SSNP136 – Test of slipping by foundation with the Camwood-Clay law

Summary
One carries out a test of foundation slipping by using the Camwood-Clay law. The calculated solutions are compared with results resulting from the code finite elements SPLASH.

1 Problem of reference

1.1 Description of the model

The model of slipping by foundation consists of a rigid foundation of width B equalize with $2\,m$ posed on a half-plane representing a ground poro-élasto-plastic. The foundation is regarded as being infinitely long, so that the problem can be brought back on a vertical plan ($2\mathrm{D}$) containing a section of the foundation (Figure 1). A vertical displacement directed to the bottom is imposed on the foundation, and one observes the evolution of the behavior of the ground located under this one. The problem also having a symmetry compared to the vertical plan dividing the foundation over its length in two equal parts, one represents only one half of the problem. One thus represents the ground by a square of $10\,m$ of with dimensions, sufficiently large not to disturb the evolution of the behavior of the ground around the foundation (assumption of the infinite half-plane for the ground).

The behavior of the ground is modelled by the Camwood-Clay law. Is also supposed the presence of a fluid (water) *in saturated condition* (coupling hydo-mechanics).

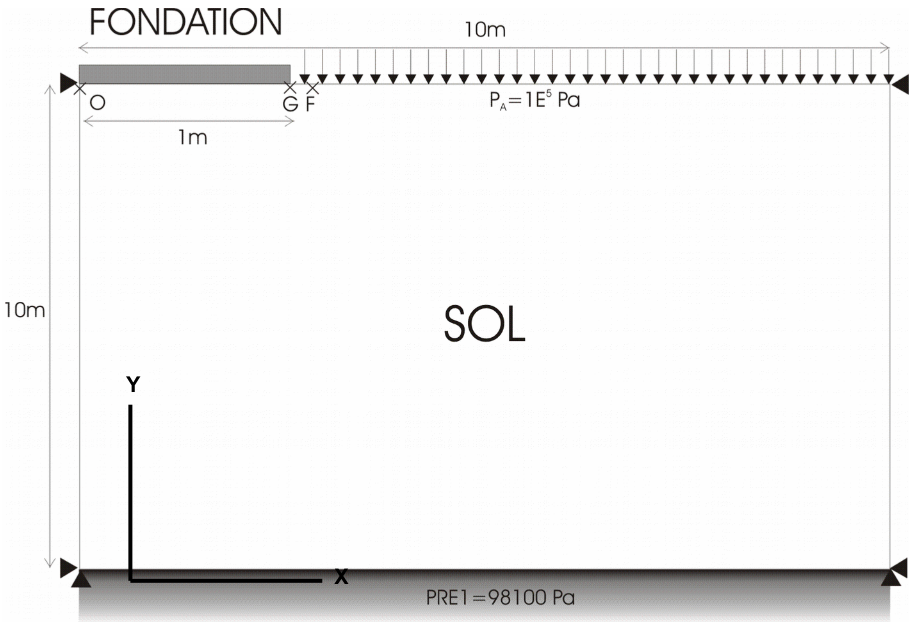

Figure 1 : model of the slipping by foundation.

1.2 Boundary conditions and conditions initial

The boundary conditions mechanical are:

- $Ux=0$ on the side edges (horizontal symmetry);
- $Uy=0$ on the lower edge (vertical symmetry sufficiently far from the foundation);
- an imposed pressure $P_A = 1.\mathrm{E}^{+5}\,Pa$ (atmospheric pressure) on the edge higher, supposed than open air;

The hydraulic conditions are:

- Pore water pressure $PRE1=98100\,Pa$ on the lower edge (drainage downwards).

