Memorandum

ARUP

To	AT+R	Date	4 March 2015
Copies		Reference number	000000-00/MAA
From	Mark Arkinstall	File reference	DynaModelling
Subject	Modelling Soil Blocks in LS-Dyna for Seismic Analysis		

1 Introduction

For seismic analysis of structures significant benefit can be gained from modelling the soil block that the structure sits upon. This memo gives the reader the information required to build a soil block mesh for analysis within LS-Dyna. The memo covers the following topics;

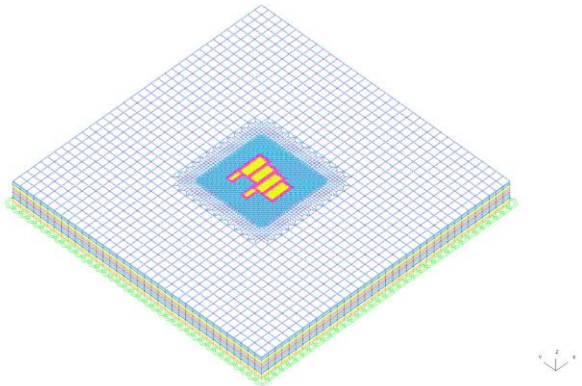
- Soil block size
    - On plan
    - Mesh refinement near structure and at edge of soil block
    - Soil block depth minimisation
    - Generation of mesh
- Geotechnical inputs for material model (from Arup Geotechnics and Siren file)
- Verification of mesh refinement under
- Boundary conditions
    - Edge of soil restraint
    - Non-reflecting boundary setup (Lysmer boundary)
- Connecting Structure to soil block
- Application of ground motions to soil block
- Javascripts to produce soil block and soil column in Primer

2 Soil Block Size

2.1 Soil Block size on plan

The soil block size on plan should be far enough away from the structure that the response of the soil at the edge of the soil block gives the same response as the single element column of soil subject to the same ground motion.

Memorandum



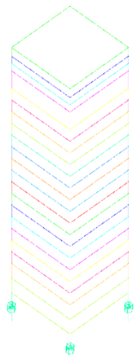


Figure 1 Soil Block(left) and Soil Column (right)

As an example a recent project of a 12mx15m terrace house had a soil block that extended 40metres clear from the edge of the building.

2.2 Mesh refinement near structure and at edge of soil block

The mesh refinement near the building should be kept as close to the building as possible and the elements as large as possible to keep model size manageable. The recommendation from Arup Geotechnics is to keep the refined mesh up to a distance of 5 times the width of the footing. At this distance the soil mesh size can be graded to increase in size.

The mesh refinement should be able to predict the bearing failure stress under the footing. On a recent house model with strip footings a uniform square mesh of 300mmx300mm was used in the vicinity of the structure. The mesh was then graded out to a size of 2.7metres x 2.7 metres at the edge of the soil block. Figure 2 below shows this mesh.

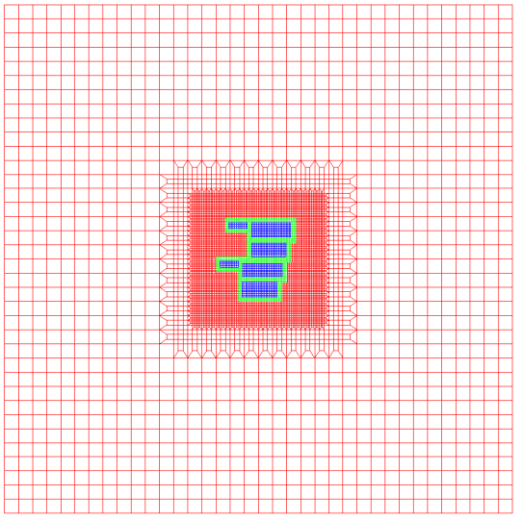


Figure 2 Example of mesh refinement on plan

Memorandum

An analysis should be carried out to show that the mesh refinement predicts the correct bearing failure load under the footing. This will be covered in a following section of this memo.

2.3 Soil block depth

The soil block will most likely consist of many different layers of soil, as soil properties may vary with depth. Typically each element in the Oasys Siren Software file provided by Arup Geotechnics will be a layer in the LS-Dyna soil block mesh. However, the model size is critical for run time so every effort should be made to minimise the number of layers of soil elements. For example, the same recent soil block as show in Figure 1 was originally 48 layers of soil but after discussions with Arup Geotechnics was reduced to 21 layers with a non-reflective boundary, more than halving the number of elements in the soil mesh.

