SDLS118 - Response of a rigid circular foundation to a variable seismic excitation in space

Summary:

This case test makes it possible to validate the calculation of the answer of a rigid shallow foundation subjected to a variable seismic movement in space via the macro one `DYNA_ISS_VARI`. The transfer transfer functions of reference come from results got by Became moth-eaten and Luco [bib2].

Modeling E is a data-processing validation of the taking into account of accélérogrammes in the three directions of space in only one call to `DYNA_ISS_VARI`.

1 Problem of reference

1.1 Geometry

Software MISS3D uses the frequential method of coupling to take account of the interaction ground - structure. This method, based on the dynamic under-structuring, consists in cutting out the field of study in three under-fields which are the ground, the foundation and the structure. One treats here the case of a shallow foundation only (without structure). It is about a circular foundation of ray $R=20\,m$. The geometry that of the foundation is treated in the reference [bib1] and represented to paragraph 3.

1.2 Properties of material

The ground corresponds to a semi-infinite homogeneous medium whose characteristics are summarized in the table hereafter:

Sleep	**Thickness** (m)	$\rho(kg/m^3)$	ν	$E(MPa)$	β
Lay down 1	40.	1875	0.33	1800	0.10
2 sleep	Substratum	1875	0.33	1800	0.10

Table 1.2-1: Soil mechanics characteristics homogeneous

The foundation is considered rigid and without weight.

1.3 Boundary conditions and loadings

The seismic loading consists of a unit excitation in the field of the frequencies. This makes it possible directly to determine the transfer transfer functions (between the seismic excitation and the structural answer). The foundation is regarded as rigid. This results in a solid connection of `GROUP_NO` to erase.

2 Reference solution

2.1 Method of calculating

One uses the function of coherence suggested by Luco and Wong (1986) [bib1]:

where d indicate the distance between two points i and j on the foundation, f is the frequency and c_{app} speed connects propagation on the surface of the wave SH. The parameter α can vary 0.1 with 0.5 according to the case but is generally taken equal to 0.5.

2.2 Sizes and results of reference

Coefficients of covariance obtained by Became moth-eaten and Luco for $\alpha=0.5$ [bib2]:

a_0	A_{11}^{11}	A_{33}^{33}
1.0	0,732	0,730
2.0	0,402	0,416

3.0	0,251	0,270

has$_0$ indicate the nondimensional frequency $a_0=\frac{\omega R}{c}$

For $\alpha=0.0$, one obtains the case without space variability, For this case one knows the solution (analytical). The foundation being rigid without weight, the answer to a unit excitation is equal to 1.0, independently of the frequency of calculation.

2.3 Uncertainties on the solution

Pas d' uncertainties.

2.4 Bibliographical references

[bib1] Luco J.E and Wong H.L.: *Answer of has rigid foundation to has spatially random ground motion* . Earthquake Engrg. Struct. Dyn. 14.1986, pp.891-908.

[bib2] Luco J.E and Mita A.: *Answer of has circular foundation to spatially random ground motion*. J. Engrg.Mech. 113.1987, pp.1-15.

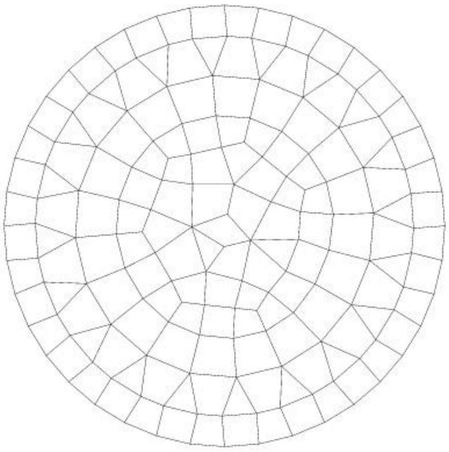
3 Modeling A

3.1 Characteristics of modeling

The characteristics used and the grid are those deduced from the data of paragraph 1. One calculated the harmonic answer and the transfer transfer functions for the reduced frequencies $a_0=1,2,3$ (where $a_0=\frac{\omega R}{c}$). The results got by Became moth-eaten and Luco for these reduced frequencies are presented in the reference [bib2].