It is pointed out that the absence of boundary conditions explicit amounts for hydraulics imposing a null flow on the edges (condition of not-drainage).
The initial conditions in the ground are:

- in the case without water

$$\sigma_y = \rho_S \,.\, g \,.\, (h-y) + P_A \,.$$
$$\sigma_x = K_0 \,.\, (\sigma_y - P_A) + P_A$$

- in the case with water

$$\sigma_y=\rho_h.g.(h-y)+P_A$$
$$\sigma_x=K_0.(\sigma_y-P_A)+P_A$$
$$PRE1=\rho_e.g.(h-y)$$

ρ_S, ρ_e and $\rho_h=\rho_S+n.\rho_e$ the densities of ground, fluid represent and homogenized, respectively;
n represent the porosity of the ground;
h represent the thickness of the ground (or free surface dimensions it), with $h=10\,m$;
P_A represent the fixed part of the initial constraint in the ground, equal to the atmospheric pressure $1.E^{+5}\,Pa$;
K_0 represent the coefficient of thorough grounds, here equalizes to 1.

1.3 Material properties

The unelastic parameters of the Camwood-Clay law are:

- porosity: $n=0.5$ (corresponds to an initial index of the vacuums $e_0=\frac{n}{1-n}=1$);
- the elastic coefficient of compressibility: $\kappa=0.05$ (elastic slope in the plan [E, ln (P)]);
- the plastic coefficient of compressibility: $\lambda=0.2$ (plastic slope in the plan [E, ln (P)]);
- the slope of the right-hand side of critical condition: M = 1.02 (corresponds to an angle of friction of 25.85°);
- critical pressure: $P_{CR}=P_{CO}/2=trace(\sigma)/6=\sigma_x/3+\sigma_y/6$;

The elastic parameters of the ground are:

- density of the grains: $\rho_S=1900\,kg/m^3$;
- the Poisson's ratio: $\nu=0.3$;
- the Young modulus[1] : $E=10\,Mpa$;
- parameters allowing to control traction: $K^{cam}=Ptrac=0$.

Lastly, the hydraulic parameters are:

- density of water: $\rho_e=1000\,kg/m^3$;
- viscosity: $\nu=0.001$;
- the intrinsic permeability[2] : $K^{\text{int}}=1.E^{-12}\,m^3/kg/s$;
- the coefficient of compressibility of water: $K_e=1.E^{+10}$;

1 One must choose a data file (E,ν) satisfying the relation: $E<\frac{3(1+\nu)P_0(1+e_0)}{\kappa}$ *at the initial state*. In our case, with $E=10\text{MPa}$ and $\nu=0.3$, one a: $E<\frac{3(1+\nu)P_0(1+e_0)}{\kappa}=156.\text{P}_{co}$, where P_{co} represent the pressure of initial consolidation of the ground. However $P_{co}=trace(\sigma_0)/3$ is strictly increasing according to the depth. The minimal value of P_{co} is thus reached at free surface, and is worth $P_{co,min}=P_A=10^{+5}\,Pa$. Thus $E=10\text{MPa}<15\,MPa$.

2 Hydraulic conductivity is written: $\lambda=\frac{\rho_e g K^{\text{int}}}{\nu}\approx1.E^{-5}\,m/s$.

1.4 Loadings

The loadings are the following:

- gravity $g=9.81\,m/s^2$, directed downwards;
- a vertical displacement going down imposed on the foundation, varying linearly 0 with $D_Y=-0.05\,m$ enter $t_0=0\,s$ and $t_1=1.\mathrm{E}^{+7}\,s$.

If one considers a step of time understood enters $1.\mathrm{E}^{+5}\,s$ and $1.\mathrm{E}^{+6}\,s$, one obtains a distance characteristic of diffusion of the fluid between each step of time understood enters $1\,m$ and $10\,m$. Compared with the size characteristic of the foundation ($2\,m$), one can consider that it *permanent mode is reached between each step of time*.

1.5 Results

The solutions post-are treated with the points O, G and F located directly under the foundation, in terms of trajectories of loading in the plan (P',Q). One is also interested in the evolution of the resultant of the vertical force over the width B foundation, according to its depression. One compares the solutions obtained by Code_Aster with those calculated by SPLASH.

2 Modeling A

2.1 Characteristics of modeling

Modeling A is *two-dimensional* and *non-linear statics*. Calculation is carried out in *pure mechanics*, without hydro-mechanical coupling (equivalent of a perfectly drained ground).

One can check the coherence of the initial state initially (in particular of the boundary conditions with the state of pre-consolidation of the ground): mechanical balance must be established when only gravity acts, therefore the state of the system should not evolve.