2.4 Soil Block mesh generation

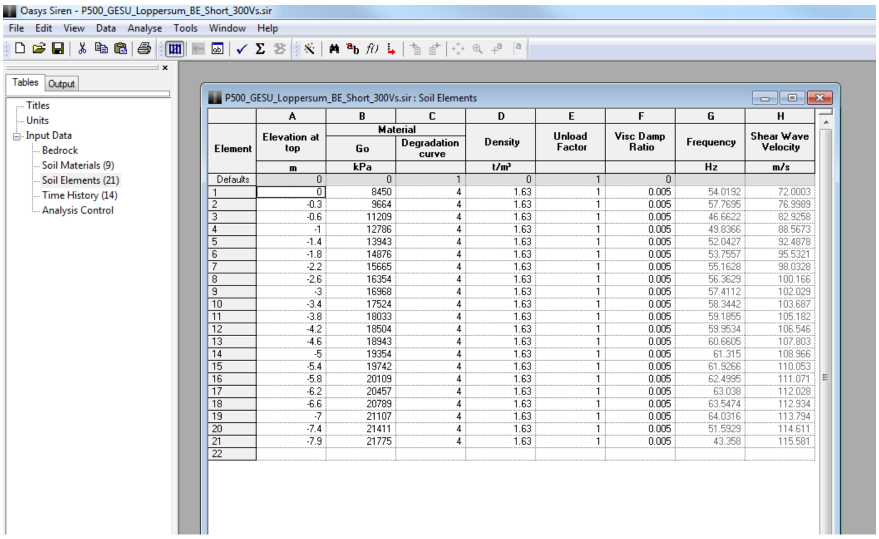
There is a javascript for Primer available to generate the soil block mesh, material properties and boundary conditions. It requires the following inputs :

- A keyword file of the top surface of the soil, meshed in shells
- A node set of the perimeter nodes of those shells
- An input CSV file with all other information about the soil and boundaries

Refer to Section 8.1 for further information on the javascript and how to use it.

3 Geotechnical inputs for LS-Dyna

Most likely you will receive an Oasys Siren file from Arup Geotechnics. The information from this Siren file will be required to make a csv file for the Soil block javascript from Section 8.1 which will set up most of the *MAT_HYSTERETIC_SOIL (MAT79) information for you.



	A	B	C	D	E	F	G	H
Element	Elevation at top	Material Go	Material Degradation curve	Density	Unload Factor	Visc Damp Ratio	Frequency	Shear Wave Velocity
	m	kPa		t/m³			Hz	m/s
Defaults	0	0	1	0	1	0		
1	0	8450	4	1.63	1	0.005	54.0192	72.0003
2	-0.3	9664	4	1.63	1	0.005	57.7695	76.9989
3	-0.6	11209	4	1.63	1	0.005	46.6622	82.9258
4	-1	12786	4	1.63	1	0.005	49.8366	88.5673
5	-1.4	13943	4	1.63	1	0.005	52.0427	92.4878
6	-1.8	14876	4	1.63	1	0.005	53.7557	95.5321
7	-2.2	15665	4	1.63	1	0.005	55.1628	98.0328
8	-2.6	16354	4	1.63	1	0.005	56.3629	100.166
9	-3	16968	4	1.63	1	0.005	57.4112	102.029
10	-3.4	17524	4	1.63	1	0.005	58.3442	103.687
11	-3.8	18033	4	1.63	1	0.005	59.1855	105.182
12	-4.2	18504	4	1.63	1	0.005	59.9534	106.546
13	-4.6	18943	4	1.63	1	0.005	60.6605	107.803
14	-5	19354	4	1.63	1	0.005	61.315	108.966
15	-5.4	19742	4	1.63	1	0.005	61.9266	110.053
16	-5.8	20109	4	1.63	1	0.005	62.4995	111.071
17	-6.2	20457	4	1.63	1	0.005	63.038	112.028
18	-6.6	20789	4	1.63	1	0.005	63.5474	112.934
19	-7	21107	4	1.63	1	0.005	64.0316	113.794
20	-7.4	21411	4	1.63	1	0.005	51.5929	114.611
21	-7.9	21775	4	1.63	1	0.005	43.358	115.581
22								

Memorandum

Figure 3 Oasys Siren Soil Elements data

The LS-Dyna model should have one layer of soil for each Siren element. The javascript allows each soil layer to be specified by the top of layer which is convenient as the Siren data is defined in the same way. The other columns of data from the Siren model that are required inputs are the G_o , Density and shear wave velocity. All of these parameters go into the javascript that generates the soil block.

