} = \frac{3F^2 l_2^2}{8E w_1 h_1^3}. \quad (28)$$

The deviation of the lower part of vertical beam y_{vb} can be calculated based on formula (3):

$$y_{vb} = \frac{4F_{vb} p^3}{E w_1 h_1^3} = \frac{3F^2 l_2^2 p^3}{4E^2 w_1 w_2 h_1^3 h_2^3}. \quad (29)$$

Similarly, the deviation of the upper part of vertical beam y_{vu} can be calculated based on formula (3):

$$y_{vu} = \frac{4F_{vu} (l_1 - p)^3}{E w_1 h_1^3} = \frac{3F^2 l_2^2 (l_1 - p)^3}{4E^2 w_1^2 h_1^6}. \quad (30)$$

With regard the fact, that $y_{vb} = y_{vu}$ the position p of the maximal deviation of the vertical beam can be calculated from the equality:

$$\frac{3F^2 l_2^2 p^3}{4E^2 w_1 w_2 h_1^3 h_2^3} = \frac{3F^2 l_2^2 (l_1 - p)^3}{4E^2 w_1^2 h_1^6}, \quad (31)$$

and after simplification

$$\frac{p^3}{w_2 h_2^3} = \frac{(l_1 - p)^3}{w_1 h_1^3}. \quad (32)$$

This equation can be solved only numerically. For our specific input data:

- $w_1 = 0.035$ m, $h_1 = 0.050$ m (dimensions of upper beam);
- $w_2 = 0.045$ m, $h_2 = 0.075$ m (dimensions of bottom beam);
- $l_1 = 2.1$ m (length of vertical beam);
- $l_2 = 1.2$ m (length of horizontal beam);
- $E = 210 \times 10^9$ Pa
- $F = 63 \times 10^3$ N

the position of of the maximal deviation of vertical beam p and maximal deviation of the vertical beam y_v are:

$$p = 1.3 \text{ m},$$

$$y_v = 2.6 \times 10^{-3} \text{ m}.$$

C. Simulation model

Visualization of the deviations and tensions of the frame construction

1) Simulation program – SolidWorks®

There is number of simulation programs that are based on FEM.

We are using at Univerzity of Hradec Kralove the program *SolidWorks®*.

Solid Works is a parasolid-based solid modeler, and utilizes a parametric feature-based approach to create models and assemblies.

SolidWorks Simulation program is fully integrated into *SolidWorks*. *SolidWorks Simulation* allow designer verify the model or assembly in terms of its strength and safety.

SolidWork Simulation program has implemented tools, that allow provide steps of process of use of the FEM method. The role of the designer is limited to the first and the second step. Other steps are executed directly by *SolidWorks Simulation* program.

2) Mechanical 3D model of elevator cab – Elementarization of the model

Elevator cub can be in the *SolidWorks Simulation* divided into several functional groups and technological units – see Fig. 7.



Fig. 7 Elevator cabin with frame

Cage: part of lift in which the persons are carried. It consists of several basic components: *frame, cab, floor, ceiling and doors*. May be both detachable or welded. The ceiling of the cabin must be able to support of service engineer. Cabins come in different load capacities. In our case study is burdened frame of elevator cab. The frame has the most important role because basic supporting and safety features are attached to it.

Counterweight: in earlier years was often used as a counterweight concrete monolith. Nowadays steel structures prevail in which concrete or steel blocks are inserted into. They provide balance of cage with accessories and a part of weight of passengers.

Guides: The guides are made from T profiles attached to the walls of the shaft. They serve to guide of the cage and the counterweight. Another function may be a transmission of brake force.

Lift machine: Lift machine consists of a geared or gearless motor and traction wheels. It is most often placed over the shaft in the engine room.

Supporting elements: Supporting elements consist of ropes or chains, on which cage and counterweight are hung.

Retainers: Retainers captures the abrupt fall of the cab in the case of increase of elevator speed. Impulse is given by speed limiter.

Bumpers: Bumpers accumulate kinetic energy of the cage or counterweight in the case of swiping their final position.