Vertical displacement is imposed on GROUP_MA = 'SUPPORT' representing the interface between the foundation and the ground, and varies between $0.$ and $-0.05\,m$ in 20 pas de time enters $t=0.\,s$ and $t=1.\mathrm{E}^{+7}\,s$.

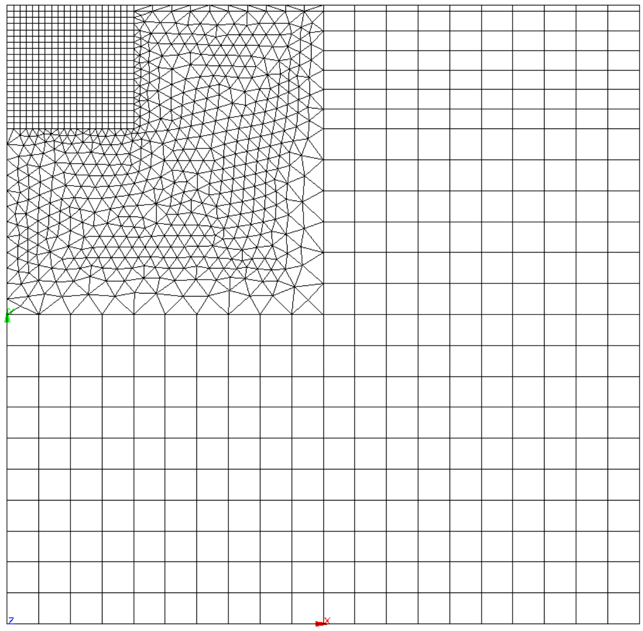

Figure 2 : grid of the foundation slipping by for modeling A.

2.2 Sizes tested and results

The solutions are calculated at the points O and F and compared with references SPLASH. They are initially given in terms of equivalent constraint Q according to the pressure of effective consolidation P', and recapitulated in the following tables:

$$P'=\frac{1}{3}.trace(\sigma') \;; \qquad Q=\sqrt{\frac{3}{2}s:s} \text{ (where } s=\sigma'-P'.1 \text{)}$$

At the point O :

P' [Pa]	Code_Aster [Pa]	SPLASH [Pa]	relative error
102000	434	450	-0,035%
110000	19662	20000	-1,689%
120000	25837	26060	-0,855%
130000	29290	29490	-0,679%
146000	34006	34040	-0,100%

At the point F :

P' [Pa]	Code_Aster [Pa]	SPLASH [Pa]	relative error
101900	227	76	+199%
100000	4945	4950	-0,110%
98000	9941	10420	-4,593%
96000	15283	16830	-9,190%
94000	20036	21870	-8,385%

One calculates then the resultant of the forces exerted on the foundation according to his depression. This one is also compared with the solution given by SPLASH:

UY [m]	Code_Aster [N/m]	SPLASH [N/m]	relative error
-0,005	-110105	-108500	+1,479%
-0.02	-129224	-125800	+2,722%
-0.04	-149470	-144600	+3,368%
-0.06	-167066	-160900	+3,832%
-0.0875	-188825	-181100	+4,266%

2.3 Comments

The comparison of the solutions given by the two codes in the preceding tables shows a relatively satisfactory convergence. Only the variation at the point F for $P'=101900\ Pa$ appears high into relative ($+199\%$), but is actually of an order of magnitude in acceptable absolute compared to the other points.

For better determining the comparison between the various solutions obtained by Code_Aster and SPLASH, one presents on the Figure **3** the comparison of the ways of loadings at the points O , G and F in the plan (P',Q) , and on the Figure **4** the comparison of the resultants of the forces on the foundation.

In term of way of loading in the plan (P',Q) (FIG.**3**), if the solutions coincide rather well at the point O , they present variations relating to the point F , but more significant at the point G . These variations can be explained by the conjunction of two factors:

- on the one hand, the two codes post-do not treat the solutions in the same way: Code_Aster with the nodes and SPLASH at the points of Gauss[3] ;
- in addition, points G and F are located around the end of the foundation, which is a rather critical place since it is the border between the compression zones (under the foundation) and dilation of the ground (apart from the foundation). The gradients of constraint are high there of a point of Gauss to the other, and one can thus understand that an extrapolation with the nodes starting from the closest points of the Gauss is only imperfectly representative of the actual values in these points of Gauss.

