FDLV112 - Calculation of stopping with reserve under seismic request

Summary:

The goal of this case test with modeling A is to validate the features of calculation coupled fluid-structure of stopping with reserve under seismic request by taking of account the assumption of incompressibility, therefore of mass added for reserve like that of forces added to model the movement of training of this reserve due to the seismic excitation. With modeling A, calculation is linear, transitory on modal basis. One also proposes, with this modeling, to validate the calculation of transfer the matrix transfer function and signals reconstituted with the macro-order `CALC_TRANSFERT` [U4.53.51]. In order to accelerate this test one will take account only of the four first second of the seismic signals (this interval contains the essence of the strong phase of the earthquake).

Modeling B contributes to the validation of the chaining *Code_Aster* - MISS3D by the frequential method of coupling in interaction ground-fluid-structure (ISFS). One tests there simply the reading of the impedances of ground and the seismic forces calculated by MISS in ISFS, in order to be able to proceed to a seismic answer by harmonic calculation in *Code_Aster* in ISFS. By taking into account in the coupling part of field of ground, one carries out a modal analysis preliminary then to an analysis harmonic. The modal results correspond to the clean modes of the stopping with added water mass obtained with modeling A and the seismic results of answers constitute a case of nonregression.

Modeling C contributes to the validation of the functionality of modeling of the mass added of fluid per assignment of specific masses to nodes of the interface fluid-structure by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM`. This modeling only requires to take into account the structure of stopping and not the water reserve, nor the ground. The modal results correspond to the clean modes of a stopping with added water mass obtained with modeling A.

Modeling D takes again modeling B with the chaining *Code_Aster* - MISS3D and fact of intervening features of resolution with taking into account or not of the space variability of the incidental seismic field by the operator `DYNA_ISS_VARI` with the keyword `ISSF`. Without variability, one notes results of seismic answers close to those of modeling A.

Modeling E takes again modeling B with the chaining *Code_Aster* - MISS3D in order to test the use of the check-points in the ground in ISFS. One tests in particular the frequential evolution of acceleration into cubes points located under the base of the foundation of the stopping.

Modelings F and G take again modeling B and seismic calculations of modelings A and D with the method Laplace-time for close results.

Modeling H makes it possible to take into account by finite elements (modeling “full-FEM”) all the fields in ISFS: structure, fluid and ground by elements 3D, border external of the ground and bottom of reserve by elements absorbents 2D. One tests results of seismic answers close to those to modelings A and D without variability.

Modeling I validates the use of the loading plane wave in harmonic, by comparison with a resolution with seismic loading inertiaL.

Modeling J L supplementsmodeling C has by validation of the functionality of modeling of the added mass of fluid in 2D by assignment of specific masses by unit thickness with nodes of the interface fluid-structure by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM`. This modeling only requires to take into account the structure of stopping and not the water reserve, nor the ground. The modal results correspond to fréquencbe clean of a stopping obtainedES with one modeling including the water reserve as well as the interface fluid-structure, on condition that increasing the celerity of water in order to represent the assumption of incompressibility.

Modeling K contribute to the validation of the functionality of request by a point source in the ground defined by `SOURCE_SOL` in the call to `CALC_MISS` option `FILE`. One check that one obtains computed values of answer of the same order of magnitude that those of modeling B, which one takes again the model and who carries out inter alia the calculation of the harmonic answer to the horizontal unit incidental force seismic of classical type per plane wave of vertical direction for 2 same frequencies: to 0.1 Hz and the frequency of resonance of 3 Hz.

1 Problem of reference

1.1 Geometry

The complete geometry is made up by the arch dam, of reserve necessary and sufficient to modeling A as well as various interfaces 2D necessary also to modeling B [Figure 1.1-a].

One has 4 possible types of interface necessary to modeling B by the chaining *CodeAster* - MISS3D [bib1] with the frequential method of coupling in interaction ground-fluid-structure (ISFS).:

- the interface ground-structure,
- the interface ground-fluid,
- the interface fluid-structure,
- the ground-free interface.

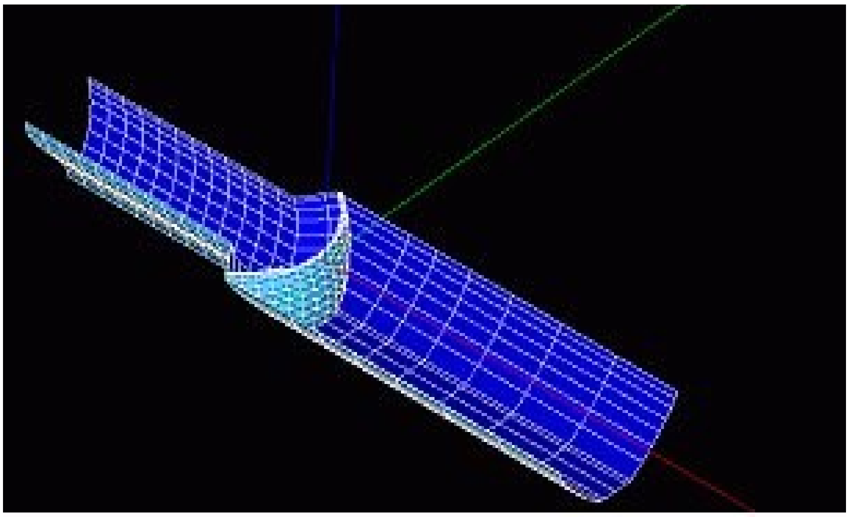

Figure 1.1-a: complete model of the stopping and its reserve with its interfaces

1.2 Properties of materials

The structure
The mechanical characteristics used for the concrete structure are indicated in table 1.2-a. :

E	$36000\ MPa$
ν	0.2
ρ	$2400\ Kg/m^3$

Table 1.2-a: structural features

Ground
The soil mechanics characteristics used only for modeling B are those indicated in table 1.2-b. They correspond to a very hard ground to approach test FDLV112A.

