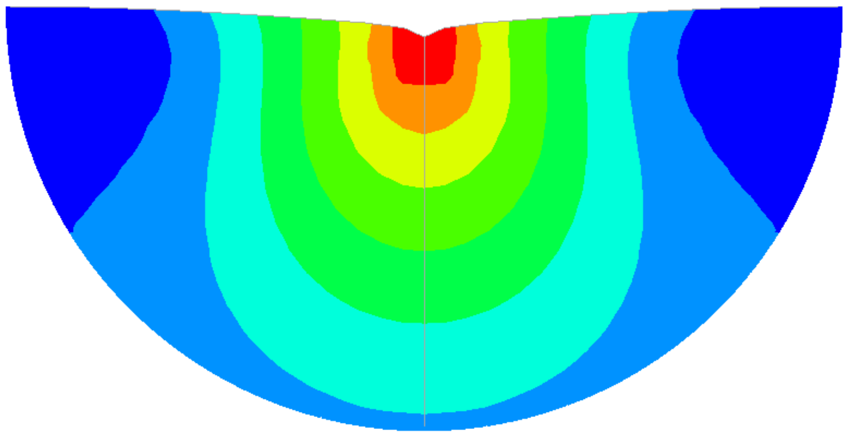

Absorbing Boundary Connection in Diana

DIANA FEA

Outline

1 Introduction

In DianaIE, absorbing boundaries provide a general purpose, user-friendly method of applying stiffness and damping properties according to Lysmer and Kuhlemeyer (1969)[1] to boundary surfaces of a model, where the assumption of a fully fixed or free boundary is not appropriate. This especially applies to transient dynamic problems in which an infinite, wave transmitting medium is modeled using a finite boundary. The consequence of using a fully fixed or free boundary condition is that the waves moving from the source to the boundary are reflected and keeping the applied energy of the loading in the model, which is not expected to happen in an infinite medium. In this tutorial, this effect is illustrated by means of a circular semi-infinite soil model, excited by a single pulse in the direction perpendicular to the free surface. Further, absorbing boundaries are considered as a solution to better simulate the effect of an infinite medium using a finite boundary.

Since the focus of this tutorial is on the absorbing boundaries, only steps pertaining to the assignment of boundary conditions and time load history are presented in detail. Other steps related to creating the geometry are not presented. For detailed information on absorbing boundaries, please see the *DIANA Documentation*.

[1] Lysmer and Kuhlemeyer, *Finite dynamic model for infinite media*, 1969

2 Model

The model shown in Figure 1 consists of one quarter circular shape, called *Soil*. The top horizontal edge is the free surface. Symmetry is considered on the right vertical edge. A point load of 500 kN is applied at the right top vertex, in the direction perpendicular to the free surface.