Other: Control system, limit sensors, safety enclosure landing and cabin door etc.

3) Mechanical parameters of the cage:

- Blind (one entrance)
- Internal dimensions:
 $w \times d \times h$: 1300 × 1200 × 2100 mm
- Material: metal - steel sheet metal panels:
walls, ceiling and entrance portals of
- Permissible load: 63,000 N
- Loading capacity: 630 kg
- Frame weight: 190 kg
- Cage weight: 332 kg
- Operator weight: 45 kg

4) Static simulation model

deformations and stresses of elevator frame – inputs

The accuracy of the calculations depends most on the exact input of boundary conditions.

In the *SolidWorks Simulation* exists “advisor” which will help even inexperienced users to resolve ambiguous or contentious examples – see Fig. 8.

SolidWorks Simulation supports parts that have only one volume as well as the parts with more volumes and assemblies. Every solid body may have different physical properties.

The main assumption of *SolidWorks Simulation* program is that all of the bodies move in the space freely and that they interact with other bodies. The degrees of freedom bodies have to be identified and correctly entered the appropriate limit.

SolidWorks Simulation takes from the set the links between the different parts - it uses sets links. On the other hand it is also possible in the Simulation the links override or add coupling of constraints appropriate for the calculation.

The *SolidWorks “advisor”* will help to choose the body to calculate, specify materials, individual components, shows how to create and run a network.



Fig. 8 Advisor of the *SolidWorks Simulation*

Fixation of the cage frame

The first step of creation of simulation model in *SolidWorks Simulation* program is selection of fixing of the construction. Fixation depends on the type of study.

In the our case study the parts of frame cabins were fixed together by cylindrical face hole pin. For simplicity, a fixed geometry was chosen – Fig. 9.

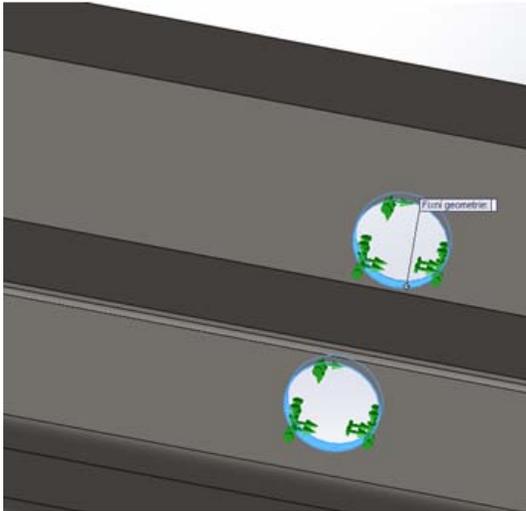


Fig. 9 Example of the fixation

Entering of material of cabin frame

Each part of the assembly can be assigned by its own material. If we analyze one part which consists more volume solid bodies, it can be applied materials to each individual solid body.

Before starting the study it is necessary to define all the necessary material properties that are required by the corresponding type of analysis.

Properties of materials can be defined at any time prior to running the analysis.

Materials are available in the library of materials. The library can be edited by user and save own user materials. In our case study the steel have been specified for all parts of the structure.

Entering of coupling limit

Touching of parts can be entered manually, or it can be generate automatically based contact surfaces. It is possible to include or ignore the influence of friction for the conditions of global contact. Static friction forces are calculated so that the coefficient of friction specified by *SolidWorks Simulation* is multiplied by the normal force generated in the contact areas.

Entering of external force

The force acting to the down part of the frame is entered to the *SolidWorks Simulation* – see Fig. 10. It is possible to set the force direction, to choose whether the force is distributed equally on all selected surfaces or whether it will act on each area separately. It is possible to choose a non-uniform load.