3.2 Characteristics of the grid

The grid of the circular foundation is represented below (see §1.1):



3.3 Sizes tested and results

For the case with space variability, one chooses $\alpha=0.5$ and one tests compared to the results of the literature (`SOURCE_EXTERNE`) with a tolerance of 10%.

Results got with `DYNA_ISS_VARI` for $\alpha=0.5$ and :

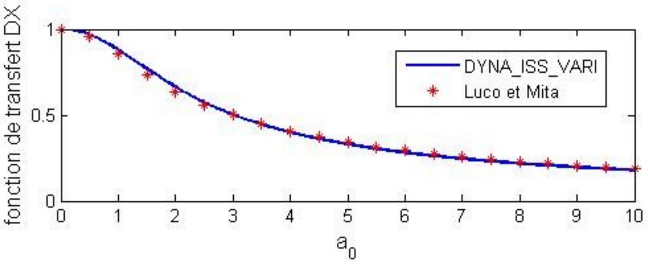
a_0	A_{11}^{11}	A_{33}^{33}
1.0	0,767	0,767
2.0	0,437	0,437
3.0	0,251	0,251

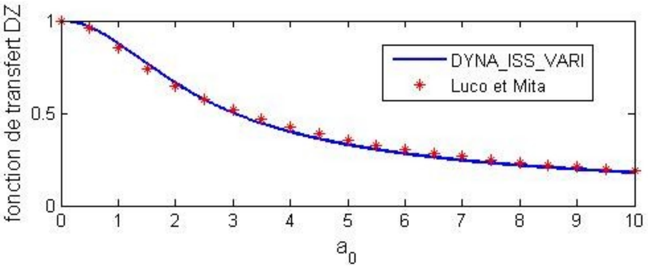
For recall, results of reference [bib2], to see too §2.2:

a_0	A_{11}^{11}	A_{33}^{33}
1.0	0,732	0,730
2.0	0,402	0,416
3.0	0,251	0,270

One makes a test in addition of `NON_REGESSION` for the computed values by `DYNA_ISS_VARI` with a tolerance of $0{,}1\%$ (value by default).

Comparison of the transfer transfer functions $\sqrt{A_{ii}^{jj}}$ obtained with `DYNA_ISS_VARI` and with Became moth-eaten and Luco:





For the case $\alpha=0.0$, one tests the answer after projection on physical coordinates. The foundation being rigid and without mass, all the nodes undergo the same displacement which is equal to 1.0 in direction x for an excitation in direction x.

$$K_S X = K_S X_0$$

K_S is the matrix of modal impedance, X the modal answer and $X_0=(1.,0.,0.,0.,0.,0.)$ for a seismic excitation in direction x and $X_0=(0.,0.,1.,0.,0.,0.)$ for a vertical earthquake.

a_0	A_{11}^{11}	A_{33}^{33}
1.0,	1.0	1.0
2.0	1.0	1.0
3.0	1.0	1.0

With a projection *via* `REST_SPEC_PHYS`, the result is got:

a_0	`SPEC N11 ‘DX’`	`SPEC N11 ‘DZ’`
1.0	1.00527E+00	1.03014E+00

A test of the type is carried out `ANALYTICAL` with a tolerance of 1% for ‘`DX'` and 10% for ‘`DZ'`.

4 Modeling B

4.1 Characteristics of modeling

The characteristics used and the grid are those deduced from the data of paragraph 1. The grid is the same one as for modeling A.

One calculated the temporal answer to the point $N11$ and determines the corresponding spectrum of answer. The transfer transfer function being equal to 1 for the case without space variability, the temporal answer is equal to the entry signal. If one takes account of space variability, then the answer is modified.