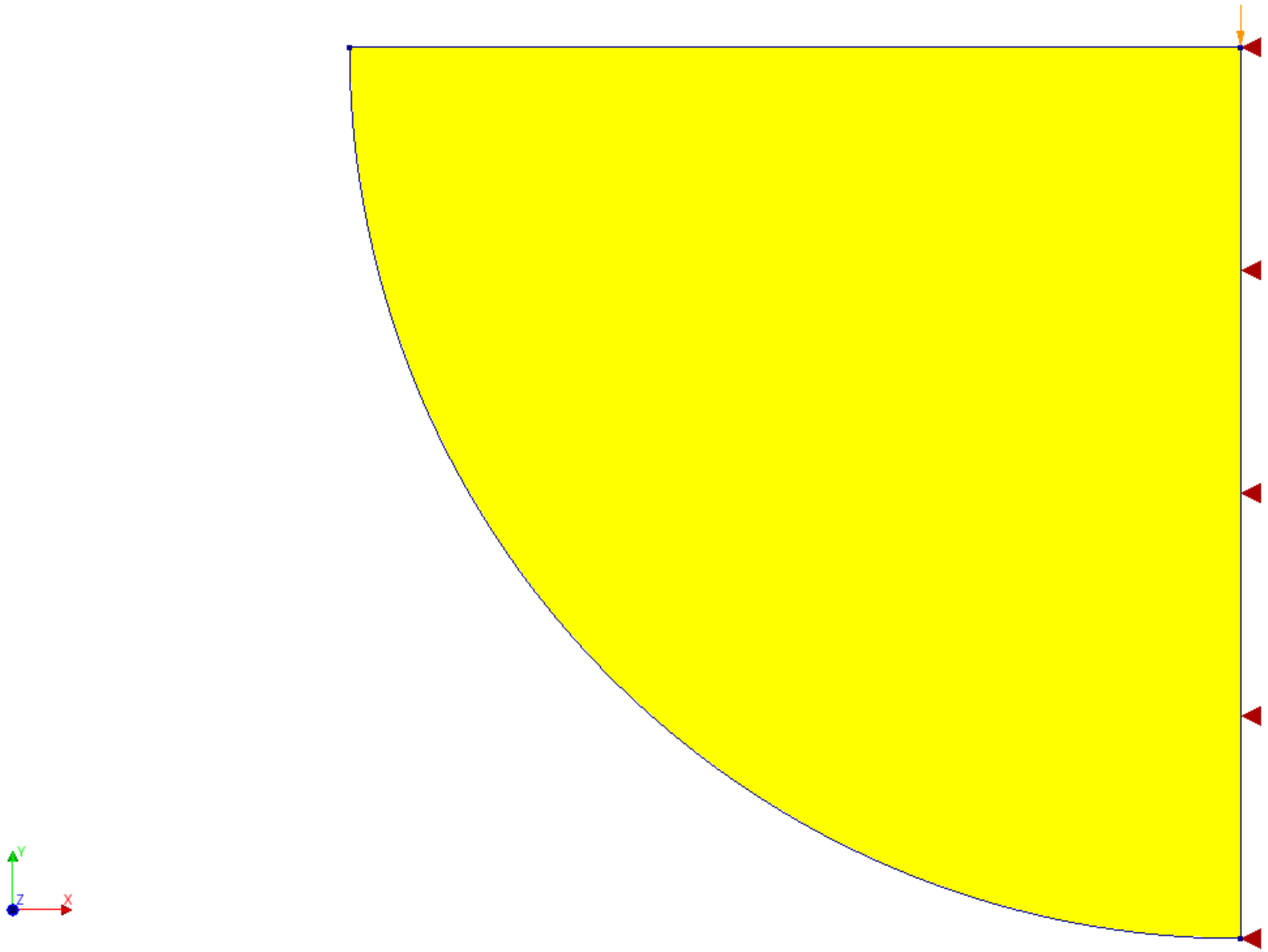

Figure 1: Model - geometry, supports and load

In brief terms, the model has the following characteristics:

- geometry:
  quarter circle: radius 50 m
- properties:
  element class: regular plane strain
  material model soil: linear elastic isotropic (Young's modulus $E = 80$ MPa, Poisson's ratio $\nu = 0.35$, saturated density $\rho = 2038$ kg/m^3)
- supports:
  right horizontal edge: T1 = 0 due to symmetry
- loads:
  force: 500 kN in the downward direction at right top vertex
- mesh:
  element size of 5 m

We begin editing the model by attaching a time history to the load, with the eventual aim of applying an appropriate boundary condition to the curved edge, such that the effect of an infinite soil medium is simulated throughout the considered time history.

2.1 Load Time History

We shall consider a single sine squared pulse for the time history of the load [Fig. 2]. We assume the quiet period t_0 to be equal to 0.1 s. Also, we choose the first eigenfrequency f of 1.4203 Hz, which implies a time period T of $1/f \approx 0.7$ s, for the duration of the single sine squared pulse. The angular velocity ω for the corresponding sine squared pulse is given by $\pi f \approx 4.462$ rad/s. We shall use the function generator to input these details.