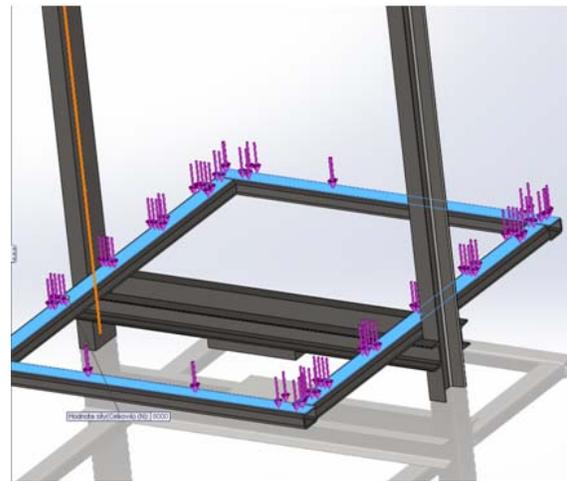


Fig. 10 External force acting to frame

5) Static simulation model

deformations and stresses of elevator frame – results

The result – visualization of stress of the frame construction (created in *SolidWorks* static simulation model) is shown on the Fig. 11.

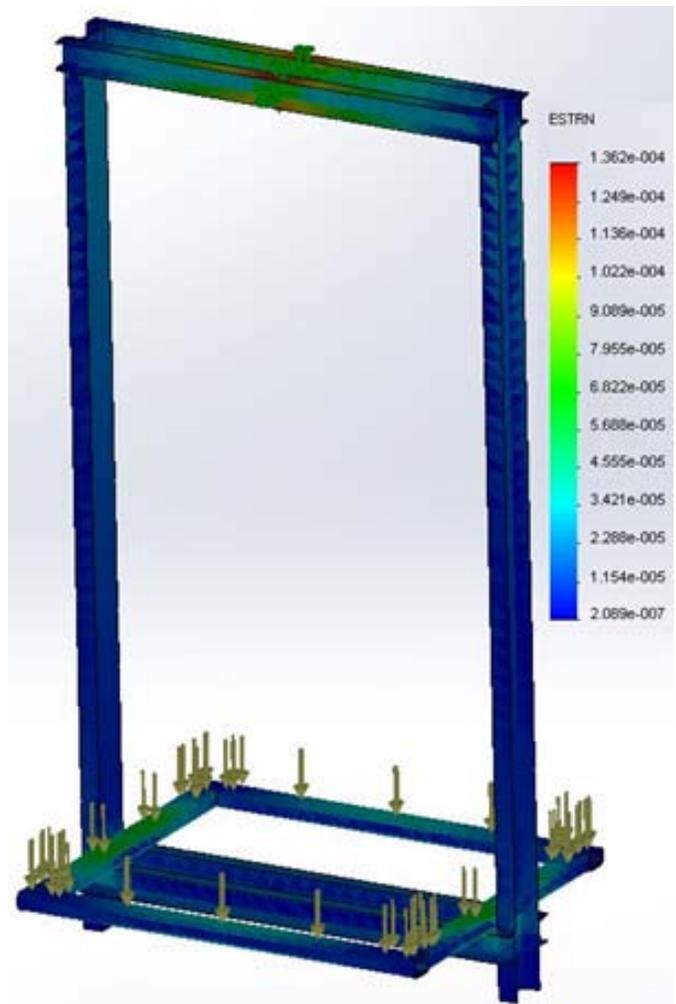


Fig. 11 Visualization of the static stress

The result – visualization of deviation of the frame construction (created in *SolidWorks* static simulation model) is shown on the Fig. 12.

