SDNP001 – Modeling of the dam Aratozawa under the strong earthquake of Miyagi, 2008, with law of Hujeux

Summary:

This case test described digital modeling construction by layers, of the setting in water and the request of the stopping ofAratozawa by a strong earthquake, that of Miyagi of 2008 magnitude $M_w=7.2$ and of maximum accelerations respectively of $a_{x,max}=10.24\,m.s^{-2}$ for the horizontal component, and of $a_{y,max}=6.91\,m.s^{-2}$ for the vertical component. Modeling takes in account at the same time hydraulic coupling and the plasticization of the ground. The compressibility of the fluid is given starting from the model Button manufacturer, while it non-linear behavior is modelled by the law Hujeux. The two components of the seismic signal are introduced on the absorbing border.

U here is considered modeling:

- modeling a: one uses hydraulic modeling under-integrated `D_PLAN_HM_IF`. The algorithm used in dynamics for the law Hujeux is `ALGO_INTE = BASCULE_EXPLCIITE` ;

1 Problem of reference

1.1 Description study

1.1.1 Description stopping

The dam Aratozawa is located north of Japan, in the prefecture of Myiagi (Figure 1.1.1-a) . It is a stopping in fill zones with core, a height of 74.4m to its greater section and a length in peak of 413.7m. The stopping was built in 1991 and commissioned in 1998 for the control of the irrigation of the grounds downstream. It consists of five zones of which the representation is given in Figure 1.1.1-b .

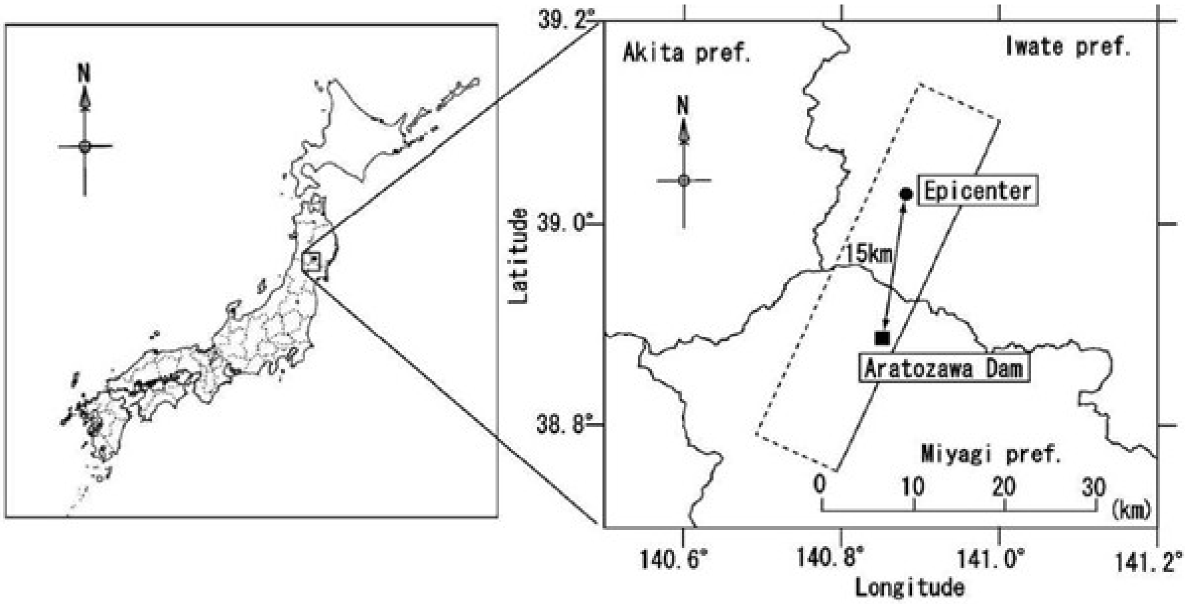
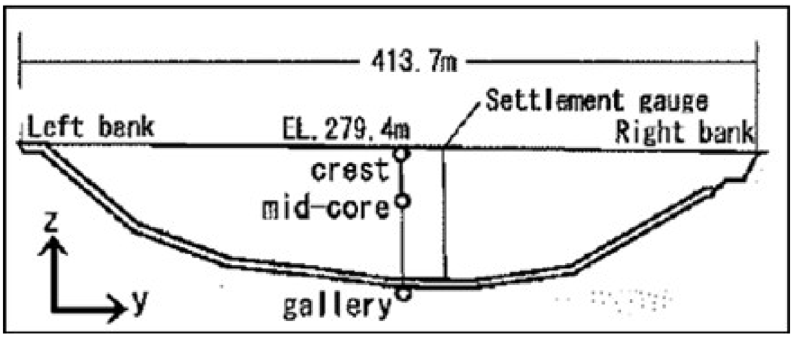


Figure 1.1.1-a : Site of the dam Aratozawa and the epicentre of the earthquake of Miyagi, 2008 [3]