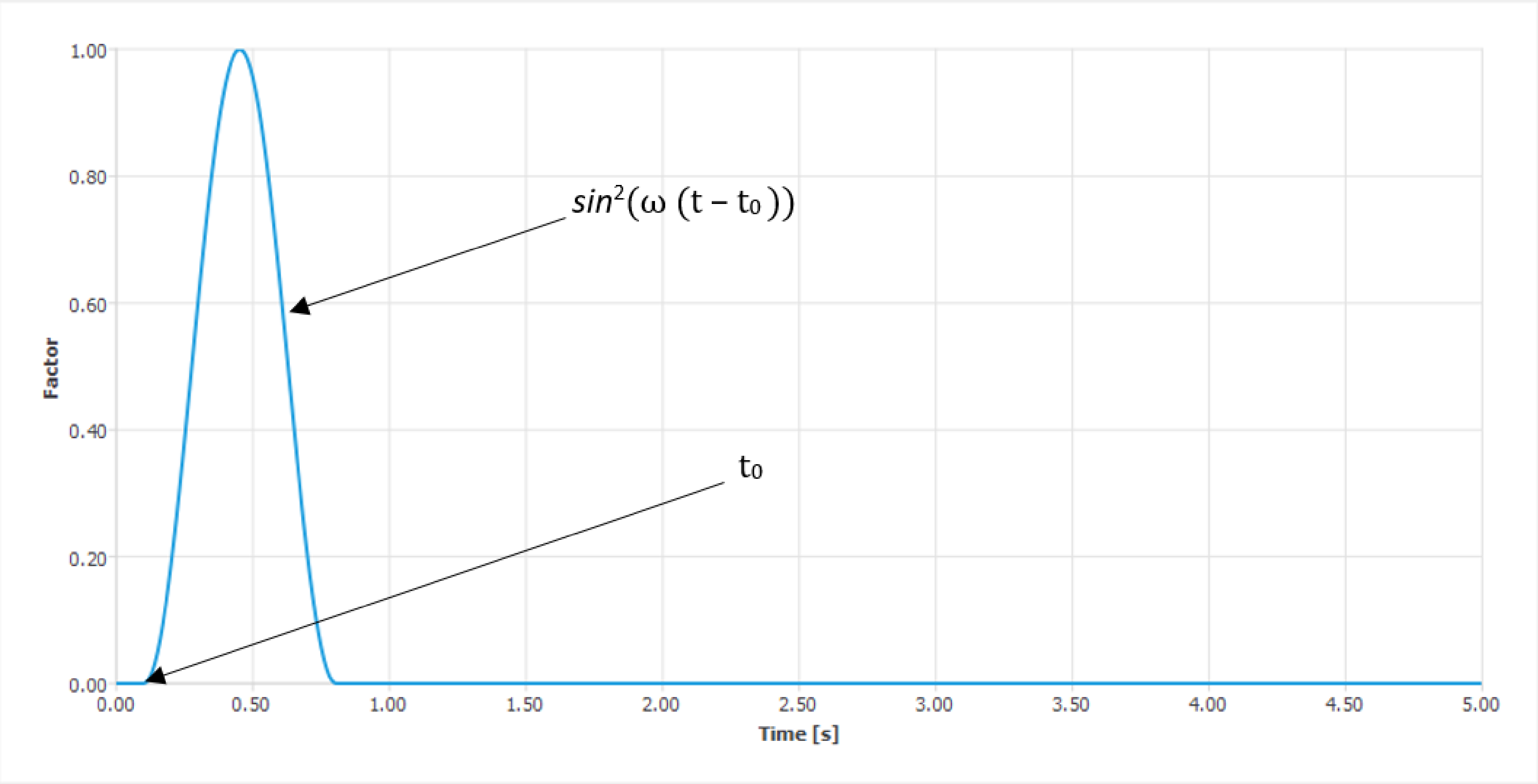

Figure 2: Load time history

We start by selecting the attached load in the *Geometry browser* and clicking on *Edit time dependent factors* [Fig. 3]. Then we generate the data points for the sine squared function by writing out the expression as seen in Figure 4, for time between t_0 and $t_0 + T$. We copy these values to the clipboard to use it later in the total time signal with preceeding and trailing zeros.

