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Biomechanics – Probabilistic anthropometry approach for sitting human and seat

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Abstract. The aim of this paper is the calculation of external forces, reactions and internal forces and internal moments acting upon human body in seated position (sedentary lifestyles, travelling, working etc.). According to mechanics/biomechanics, the model of a human is created as a simple (2D truss structure) four segment model with joints (articulationes). Input and output values are given by real anthropometric stochastic parameters of human population. Results are determined and evaluated via the direct Monte Carlo Method (truncated histograms etc).

Introduction

When so many people spend so much time sitting in their lives, at work, at home and in transport between destinations etc., the risks of contracting the different types of disorders that sitting can actually cause increase dramatically. In order to take the right action, we must understand the factors that contribute to the problems (medical treatment, ergonomics, prevention etc.). Hence, there is a conflict between the life humans are adapted to and the sedentary life so many people are now living.

Therefore, the sitting, see Fig. 1, can be sources of medical problems, e.g. causing or influencing injuries, pains or deformities in dorsum etc.

Subsequently, in the engineering design of machines, tools, medical treatment and implants, sports etc., proper databases of anthropometry based on stochastic/probabilistic are needed.

For calculations a simple four segment (feet + legs, thighs, lower part of trunk, upper part of trunk + neck + head) model was made, see Fig. 1. This model has similar traits as truss, therefore can be calculated as one.

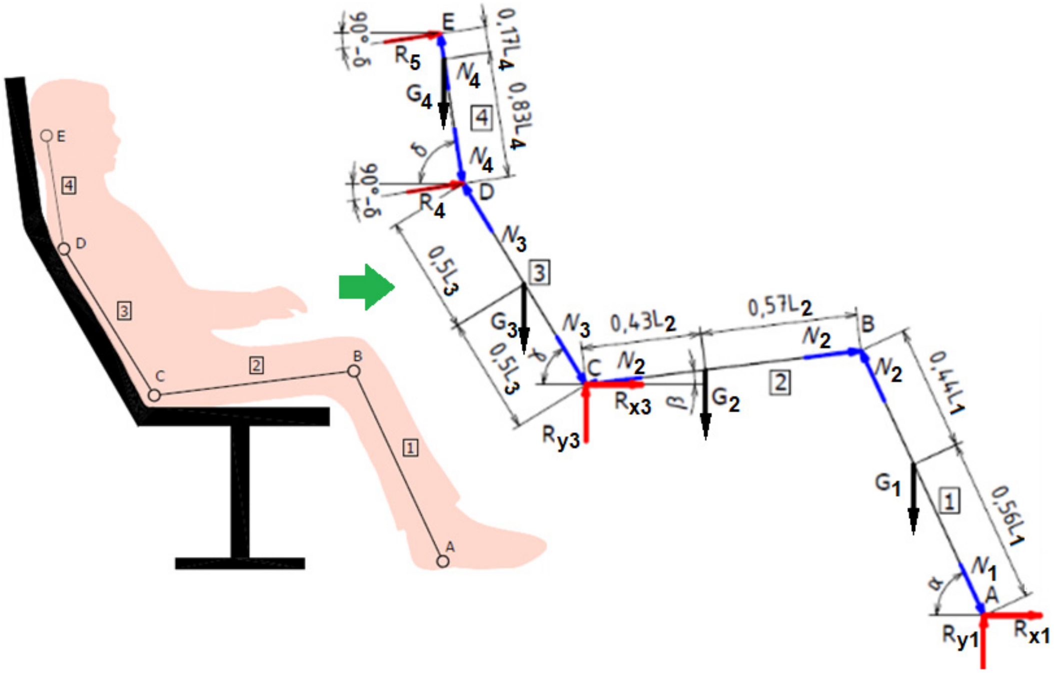


Fig. 1: (a) Sitting human, (b) Model of a sitting human (gravity loadings G_i [N], reactions R_i [N], and internal normal forces N_i [N])

However, human populations and their seats or way of sitting are of stochastic/probabilistic quantities. Therefore, for the interaction between human and seat, the Monte Carlo approach is applied for calculations and evaluations of loading, reactions, normal forces and bending moments.