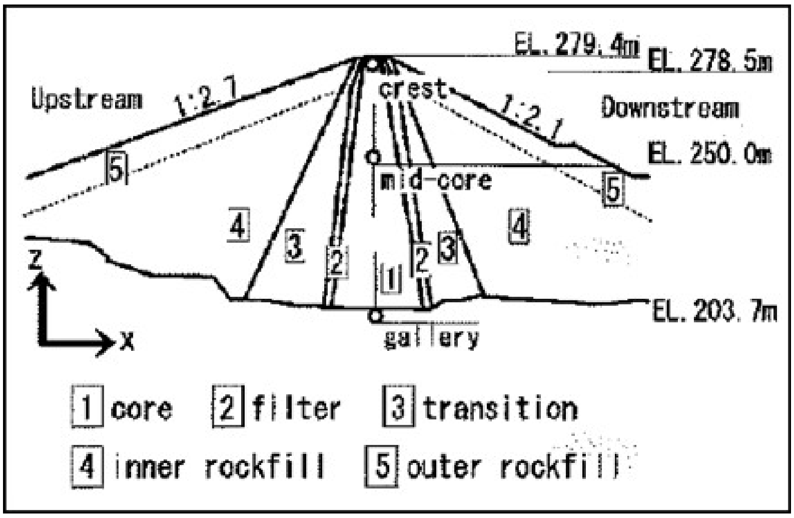
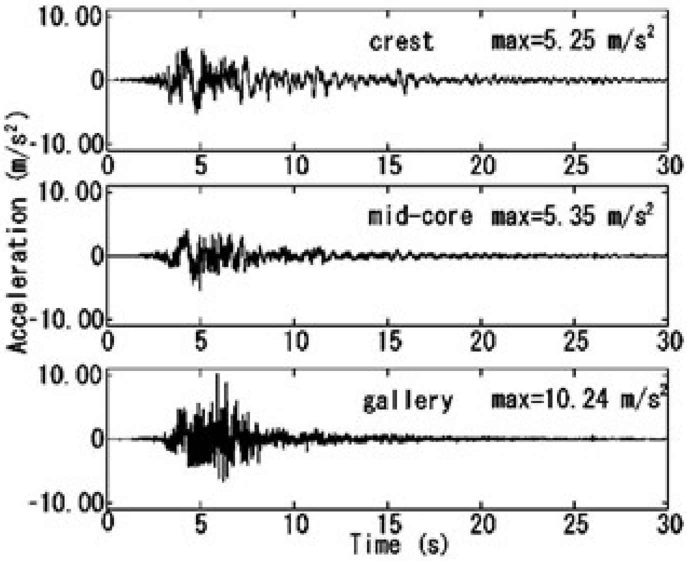


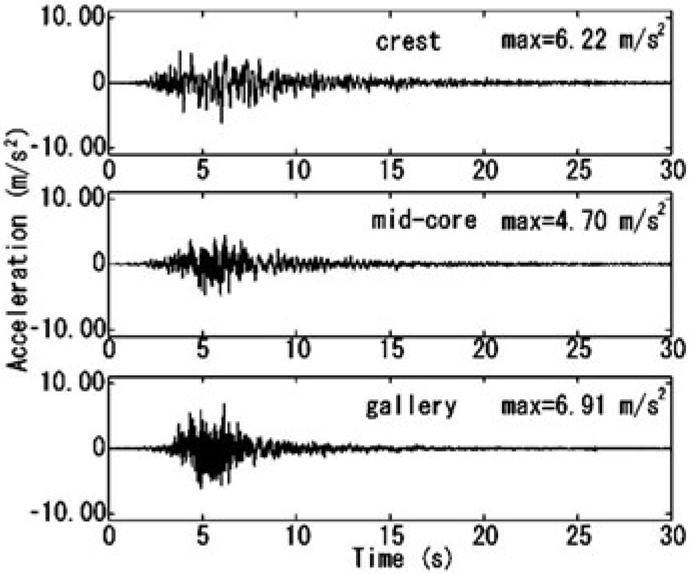
Figure 1.1.1-b : Sections longitudinal (in top) and transversal (in bottom) of the stopping

1.1.2 Description of the strong earthquake

The earthquake of Iwate-Myiagi Nairiku a magnitude of 7.2 occurred at 8:43 on June 14th, 2008. Its epicentre was with approximately 15km north of dam Aratozawa (Figure 1.1.1-a) . Accelerations of the earthquake of 2008 were recorded by three accelerometers located in gallery, in the center and in peak of the stopping (Figure 1.1.1-b). Maximum acceleration in the direction upstream-downstream measured at the base of the stopping (in gallery) reached 10.24 m/s ^{2} while that measured in peak is désamplifiée of a factor two, to 5.25 m/s ^{2} (Figure 1.1.2-a - has) , which is unusually important for the answer of a stopping. This important damping lets predict the dominating influence of nonthe linearities of the ground on this answer. The maximum acceleration measured in the vertical direction reaches 6.91 m/s ^{2} at the base of the stopping (in gallery) and 6.22 m/s ^{2} in peak (Figure 1.1.2-a - B). Minor cracks on the mask upstream, and a compressing in peak of 19cm on the level of the facings, and of approximately 40cm above core were observed [3].



(A)



(b)

Figure 1.1.2-a : (A) AccelerationS horizontalS at the base (gallery), in the middle of the core and in peak;
(b) Vertical accelerations at the base (gallery), in the middle of the core and in peak

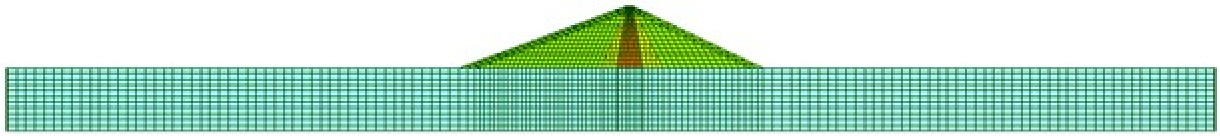
1.2 Description of the grid

The grid of the stopping is two-dimensional (plane deformation) and corresponds to the greatest cross section, like illustrated on Figure 1.2-a . I L is consisted by the stopping and of a foundation. The various zones of the stopping are modelled, namely the core (orange dark), the filters (orange clearly), the transitions (yellow) and the refills (green). The horizontal extension of the rock foundation is equal to twice its influence to the base, and its vertical extension equal to once its height. The grid is of type quadratic : the number of meshs is of 3 003 , including 2326 QUA8 and 38 TRIA6 and the number of nodes of 7546.

