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FINITE ELEMENT ANALYSIS OF FRICTIONAL CONTACTS

BY

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Abstract. Friction is a complex process, involving the simultaneous appearance of several phenomena such as wear, thermal, etc. Seismic protection of structures using frictional passive energy dissipaters is being lately used. Given that the coupled phenomenon can influence the behaviour over time of tribological assemblies, a thorough study of their effects is necessary in order to ensure a proper operation of frictional devices. In this respect, a method of analysis, commonly used today, is the finite element method. As with any approximate methods of calculus, this leads, in some cases, to partially correct results. This paper analyses the frictional heating phenomenon using the finite element method. Stress and the overall temperature distribution are presented for a particular case, as well as their dependence on the coefficient of friction and the force normally acting to the contact surface. The errors caused by this type of analysis are discussed also. ANSYS software was used for the performed coupled analysis.

Key words: frictional heating; finite element method.

1. Introduction

It is well known that the frictional phenomenon implies that part of the mechanical energy is transformed into heat (Bos, 1995; Dieter & Kuhn, 2003;

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Alart *et al.*, 2006). The maximum temperature that occurs at the contact surface can have an important influence on the behaviour of the contacting elements.

Given the fact that frictional dampers are widely used as earthquake protective systems, such a coupled effect can lead to malfunction of the device with negative impact on structural system's response to seismic action. This paper performs about a parametric termomechanical analysis of a commonly used configuration for such devices. The software used for this analysis is ANSYS Workbench version 12.0.1 (ANSYS Workbench 2.0, 2009).

2. Finite Element Used for the Contact Problem

To model the frictional contact, the CONTA174 (ANSYS Inc, 2009) finite element is utilized. CONTA 174 is an 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis and is used to represent contact and sliding between 3-D surfaces. The element is applicable to 3-D structural and coupled field contact analyses.

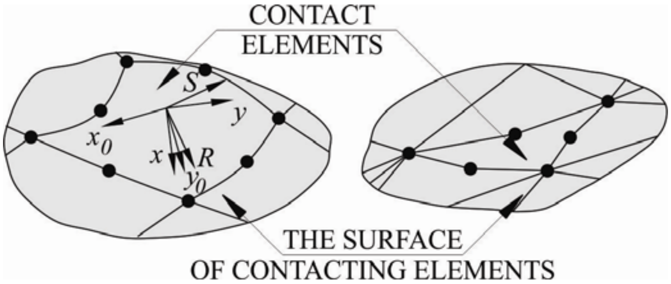


Fig. 1 – Contact element – CONTA174.

The contact element allows the use of both isotropic and orthotropic friction models. In this case an isotropic friction model was used with a variable coefficient ranging between 0.35 and 0.55 and a starting value of 0.45 that corresponds to the coupling materials – determined experimentally (Ştefancu & Urzică, 2011). A uniform stick-slip behaviour in all directions is also presumed.

For the finite element CONTACT174, the rate of frictional dissipation is evaluated using the frictional heating factor and is given by

$$q = \text{FGTH}\,\tau V, \tag{1}$$

where: τ is the equivalent frictional stress, V – the sliding rate and FGTH – the fraction of frictional dissipated energy converted into heat (the default value of 1 was used for this parameter)

The amount of frictional dissipation on contact and target surfaces is given by

$$q_c = F_w F_f t v\,, \qquad (2)$$

$$q_T = (1 - F_w) F_f t v\,, \qquad (3)$$

where: q_c is the amount of frictional dissipation on the contact side, q_T – the amount of frictional dissipation on the target side and FWGT is a weighted distribution factor (the default value of to 0.5 was used for this parameter).

The relationships presented previously are valid only for the sliding mode of friction and a coefficient of friction greater than zero.

3. The Model Used in the Finite Element Analysis

The parametric analysis was performed using a model made up of two solids. The top one is made of friction material while the bottom one is made of structural steel. A frictional contact is defined between the two of them. The thermal properties of the materials, as used in the analysis, are listed in Table 1.

Table 1
The Thermal Characteristics of Materials Used in the Analysis
(220°C reference temperature)

	Specific heat J.kg^{-1}.C^{-1}	Coefficient of thermal expansion, [C^{-1}]	Thermal conductivity W.m^{-1}.C^{-1}
Steel	434	1.2e-005	60.5
Friction material	1,034	3e-005	0.5

On top of the upper solid a variable normal force is applied, and an alternative displacement is applied so that the frictional heating phenomenon can occur.