In this modeling, one tests the various functions of coherence available in code_aster (`MITA_LUCO`, `ABRAHAMSON`, `ABRA_ROCHER`, `ABRA_SOLMOYEN`).

4.2 Characteristics of the grid

The characteristics are those of modeling A.

4.3 Sizes tested and results

4.3.1 Function of coherence of Became moth-eaten & Luco

It is checked that, for $\alpha=0.0$, the answer in acceleration is equal to the accélérogramme as starter of calculation (it is pointed out that the transfer transfer function is worth 1 and that the function is rigid for this case of study). The answer is determined $q(t)$ in '`DX`'at the point $N11$ for an excitation $a(t)$ in '`DX`'. One calculates the error like the standard deviation of the difference (residue) between the signal and the answer. This is done for the case where the transfer transfer function is calculated for all the points (discretization of the accélérogramme) and for the case where the user informs `FREQ_PAS`, `FREQ_FIN`. In this last case, `DYNA_ISS_VARI` interpolate computed values to determine the temporal answer due to the excitation by the accélérogramme.
One also adds to this case a test of `NON_REGRESSION` for the value of maximum displacement positive E`DX`'at the point $N11$ who corresponds to the center of the foundation.

type of test	value of reference	tolerance (ABS.)
`ANALYTICAL`	0.0	0.01

In the same way, for $\alpha=0.0$, the oscillating spectrum of answer (SRO) of the answer in calculated acceleration must be equal to the SRO of the accélérogramme as starter. Thus, one tests the error, namely the difference between these two SRO. One compares evaluates in particular the maximum difference between the two SRO and the standard deviation of the error

type of test	value	value of reference	tolerance (ABS.)
`ANALYTICAL`	`MAX`	0.0	0.01
`ANALYTICAL`	`STANDARD DEVIATION`	0.0	0,001

For the case with space variability, the values $\alpha=0.7\,, V_s=200\ m/s$ were selected. One consider a temporal seismic excitation in direction '`DX`' data by a accélérogramme corresponding to the Euro spectrum for a rock site (cf, curves red figure below). There is no reference solution (analytical) for this case. Also, one makes a test of `NON_REGRESSION` for the SRO obtained with space variability. Two cases are tested.

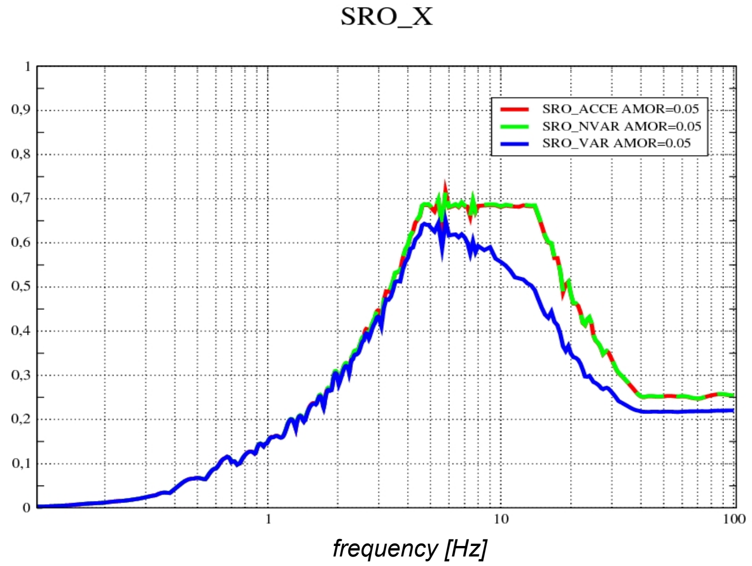
1) `FREQ_FIN` is equal to the cut-off frequency:

type of test	frequency (Hz)	reference SRO (G)	tolerance (%)
`NON_REGRESSION`	10.0	5.34727E-01	$2*10^{-4}$
`NON_REGRESSION`	30.0	2.3855E-01	$2*10^{-3}$