By simplification, only two materials are considered:

- The material core is affected at the zones of core and filters
- The material refill is affected at the zones of transitions and refills

Their behavior is modelled by the law constitutive of Hujeux, of which the parameters were discussed previously in the paragraphs § 1.4.1 . The refills being supposed drained, the hydraulic coupling is not taken there into account. However, the presence of a reserve in refill upstream is modelled all the same while using mass of material déjaugée at the time of static calculation . On the other hand, the hydraulic coupling is taken into account in the core using a perfectly saturated model. The presence of entrained air will be modelled by taking account of the properties of the fluid are equivalent given to the paragraph § 1.4.2 using the model of Button manufacturer.



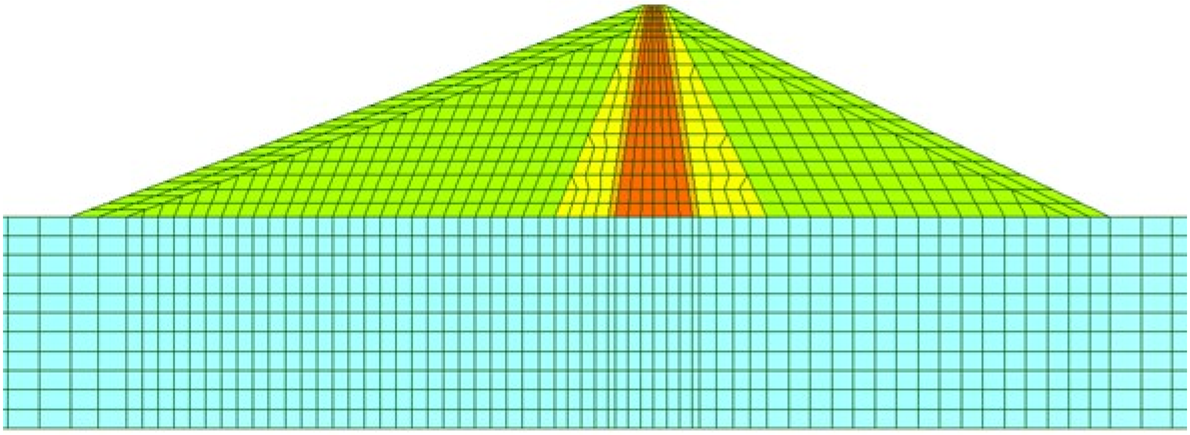


Figure 1.2-a : Grid of the dam Aratozawa (in top)

1.3 Modeling

Modeling is `DPLAN_SI` (planes under-inTégrée) in the faces upstream and downstream, and `DPLAN_HM_SI` in the filters and the core, considered as formant the "core". To take account of the presence of reserve with the upstream, the déjaugée density (taking account of the push of Archimedes) is used for facing upstream.

1.4 Properties ofS materials

1.4.1 Mechanical properties

The foundation is regarded as being a linear elastic material infinitely rigid, whose properties are the following ones:

- $E=143 GPa$
- $\nu=0.3$
- $\rho=2200\, kg.m^{-3}$

values of the parameters of the law of Hujeux for the facings and the core are given in Table 1.4.1-1 hereafter. The core is considered COME being a material of the type sand (b=0,2) with $C_c=0.11$ correspondent with fine 25%. The facing is made incompressible with the upstream $(\nu=0.45)$ and only under isotropic loading $(\nu=0.3;\beta=200)$ with the downstream. The profile of modulus Young in the facings is adjusted according to the relation given by Sawada [5] (Table 1.4.1-2 and Figure 1.4.2-a) in order to obtain a fundamental frequency of resonance f_0 stopping ranging between 2.86 Hz and 3,125 Hz.

Hujeux parameters	Riprap	Core
$E[GPa]$	3.52	5.2
ν	0.3 − 0.45	0.36
$\rho_h[t.m^{-3}]$	2. 13 − 2.33	2.1
Porosity	0.2	0.36
n	0.4	0.7
β	200	32

$\lambda=\frac{e_0}{1+\beta}$	–	0.05
$C_c=\lambda\ln(10)$	–	0.11
d	3.5	2
b	0.6	0.2
$\phi[°]$	40	30
$\psi[°]$	30	30
f_0	224	200
$p'_{c0}=d\,p'_{crit\,0}[kPa]$	785	400
$p_{réf}[MPa]$	1	1
a_{mon}	0.03	0.001
a_{cyc}	10^{-5}	10^{-5}
c_{mon}	3.10^{-4}	0.01
c_{cyc}	3.10^{-4}	0.01
$r_d^{éla}$	0.01	0.05
$r_i^{éla}$	0.01	0.015
R_{hyst}	0.1	0.5
r_{mob}	0.9	0.9
X_m	2	1
r_d^{cyc}	0.01	0.05
r_i^{cyc}	0.01	0.015
α	1	1

Table 1.4.1-1 : Values of the parameters of the law Hujeux for the ripraps and the core

Zone / Depth Z (m)	Rock		Core	
	Non-Saturated	Saturated	High	Low
0-5	Vs = 245		Vs = 210	
5-30	Vs = 250 $Z^{0.20}$	Vs = 250 $Z^{0.20}$	Vs = 180 $Z^{0.35}$	Vs = 140 $Z^{0.34}$
30-	Vs = 200 $Z^{0.315}$			
Poisson's Rato	ν = 0.375-0.006$Z^{0.58}$	ν = 0.49-0.00/$Z^{0.95}$	ν = 0.45-0.006$Z^{0.60}$	

Table 1.4.1-2 : Profiles speed of the waves of shearing and Poisson's ratio in the facings (on the left) and the core (on the right) of the dam Aratozawa, according to Sawada [5]