Reactions and internal forces and moments

To define reactions and normal forces by the Method of Joints, gravity forces acting in centroids must be divided into joints (chosen articulationes), see Fig. 2. Hence, human body can be suitable approximated via 2D truss structure.

Bending moments were calculated considering gravity forces acting outside of joints in (in centroids of body segments).

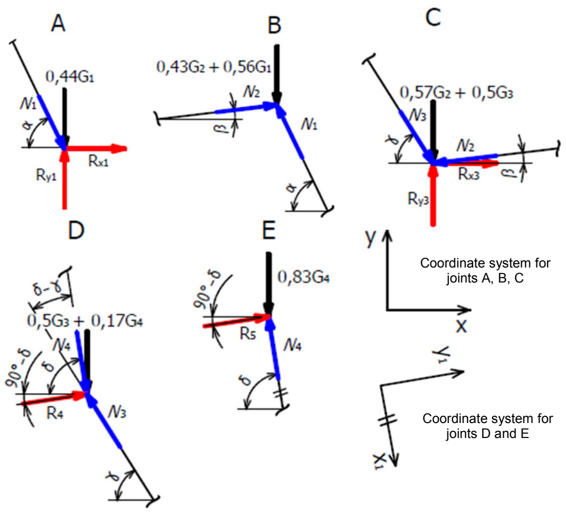


Fig. 2: Free body diagrams of joints and their coordinate systems

Final formulas of reaction and internal normal forces are derived from equilibrium equations, see Fig. 2 and Eq. 1 to 10.

Bending moments can be calculated like 2D truss with loading outside of joints, or, which was used, we can look at the model as "an angled beam". Maximum moments are in Eq. 11 to 14.

$$N_1 = \frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\beta)}{\sin(\alpha + \beta)} \tag{1}$$

$$N_2 = \frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\alpha)}{\sin(\alpha + \beta)} \tag{2}$$

$$N_3 = \frac{[0.5 \cdot \mathrm{G}_3 + \mathrm{G}_4] \cdot \sin(\delta)}{\cos(\delta - \gamma)} \tag{3}$$

$$N_4 = 0.83 \cdot \mathrm{G}_4 \cdot \sin(\delta) \tag{4}$$

$$\mathrm{R}_{x1} = -\frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\beta) \cdot \cos(\alpha)}{\sin(\alpha + \beta)} \tag{5}$$

$$\mathrm{R}_{y1} = 0.43 \cdot \mathrm{G}_1 + \frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\beta) \cdot \sin(\alpha)}{\sin(\alpha + \beta)} \tag{6}$$

$$\begin{aligned} \mathrm{R}_{x3} = &-\frac{[0.5 \cdot \mathrm{G}_3 \cdot \sin(\delta) + \mathrm{G}_4 \cdot \sin(\delta)] \cdot \cos(\gamma)}{\cos(\delta - \gamma)} + \\ &+\frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\alpha) \cdot \cos(\beta)}{\sin(\alpha + \beta)} \end{aligned} \tag{7}$$

$$\begin{aligned} \mathrm{R}_{y3} = &\ 0.57 \cdot \mathrm{G}_2 + 0.5 \cdot \mathrm{G}_3 + \frac{(0.56 \cdot \mathrm{G}_1 + 0.43 \cdot \mathrm{G}_2) \cdot \cos(\alpha) \cdot \sin(\beta)}{\sin(\alpha + \beta)} + \\ &+\frac{[0.5 \cdot \mathrm{G}_3 + \mathrm{G}_4] \cdot \sin(\delta) \cdot \sin(\gamma)}{\cos(\delta - \gamma)} \end{aligned} \tag{8}$$

$$\mathrm{R}_4 = 0.5 \cdot \mathrm{G}_3 \cdot \cos(\delta) + 0.17 \cdot \mathrm{G}_4 \cdot \cos(\delta) + \frac{[0.5 \cdot \mathrm{G}_3 + \mathrm{G}_4 \cdot] \cdot \sin(\delta) \cdot \sin(\delta - \gamma)}{\cos(\delta - \gamma)} \tag{9}$$