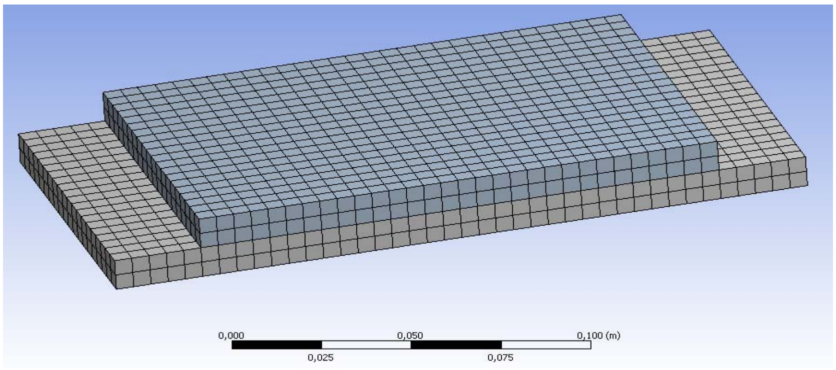


Fig. 2 – The model used in the parametric analysis.

A special attention, as will be pointed out in the forthcoming, needs to be paid out to the characteristics of the mesh (presented in Table 2) and the thermal conductivity coefficient of the friction material.

Table 2

Characteristics of the Mesh

Element size	5.e-003 m
Element Midside Nodes	Dropped
Nodes	4,536
Elements	2,800

It should be noticed that a low order finite element formulation was used to mesh the two solids. This approach was preferred because it leads to smaller run times than a formulation using high order finite elements.

4. The Results of the Analysis

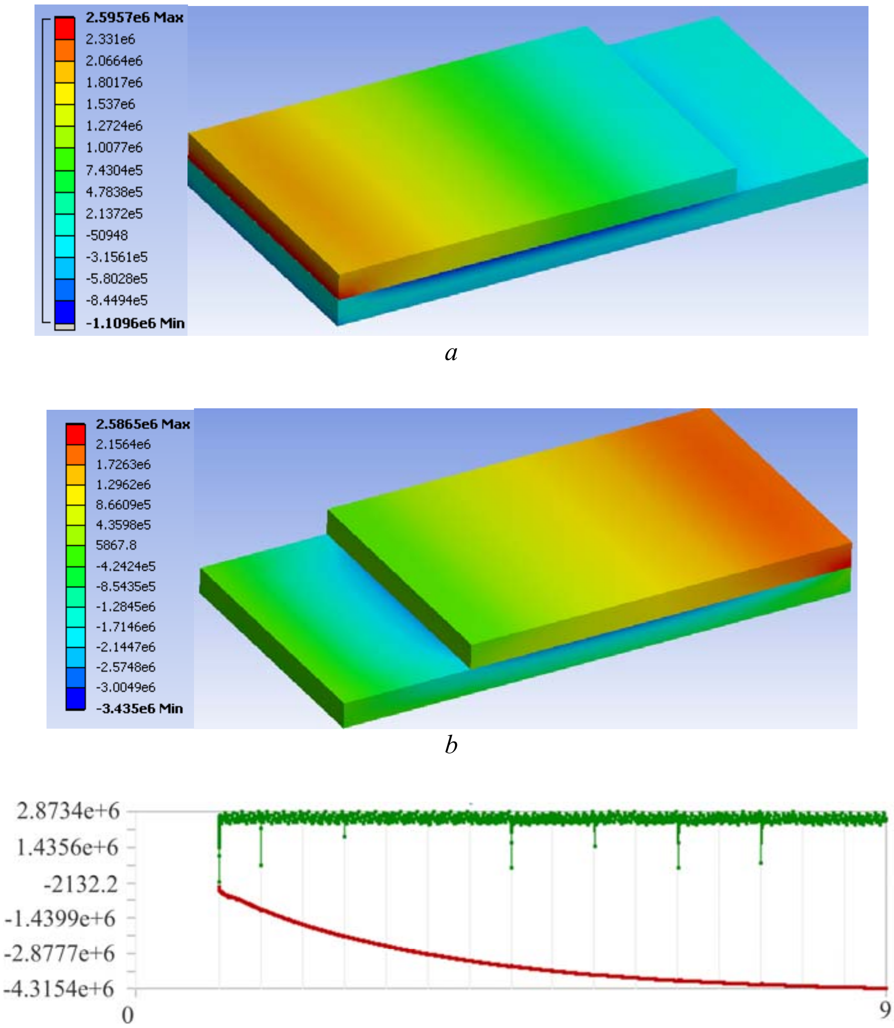
The input parameters of the analysis are, as stated before, the force acting normal to the contact surface, and the frictional coefficient. The results will be presented in the first instance for a friction coefficient of 0.45, and an applied force of 5,000 N, and afterwards for a coefficient ranging between 0.35 and 0.45 and a normal force taking values between 3,000 N and 7,000 N.