There is also one other parameter required for the javascript and that is the degradation curve number from the Siren file. The Siren Degradation curve specifies how shear modulus changes as the shear strains increase. Note that the Siren units will probably be in kPa so they may need to be converted to the units you are using for the LS-Dyna model.

The degradation curve information is also available in Siren, as shown in Figure 4

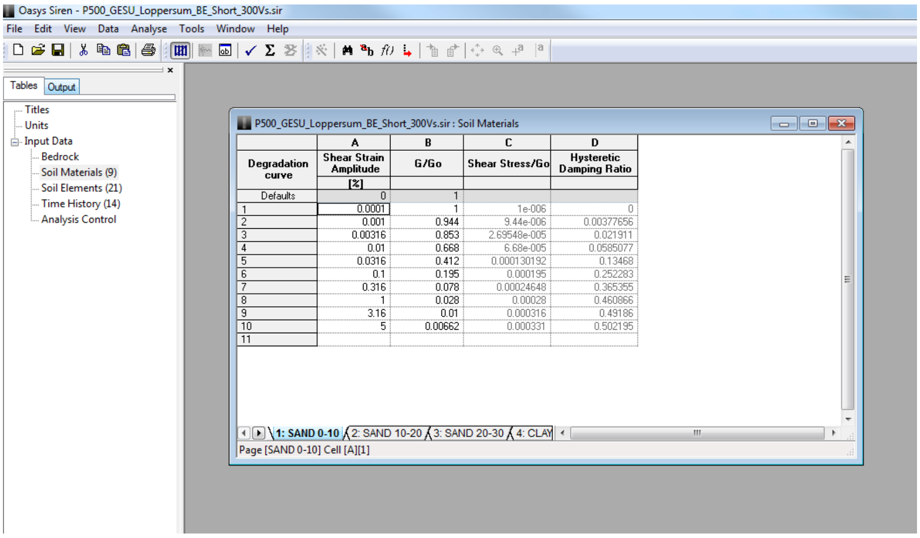


Figure 4 Siren Degradation Curve

Note that LS-Dyna will require the actual shear strain amplitude (not the % as shown in Siren) so you will need to divide the siren shear strain number by 100.

A *DEFINE_CURVE will be needed that defines each Siren Degradation curve specified. The X axis of the define curve is the actual shear strain value while the Y axis of the define curve is the shear stress. The javascript in Section 8.1 does not set up this *DEFINE_CURVE.

A single degradation curve can be used by multiple soil layers. The best way to set up the *DEFINE_CURVE is to use column A (divided by 100) and Column C from the Siren file degradation curve. The *MAT79 input then allows you to scale the degradation curve for each part (soil layer) by the actual G_o of that layer.

Arup Geotechnics will provide guidance on Poisson's ratio. There are some other soil properties that will need to be calculated. Namely the bulk modulus (K_0) and the vertical shear wave velocity (V_p) . Equations to calculate these are given below.

$K_0 = [2*G_0 (1 + \nu)]/[3*(1-2*\nu)]$
$V_P = \mathrm{sqrt}(K_0/\rho)$

4 Verification of mesh refinement and soil properties under footing

It is important to ensure the mesh refinement and soil properties are predicting the bearing stress failure correctly. For this task a slice of the model can be extracted and converted to a pseudo plane strain problem. An example of this is show below in Figure 5. If there is a Lysmer boundary it should be removed and replaced with an a XYZ restraint along the base. Gravity should be applied using dynamic relaxation and then a pressure load applied to the top of the foundation during the time history phase slowly increasing until the footing has a bearing failure. This should be checked against bearing failure estimates by Arup Geotechnics. If the two answers are similar this is an indicator that the mesh refinement and soil properties are capturing the correct soil behaviour.

Image goes here (Alasdair is still working on this)

Figure 5 Pseudo Plane Strain model

5 Boundary Conditions

There are two things required for the boundary conditions of the soil block ;

- Constraining the perimeter of each layer of soil edge nodes
- The conditions at the base

Each of these is discussed below.

5.1 Soil perimeter nodes

If you imagine the soil block when gravity is applied then the edges would want to move outward. The way to stop this is to set up a nodal rigid body for each set of nodes on the perimeter at the varying depths.

Fortunately the javascript in Section 8.1 will set these up for you, providing you ask it to. Note that the script will ask you for the Node set when it runs. You need to set this node set up before running the script.