2) `FREQ_FIN` is lower than the cut-off frequency ($35 Hz$ instead of $50 Hz$) and one supplements by zero:

type of test	frequency (Hz)	reference SRO (G)	tolerance (%)
`NON_REGRESSION`	10.0	5.34727E-01	$2*10^{-1}$
`NON_REGRESSION`	30.0	2.3855E-01	$2*10^{-2}$

The spectrum of answer of the accélérogramme (`SRO_ACCE`) and calculated in answer to the point $N11$, without space variability (`SRO_NVAR`) and with space variability (`SRO_VAR`), are shown on the figure below:



Note: For the case test, the step of time of the accélérogramme Euro was multiplied by 2 (0.013672s instead of 0.006836s) in order to accelerate calculations. Also, the SRO calculated in sdls118b, go from 0 *with* $50 Hz$ *and not of* 0 *with* $100 Hz$ *as on the figure above .*

4.3.2 FunctionS of coherence of Abrahamson

One tests the various functions of coherence of Abrahamson available in code_aster (`ABRAHAMSON`, `ABRA_ROCHER`, `ABRA_SOLMOYEN`).

One consider a temporal seismic excitation in direction '`DX`' data by a accelerogramme corresponding to the Euro spectrum for a rock site (cf, curves red figure above). One makes a test of `NON_REGRESSION` for the SRO obtained with space variability.

5 Modeling C

5.1 Characteristics of modeling

The characteristics used and the grid are those deduced from the data of paragraph 1. One calculated the harmonic answer and the transfer transfer functions for the reduced frequencies $a_0=1,2,3$ (where $a_0=\frac{\omega R}{c}$). The results got by Became moth-eaten and Luco for these reduced frequencies are presented in the reference [bib2].

This modeling is used to test the option of interface of the type ' `QUELCONQUE'` keyword `MODE_INTERF` with unspecified modes of foundation different from the modes of rigid body. One will compare his results with those of modeling A.

5.2 Characteristics of the grid

The characteristics are those of modeling A.

5.3 Boundary conditions of modeling

For the representation of the movement of foundation, instead of the modes of rigid body of translation, one uses a base of 30 unspecified modes obtained like clean modes, without conditions of blocking, on carpet of springs established starting from the static impedances of ground for the ground defined in §1,2.

One thus takes as values of total rigidities to distribute under the foundation with the option `RIGI_PARASOL` of `AFFE_CARA_ELEM` :

$$KX=KY=6.36E10,\ KZ=8.02E10,\ KRX=KRY=2.07E13,\ KRZ=2.70E13$$

5.4 Sizes tested and results

For the case $\alpha=0.0$, one tests obligatorily the answer after projection on physical coordinates because, unlike modeling A, the modal coordinates do not coincide with the physical coordinates. The foundation being rigid and without mass, all the nodes undergo the same displacement which is equal to 1.0 in direction x for an excitation in direction x. In the same way, all the nodes undergo the same displacement which is equal to 1.0 in direction z for an excitation in direction z.

With a projection *via* `REST_SPEC_PHYS`, the result is got:

a_0	`SPEC N11 'DX'`	`SPEC N11 'DZ'`
1.0	1.00001E+00	1.00383E+00

A test of the type is carried out `ANALYTICAL` with a tolerance of 1% for '`DX'` and 10% for '`DZ'`.

For the case with space variability, one chooses $\alpha=0.5$ and one tests compared to the results of the literature (`SOURCE_EXTERNE`) with a tolerance of 10% .