4.1. The Stress State

From Fig. 3 *c* two main conclusions can be drawn namelz

a) Due to the way the alternative displacement has been applied (a triangular shaped function) artificially high accelerations occur at the change of the direction of motion. This leads to a peak in the normal stress diagram, hence when evaluating the stress state in such an assembly such values should be excluded from the analysis.

b) A parabolic increase of the minimum normal stress occurs, because of type of analysis performed – transient coupled analysis.

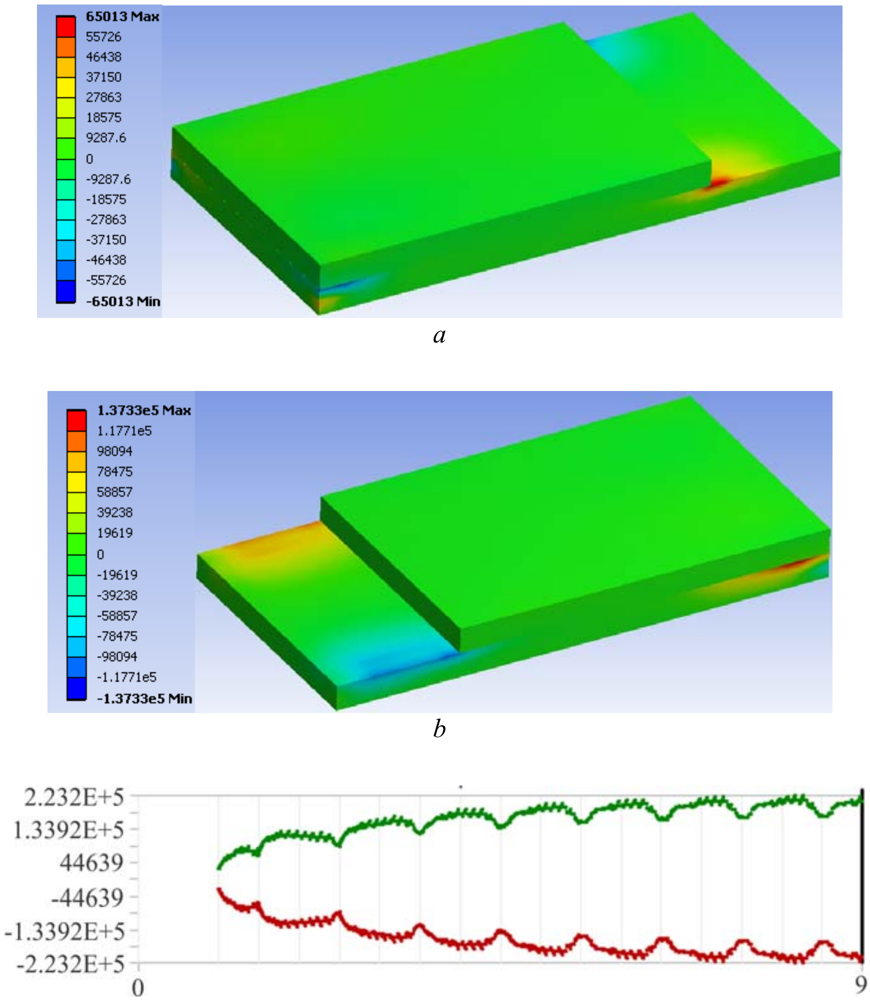


a

b

c

Fig. 3 – Normal stress distribution: *a* – 1.5 s; *b* – 4.5 s; *c* – overall variation of normal stress.



