SSNP143 – Validation of keying-up for the model of joint of stud of the stoppings

Summarized:

Keying-up is presented in the form of an injection of the concrete under pressure between the studs of a stopping. It is an intermediate stage of the construction of an arch dam, it is used to reinforce its sealing after the phase of construction of vertical studs. This test makes it possible to validate the procedure of keying-up between the two regular studs embedded on the ground and subjected to the gravitational force. The procedure is defined via a keyword PRES_CLAVAGE in DEFI_MATERIAU for material JOINT_MECA_RUPT. The model bears the same name. One tests the behavior of the two-dimensional and three-dimensional joints, corresponding to the modelizations: PLAN_JOINT and 3D_JOINT.

Modelization a: Keying-up 2D between two rectangles
Modelization b: Keying-up 3D between two cubes

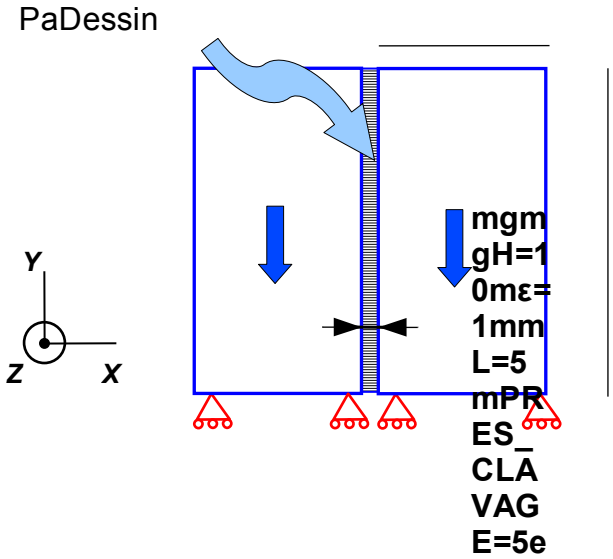
One compares the profile of thickness of the joints after keying-up with the results provided by another computer code (SOURCE_EXTERNE *GEFDYN),* used by the Hydraulic Center of Engineering (CIH). In addition one makes tests of NON_REGRESSION of the values of the thickness of the joint, as well as corresponding normal force.

1 Problem of reference

1.1 Geometry and loading

One considers two studs of stopping, represented by regular cubes of length $L=5\mathrm{m}$, height $H=10\mathrm{m}$ and depth $P=1\mathrm{m}$. The distance between the studs is supposed to be non-zero to simplify the generation of the mesh of the joints ($\varepsilon=1\mathrm{mm}$). The lower parts of the studs are clamped. The studs are subjected to their gravitational weights. The loading proceeds in two stages:

- The studs balance under the gravitational loading. The joint opens in the upper part because of compression of the lower parts of studs.
- The procedure of keying-up is activated: "the concrete is injected" between the studs with PRES_CLAVAGE= $5\,10^4\,Pa$. The profile of the thickness of joint is then modified of kind to obtain the pressure of keying-up on the lips of crack. It is this profile which is stored then by one of the local variables "to memorize" the quantity of concrete injected.



1: Diagram of the studs of stopping, boundary conditions and loading

2 Reference solution

We take as reference the solution given by the computer code *GEFDYN*, used by the hydraulic center of engineering (CIH). This procedure was validated on many industrial works. The opening of the joint after keying-up is tested.

3 Parameters of the material

the values of the mechanical parameters of the studs (Young's modulus, Poisson's ratio, voluminal density) are in the following way selected:

$$E=3.10^2\,Pa \qquad \nu=0,25 \qquad \rho_b=2400\,kg/m^3$$

For the joint, one takes the normal stiffness equal to the tangential stiffness. There is no tensile strength. The coupling between the normal opening and the tangential stiffness is selected of kind to have the tangential slope null as soon as the joint reaches the threshold of complete normal damage. The slope of softening in fracture is five times stiffer than the normal slope of loading (see R7.01.25 document). One clave after the gravitational mechanical loading with a non-zero pressure of keying-up:

$$K_N=K_T=10^{12}\,Pa/m \qquad \sigma_{max}=0\,Pa$$

$$\alpha=1 \qquad \text{pena\_rupt}=0.2 \qquad \text{pres\_clav}=4.10^4\,Pa$$

(NB: values “tests” provided by the CIH which does not correspond to any material in particular)

4 Modelization A

4.1 Characteristic of the modelization

simulation is carried out with modelization PLAN_JOINT. The elements are of type TRIA3 for the studs and QUAD4 for the elements of joint. The corresponding constitutive law is JOINT_MECA_RUPT, the associated material bears the same name. The surface elements are elastic.

4.2 Characteristics of the mesh

One carries out a linear mesh of two studs and crack.
Voluminal elements (studs): 548 TRIA3
Elements of joint: 20 QUAD4

4.3 Quantities tested and results

4.3.1 external Comparison source

the first test is carried out on the values of profile of the thickness of joint after keying-up by comparing it with the results of GEFDYN. One notes δ_n (V7) the normal opening of joint after keying-up:

Quantity tested	*Code_Aster*	*GEFDYN*	*error relating*
δ_n to the height : $2\,m$	6.0216D-07	6.38D-7	5.6%
δ_n with the height : $5\,m$	2.0034D-06	2.14D-6	6.4%
δ_n with the height : $8\,m$	3.623D-06	3.88D-6	6.6%

4.3.2 Tests of non regression

the values of the normal opening of joint δ_n (V7), as well as the normal stresses σ_n are tested with various heights.