E	$300000\ MPa$
NAKED	0.16
RHO	$2000.\ kg/m^3$
BETA	0.1

Table 1.2-b: characteristics of the ground

Fluid

Celerity	$1500\ m/s$

RHO	$1000. kg/m^3$
BETA	$0.$

Table 1.2-c: characteristics of the fluid

2 Reference solution

2.1 Method of calculating used for the reference solution

The data of this test are drawn from a general study implementing the features from *Code_Aster* to deal with the problems of seismic analysis of the concrete dams [bib2]. For modeling A, the results got were confronted with those obtained with software EACD dedicated to this kind of calculation. However, there no were precise statements of value with this software. This is why one directs oneself towards a digital solution and results of nonregression got exclusively with *Code_Aster*. For modeling B, the results got in modal analysis on the first frequencies are compared with the peaks of resonance of modeling A. nature different from the results makes that one also directs oneself towards a digital solution and results of nonregression got exclusively with *Code_Aster*.

For modeling A and within the framework of the validation of the reconstitution of signals, the reference solution corresponds to the dynamic response of the structure.

2.2 Results of reference

One tests maximum acceleration according to the 3 directions and the spectrum of answer of oscillator corresponding for a damping of 5% to the node medium of the higher edge of the stopping. One also looks at the first peaks of resonance or Eigen frequencies due coupled system.

For the validation of the reconstitution of signals, one carries out beforehand three calculations with an one-way loading according to directions X, there or Z. One tests then the parts real and imaginary obtained for the frequency 1.08520E+01.

2.3 Uncertainty on the solution

Digital solution.

2.4 Bibliographical references

1) D. CLOUTEAU: “Manual of reference of MISS3D – version 6.3 – Power station Searches SA”

2) E CHAMPAIN: “Seismic analysis of the concrete dams with *Code_Aster*“- NT HT - 62/01/023/B

3) I. ZENTNER: “Interaction ground-structure in seismic analysis with space variability” document *Code_Aster* U2.06.12

3 Modeling A

3.1 Characteristics of modeling

Modeling A relates to the incompressible fluids with added masses. One thus models only the stopping and not the reserve of water. The latter is taken into account only in the macro - order `MACRO_MATR_AJOU`.

3.2 Characteristics of the grid

The grid understands 80 meshs of the type PENTA15 and 696 meshs of the type HEXA20.
The stopping is modelled in 3D.

3.3 Boundary conditions and loadings mechanical

The node is blocked $N130$ on the base of the stopping and one imposes on the group of nodes $BARFOND$ who constitutes the bottom of the stopping in contact with the foundation, a uniform displacement in all the directions. The node $N130$ interdependent of all the group $BARFOND$ is subjected to a seismic excitation in the 3 directions of space. The 3 accélérogrammes are represented on the figures [Figure 1.3 - has], [Figure 1.3-b], [Figure 1.3-c] below.