$$\mathrm{R}_5 = 0.83 \cdot \mathrm{G}_4 \cdot \cos(\delta) \tag{10}$$

$$M_{\mathrm{omax1}} = \mathrm{R}_{y1} \cdot 0.56 \cdot \mathrm{L}_1 \cdot \cos(\alpha) + \mathrm{R}_{x1} \cdot 0.56 \cdot \mathrm{L}_1 \cdot \sin(\alpha) \tag{11}$$

$$\begin{aligned} M_{\mathrm{omax2}} = &\ \mathrm{R}_{y1} \cdot (\mathrm{L}_1 \cdot \cos(\alpha) + 0.57 \cdot \mathrm{L}_2 \cdot \cos(\beta)) + \\ &+\mathrm{R}_{x1} \cdot (\mathrm{L}_1 \cdot \sin(\alpha) - 0.57 \cdot \mathrm{L}_2 \cdot \sin(\beta)) - \mathrm{G}_1 \cdot (0.44 \cdot \mathrm{L}_1 \cdot \cos(\alpha)) + \\ &+0.57 \cdot \mathrm{L}_2 \cdot \cos(\beta) \end{aligned} \tag{12}$$

$$\begin{aligned} M_{\mathrm{omax3}} = &-\mathrm{G}_4 \cdot (0.83 \cdot \mathrm{L}_4 \cdot \cos(\delta) + 0.5 \cdot L_3 \cdot \cos(\gamma)) + \\ &+\mathrm{R}_5 \cdot \sin(\delta) \cdot (\mathrm{L}_4 \cdot \sin(\delta) + 0.5 \cdot L_3 \cdot \sin(\gamma)) + \\ &+\mathrm{R}_4 \cdot \cos(\delta) \cdot 0.5 \cdot \mathrm{L}_3 \cdot \cos(\gamma) + \mathrm{R}_4 \cdot \sin(\delta) \cdot 0.5 \cdot \mathrm{L}_3 \cdot \sin(\gamma) + \\ &+\mathrm{R}_5 \cdot \cos(\delta) \cdot (\mathrm{L}_4 \cdot \cos(\delta) + 0.5 \cdot \mathrm{L}_3 \cdot \cos(\gamma)) \end{aligned} \tag{13}$$

$$M_{\mathrm{omax4}} = \mathrm{R}_5 \cdot 0.17 \cdot \mathrm{L}_4 \tag{14}$$

These relationships are used for stochastic/probabilistic evaluation.

Internal (pressure) normal forces and bending moments are presented in Fig. 3.

