Numerical Simulation In Geomechanics On Local Nonlinearity Of Contact

SELKA. GHOUTI
dept. of Architecture
Faculty of Technology
P.O. Box: 213 Tlemcen , Algeria
g_selka@yahoo,fr

***Abstract*—In the current practice of numerical analyses of structure problems, it is often necessary to model contacts between two solids (concrete-rock contact surface, soil-structure contact surface, etc.). The problem is to model the behavior of a discontinuity surface between two solids 1 and 2. The model is composed of a series of two node contact elements Therefore a program using the finite element method was elaborated. It uses nine (09) nodes quadratic rectangular element for modeling the solids and a contact element with two nodes (using springs with an important stiffness) for modeling the interface. The program allows the determination of the final state of the contact with the determination of there strain and stress states.**

Keywords—Contact - Discontinuity - Friction - sliding.- Interface – structure

I. INTRODUCTION

The phenomena of contact [1] are omnipresent in various sectors of mechanical engineering, the civil engineering or in the industrial methods.They appear for example, during the assemblies by bolts or in the bearings or in the interactions ground structure. For their calculation, they present several difficulties, inherent in their non-linear and irregular characters, making their resolution analytical often impossible. To overcome this difficulty, the studies were directed towards the numerical modelling of the behaviour of discontinuity, by taking of account the conditions local of the contact (friction, slipping and separated nodes) [2]. These studies are of particular interest to make it possible to follow on the one hand the evolution of the mechanical characteristics of the solids in contact: deformation, degradation, ruptures. and in addition distribution of the constraints of contact.

An approach of the problem consists in representing each discontinuity by finite elements of contact.

By taking of account real geometry of discontinuity and its mechanical characteristics, in order to determine the final state in any point of discontinuity starting from a given initial state and according to the conditions of loading and the laws of contact

II. NUMERICAL MODEL

The resolution of the problem [2] consists in modelling the behaviour of discontinuity surface Sc between two solids S_1 and S_2 which can slip with friction, to fall apart or return in contact. The model is composed of a series of standard element of contact arises, connecting a point of the S_1 solid to a point of the solid S_2 (1-2, 3-4, 5-6, etc), (see figure 1). These elements are compatible with the elements of the solid mass used to model S_1 and S_2

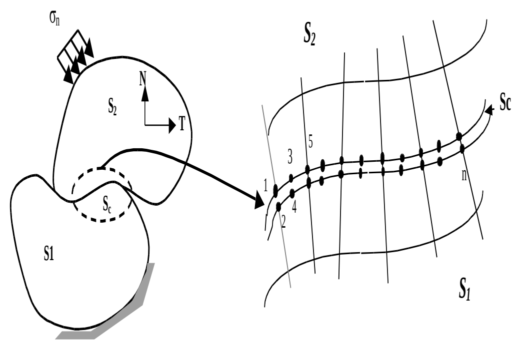


Figure 1 two bodies in contact

2.1 Elements of contact

On the two points of the element (see figure 2), the forces of contact in the local frame:

$$\mathbf{F}_{X2} = -F_{X1} = F_T \qquad \text{et} \qquad \mathbf{F}_{Y2} = -F_{Y1} = F_N \qquad (1)$$

Displacements are noted (u_1,v_1) for node 1 and (u_2 ,v_2) for node 2 in this frame. The matrix of stiffness' of the element of contact [3] in the local frame of reference :

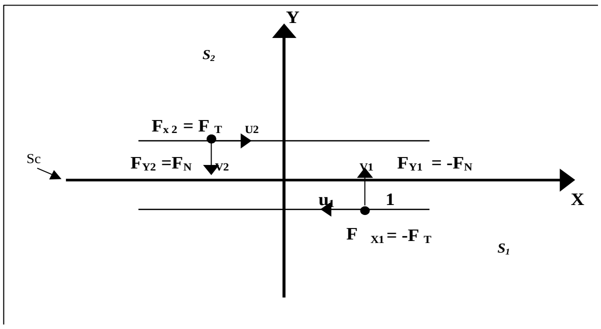


Figure 2 two nodes contact element

$$\begin{Bmatrix} Fx_1 \\ Fy_1 \\ Fx_2 \\ Fy_2 \end{Bmatrix} = K \bullet \begin{bmatrix} T & O & -T & O \\ & N & O & -N \\ Sym & & T & O \\ & & & N \end{bmatrix} \cdot \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \end{Bmatrix} \quad (2)$$

T = 1 or 0, according to whether the tangential spring exists or not.

N= 1 or 0, according to whether the normal spring exists or not.