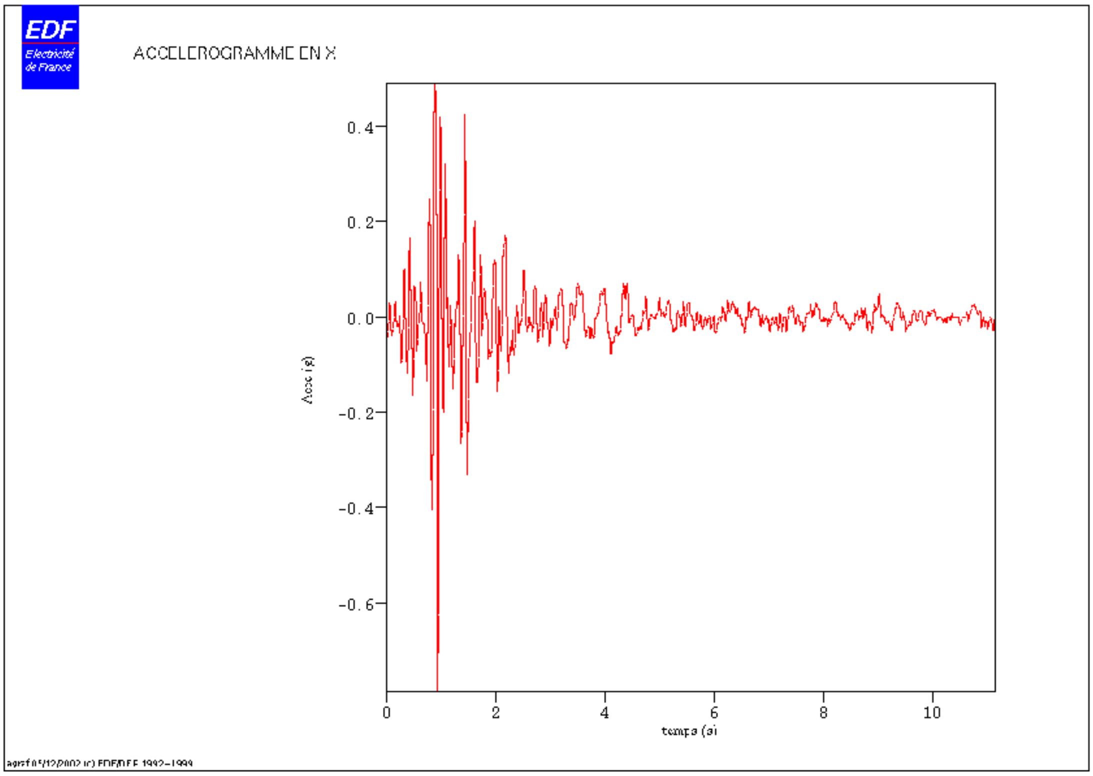

Figure 1.3-a: Acceleration in X

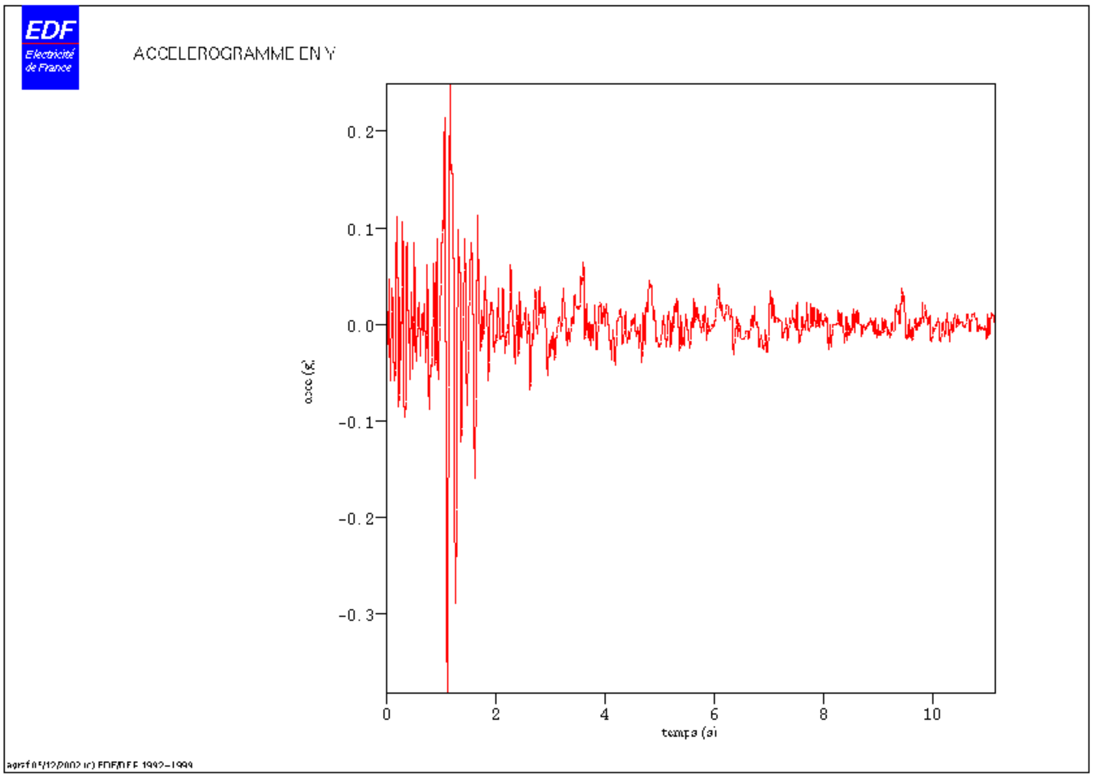

Figure 1.3-b: Acceleration in Y

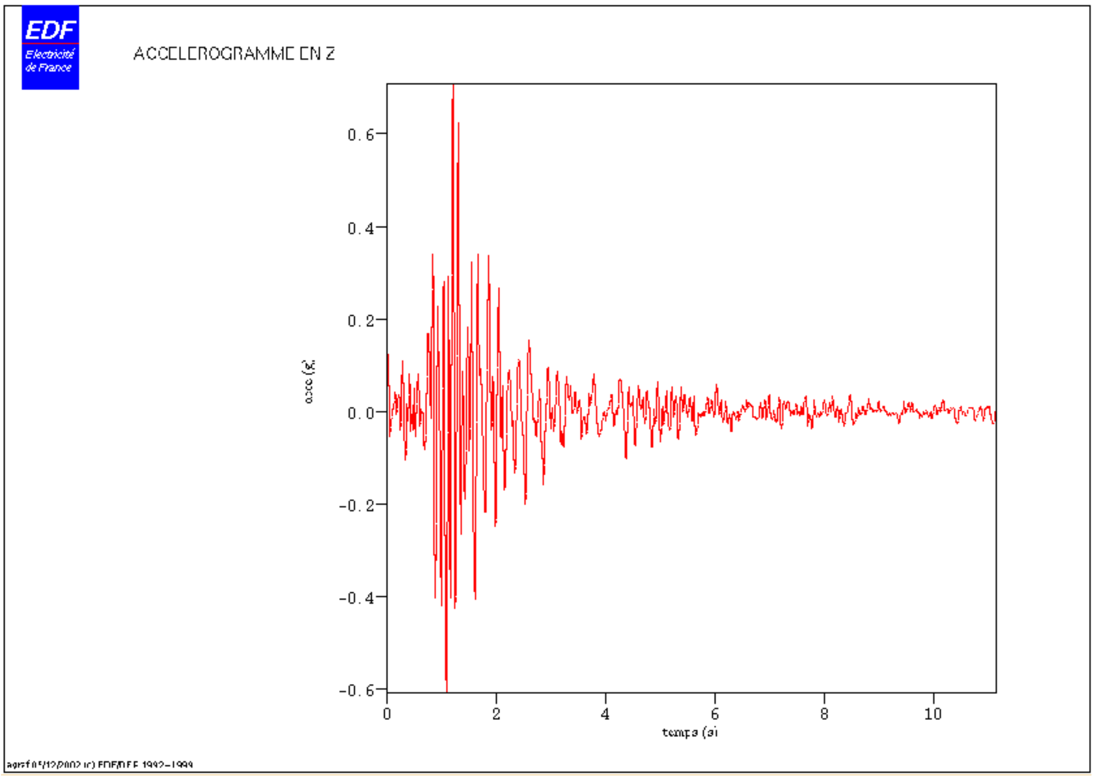

Figure 1.3-c: Acceleration in Z

3.4 Sizes tested

One tests in m/s^2 maximum acceleration according to the 3 directions and the spectrum of answer of oscillator corresponding (SRO) for a damping of 5% with the node $N1909$, medium of the higher edge of the stopping.

For the validation of `CALC_TRANSFERT` [U4.53.51] one compares the value of the harmonic answer to the frequency 1.09720E+01 with the node $N1996$.

4 Results of modeling A

4.1 Values tested

Values tested to validate the features of calculation coupled fluid-structure of stopping:

Identification	**Reference (m/s^2)**
`ACCEX` ($t=1.0\,s$)	5.858849
`SROX` ($f=9.0\,Hz$)	17.57892
`ACCEY` ($t=1.0\,s$)	2.807564
`SROY` ($f=9.0\,Hz$)	9.749478
`ACCEZ` ($t=1.02\,s$)	– 0.77467029
`SROZ` ($f=17.4\,Hz$)	3.805157

Value tested for the validation of `CALC_TRANSFERT`:

Identification	**Reference (m/s^2)**
`ACCEX` ($f=1.09726\text{E}+01\,Hz$	6,26352+8,87646j

4.2 Summary of the results

The got results were confronted with those obtained with software EACD dedicated to this kind of calculation. Although there no were precise statements of value with this software, the study [bib2] concluded with a good agreement with *Code_Aster*. However, one refers in this test with results of nonregression got exclusively with *Code_Aster*.