DianaIE

Geometry browser → Loads → Cases → Loadcase name → Load name → Edit time dependency [Fig. 3] [Fig. 4] [Fig. 5]

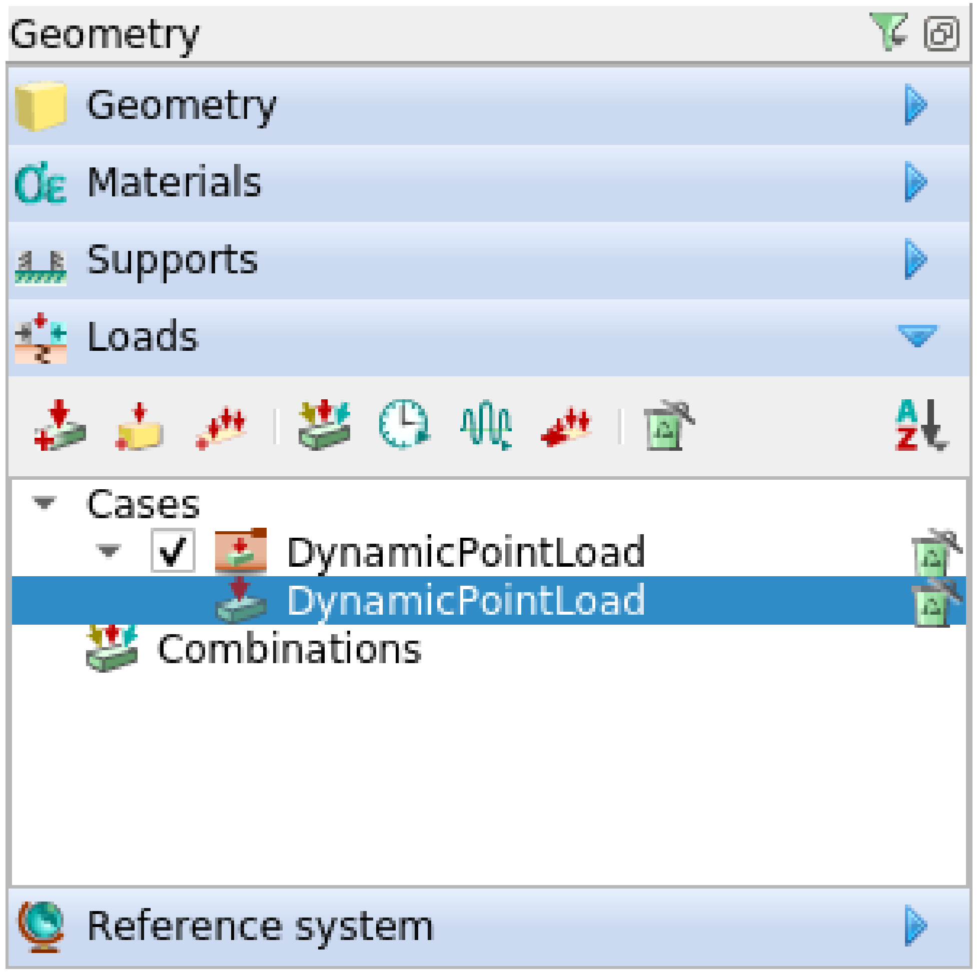

Figure 3: Geometry browser - attached load

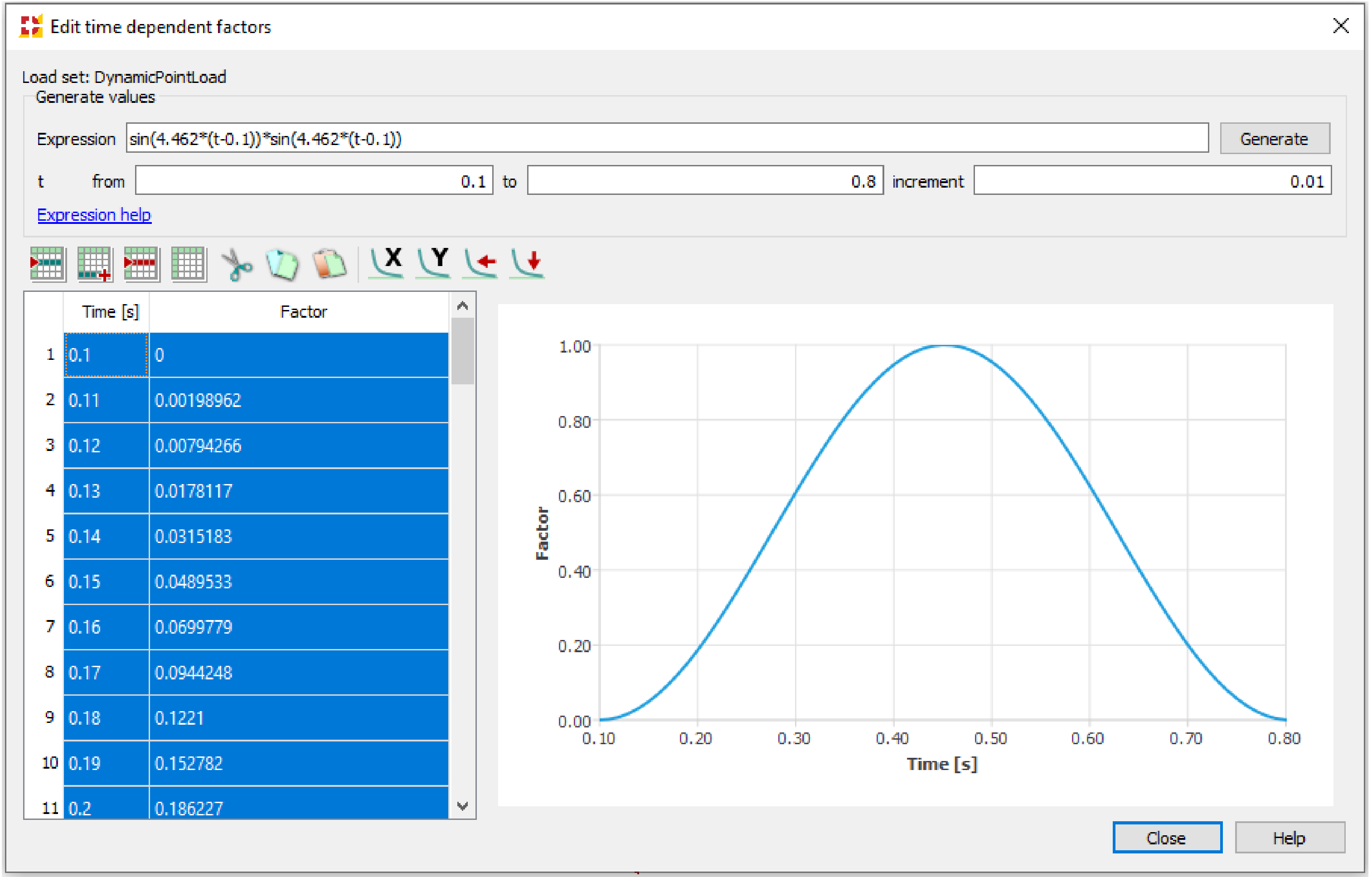

Figure 4: Generate and copy function data points

Next, we generate zeros from the start (0 s) to the end point (5 s) of the time domain [Fig. 5]. We then paste the copied values of the sine squared function over the data points from t_0 to $t_0 + T$ to get the required time history of the load. After clicking on *Close*, the time dependent attachment should be visible in the *Geometry browser* under the appropriate load set [Fig. 6].