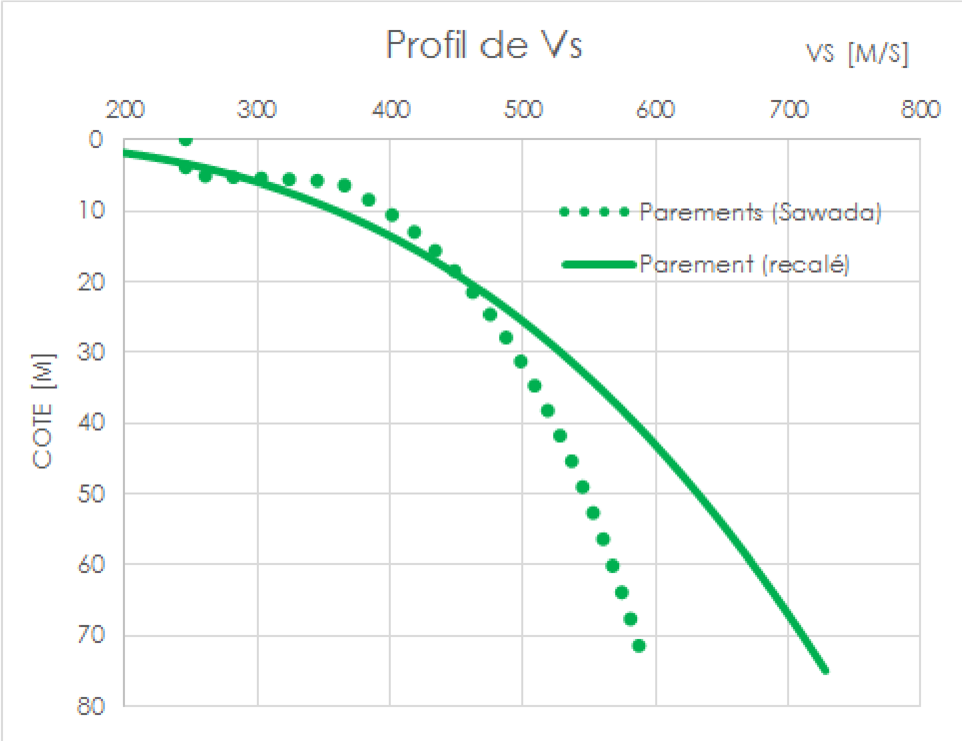


Figure 1.4.1-a : Profile of Vs in the facings.
The modulus of rigidity G results by the relation $G=\rho_h V_s^2$

Foot-note :

The sets of parameters ECP, JEU2 and JEU3 proposed in the command file are sets of alternative parameters described in the document [2].

1.4.2 Hydraulic properties

The face downstream is regarded as dryness. The face upstream is regarded as drained perfectly compared to core. The piezometric line is with the same dimension as the water reserve located with 10m under the peak. The body of the facing is thus treated in total constraints (purely mechanical modeling `D_PLAN`) with the déjaugée density.

The core is regarded as quasi-saturated. The model of Button manufacturer [1] is used to calculate the compressibility of the fluid are equivalent made up of water and bubbles of air. Evolution of the module of compressibility $K_w(u_w)$ according to the pore water pressure u_w (positive in compression) is illustrated on the Figure 1.4.2-a. Values of the parameters hydraulics of the core are data in the Table 1.4.2-1. By approximation, a constant value of module of compressibility K_w is assigned to each soil horizon, calculated starting from the assumption of one profile geostatics of water pressure at the end construction by layers, namely $\rho_w g[z_0 - z]$ where z_0 is the coast of the watermark presumedly located in peak of the stopping and [X] the positive part of X.

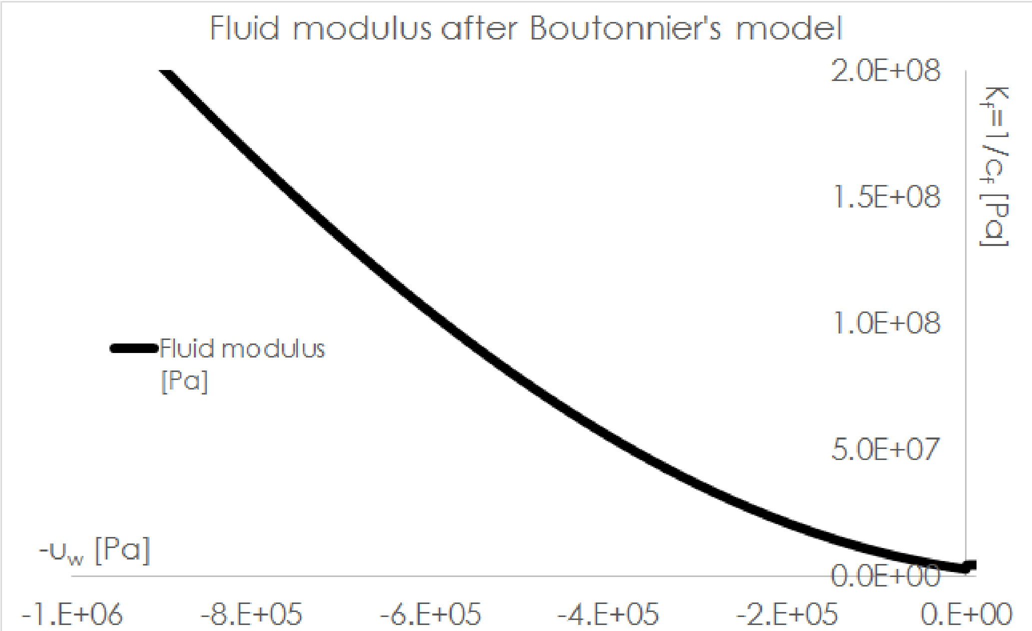


Figure 1.4.2-a : Module of compressibility of the fluid are equivalent according to pressure interstitial, according to the model of Button manufacturer [1]

Parameter	Value
Permeability [$m.s^{-1}$]	10^{-7}
Density of water [$kg.m^{-3}$]	1000
Coefficient of Biot	1
Viscosity ν	10^{-3}
Dépendance of ν compared to the temperature $\frac{d\nu}{dT}$	0

Table 1.4.2-1 : Values of the hydraulic parameters in the core

1.5 Boundary conditions and loadings

Establishment of the boundary conditions and ofS loadingS is based on the methodology described in documentation [U2.04.08]. In addition, one will find of it a description detailed in the note [2]. In what follows, one mentions only the information worthiest of interest according to us.