For the validation of `CALC_TRANSFERT` one tests operation in harmonic, into temporal, for a treatment in relative or absolute reference mark. ON obtains a very good agreement of the results with a very weak tolerance about the precision machine.

5 Modeling B

5.1 Characteristics of modeling

Modeling B contributes to the validation of the chaining *Code_Aster* - MISS3D by the frequential method of coupling in interaction ground-fluid-structure (ISFS).

The software ProMISS3D [bib1] uses the frequential method of coupling to take account of the interaction ground - fluid-structure. This method, based on the dynamic under-structuring, consists in cutting out the field of study in three under-fields:

- ground,
- fluid,
- the structure.

It results 4 possible types of interface from them:

- the interface ground-structure,
- the interface ground-fluid,
- the interface fluid-structure,
- the ground-free interface.

Modeling B by *Code_Aster* only require to take into account the structure of stopping and not the water reserve, nor the ground. It is enough to define their different interfaces in 2D.

5.2 Characteristics of the grid

The use of the chaining *Code_Aster* - ProMISS3D requires to only net:

- the stopping arches in 3D,
- the various interfaces in 2D which are: ground on the surface, the surface of ground in contact with the bottom of reserve, the foundation of the stopping in contact with the ground, the surface of the stopping in contact with reserve.

Grid provided to *Code_Aster* on the whole understands 1745 nodes and the following elements:

- Voluminal grid of the structure of stopping of 625 elements tetrahedrons TETRA10 in the group $STRVOU$,
- Grid of the interface ground-structure including 80 surface elements QUAD8 and TRIA6 in the group $ISOLSTR$. This group of meshs must be directed with its directed normal towards the ground,
- Grid of the interface fluid-structure including 142 surface elements QUAD8 and TRIA6 in the group $IFLUSTR$. This group of meshs must be directed with its directed normal towards reserve,
- Grid of the interface fluid-ground including 126 surface elements QUAD8 and TRIA6 in the group $IFLUSOL$. This group of meshs must be directed with its directed normal towards reserve,
- Grid of the free ground including 280 surface elements QUAD8 and TRIA6 in the group $SLIBREM$.

5.3 Boundary conditions and loadings mechanical

One excites the structure in the horizontal direction X with a loading of acceleration imposed on the surface of the ground in harmonic far field $\gamma=\gamma_o \sin\omega t$ of unit module for various pulsations. That returns in *Code_Aster* to impose this loading by means of the keyword `EXCIT_SOL` in `IMPR_MISS_3D`.

One calculates the clean modes on basis blocked by considering a limiting condition of embedding to the interface ground – structure in blocking the node $N316$ at the base of the stopping and while imposing on the group of nodes $ISOLSTR2$ who constitutes the bottom of the stopping in contact with the foundation, a solid condition of connection.

Then, one calculates the static modes of constrained type starting from this limiting condition of embedding by successively imposing a unit displacement of each of the 6 degrees of freedom of node $N316$ of this interface.

5.4 Sizes tested and results

One carries out the calculation of the first Eigen frequencies by integrating the impedance of ground and fluid with that of the field of structure.
One tests in m/s^2 acceleration in the direction X obtained for 2 frequencies with the node $N253$, medium of the higher edge of the stopping.
One finds the first 5 Eigen frequencies of a stopping with added water mass obtained with modeling A around respectively: $3.5\,Hz$, $3.6\,Hz$, $4.9\,Hz$, $6.2\,Hz$, $7.5\,Hz$.

5.5 Summary of the results

The modal results correspond to the clean modes of a stopping with added water mass obtained with modeling A and the seismic results of answers constitute a case of nonregression.

6 Modeling C

6.1 Characteristics of modeling and the grid

Modeling C contributes to the validation of the functionality of modeling of the mass added of fluid per assignment of specific masses to nodes of the interface fluid-structure by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM`.
Modeling C by *Code_Aster* only require to take into account the structure of stopping and not the water reserve, nor the ground. It is enough to define them interfaces ground-structure and fluid-structure.

Grid provided to *Code_Aster* is exactly the same one as that of modeling B but one takes into account in modeling only the following parts :

- The stopping arches in 3D, who is based on the voluminal grid of the structure of stopping of 625 elements tetrahedrons TETRA10 in the group $STRVOU$,
- The interface ground-structure whose grid understands 80 surface elements QUAD8 and TRIA6 in the group $ISOLSTR$,
- The interface fluid-structure whose grid understands 142 surface elements QUAD8 and TRIA6 in the group $IFLUSTR$.

6.2 Boundary conditions and loadings mechanical

One calculates the clean modes on basis blocked by considering a limiting condition of embedding to the interface ground-structure in blocking the group of nodes $ISOLSTR2$ who constitutes the bottom of the stopping in contact with the foundation. One affects then characteristics of specific mass on the interface fluid-structure consisted the group $IFLUSTR$ by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM` .

6.3 Sizes tested and results

One carries out the calculation of the first Eigen frequencies.
One finds the first 4 Eigen frequencies of a stopping obtained with modelings A and B around respectively: $3.5\,Hz$, $3.6\,Hz$, $4.9\,Hz$, $6.1\,Hz$.

6.4 Summary of the results

The modal results correspond to the clean modes of a stopping with added water mass obtained with modeling A and confirmed by modeling B with chaining *Code_Aster* - MISS3D by the frequential method of coupling.

7 Modeling D

7.1 Characteristics of modeling

Modeling D, like modeling B, contributes to the validation of the chaining *Code_Aster* - MISS3D by the frequential method of coupling in interaction ground-fluid-structure (ISFS).
Moreover, it also utilizes the features of resolution with taking into account of the space variability of the incidental seismic field by the operator `DYNA_ISS_VARI` [bib3] with the keyword `ISSF`.
Modeling D, like modeling B, only requires to take into account the structure of stopping and not the water reserve, nor the ground. It is enough to define their different interfaces in 2D.