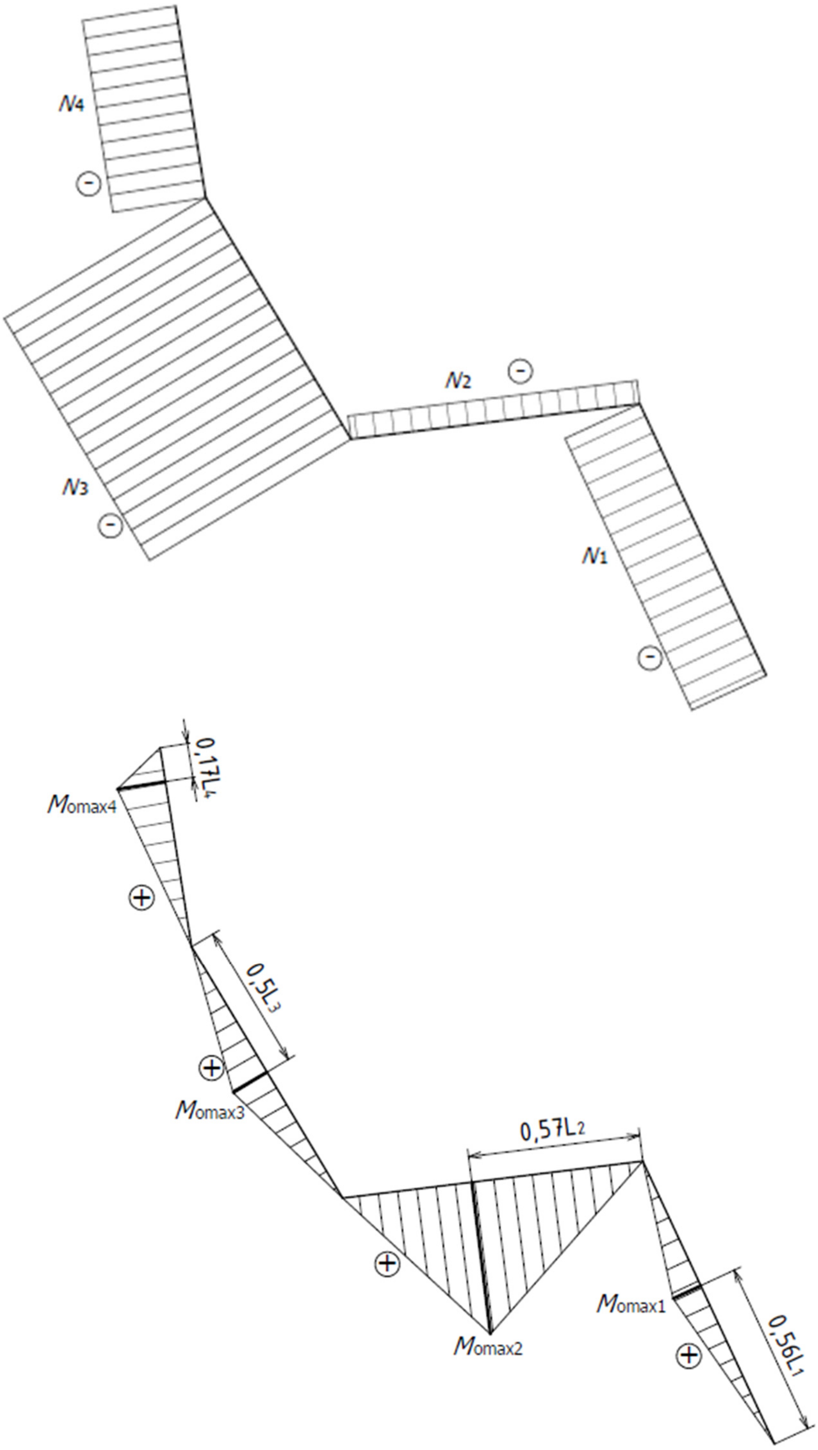


Fig. 3: Example of sitting human evaluation (a) Normal force (N_i [N]) diagram, (b) Bending moment (M_i [Nm]) diagram

Stochastic evaluation

Stochastic approach (direct Monte Carlo Method) is used to take into account the real randomness of human population.

Every input value has truncated normal distribution, see Fig. 4. Inputs, see Tab. 1, are given by real long-time measured anthropometric parameters of human population, angles α, β and δ are depended on seat (chair) design (for more realistic results angle γ is related to δ), and by location on Earth (gravity acceleration g). Outputs are in Tab 2.