1.5.1 For the static stage of construction by layers and setting in water

According to S. Rachdi [4], to simulate the stage of setting in water after construction by layers or at the same time significantly does not modify the final fields of displacement, constraints and pressure interstitial. Perhaps that is explained by the smallness of zone concerned, namely the core in which modeling is DPLAN_HM_SI. One will thus adopt this more economic solution in time CPU.

The stopping is divided into 15 soil horizons, and the total duration of construction by layers is three years. The boundary conditions around the foundation are thus the following ones:

- embedding of the base of the foundation;
- blocking of horizontal displacement on the sides of the foundation;

Conditions initial and in extreme cases during construction by layers are thus the following ones:

- application of a mechanical pressure “small” $P_{libre}=10\,kPa$ on the free surface of the stopping;
- state of isotropic effective initial stresses in the core and the facings equal to $\sigma'_0=125\,kPa$. This state of stress corresponds to the residual stress after compaction of the layers, estimated by the approach suggested by Button manufacturer [];
- To guarantee the coherence of the initial state of stress with the free condition of pressure, the initial state of water pressure is fixed at $PRE1=u_w=-115\,kPa$, so that $P_{libre}=\sigma'_0+u_w$ in the core;
- application of a worthless water pressure $PRE1=0$ on the interface enters the core and the face downstream;
- application of one water pressure $PRE1=u_w(z;t)=\rho_w g[z_0(t)-z]$ on the interface between the core and the facing hasmount in the shape of a function of time and coast $z_0(t)$ simulating the progressive rise of reserve to the upstream. At the stage of construction of each layer, one supposes that the tablecloth is located at the base of the layer at the beginning of stage, and at its top at the end of the stage;

Finally the loading consists of the acceleration of gravity.

1.5.2 For the dynamic stage of seismic request

The dynamic stage of calculation is a continuation of static calculation. The boundary conditions at the static end of the stage apply to dynamic calculation. The only loading relates to the boundary conditions around the foundation. The conditions of blocking of displacements are initially replaced by equivalent conditions of imposed forces. That is carried out thanks to the use of specific stiffnesses 2D_DIS_T , initially allowing to recover the values of equivalent forces, then in the second time D-to apply them all while disabling itself (by cancelling their own stiffness).

Finally the seismic signal describes in the paragraph § 1.1.2 is introduced in the form of a plane wave of types P and SV of vertical incidence using the elements of border absorbing DPLAN_ABSO . The signal is declined in two loadings: horizontal acceleration and vertical acceleration, applied at the same time to the base of the foundation and on the sides. On the sides, the loading is that of the homogeneous half space which one activates by assigning a nonworthless value to the keyword:

```
DIST_REFLECHI = cote_de_la_surface_libre
```

1.6 Parameter setting of calculation

Parallelism MPI is used with 24 hearts out of 4 nodes of calculation. Required time CPU total is 12 midnight.

1.6.1 For static calculation

The parameter setting general is the following:

- SUBD_PAS = 2;
- SUBD_NIVEAU = 6;
- Solvor MUMPS ;
- RESI_GLOB_RELA = 5.10^{-4} for 8 first layers and 10^{-3} for the following ones;
- ITER_GLOB_MAXI = 10 for the first 8 layers and 20 for the following ones;

For the law Hujeux:

- ALGO_INTE = SEMI_EXPLICITE
- ITER_INTE_PAS = -2 for the first 8 layers and -4 for the following ones;
- ITER_INTE_MAXI = -50;
- RESI_INTE_RELA = 10^{-8};

1.6.2 For dynamic calculation

By concern of limiting the duration of the CAS-test, one restricts oneself at 7 seconds of signal with a step of time . The temporal diagram used is the diagram HHT with MODI_EQUI = YES and $\alpha=-0.3$. Digital damping correspondent is of 0.2 % from 20 Hz.

The parameter setting general is the following:

- SUBD_PAS = 2;
- SUBD_NIVEAU = 6;
- Solvor PETSC with METHOD = NEWTON_KRYLOV ;
- RESI_GLOB_RELA = 5.10^{-4} ;
- ITER_GLOB_MAXI = 10 ;

For the law Hujeux:

- ALGO_INTE = ROCK _EXPLICITE
- ITER_INTE_PAS = -4 ;
- ITER_INTE_MAXI = -50;
- RESI_INTE_RELA = 10^{-2};

1.6.3 Redimensioning of the hydraulic problem

Hydraulic redimensioning is used for dynamic calculation, with the following parameters:

$$P_0=\frac{1}{K_0}=10^{+4}$$

1.7 Results of reference

1.7.1 Bench-mark data

The results of reference result from Japanese measurements mainly given by Ohmachi []. They are synthesized in the Table 1.7.1-1 into cubes points located on a vertical cut along the core (see localization on the Figure 1.7.2-a)