In terms of resultant of the forces (figure **4**), the solutions given by Code_Aster and SPLASH coincide relatively well, but tend to deviate as the depression of the foundation increases.

3 One could also recover the solutions of Code_Aster at the points of Gauss, but it is difficult to automate the intercomparison of the solutions obtained by the two codes in this case (`TEST_RESU` does not allow it).

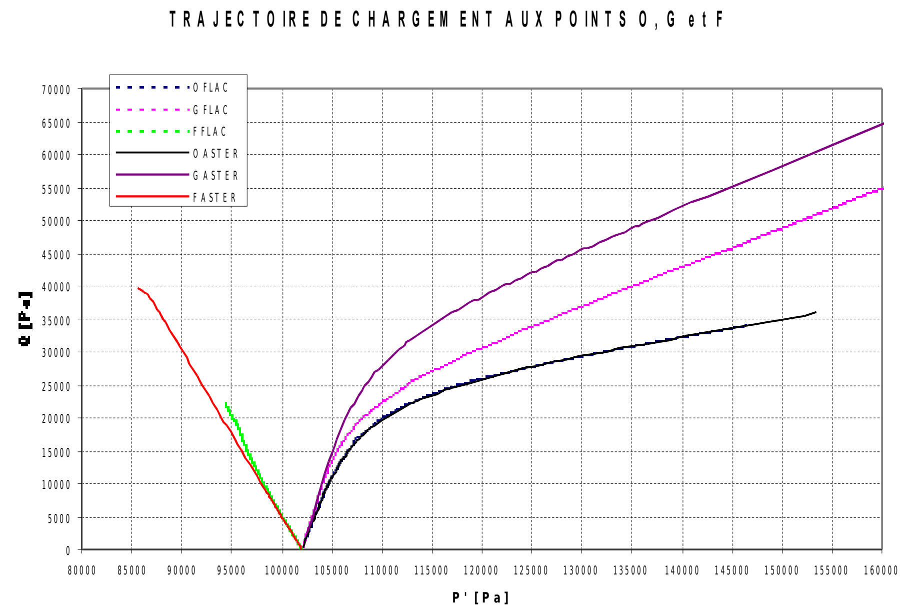

Figure 3 : comparison of the ways of loading in the plan (P', Q) at the points O, G and F given by Code_Aster and SPLASH for modeling A.

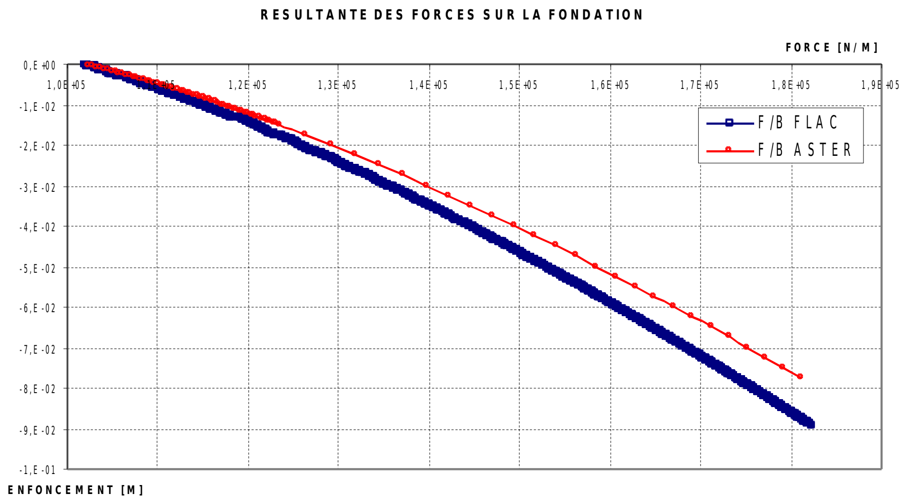

Figure 4 : comparison of the resultants of the forces exerted on the foundation data by Code_Aster and SPLASH for modeling A.