7.2 Characteristics of the grid

The use of the chaining *Code_Aster* - ProMISS3D requires to only net:

- the stopping arches in 3D,
- the various interfaces in 2D which are: ground on the surface, the surface of ground in contact with the bottom of reserve, the foundation of the stopping in contact with the ground, the surface of the stopping in contact with reserve.

Grid provided to *Code_Aster* on the whole understands 1745 nodes and the following elements:

- Voluminal grid of the structure of stopping of 625 elements tetrahedrons TETRA10 in the group $STRVOU$,
- Grid of the interface ground-structure including 80 surface elements QUAD8 and TRIA6 in the group $ISOLSTR$. This group of meshs must be directed with its directed normal towards the ground,
- Grid of the interface fluid-structure including 142 surface elements QUAD8 and TRIA6 in the group $IFLUSTR$. This group of meshs must be directed with its directed normal towards reserve,
- Grid of the interface fluid-ground including 126 surface elements QUAD8 and TRIA6 in the group $IFLUSOL$. This group of meshs must be directed with its directed normal towards reserve,
- Grid of the free ground including 280 surface elements QUAD8 and TRIA6 in the group $SLIBREM$.

7.3 Boundary conditions and loadings mechanical

One excites the structure in the horizontal direction X with a loading of acceleration imposed on the surface of the ground in far field.
The node $N316$ interdependent of all the group $ISOLSTR2$ is thus subjected to the seismic excitation in the form of imposed acceleration. The accélérogramme is the same one as that used in modeling A and is represented on the figure [Figure 1.3 - has].
One calculates the clean modes on basis blocked by considering a limiting condition of embedding to the interface ground – structure in blocking the node $N316$ at the base of the stopping and while imposing on the group of nodes $ISOLSTR2$ who constitutes the bottom of the stopping in contact with the foundation, a solid condition of connection.
Then, one calculates the static modes of constrained type starting from this limiting condition of embedding by successively imposing a unit displacement of each of the 6 degrees of freedom of node $N316$ of this interface.

7.4 Sizes tested and results

One proceeds to 2 resolutions with the operator `DYNA_ISS_VARI`, one with a parameter of space variability `PARA_ALPHA`=0 equivalent with an answer without taking into account of the space variability and the other with a parameter of space variability `PARA_ALPHA`=0.5.
For these 2 results, one tests in m/s^2 maximum acceleration in the direction X obtained with the node $N253$, medium of the higher edge of the stopping, at the same time on the temporal

accélérogramme like on the spectrum of answer of oscillator corresponding (SRO) for a damping of 5%.

For calculation without space variability, one finds results close to those of modeling A. the results of maximum acceleration in the direction X obtained with the node $N253$ with or without space variability are synthesized on the table below:

Without Variability	**Acceleration (m/s^2)**
ACCEX ($t=1.0s$)	4.88
SROX ($f=10.7Hz$)	17.40
With Variability	**Acceleration (m/s^2)**
ACCEX ($t=1.0s$)	3.75
SROX ($f=10,7Hz$)	13.72

One also proceeds to 2 spectral resolutions with the operator `DYNA_ISS_VARI`, one with a parameter of space variability `PARA_ALPHA`=0 equivalent with an answer without taking into account of the space variability and the other with a parameter of space variability `PARA_ALPHA`=0.5.
For these 2 results, one tests the spectral concentration of answer (DSP) in the direction X obtained with the node $N253$, medium of the higher edge of the stopping.

One finds the same report ($0{,}77$), here high with the square, which one had between the answers of spectrum of answer of oscillator (SRO), with that obtained between the answers of spectral concentration of answer (DSP) calculations with or without space variability at the frequency $f=10{,}7Hz$ who are synthesized on the table below:

Without Variability	**Acceleration**
DSPX ($f=10.7Hz$)	43,3
With Variability	**Acceleration**
DSPX ($f=10,7Hz$)	25,79

7.5 Summary of the results

The seismic results of answers constitute a case of nonregression but one can say that those obtained without seismic space variability correspond to those of a stopping with added water mass obtained with modeling A. the results of seismic answers with space variability present compared to the case without variability a profit of an order of magnitude expected from approximately 25%.

8 Modeling E

8.1 Characteristics of modeling

Modeling D is identical to modeling B.
It is only a question of testing the seismic answer to a unit acceleration into cubes check-points located without the ground and defined by the discrete specific ones of type `DIS_T` .

8.2 Characteristics of the grid

They are also identical to those of modeling B. One adds to it only 3 discrete specific located respectively at the dimensions $-72\,m$ (foundation bases), $-80\,m$ and $-100\,m$ but at a distance from $200\,m$ center of the foundation.

8.3 Boundary conditions and loadings mechanical

One proceeds exactly in the same way that with modeling B. One defines moreover the group of meshs of the check-points which one informs in the keyword `GROUP_MA_CONTROL` of the operator `CALC_MISS`.
One excites the structure in the horizontal direction Z with a loading of acceleration imposed unit harmonic, or transitory sinusoidal unit for one period of $0{,}2\,s$ with a frequency $5.0\,Hz$, on the surface of the ground in far field.
It is necessary compared to modeling B, to add in the description of the ground by `DEFI_SOL_MISS` 2 layers with the dimensions of the 2 check-points under the foundation, where one positions at the same time a source and a receiver.

8.4 Sizes tested and results

One proceeds to a call of the operator `CALC_MISS`, with the option `TYPE_RESU=TABLE_CONTROL`.
The sizes tested are primarily the harmonic answers in each check-point to the frequency $5.0\,Hz$ who represent values of not-regression. The results are summarized on the table below:

Not control	Acceleration (m/s^2)
P1	9.84140E-01+4.96964E-03j
P2	9.61780E-01+2,61026E-02j
P3	9.51352E-01+2,63920E-02j

8.5 Summary of the results

These values are identical in module to those obtained for the moment $0{,}05\,s$ quarter of period respectively like transitory answers to unit sinusoidal transitory acceleration imposed with a frequency $5.0\,Hz$.