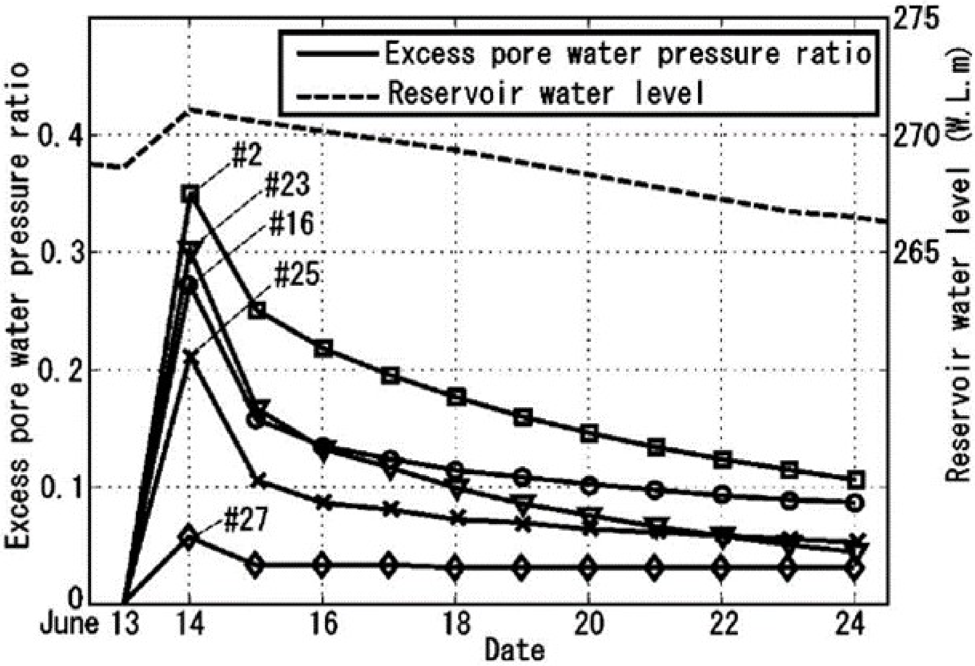
	Summit	**Medium (#23)**	**1/3 inférlaughedor (#16)**	**Base (#2)**
$max_{t\in[0;7]}\lvert a_x\rvert$	5.35 m/s^2	5.25 m/s^2	—	10.24 m/s ^{2}
$max_{t\in[0;7]}\lvert a_y\rvert$	4.70 m/s^2	6.22 m/s^2	—	6.91 m/s ^{2}
$u_y(t=7\,sec)$	39 cm	—	—	—
$moy_{t\in[4;7]}\Delta u_w$	—	150 – 180 kPa	250 – 310 kPa	400 – 410 kPa

Table 1.7.1-1 : Values measured along a vertical profile in the core

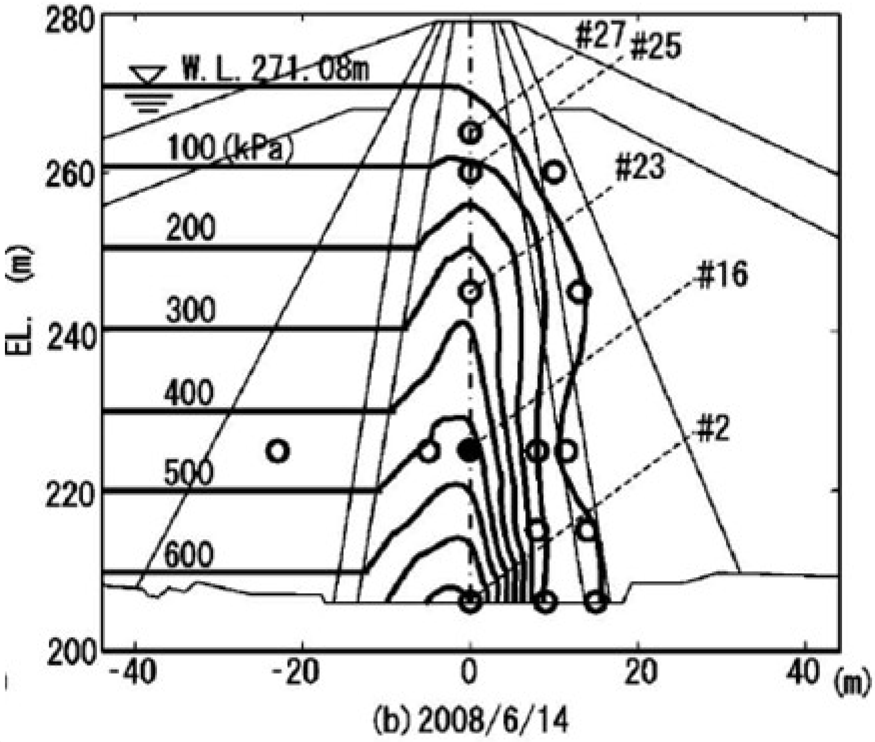
1.7.2 Tests of validation

The tests are the following:

- 1 TEST_RESU carry on the fundamental frequency of resonance of the stopping after the static phase;
- 2 TEST_RESU relate to the maximum ones of acceleration <u>horizontal</u> calculated with the node top and with the node medium (#23) between t=0 and t=7sec;
- 2 TEST_RESU relate to the maximum ones of acceleration <u>vertical</u> calculated with the node top and the node medium (#23) between t=0 and t=7sec;
- 1 TEST_RESU relate to compressing vertical calculated with the node top with t=7sec;
- Lastly, 2 TEST_RESU relate to the average of variation of the pressure interstitial calculated with the node medium (#23), the node located at the 1/3 inferior (#16) and the node located at the base (#2) between t=4 and t=7sec;



(A)



) (b)

Figure 1.7.2-a : Measurements of increase in pressure interstitial after the earthquake (at June 14th, 2008):
(A) in terms of Ru; (b) in terms of isovaleurs of pressure interstitial