K : is the factor of penalization [4] which is equal to

$$K = 10^9 . \frac{E_1}{E_2} \quad (3)$$

Where E_1, E_2; Young modules of the solids S_1 and S_2

The study is made in plane elasticity, then the field of displacement will be defined by displacements U and V in the Cartesian frame of reference. The solids will be modelled by quadratic rectangular elements with (09) nodes.

These elements have a quadratic variation along dimensioned vertical and horizontal of the rectangular element [3].

The function of interpolation φ(x, y) will be provided by polynomial φ(x, y) of the 2nd order expressed in x and y and presenting nine (09) coefficients:

$$\phi(x,y) = \alpha_1 + \alpha_2 x + \alpha_3 y + \alpha_4 x^2 + \alpha_5 y^2 + \alpha_6 xy + \alpha_7 x^2 y + \alpha_8 xy^2 + \alpha_9 x^2 y^2$$

(4)

III. Law of Contact and Friction

The different criteria [4] are expressed in terms of constraint:

3-1 *Tensile strength criterion*

$$\sigma_n \leq R_T \quad (5)$$

σ_N: Normal constraint with discontinuity

R_T: Tensile strength of discontinuity

3-2 Coulomb's friction criterion

$$|\sigma_T| \leq |\mu.\sigma_n| \quad (6)$$

σ_T: Tangential constraint with discontinuity.

μ: Coefficient of friction.

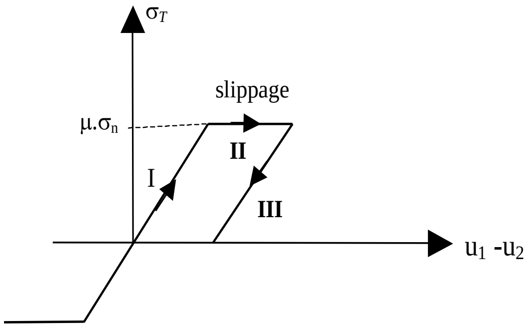
3-3 Opening Criterion

$$(v_1 - v_2) > e \quad (7)$$

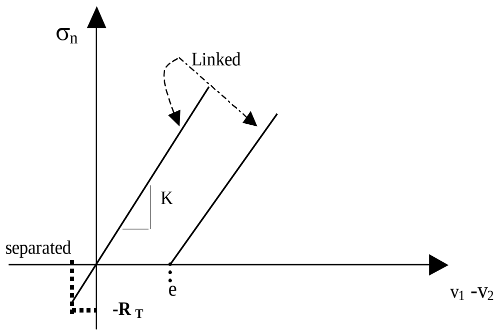
e: is the initial opening of the discontinuity

v_1,v_2: Displacement vertical of the solids S_1 and S_2

These different criteria are represented in figure 4.



(a)



(b)

Figure 4: a) Behaviour in the tangential direction

(b) Behaviour in the normal direction

The method consists [4, 5] in imposing or removing high tangential k_T and /or normal k_N stiffness Between the nodes into contact element. At the end of each iteration, one calculates the constraints of contact in the elements of contact, and one will check if the criteria are satisfied. If it is not the case, tangential K_T and / or normal rigidity k_N will be modified. Consequently:

- If the criterion (4-1) is not satisfied, K_T , k_N are set to zero, the two points are separated.

- If the criterion (4-2) is not satisfied, slippage occurs and K_T only is set to zero

- If the criterion (4-3) is not satisfied, (i.e. the two solids interpenetrate), both K_T and k_N are set (or reset) to very large value : the two points are linked or relined together

IV. Results and Discussions

The description given herein corresponds to the method implemented on fem code [2,3], which is an incremental method for each iteration step, ie the displacements calculated at each iteration step are added to the displacements of the previous iteration of the local increment under consideration. At the end iteration step these relation allow to calculate the part of the contact constraints due to the spring and to check if criteria are satisfied. If it is not the case the tangential and / or the normal stiffness is modified.

4.1 Behaviour of a rock fissured

It is of a fissured rock, rectangular section, thickness the unit, height H = 4 cm and length L = 12cm. It is subjected in its loose lead to a Load P = 100 kg (figure 5).

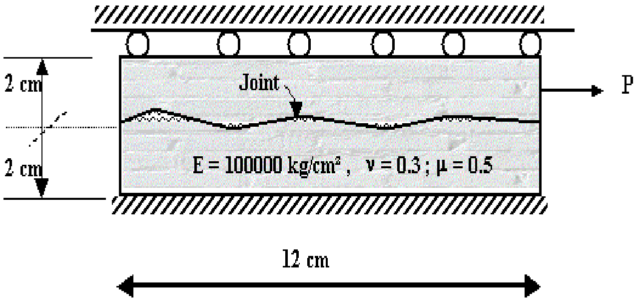


Figure 5 beam fissured

The model of calculation comprises 54 nodes, 08 *Quadratic element* and 09 elements of contact, having a tensile strength null (see figure 6). These elements are linked at the beginning.