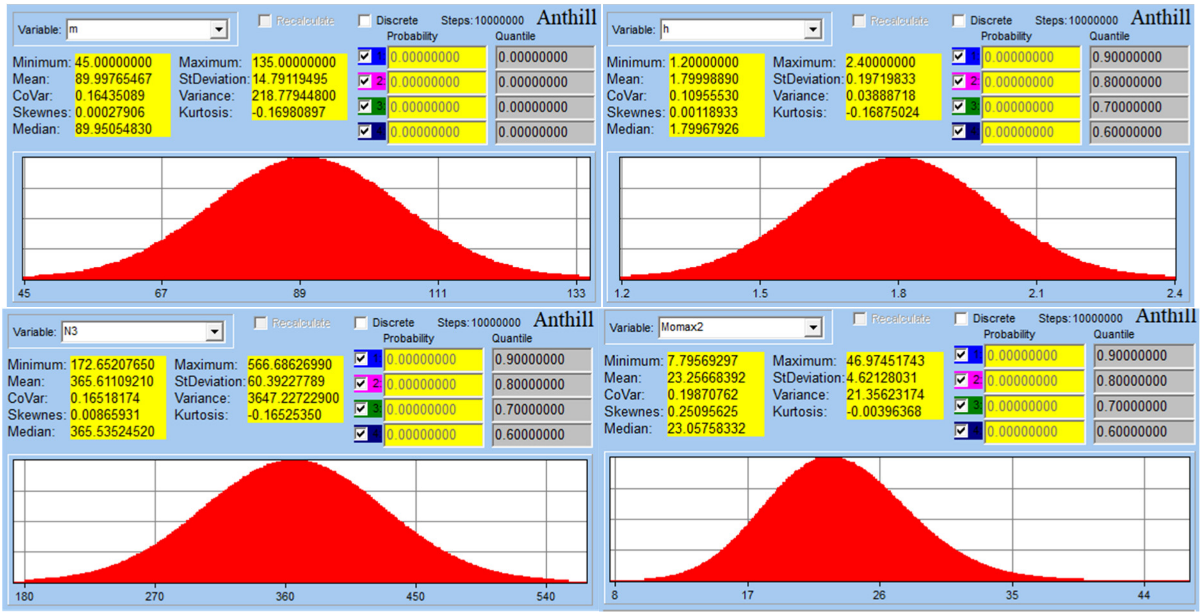


Fig. 4: Examples of inputs and outputs: (a) Total weight, (b) Total height, (c) Maximum normal force, (d) Maximum bending moment

Table 1: Input data (anthropometry, measuring)

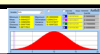
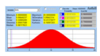
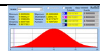
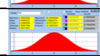
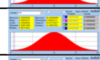
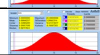
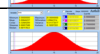
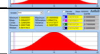
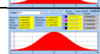
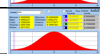
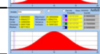
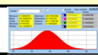
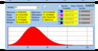
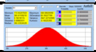
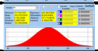
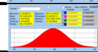
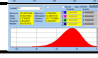
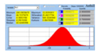
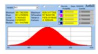
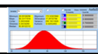
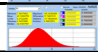
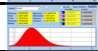
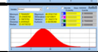
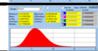
Variable name		Symbol	Min. value	Mean value	Median value	Max. value	Histogram
Total weight [kg]		m	45	89.998	89.951	135	
Total height [m]		h	1.2	1.8	1.8	2.4	
Angle of segment $\boxed{1}$ [deg]		α	60	74.998	74.991	90	
Angle of segment $\boxed{2}$ [deg]		β	0	9.998	9.981	20	
Angle of segment $\boxed{3}$ [deg]		$\gamma = \frac{14}{15} \cdot \delta$	60.67	69.999	69.988	79.33	
Angle of segment $\boxed{4}$ [deg]		δ	65	74.999	74.987	85	
Gravitational acc. [m/s^2]		g	9.78	9.806	9.806	9.832	
Length [m]	Segment $\boxed{1}$	$L_1 = 0.285 \cdot h$	0.342	0.513	0.512	0.684	
	Segment $\boxed{2}$	$L_2 = 0.245 \cdot h$	0.294	0.441	0.441	0.588	
	Segment $\boxed{3}$	$L_3 = 0.24 \cdot h$	0.288	0.432	0.432	0.576	
	Segment $\boxed{4}$	$L_4 = 0.165 \cdot h$	0.198	0.297	0.297	0.396	
Weight [kg]	Segment $\boxed{1}$	$m_1 = 0.124 \cdot m$	5.58	11.158	11.138	16.74	
	Segment $\boxed{2}$	$m_2 = 0.248 \cdot m$	11.16	22.317	22.275	33.48	
	Segment $\boxed{3}$	$m_3 = 0.4 \cdot m$	18	35.996	35.928	54	
	Segment $\boxed{4}$	$m_4 = 0.228 \cdot m$	10.26	20.518	20.479	30.78	
Gravit. force [N]	Segment $\boxed{1}$	G_1	54.58	109.429	109.435	164.567	
	Segment $\boxed{2}$	G_2	109.161	218.859	218.87	329.134	
	Segment $\boxed{3}$	G_3	176.066	352.998	353.016	530.862	
	Segment $\boxed{4}$	G_4	100.357	201.209	201.219	302.591	

Table 2: Output data (forces, bending moments)