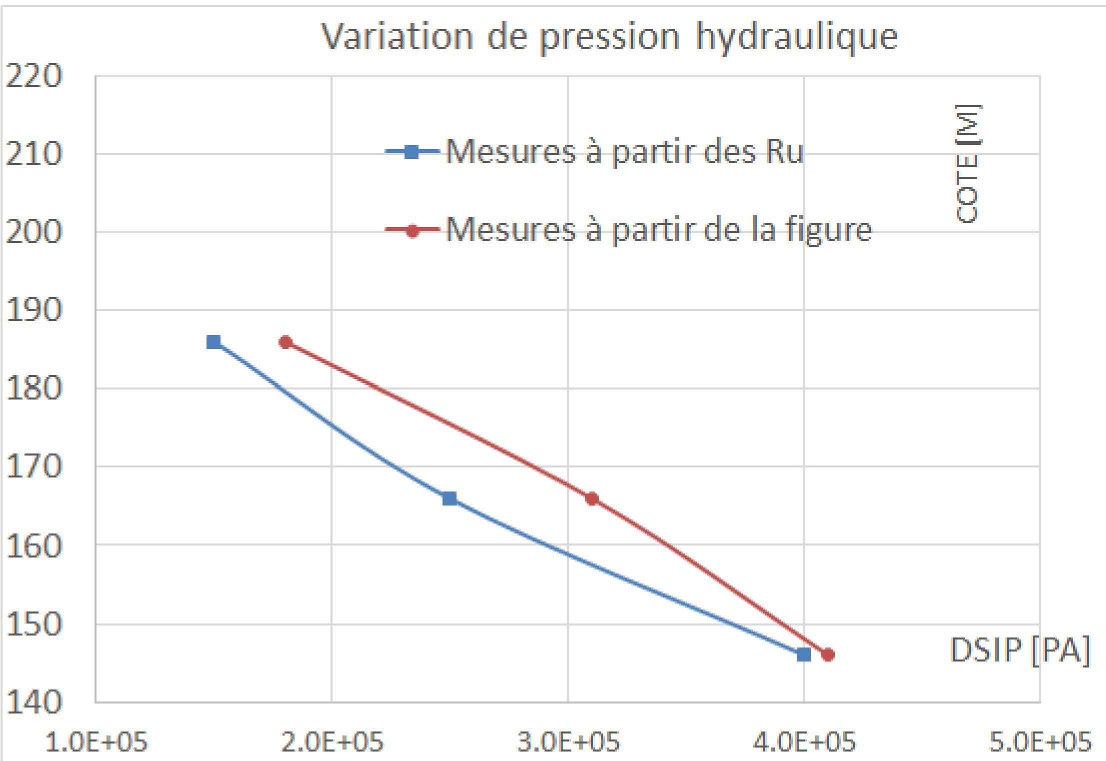


Figure 1.7.2-b : Increase DE pressure interstitial after the earthquake (at June 14th, 2008) calculated starting from Ru and isovaleurs of pressure interstitial Figure 1.7.2-a

2 Modeling A

2.1 Characteristics of modeling

Modeling A is plane and of hydraulic type coupled (DPLAN_HM_IF).

2.2 Calculation of the answer to the seismic request

The calculation of the answer to the seismic request takes place over one duration of 7 second sufficient for the passage of the strong phase. The step of time is of 0,004 secondS that is to say 1750 calculated steps and 875 not filed.

2.3 Features tested

The new algorithms of Hujeux are tested:

- ALGO_INTE = SEMI_EXPLICITE for the static stage;
- ALGO_INTE = BACULE_EXPLICITE for the dynamic stage;

2.4 Sizes and results tested of modeling A

2.4.1 Fundamental frequency of resonance before dynamic calculation

Identification	Reference	Tolerance
$f_0 \in [2.86-3.125]\, Hertz$	2.9 Hz	2%

Table 2.4.1-1

2.4.2 Values of acceleration maximum horizontal

Identification	Reference	Tolerance
Summit	5.25 m/s^2	15%
#23	5.35 m/s^2	15%

Table 2.4.2-1

2.4.3 Values of acceleration maximum verticale

Identification	Reference	Tolerance
Summit	6.22 m/s^2	40%
#23	4.70 m/s^2	30%

Table 2.4.3-1

2.4.4 Value DU compressing in peak with T = 7 dryness

Identification	Reference	Tolerance
Summit	-0.39 m	50%

Table 2.4.4-1

2.4.5 Values of average pore water pressure between 4 and 7 dryness

Identification	Reference	Tolerance
#23	400 kPa	5%
#16	310 kPa	5%
#2	165 kPa	5%

Table 2.4.5-1

3 Summary of the results of modeling A

One represents in the Figures 3-a with 3-b a comparison compared to the reference solution described to the paragraph **§1.7.1** following calculated solutions :

- profile of compressing to T = 7 dryness along a vertical line passing by the medium of the core (Figure 3-a);
- profile of pore water pressure to T = 7 dryness along a vertical line passing by the medium of the core (Figure 3-b);

One can note that:

- profile of calculated compressing coincide not with that measured. That lets think that the facings are not sufficient rigid and that a better calibration of the law Hujeux is possible ;
- the profile of increase in the water pressures in the core is as for him excel compared to the spindle of the measured values ;