Results got with `DYNA_ISS_VARI` with a projection *via* `REST_SPEC_PHYS`, for $\alpha=0.5$ and :

a_0	A_{11}^{11}	A_{33}^{33}
1.0	0,767	0,770
2.0	0,437	0,438
3.0	0,251	0,252

For recall, results of reference [bib2], to see too §2.2:

a_0	A_{11}^{11}	A_{33}^{33}
1.0	0,732	0,730
2.0	0,402	0,416
3.0	0,251	0,270

One makes a test in addition of `NON_REGRESSION` for the computed values by `DYNA_ISS_VARI` with a tolerance of $0{,}1\%$ (value by default).

A test is also made `AUTRE_ASTER` compared to the results of modeling A.

6 Modeling D

6.1 Characteristics of modeling

The characteristics used and the grid are those deduced from the data of paragraph 1. The grid is the same one as for modeling A.
As for modeling B, one calculated the temporal answer to the point $N11$ and determines the corresponding spectrum of answer. The transfer transfer function being equal to 1 for the case without space variability, the temporal answer is equal to the entry signal.
If one takes account of space variability, then the answer is modified.
This modeling is used to test the option of interface of type ' `QUELCONQUE'` keyword `MODE_INTERF` with unspecified modes of foundation different from the modes of rigid body. One will compare his results with those of modeling B.

6.2 Characteristics of the grid

The characteristics are those of modeling A.

6.3 Boundary conditions of modeling

For the representation of the movement of foundation, instead of the modes of rigid body of translation, one uses a base of 30 unspecified modes obtained like clean modes, without conditions of blocking, on carpet of springs established starting from the static impedances of ground for the ground defined in §1,2.
One thus takes as values of total rigidities to distribute under the foundation with the option `RIGI_PARASOL` of `AFFE_CARA_ELEM` :

$$KX=KY=6.36E10 \text{ , } KZ=8.02E10 \text{ , } KRX=KRY=2.07E13 \text{ , } KRZ=2.70E13$$

6.4 Sizes tested and results

6.4.1 Function of coherence of Mita&Luco

It is checked that, for $\alpha=0.0$, the answer in acceleration is equal to the accélérogramme as starter of calculation (it is pointed out that the transfer transfer function is worth 1 and that the function is rigid for this case of study). The answer is determined $q(t)$ in '`DX`'at the point $N11$ for an excitation $a(t)$ in '`DX`'.
One treats the case where the transfer transfer function is calculated for all the points (discretization of the accélérogramme) and the case where the user informs `FREQ_PAS, FREQ_FIN.` In this last case, `DYNA_ISS_VARI` interpolate computed values to determine the temporal answer due to the excitation by the accélérogramme.
One checks as into 4,3,1 that the oscillating spectrum of answer (SRO) of the answer in calculated acceleration is equal to the SRO of the accélérogramme as starter.

type of test	frequency (Hz)	reference SRO (g)	tolerance (%)
`ANALYTICAL`	10.0	0.6573	0.1
`ANALYTICAL`	30.0	0.2970	0.2

For the case with space variability, the values $\alpha=0.7, V_s=200\ m/s$ were selected. One consider a temporal seismic excitation in direction '`DX'` data by a accélérogramme corresponding to the Euro spectrum for a rock site (cf, curves red figure in §4.3.1). There is no reference solution (analytical) for this case. Also, one makes a test of `NON_REGRESSION` for the SRO obtained with space variability.
A test is also made `AUTRE_ASTER` compared to the results of modeling B.
Two cases are tested.

1) `FREQ_FIN` be T equalizes at the cut-off frequency:

type of test	frequency (Hz)	reference SRO (G)	tolerance (%)
`NON_REGRESSION`	10.0	0.5418	0.0001
`NON_REGRESSION`	30.0	0.2348	0.0002
`AUTRE_ASTER`	10.0	0,535	1.3E0
`AUTRE_ASTER`	30.0	0.2386	1.6E0