a

b

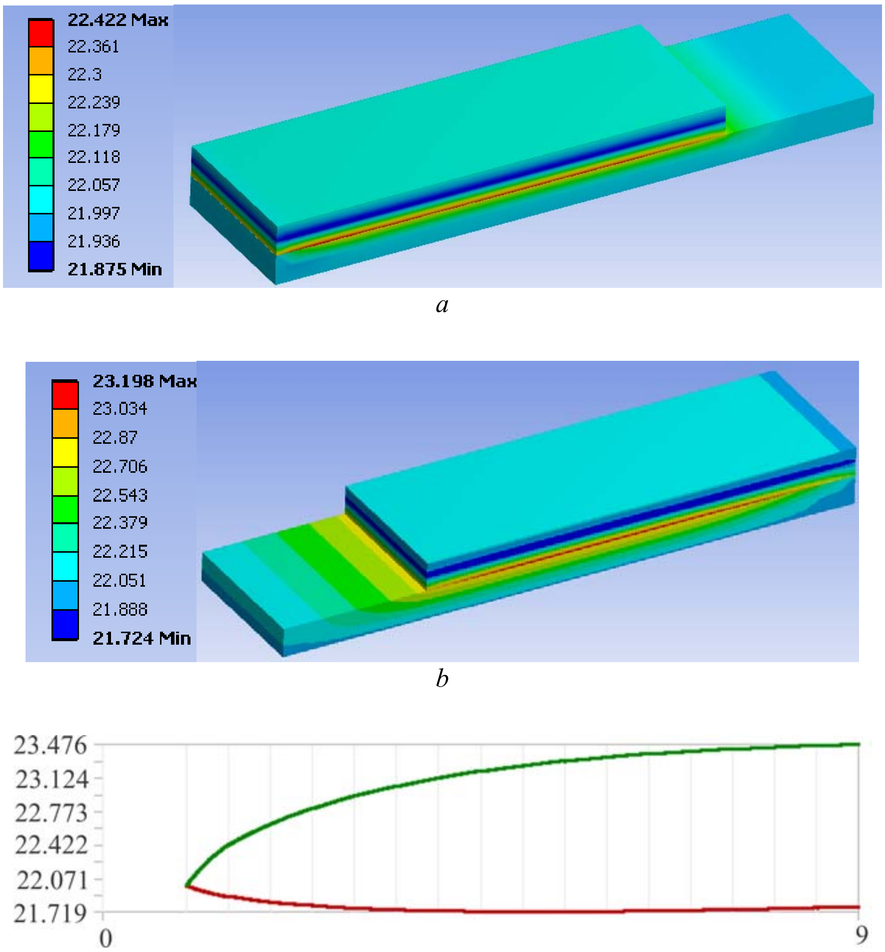
c

Fig. 4 – Shear stress distribution: *a* – 1.5 s; *b* – 4.5 s; *c* – overall variation of shear stress.

Analysing Fig. 4 *c* one may come to the following conclusions:

a) The evolution of the extreme shear stresses is not smooth as one might have previously presumed. Given the fact that the model accounts for the stick-slip phenomenon the resulting shear stress variation is of spurious nature (this observation is valid for case represented in Fig. 3 *c* also);

b) Unlike the normal stresses variation, given the alternating nature the applied displacement, the variation of shear stresses follows an ascending trend for the minimum as well as for the maximum value.