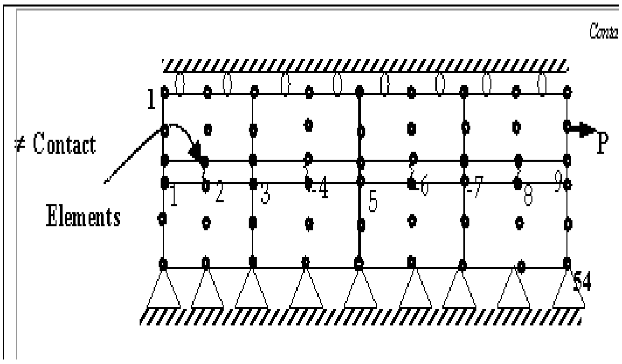


FIGURE 6 MESH OF BEAM The variations of the contact stresses of σn and σT according to tangential displacement U are shown in figure 7.

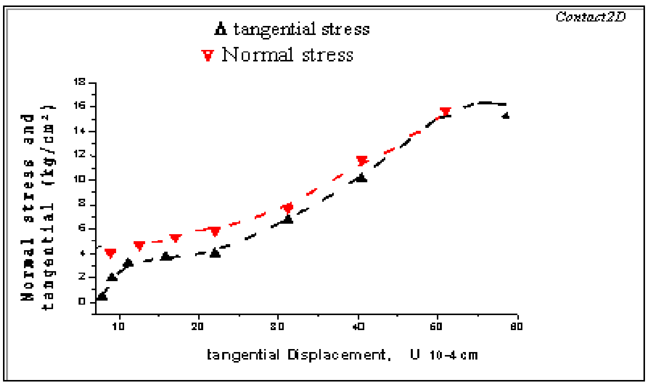


Figure 7 Variation of the normal constraints and

tangential according to displacement U

The evolution of shear stresses τxy along the piece are shown in figure 8. The points noted by the symbol ≠ represent the elements of contact found in a state of separation, while the points noted by symbol ≒ represent the elements of contact found in a state of slip. One can also notice the concentration of the constraints τ_{xy} along the interface. The arrows indicate the extension of the zones of deformation in the piece.

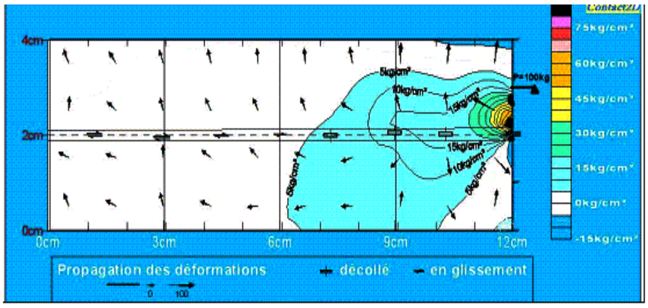


Figure 8 Evolution of the contact stress τ_{xy}

The contact considered in this example has surface roughness that is small compared with the macroscopic contact area and has well defined normal and tangent direction to the contact surface

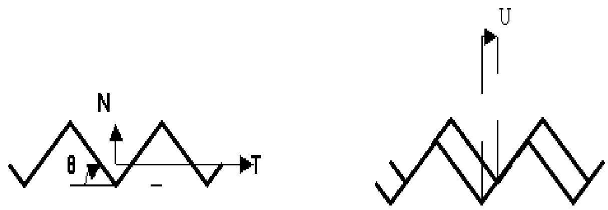


Figure 9 irregularity Surface

We considered an initial slope of the joint θ between the two pieces and by keeping the same conditions as previously. The modification made on the field of displacements can be judged starting from figure 10.

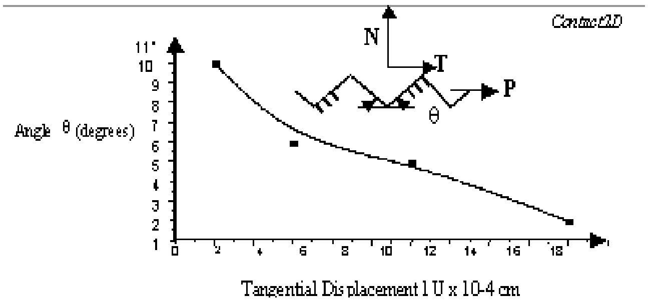


Figure 10 Variation of displacement tangential u

V. CONCLUSION

This study was devoted to the development of a digital model for the analysis of the elastic behaviour of a composite beam subjected to stresses of contact.

That required the determination of the stresses of contact between the various layers in contact. The resolution of the equations of elasticity was carried out by the finite element method. This model makes it possible to study the influence of the parameters like: the state of the interface, the thickness of the joint and the property mechanics of the various layers.