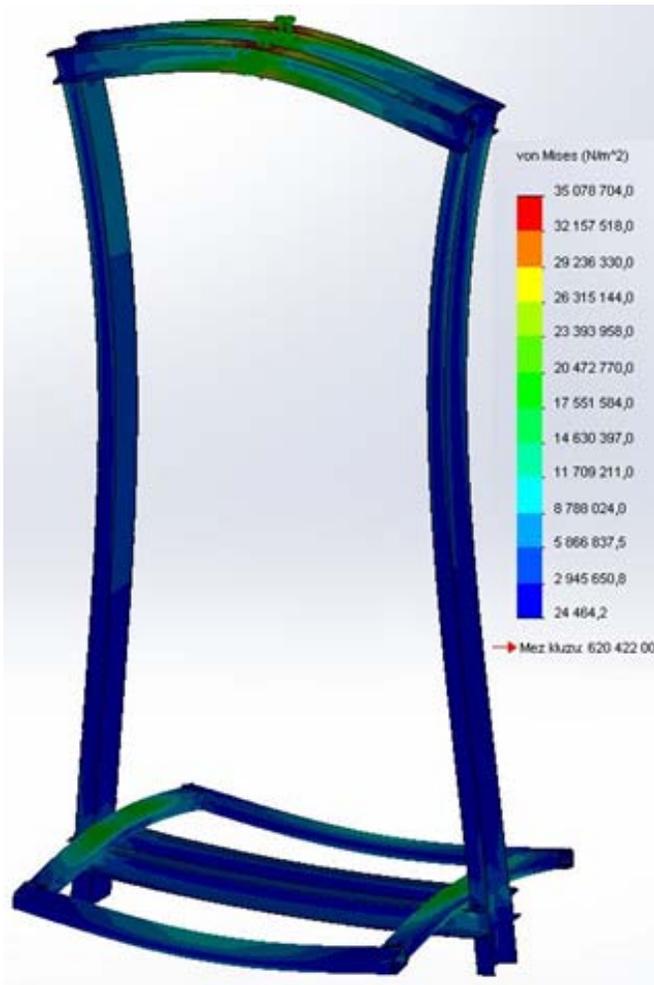


Fig. 12 Visualization of the static deviation

The result of the simulation model created in *SolidWorks* based on FEM is in accordance with the result obtained from mathematical model calculated based on the bending of the beam.

VI. CONCLUSION

Modeling and computer simulation together with a multidisciplinary approach provides new methodology of experimental research in current science.

In this paper the case study of process of creation of mathematical model and simulation model of static mechanical properties or real technical device – deviation of the frame of elevator cab is offered. This process is shown step by step from the formation of the mathematical model based on bending theory of beam to creation of simulation model in *SolidWorks®* program, which is based on finite element method.

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REFERENCES

- [1] S. Hubalovsky, J. Jelinek, J. Sedivy, „Mathematical modeling and computer simulation of optimal reaction time of the Lupine protein hydrolysis using fermented whey”, *International Journal of Mathematical Models and Methods in Applied Sciences*. Vol. 6, No. 2, 2012.
- [2] J. Sedivy, S. Hubalovsky, “Mathematical foundations and principles in practice of computer aided design simulation”, *International Journal of Mathematics and Computers in Simulation*. vol. 6, No. 1. 2012.
- [3] S. Hubalovsky, J. Jelinek, J. Šedivý, Mathematical modeling and computer simulation of optimal reaction time of the Lupine protein hydrolysis using fermented whey. *International Journal of Mathematical Models and Methods in Applied Sciences*, Vol. 6, No. 2, 2012.
- [4] S. Hubalovsky, “Modeling and computer simulation of real process – solution of Mastermind board game”, *International Journal of Mathematics and Computers in Simulation*. vol. 6, No. 1. 2012.
- [5] J. Bailer, M. Daniela, “Tracing the Development of Models in the Philosophy of Science”, *Magnani, Nersessian and Thagard*, 1999.
- [6] S. Hartmann, “The World as a Process: Simulations in the Natural and Social Sciences”, In R. Hegselmann, et al., *Modelling and Simulation in the Social Sciences from the Philosophy of Science Point of View*, Theory and Decision Library. Dordrecht: Kluwer, 1996.
- [7] A. P. Boresi, R. J. Schmidt, O. M. Sidebottom, “Advanced mechanics of materials”. *John Wiley and Sons*, New York, 1993.
- [8] W. Weaver, J. M. Gere, “Matrix Analysis Of Framed Structures”. *Springer-Verlag*, New York, 1966.
- [9] P. Kadlec, “Physical modeling and measurement of collision situations in construction programs”. *Diploma thesis*. Hradec Kralove, 2012.

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