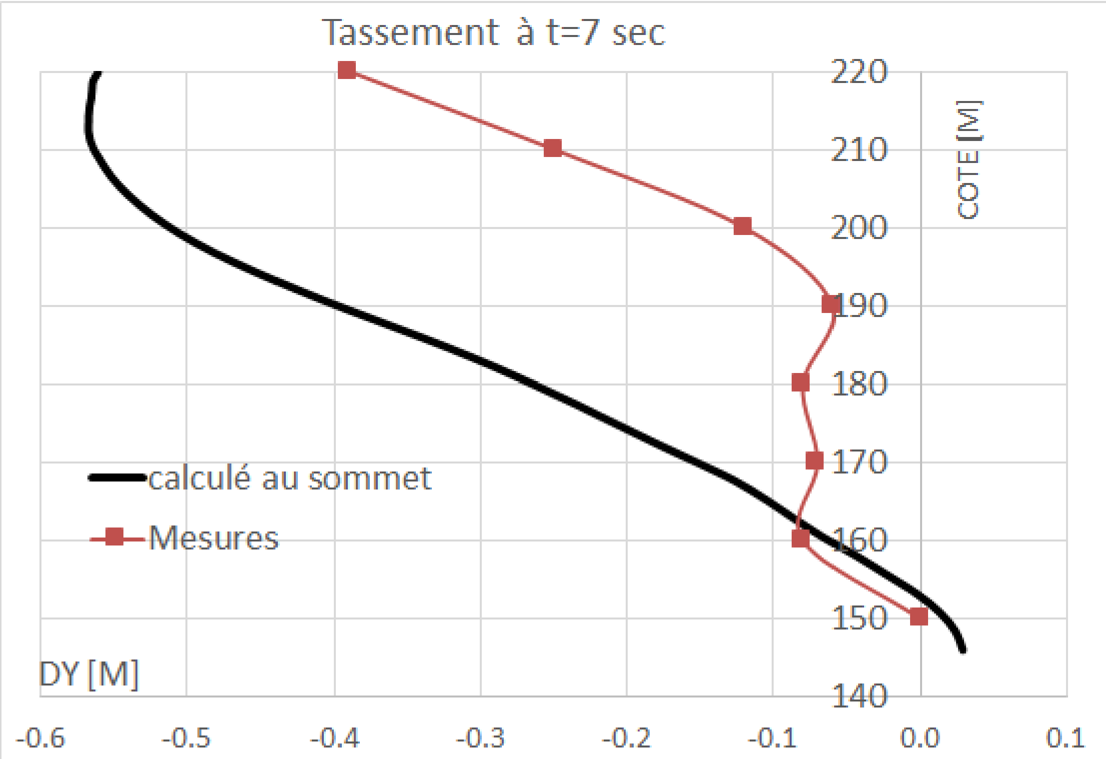


Figure 3-a : Profile of compressing Δu_y **along a vertical cut of the core with T = 7sec**

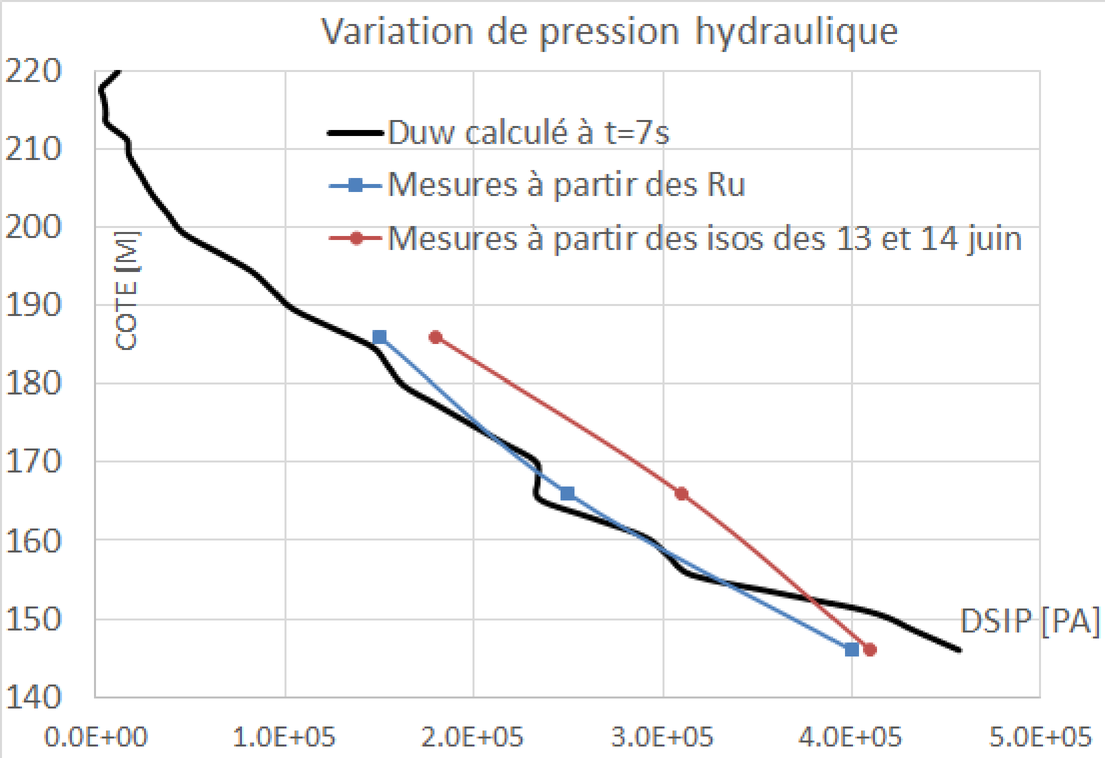


Figure 3-b : Profile of variation of pore water pressure Δu_w
along a vertical cut of the core between T = 0 and T = 7sec

4 Bibliography

[1] Button manufacturer L. "*Hydraulic behavior of the fine grained soils close to saturation. Case of the ground works: coefficient B, instantaneous and differed strains, withdrawal/swelling*", Doctorate of the Institut National Polytechnique of Grenoble, 2007

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