Variable name		Symbol	Min. value	Mean value	Median value	Max. value	Histogram
Internal normal force [N]	Segment $\boxed{1}$	N_1	73.367	154.2	154.145	262.296	
	Segment $\boxed{2}$	N_2	0	40.535	39.554	128.811	
	Segment $\boxed{3}$	N_3	172.652	365.611	365.535	566.686	
	Segment $\boxed{4}$	N_4	76.115	161.038	161.006	249.36	
Reaction force [N]	Feet – X direction	R_{x1}	-128.809	-39.856	-38.879	0	
	Feet – Y direction	R_{y1}	91.425	196.529	196.475	305.431	
	Buttock – X direction	R_{x3}	-240.59	-84.724	-83.425	12.204	
	Buttock – Y direction	R_{y3}	305.726	651.419	651.192	1029.748	
	Dorsum	R_4	28.091	86.332	85.601	172.559	
	Head	R_5	7.546	43.15	42.456	105.244	
Max. internal bending moment [Nm]	Segment $\boxed{1}$	M_{OMAX1}	0	3.566	3.464	12.567	
	Segment $\boxed{2}$	M_{OMAX2}	7.796	23.257	23.058	46.975	
	Segment $\boxed{3}$	M_{OMAX3}	3.011	13.02	12.771	34.983	
	Segment $\boxed{4}$	M_{OMAX4}	0.324	2.179	2.126	6.63	

Conclusions

In the engineering design of machines, tools, medical treatment and implants, sports etc., proper databases of anthropometry based on stochastic/probabilistic are needed. The aim of this paper is a new and original biomechanical evaluation of the interaction between load forces to which a sitting man and the seat are exposed; see Fig. 1 and Tab. 1 and 2. All loads and dimensions, which consider actual anthropometry histograms of human population (i.e. measured and applied segmentation of human weight, height, centroids, gravity and shape of seat) are determined using the Monte Carlo Method.

A simple plane model (i.e. calculated probabilistic normal forces and bending moments) shows a sufficient stochastic/probabilistic evaluation connected with biomechanics, ergonomics or industrial design. According to anthropometry, the simple but accurate plane model for the stochastic solution of seat and seating man interaction was applied. The output data show the biggest normal force $N_{MAX} = N_{3MAX} = 566.7$ N in dorsum; see Fig. 2(a) and Fig 4(c). Maximum bending moment $M_{OMAX} = M_{OMAX2} = 46.975$ Nm is in thighs; see Fig. 2(b) and Fig.4(d).

For the further calculations, shear forces and dynamics effects could be added and finally a spatial (3D) model can be applied. This analysis can serve e.g. as an initial part in designing or improving chairs or as a good support for ergonomics, rehabilitation, implant design etc. The acquired results fill the information gap about this problem.

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References

[1] K. Frydrýšek, D. Čepica, T. Halo, Biomechanics – Simple Stochastic Model of Sitting Human, VSB – Technical University of Ostrava, Faculty of Mechanical engineering, Department of Applied Mechanics, 2019.

[2] D. Čepica. Biomechanics – Stochastic Loading of a Human (unpublished bachelor thesis written in Czech language, VSB - Technical University of Ostrava, 2019, head of thesis Karel FRYDRÝŠEK).

[3] K. Frydrýšek, Biomechanika 1 (Biomechanics 1), monograph written in Czech language, VSB – Technical University of Ostrava, Faculty of Mechanical Engineering, ISBN 978-80-248-4263-92019, (in print).

[4] I. Kingma, J.H. van Dieën, Static and Dynamic Postural Loadings During Computer Work in Females: Sitting on an Office Chair Versus Sitting on an Exercise Ball, Applied Ergonomics, ISSN 0003-6870, Volume 40, Issue 2, 2009, pp. 199-205.

[5] A. Kyvelidou, R.T. Harbourne, J. Haworth, K.K. Schmid, N. Stergiou, Children with Moderate to Severe Cerebral Palsy May not Benefit from Stochastic Vibration when Developing Independent Sitting, Developmental Neurorehabilitation, vol. 21, no. 6, 2018, pp. 362-370, DOI: 10.1080/17518423.2017.1290705.

[6] J. Grepl, K. Frydrýšek, M. Penhaker, A Probabilistic Model of the Interaction between a Sitting Man and a Seat, Applied Mechanics and Materials, Vol. 684, 2014, pp. 413-419.