9 Modeling F

9.1 Characteristics of modeling and the grid

One uses for this modeling exactly the same grid and the same model at the beginning as those of modeling B, with the chaining *Code_Aster* - MISS3D by the frequential method of coupling in interaction ground-fluid-structure (ISFS). In the model, one adds a super - element including a macro - element obtained starting from the temporal evolution of the impedance of the fields of joined together ground and fluid obtained using the chain *Code_Aster* – MISS3D by the option `TYPE_RESU=' FICHIER_TEMPS'` of `CALC_MISS` with the option '`ISFS=' OUI'`, then integrated by a method of Laplace-time. This macro - element represents the behavior of the fields of joined together ground and fluid broken up on a basis of 60 modes representative of the flexibility of the foundation to the interface ground-structure. To optimize the computing time of the temporal impedances, one introduced into `CALC_MISS` for the option `TYPE_RESU=' FICHIER_TEMPS'` parameters of interpolation: `PCENT_FREQ_CALCUL=0` and `FACTEUR_INTERPOL=7` .

9.2 Boundary conditions and loadings mechanical

The connection between the model of joined together ground and fluid and the structure is defined by a load of connection of the type `LIAISON_INTERF` ensuring a relation between the modal coordinates of the 30 modes of interface and the physical degrees of freedom of the interfaces ground-structure and fluid-structure joined together in the same group of nodes $NISFS$. The answer to the seismic request is obtained by a transitory dynamic calculation by means of the operator `DYNA_NON_LINE`. The internal load of force of ground is introduced by only one occurrence of the keyword `EXCIT` with the keyword `FORCE_SOL` in a dynamic resolution in absolute reference mark. The seismic load is calculated in the form of mechanical load by `CALC_MISS` with the option `TYPE_RESU=' CHARGE'` starting from the temporal integration of the seismic forces contained in the file of which the logical unit is specified by the keyword `UNITE_RESU_FORC`. It is combined with the double temporal integration of acceleration in the form of displacement imposed behind the keyword `FONC_SIGNAL`. The place of interface ground-fluid-structure is defined explicitly by means of the keyword `NOEUD_AFFE` : it is made up by the data of 5 fictitious nodes playing the part of 30 modal coordinates. There is a seismic load corresponding to the component according to X. This seismic load is also introduced like an occurrence of the keyword `EXCIT` of the operator `DYNA_NON_LINE`. One uses for this load the taking into account of variability with the same parameters as in modeling D. the acceleration imposed on the surface of the ground in far field is that definite on [Figure 1.3 - has].
The size of the window of calculation is of $1,3s$ by step of $0,01s$ sufficient to collect the peaks of transitory answer and SRO in acceleration in the direction X with the node $N253$, medium of the higher edge of the stopping. One uses digital diagram HHT with the parameter $alpha=-0,05$ and 2 options: `MODI_EQUI=' NON'` until $0,15s$ and `MODI_EQUI=' OUI'` beyond.

9.3 Sizes tested and results

One tests in m/s^2 maximum acceleration in the direction X obtained with the node $N253$, medium of the higher edge of the stopping, at the same time on the temporal accélérogramme like on the spectrum of answer of oscillator corresponding (SRO) for a damping of 5%.
The results of maximum acceleration are synthesized on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` ($t=1.0s$)	3.47
`SROX` ($f=10.7Hz$)	12.19

9.4 Summary of the results

One then finds results close to those of modeling D with space variability which constitute the reference `AUTRE_ASTER` .

10 Modeling G

10.1 Characteristics of the grid

One uses for this modeling almost the same grid as that of modeling F, indeed, only nodes NO* as well as the corresponding meshs were unobtrusive. These nodes correspond to the fictitious meshs necessary to make dynamic reduction in non-linear analyses. In particular, one is interested in this modeling in calculations of interaction ground-fluid-structure (ISFS) realized with the chaining *Code_Aster*- MISS3D.

10.2 Characteristics of modeling

This modeling reproduces that of modeling F by means of the macro-order `PRE_SEISME_NONL`. Thus, this macro-order is tested in the phase of the calculation of the modal base of ISFS (option `PRE_CALC_MISS`) and in the phase of the dynamic reduction using the macronutrients (option `POST_CALC_MISS`).
For each phase, the characteristics of the model to be built are to be defined:
– First stage: one defines a model of stopping which will be used for calculation of the modes, i.e. a model resting on a carpet of springs of ground for the calculation of the modes pulled by reserve (fluid) and on a discrete element for the calculation of the modes of rigid body of the foundation.
– Second phase: one defines the model of stopping on which one wishes to evaluate the non-linear answer directly.

10.3 Sizes tested and results

One test in m/s^2 maximum acceleration in the direction X obtained with the node $N253$, medium of the higher edge of the stopping, at the same time on the temporal accélérogramme like on the spectrum of answer of oscillator corresponding (SRO) for a damping of 5%.
The results of maximum acceleration are synthesized on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` ($t=1.0s$)	4.68
`SROX` ($f=10.7Hz$)	14.93

10.4 Summary of the results

One then finds results close to those to the modeling A and D without space variability which constitute the reference `AUTRE_ASTER` .

11 Modeling H

11.1 Characteristics of modeling

Modeling H allows to take into account by finite elements (modeling “full-FEM”) all the fields in ISFS: structure, fluid and ground by elements 3D, respective modelings `3D` and `3D_FLUIDE`, and border external of the ground and bottom of reserve by elements absorbents 2D, respective modelings `3D_ABSO` and `3D_FLUI_ABSO`.

The dynamic resolution takes place completely by Code_Aster by means of the linear operator of calculation `DYNA_VIBRA` by a harmonic calculation on modal basis by taking into account a seismic loading in the horizontal direction X with an excitation of type mono-support calculated by means of the operator `CALC_CHAR_SEISME` .

11.2 Characteristics of the grid

The grid of the model understands, in addition to the structure of stopping itself, of the voluminal fields of ground and fluid, like their surface borders.