2) `FREQ_FIN` is lower than the cut-off frequency ($35 Hz$ instead of $50 Hz$) and one supplements by zero:

type of test	frequency (Hz)	reference SRO (G)	tolerance (%)
`NON_REGRESSION`	10.0	0.5418	0.0002
`NON_REGRESSION`	30.0	0.2333	0.0001
`AUTRE_ASTER`	10.0	0,535	1.2E0
`AUTRE_ASTER`	30.0	0.2386	2.2E0

6.4.2 Function of coherence of Abrahamson

One consider a temporal seismic excitation in direction '`DX'` data by a accélérogramme corresponding to the Euro spectrum for a rock site (cf, curves red figure in §4.3.1). One makes a test of `NON_REGRESSION` for the SRO obtained with space variability. A test is also made `AUTRE_ASTER` compared to the results of modeling b:

type of test	frequency (Hz)	reference SRO (G)	tolerance (%)
`NON_REGRESSION`	10.0	0.5747	0.0001
`NON_REGRESSION`	30.0	0.23877	0.0001
`AUTRE_ASTER`	10.0	0.5723	0.4
`AUTRE_ASTER`	30.0	0.23903	0.1

7 Modeling E

7.1 Characteristics of modeling

This modeling is identical to modeling B.

7.2 Principle

One carries out a calculation with `DYNA_ISS_VARI` by informing a different signal in each direction (operands `ACCE_X` , `ACCE_Y` and `ACCE_Z` of `EXCIT_SOL`). One launches then three other calculations for which only one signed is indicated (`ACCE_X` , `ACCE_Y` then `ACCE_Z`). The results are brought back on physical basis. One then combines the results of one-way calculations using `CREA_CHAMP` and `CREA_RESU` . The result created constitutes the reference for the result with signals in the three directions.

7.3 Sizes tested and results

Result of reference:

Identification	Value of Référence	Type of reference	Tolerance
Field `DEPL`, Node `N11`, Component `DX`, moment 2	-	`'NON_REGRESSION'`	-
Field `DEPL`, Node `N11`, Component `DRX`, moment 2	-	`'NON_REGRESSION'`	-
Field `QUICKLY`, Node `N11`, Component `DY`, moment 2	-	`'NON_REGRESSION'`	-
Field `QUICKLY`, Node `N11`, Component `DRY MARTINI`, moment 2	-	`'NON_REGRESSION'`	-
Field `ACCE`, Node `N11`, Component `DZ`, moment 2	-	`'NON_REGRESSION'`	-
Field `ACCE`, Node `N11`, Component `DRZ`, moment 2	-	`'NON_REGRESSION'`	-

Threedirectional result:

Identification	Value of Référence	Type of reference	Tolerance
Field `DEPL`, Node `N11`, Component `DX`, moment 2	0.00108384851924	`'AUTRE_ASTER'`	1E-8
Field `DEPL`, Node `N11`, Component `DRX`, moment 2	-9.65779984763E-07	`'AUTRE_ASTER'`	1E-8
Field `QUICKLY`, Node `N11`, Component `DY`, moment 2	-0.00917620109214	`'AUTRE_ASTER'`	1E-8
Field `QUICKLY`, Node `N11`, Component `DRY MARTINI`, moment 2	-2.6388744608E-07	`'AUTRE_ASTER'`	1E-8
Field `ACCE`, Node `N11`, Component `DZ`, moment 2	-0.207431127511	`'AUTRE_ASTER'`	1E-8
Field `ACCE`, Node `N11`, Component `DRZ`, moment 2	-0.00037170431950	`'AUTRE_ASTER'`	1E-8

8 Summary of the results

This case test makes it possible to validate the order `DYNA_ISS_VARI` through the calculation of the answer of a rigid shallow foundation represented either by modes of rigid body (`MODE_INTERF=' CORPS_RIGI'`), that is to say by unspecified modes on carpet of springs determined starting from the static impedances of ground (`MODE_INTERF=' QUELCONQUE'`). Results got with `DYNA_ISS_VARI` are in concord with the results of the reference of Became moth-eaten and Luco.