5.2 Soil Base boundary condition – Lysmer Boundary

For a non-reflective boundary (Lysmer boundary) you will need to specify the following parameters in the javascript ;

- Vs (horizontal shear wave velocity)
- Vp (vertical shear wave velocity)
- Density

The script will also ask for three curve numbers will will provide the prescribed motion input for the time history analysis in LS-Dyna. Note that the prescribed motion must be in terms of velocity.

The javascript will set up Lysmer dampers on every node on the base of the soil block and link the prescribed motion input curves to them.

5.2.1 Dynamic Relaxation initialisation with Lysmer boundary

If a non-reflective Lysmer boundary is used then when the analyst initialises the model with dynamic relaxation the model will simply sink and keep sinking. To avoid this problem a method has been developed where the following steps are taken ;

- Run 1 – Add stiff springs underneath the model (see below). Dynamic relaxation only – set termination time to 1e-6. These will stop the downward displacement during gravity loading, but we mustn't keep them during the earthquake or they will stop the dampers working.

    - Step 2 – D3PLOT with a Javascript (see section 8.2) to extract the forces from the stiff springs and write some *LOAD_NODE cards. These will use the same DEFINE_CURVES as the gravity loading: ramping up during dynamic relaxation, and constant during transient analysis. The loads will be upwards, on the underside of the soil block. The load on each node will be the same as measured by the stiff springs.

- Run 2 – Remove the stiff springs, change the termination time back to the correct one, add the *LOAD_NODE written in step 2. Run the model normally (dynamic relaxation plus transient). The nodal loads will balance the gravity loads. Although downward movement will not be prevented, at least it will be minimised.

This method sounds quite clumsy but it will fit well with our current modelling methods. There is a javascript that will do this.

Add the stiff springs to the model, like this (it will be easiest in Primer)

- Copy all the Lysmer damper elements. These all have the same Part ID, but different scale factors because of the different areas. (Do this in Primer's ELEMENT=>Discrete main menu)
- Change the part ID of the copied elements to a new Part ID having *SECTION_DISCRETE and MAT_SPRING_ELASTIC.
- The stiffness of MAT_ELASTIC can be 1e6 N/m.
- Also change termination time to 1.e-6.

6 Connecting the structure to the Soil Block

If you want to keep the number of soil block element to a minimum then the easiest way is to mesh the footings and surrounding soil as coarser mesh than the structural model and connect them together using a *TIED_NODE_TO_SURFACE_CONTACT. This contact does not affect timestep. This gives the advantage that someone can work on the soil block with another person can work on the structure concurrently.

6.1 Strip footings

Strip footings should be meshed into the soil block. When creating the soil top surface mesh make the footings a different part. Also make any bits of soil that may need to be removed later different parts. When the soil block javascript (see section 8.1) is run it will extrude these different parts downward. This will allow soil to be removed in the building zone, and other bits of soil where footings exist to be converted to concrete properties as required. Note that the concrete footings will be directly meshed to the soil nodes. The parts for the concrete footings should be fully integrated solids as they may only be one element thick (to match the soil layers).

6.2 Piles

If your foundation includes Piles these will need to be connected to the soil elements.

6.3 Merging the structure and soil model in Primer

Primer is the best place to merge the structure and soil models. When you merge them you can get Primer to increment all of the numbering information in the second model so the two models do not have numbering clashes. If you have coincident nodes that need merging you can do that in Primer. If you are going to use a tied contact to connect structure and soil then you can set up the tied contact in Primer also.

7 Ground Motions application

The ground motions need to be specified in terms of velocity if a Lysmer boundary is used. The javascript will ask for three curve numbers which specify the X, Y and Z components of the ground motion.

8 Javascripts

8.1 Script for generating soil block mesh

The script is run in Primer and requires the top surface mesh that will be extruded downward. It also requires that surface mesh to have a node set defining its perimeter nodes. Finally it requires a CSV input file with all information required to generate the soil block.

The latest version of the script is called :

Layer_create_version_2.js

There is a word document that goes with it that explains how to use it and its inputs. The word document is called ;

Memo_layer_create.docx

The memo was last updated on 18th December 2010

The author of the script and memo was Richard Sturt.

8.2 Script for calculating dynamic relaxation phase Node loads

The script has been written to run in D3PLOT in March 2015 by Richard Sturt. The latest version of the script is called ;

Name???.js

The description of how to use it is in this memo.