In particular (cf Appears 11.2-a):

Grid provided to *Code_Aster* on the whole understands 1745 nodes and the following elements:

- Voluminal grid of the structure of stopping of 84 elements PENTA15 and HEXA20 in the group $STRVOU$,
- Voluminal grid of the fluid field of 532 elements PENTA15 and HEXA20 in the group $FLUIDE$,
- Voluminal grid of the ground field out of riprap of 1260 elements PENTA15 and HEXA20 in the group $VOLSOL$,
- Surface grid of the border absorbing elastic outside the ground including 540 elements QUAD8 and TRIA6 in the group $TH-SOL$.
- Surface grid of the border absorbing fluid in bottom of reserve including 76 surface elements QUAD8 and TRIA6 in the group $IFLUSOLF$.

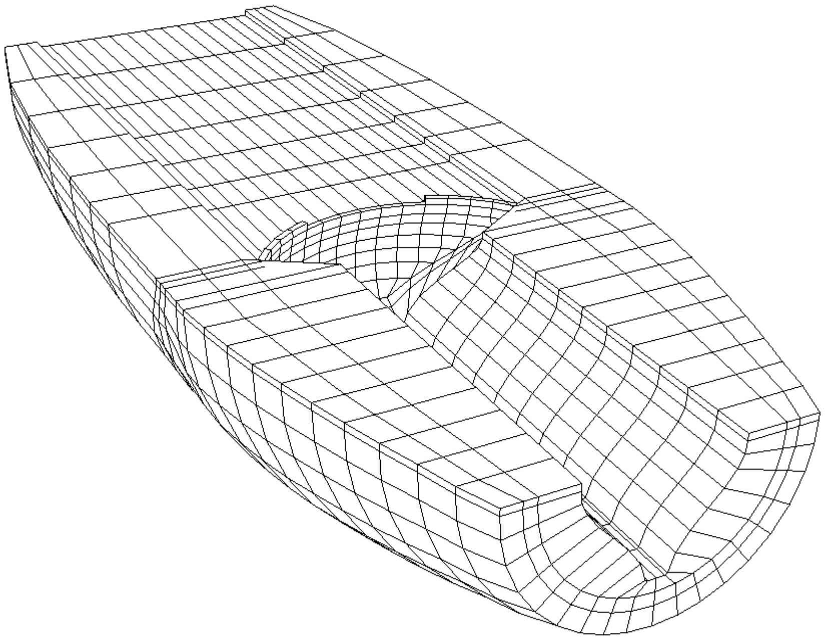

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Figure 11.2-a: complete model “full-FEM” of the stopping, the ground and its reserve

11.3 Boundary conditions and loadings mechanical

One excites the structure in the horizontal direction X with a loading of acceleration imposed on the surface of the ground in harmonic far field $\gamma=\gamma_o \sin\omega t$ of unit module for various pulsations. To impose this seismic loading, the node is blocked $NO6288$ on the base of the field of ground and one imposes on the group of nodes TH_SOL at the border of the ground a solid condition of connection. The vector of loading is calculated then by the operator `CALC_CHAR_SEISME` with the option of type mono-support.
The clean modes are calculated with this condition supplemented by static modes of constrained type starting from this condition limits embedding. The resolution takes place then in harmonic on this complete basis of Ritz.

11.4 Sizes tested and results

One test in m/s^2 maximum acceleration in the direction X obtained with the node $NO10027$, medium of the higher edge of the stopping, at the same time on the temporal accélérogramme like on the spectrum of answer of oscillator corresponding (SRO) for a damping of 5%.
The results of maximum acceleration are synthesized on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` ($t=1.0s$)	5.04
`SROX` ($f=10.7Hz$)	19.31

11.5 Summary of the results

One then finds results close to those of modeling D without space variability which constitute the reference `AUTRE_ASTER` .

12 Modeling I

12.1 Characteristics of modeling

One takes again here the modeling H which allows to take into account by finite elements (modeling "full-FEM") all the fields in ISFS: structure, fluid and ground by elements 3D, respective modelings `3D` and `3D_FLUIDE`, and border external of the ground and bottom of reserve by elements absorbents 2D, respective modelings `3D_ABSO` and `3D_FLUI_ABSO`.
For modeling I the dynamic resolution takes place completely with the linear operator of calculation `DYNA_VIBRA` by a harmonic calculation on physical basis. The seismic loading used in this calculation corresponds to the transitory evolution of a plane wave of type SV (horizontal direction X), with vertical incidence, calculated by means of the operator `AFFE_CHAR_MECA_F` who thereafter, is evaluated in the frequential field according to a particular approach using the operator `REST_SPEC_TEMP`.
For a harmonic resolution, there is the possibility of representing the damping of the structure of two ways: maybe in the form of damping of Rayleigh which will be assembled in the matrix `AMOR_MECA` , that is to say in the form of damping hysteretic whose assembly will require the constitution of the matrix and the keyword `RIGI_MECA_HYST` . It is this last form which is selected in the case test, the results of the other form being used as reference `AUTRE_ASTER` .
One also considers a dependence of the Young modulus of the material concrete with a variable of order dependent on the geometry of the grid.

12.2 Characteristics of the grid

The grid of modeling H is also used. Nevertheless, Dthem groups of nodes $GNOB$ and $GNOH$ corresponding respectively to a node in bottom and at the top of stopping were added to simplify postprocessing.

12.3 Boundary conditions and loadings mechanical

Calculation being harmonic, the loading in the form of plane wave SV (direction X) calculated using `AFFE_CHAR_MECA_F` in the temporal field must be transformed in the frequential field.

With this intention, a frequential loop must be initially installation to constitute an evolution of the type `DYNA_TRANS` with the total vectors of second member containing the contribution of all loadings (P, SV, HS). Then, it is by means of the operator `REST_SPEC_TEMP` that evolution of the type `DYNA_TRANS` is transformed in a harmonic evolution which will feed the second member of a calculation `DYNA_VIBRA`. listE of frequencies of calculation must be coherent with the FFT of the seismic signals. Finally, one can re-use the operator `REST_SPEC_TEMP` to bring back the result of `DYNA_VIBRA` in the temporal field.