a

b

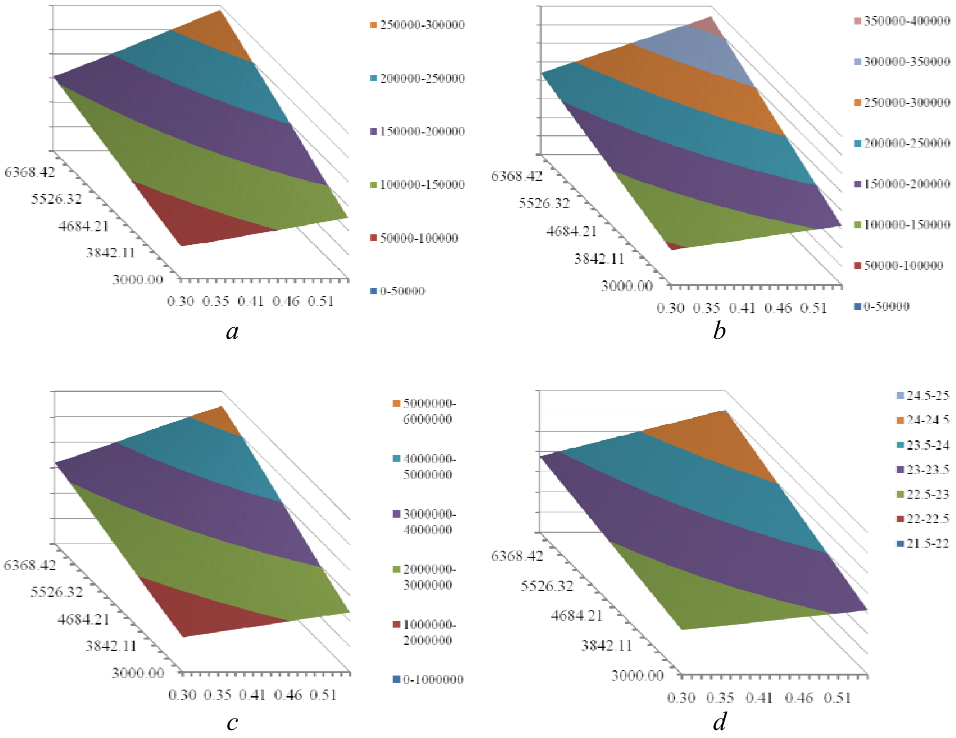
c

Fig. 5 – Temperature distribution: *a* – 1.5 s; *b* – 4.5 s; *c* – overall variation temperature.

The first thing that one notices when analysing Figs. 5 *a* and 5 *b* is the occurrence of “colder” areas inside the friction material. This is caused by the low order finite element formulation, and does not affect the maximum temperature, which is of interest. It should be observed though, that the minimum temperature, which accounts for this fictitious area, increases in time. This leads to the conclusion that after a number of loading cycles this zone fades out.

4.1. The Results of the Parametric Analysis

As expected, given the way the heat generated by friction is computed, the maximum values of the frictional stresses, shear stresses and normal stress are proportional to the frictional coefficient and normal force.



a *b*

c *d*

Fig. 6 – Variation with friction coefficient and normal force:
a – frictional stress maximum; *b* – shear stress maximum;
c – normal stress maximum; *d* – temperature.

5. Conclusions

Given the multiple coupled processes that simultaneously occur at the contacting surface of two bodies in relative motion, there isn't a model that can accurately describe all of them. The case presented previously may be applied only to a particular case, when needed, experimental measurement should be taken to confirm the results of the numerical analysis.

When a termo-mechanical analysis is performed, that seeks solely for the maximum temperature, finite elements without midside node can be used.

When an accurate distribution of the temperature is needed, and only for certain values of thermal conductivity coefficient (values characteristic to thermal-insulator materials) high order finite element should be used.

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ANALIZA CU ELEMENT FINIT A CONTACTELOR CU FRECARE

(Rezumat)

Frecarea este un proces complex ce implică apariţia simultană a mai multor fenomene cum sunt cele de uzură, termice, etc. În protecţia antiseismică a structurilor dispozitivele pasive de disipare a energiei cu frecare şi-au gasit o întrebuinţare largă. Având în vedere faptul că fenomenele cuplate pot influenţa comportarea în timp a ansamblelor tribologice studiul cât mai amănuţit al acestora este necesar pentru a asigura o funcţionare corespunzătoare a dispozitivelor disipative. În acest sens, o metodă de analiză, frecvent utilizată în prezent, este cea bazată pe folosirea elementului finit. Similar oricărei metode aproximative de calcul, şi aceasta conduce, în unele cazuri, la rezultate parţial correct. Lucrarea de faţă propune analiza procesului de degajare de căldură cuplat fenomenului fricţional utilizând metoda elementului finit. Este prezentată distribuţia tensiunilor şi a temperaturilor în ansamblu, pentru un caz particular, precum şi dependennţa acestora de coeficientul de frecare şi forţa normală pe supraţa de contact. Sunt discutate, de asemenea, erorile cauzate de tipul de analiză. A fost utilizat pachetul software ANSYS 12, efectuându-se o analiza cuplată.