Quantity tested	*Code_Aster*
δ_n with the height : $2\,m$	6.02163D-07
δ_n with the height : $4.5\,m$	1.74369D-06
δ_n with the height : $8.5\,m$	3.89115D-06
σ_n with the height : $2\,m$	-4.99999D+04
σ_n with the height : $4.5\,m$	-4.99997D+04
σ_n with the height : $8.5\,m$	-4.99992D+04

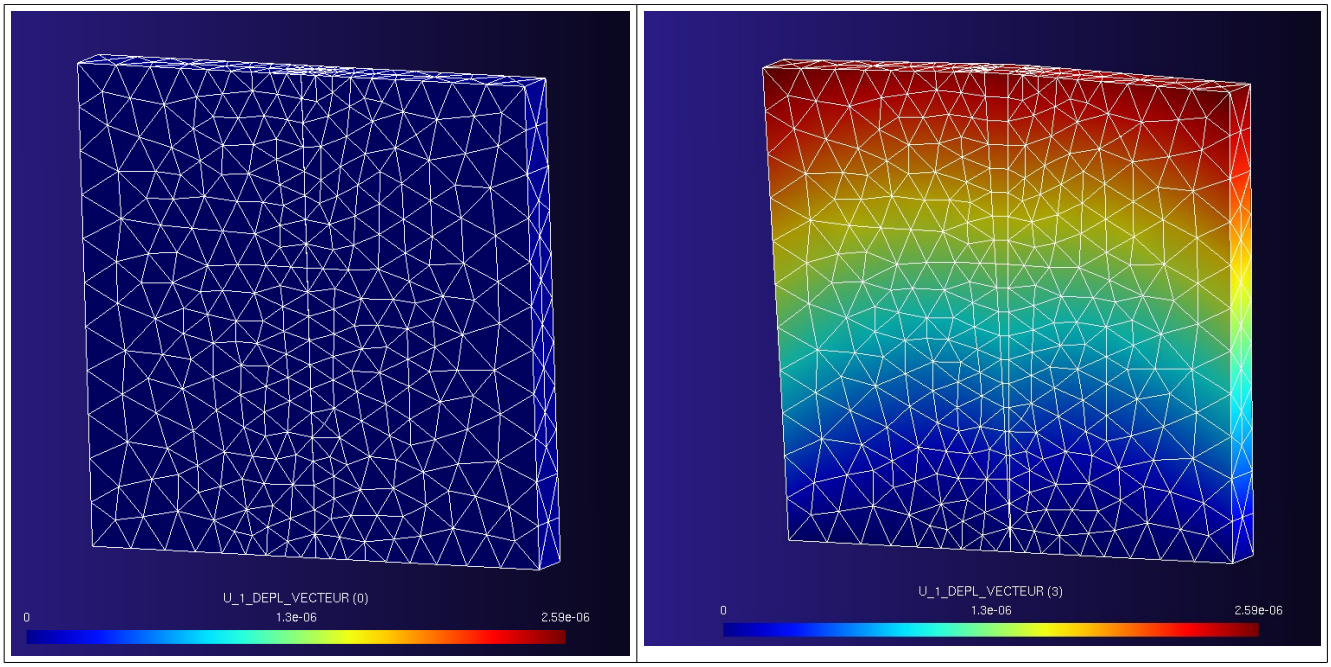
5 Modelization B

5.1 Characteristic of the modelization

simulation is carried out with modelization 3D_JOINT. The elements are of type TETRA4 for the studs and PENTA6 for the elements of joint. The corresponding constitutive law is JOINT_MECA_RUPT, the associated material bears the same name. The voluminal elements are elastic.

5.2 Characteristics of the mesh

One carries out a linear mesh not structured by extrusion of the mesh 2D (figure below).
Voluminal elements (studs): 2761 TETRA4
Elements joined: 92 PENTA6



Drawing 2: Mesh 3D, on the left the initial state, on the right the state after keying-up

5.3 Quantities tested and results

5.3.1 external Comparison source

the first test is carried out on the values of profile of the thickness of joint after keying-up by comparing it with the results of *GEFDYN*. The meshes of *GEFDYN* and *Code_Aster* are not the same ones what explains the accuracy of rather high comparison. One notes δ_n (V7) the normal opening of joint after keying-up:

Quantity tested	*Code_Aster*	*GEFDYN*	*error relating*
δ_n to the height : 2 m	6.1702D-07	6.38D-7	3.3%
δ_n with the height : 5 m	2.0520D-06	2.14D-6	4.1%
δ_n with the height : 8 m	3.7610D-06	3.88D-6	3.1%

5.3.2 Tests of non regression

the values of the normal opening of joint δ_n (V7), as well as the normal stresses σ_n are tested with various heights.

Quantity tested	Code_Aster
δ_n with the height : $2\,m$	6.17022D-07
δ_n with the height : $4.5\,m$	1.80120D-06
δ_n with the height : $8.5\,m$	4.03898D-06
σ_n with the height : $2\,m$	-4.99999D+04
σ_n with the height : $4.5\,m$	-4.99997D+04
σ_n with the height : $8.5\,m$	-4.99993D+04

6 Summary of the results

the procedure of keying-up implemented in *Code_Aster* via the model JOINT_MECA_RUPT and key word PRES_CLAVAGE coincides with the results of code *GEFDYN*.

Keying-up generally requires a nombre of iterations of rather important Newton, but as this one is carried out only once that does not pose a problem for its use in an industrial context.