In the same way, to be able to take account of the acoustic impedances (voluminal product bulk and the celerity of the waves) defined in the level of the border external of the fluid field ($IFLUSOLF$), the particular calculation of a load assembled (with the option `IMPE_FACE`) as well as the information of the keyword `MATR_IMPE_PHI` in the operator of calculation `DYNA_VIBRA` had to be realized.

12.4 Sizes tested and results

For a calculation of duration $T_{FIN}=0{,}32\,s$, one tests in m/s^2 maximum acceleration in the direction X obtained with the node $GNOH$, medium of the higher edge of the stopping, at the same time on the temporal accélérogramme like on the spectrum of answer of oscillator corresponding (SRO) for a damping of 5%. One compared to results got with the same model but with an inertial seismic loading. The results of maximum acceleration are synthesized on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` ($t=0.27\,s$)	1.26
`SROX` ($f=10.7\,Hz$)	3.41

The duration of calculation is skeletal in order to give the opportunity of evaluating the same sizes on a longer calculation. In particular, for one duration of $T_{FIN}=20{,}48\,s$ the results of maximum acceleration are provided on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` ($t=1.02\,s$)	4.52
`SROX` ($f=10.7\,Hz$)	17.40

13 Modeling J

13.1 Characteristics of modeling and the grid

Modeling J L supplements modeling C has by validation of the functionality of modeling of the added mass of fluid in 2D by assignment of specific masses by unit thickness with nodes of the interface fluid-structure by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM`.
This modeling only requires to take into account the structure of stopping and not the water reserve, nor the ground.
Grid 2D model (cf Figure 1 3 . 1 -a) understands, in addition to the structure of stopping itself, of the fields surfacic of ground and fluid, like their borders linéic:

- Grid provided to *Code_Aster* on the whole understands 1745 nodes and the following elements:
- Grid surface structure of stopping of 225 elements TRIA3 and QUAD4 in the group $barrage$,
- Grid surfacic of the fluid field of 294 elements TRIA3 and QUAD4 in the group $fluide$,
- Grid surfacic of the ground field out of riprap of 887 elements TRIA3 and QUAD4 in the group $FONDAT$,
- Grid linéithat border absorbing elastic outside the ground including 85 elements SEG2 in the group $FOND$.
- Grid linéithat border absorbing fluid in bottom of reserve including 15 elements SEG2 in the group $infeau$.

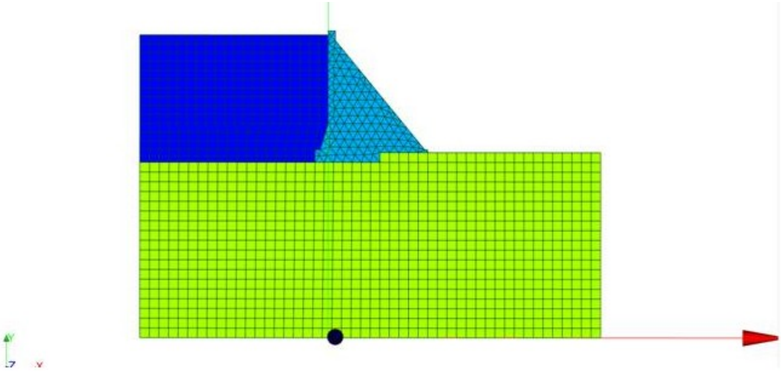

Figure 13.1- has: complete model 2D "full-FEM" of the stopping, the ground and its reserve

13.2 Boundary conditions and loadings mechanical

One calculates the clean modes on basis blocked by considering a limiting condition of embedding to the interface ground-structure in blocking the group of nodes $FOND$ who constitutes the bottom of the foundation. One affects then characteristics of specific mass on the interface fluid-structure consisted the group $barreau$ by means of the option `MASS_AJOU` of the operator `AFFE_CARA_ELEM`.

13.3 Sizes tested and results

One carries out the calculation of 2 first Eigen frequencies in X and Y .
One obtains respectively: $2.77\,Hz$, $3.57\,Hz$.

13.4 Summary of the results

Results frequential correspond exactly with $0{,}2\%$ near with frequencyS clean of a stopping obtainedES with one modeling including the water reserve as well as the fluid interfacestructure, on condition that increasing the celerity of water in order to represent the assumption of incompressibility.

14 Modeling K

14.1 Characteristics of modeling and the grid

Modeling K contribute to the validation of the functionality of request by a point source in the ground defined by `SOURCE_SOL` in the call to `CALC_MISS` option `FILE`.
Grid provided to *Code_Aster* is exactly the same one as that of modeling B.

14.2 Boundary conditions and loadings mechanical

One excites the structure in the horizontal direction X with a loading of point source catch in a point in the ground close to the higher edge of the stopping in the form of an imposed displacement $u=u_o \sin \omega t$ of unit module for various pulsations.
The seismic force obtained correspondent with one mouv ement unit imposed is made homogeneous with a force imposed by product by the value of horizontal impedance $Kx=3.6\mathrm{E}13\ N/m$.
One calculates the clean modes on basis blocked by considering a limiting condition of embedding to the interface ground – structure in blocking the node $N316$ at the base of the stopping and while imposing on the group of nodes $ISOLSTR2$ who constitutes the bottom of the stopping in contact with the foundation, a solid condition of connection.
Then, one calculates the static modes of constrained type starting from this limiting condition of embedding by successively imposing a unit displacement of each of the 6 degrees of freedom of the node $N316$ of this interface.

14.3 Sizes tested and results

One tests in m/s^2 maximum acceleration in the direction X obtained with the node $N253$, medium of the higher edge of the stopping, for the quasi-static answer and the frequency of resonance from 3 Hz.
The results of maximum acceleration are synthesized on the table below:

Calculation Laplace-time	**Acceleration (m/s^2)**
`ACCEX` $f=0,1\ Hz$ `()`	1.047
`ACCEX` ($f=3.0\ Hz$)	4.057

14.4 Summary of the results

One computed values of the same order of magnitude obtains that those of the modeling B which carries out inter alia the calculation of the harmonic answer to the horizontal unit incidental force seismic of classical type per plane wave of vertical direction for 2 same frequencies to 0.1 Hz and the frequency of resonance of 3 Hz.