The analysis of the results of the treated applications makes it possible to draw from them several conclusions of which most important are:

The conventional description of the contact which under hears the deformations of a semi-infinite medium is insufficient.

The treated example shows that balance in a contact is not only one problem of surface.

* Stresses of contact and friction not depending only on materials in contact, but also on the state of surfaces in contact

* Assimilation of a fissured beam as being a continuous body [12,17] pleasing to neglect the role of the interfaces and do not reflect the real behaviour of the beam.

The state of the interfaces has a great influence on the value and the distribution of the stresses.

The angle Θ of the interfaces has a great influence on the value and the distribution of displacements

REFERENCES

[1] C. ZAMMALI . " Contribution à la modélisation mécanique et numérique des problèmes de contact " thèse doctorat d'état Ecole centrale Paris France (2005).

[2] G.SELKA. ″ Numerical modelling of the contact problems in mechanics. ″ Proc. 3ième Séminaire sur les technologies mécaniques avancées STEMA 03 Vol. 1. 31-33 (2013).

[3] D.E KERDAL & G. SELKA." Etude Par Eléments Finis des Problèmes de contacts'' Algérie Equipement. Revue Technique de l'Ecole Nationale des Travaux Publics N° 35 p2-4 N° ISSN 111-5211 (2002).

[4] G DE SAXCÉ. et *al* « The bi-potential method : a constructive approach to design the complete contact law with friction and improved numerical algorithms », Mathematical and Computer Modelling, vol. 28(4-8), p. 225-245, special issue Recent Advances in Contact Mechanics. (1998)

[5] K.J.BATHE et *al* '' Stability of finite element mixed interpolation for contact problems. Rend. Mat. Acc. Lincei . V.12(9): p167-183. (2001).

[6] S. LAMARCHE. et *al* '' Validation of contact impact approaches for FEM software. In Soize et al , editor , the Sixth European Conference on Structural Dynamics'(Eurodyn05) Paris France p 04-07 (2005).

[7] P. BISEGNA, et *al* ," Relaxation procedures for solving Signorini-Coulomb contact problems, Advances in Engineering Software, Vol 35, 595-600. (2004).

[8] T. A. LAURSEN "Computational Contact and Impact Mechanics; Fundamentals of modeling interfacial in nonlinear finite element analysis" Ed Springer-Verlag Heidelberg (2002)

[9] H. Ben Dhia et *al* '' Modèles et schéma mixtes pour le contact en dynamique '' 6ème colloque national en calcul des structures 20-23 Mai, II:385-392 ; (2003).

[10] M. A. KARRAY, et *al* ''Traitement de la liaison béton-acier par un modèle d'interface couplant adhésion et frottement, Annales Maghrébines de l'Ing, v.18, n°2, (2004).

[11] H. Ben Dhia et *al* '' Hybrid frictional contact particles in elements. Revue Européenne des éléments finis. P 417-430, (2002).

[13] M. ZARROUG '' Eléments mixtes de contact frottant en grandes transformations et applications PhD thesis, Ecole centrale Paris France (2002).

[14] F.ZAITTOUNI et *al* '' Etude théorique et numérique du comportement d'un assemblage de plaques, Compte Rendus Académie des Sciences, Série Mécanique, Vol. 330, 359-364, (2002).

[15] Q.H. Shah et *al* '' Predicting the Crack Initiation Fracture Toughness for a Crack along the Bimaterial Interface '' Journal of Applied Sciences 5 (2): 253-256, ISSN 1812-5654 (2005).

[16] B. Christina, and C. Persson," A numerical mixed method for calculating stress intensity factors for interface cracks in bimaterials." Engineering Fracture Mechanics, 68: 235-246. (2001)

[17] F.Jiang et *al* '' Evaluation of interfacial crack growth in bimaterial metallic joints loaded by symmetric three-point bending." Intl. J. Pressure Vessels and Piping, 80: 129-137 (2003.)

[18] L .SOON-SEOK ″ A computation method for frictional contact problem using finite element method ″ International Journal for numerical methods in engineering, Vol.37 p217-228 (1994).

[19] F.Jiang, et *al* '' Evaluation of interfacial crack growth in bimaterial metallic joints loaded by symmetric three-point bending." Intl. J. Pressure Vessels and Piping, 80: 129-137 (2003.)

[20] J.Ting, et *al* "Computational Laboratory for Discrete Element Geomechanics." J. Comput. Civ. Eng., 10.1061/(ASCE)0887-3801(1992)6:2(129), 129-146. (1992).

[21] A. Lashkari. and M. Kadivar,. "A constitutive model for unsaturated soil-structure interfaces." International Journal for Numerical and Analytical Methods in geomechanics, 10.1002/NAG.2392, 207-234. (2016)