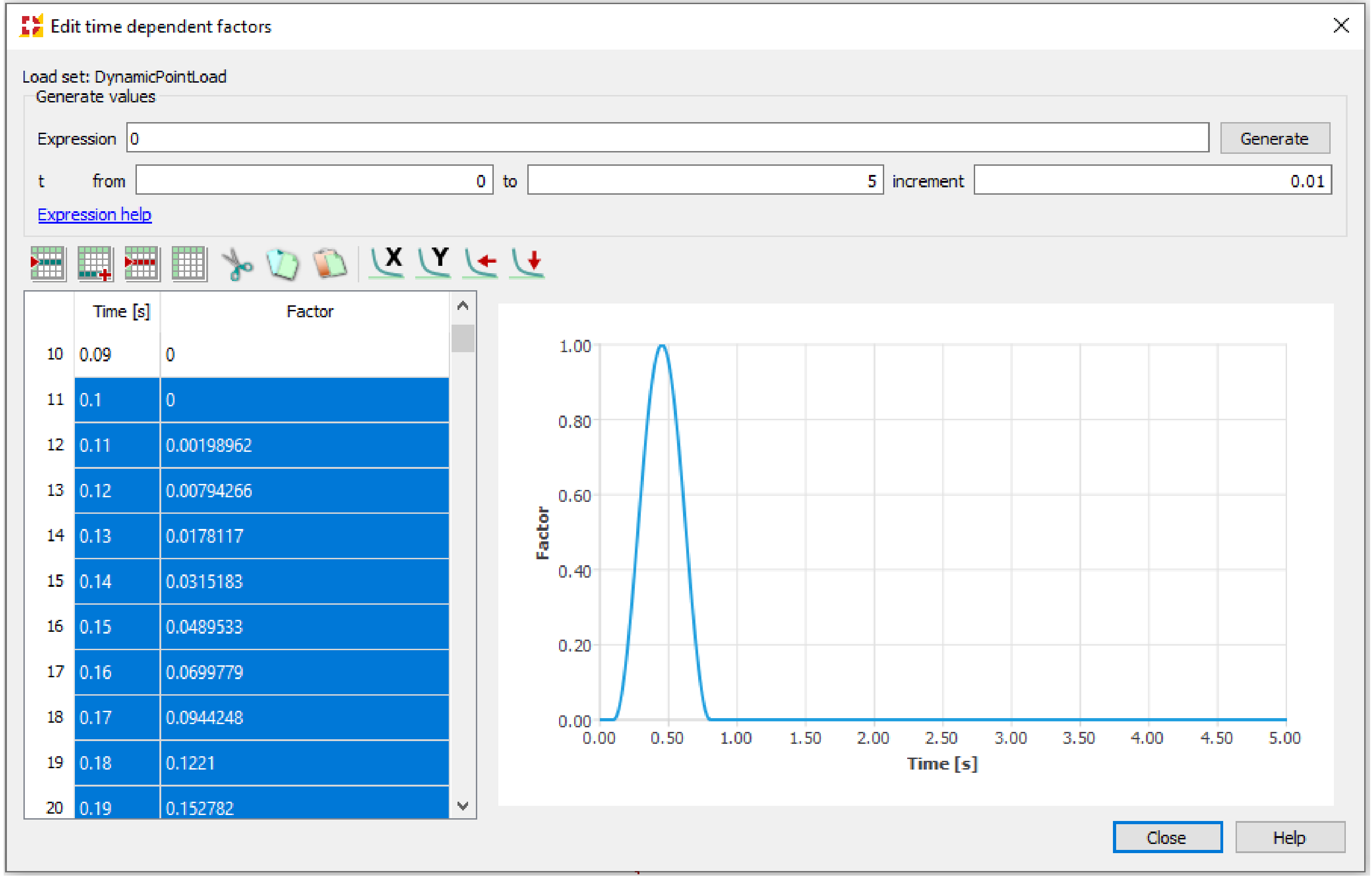

Figure 5: Generate zeros for the entire time domain and paste function data points in the required period

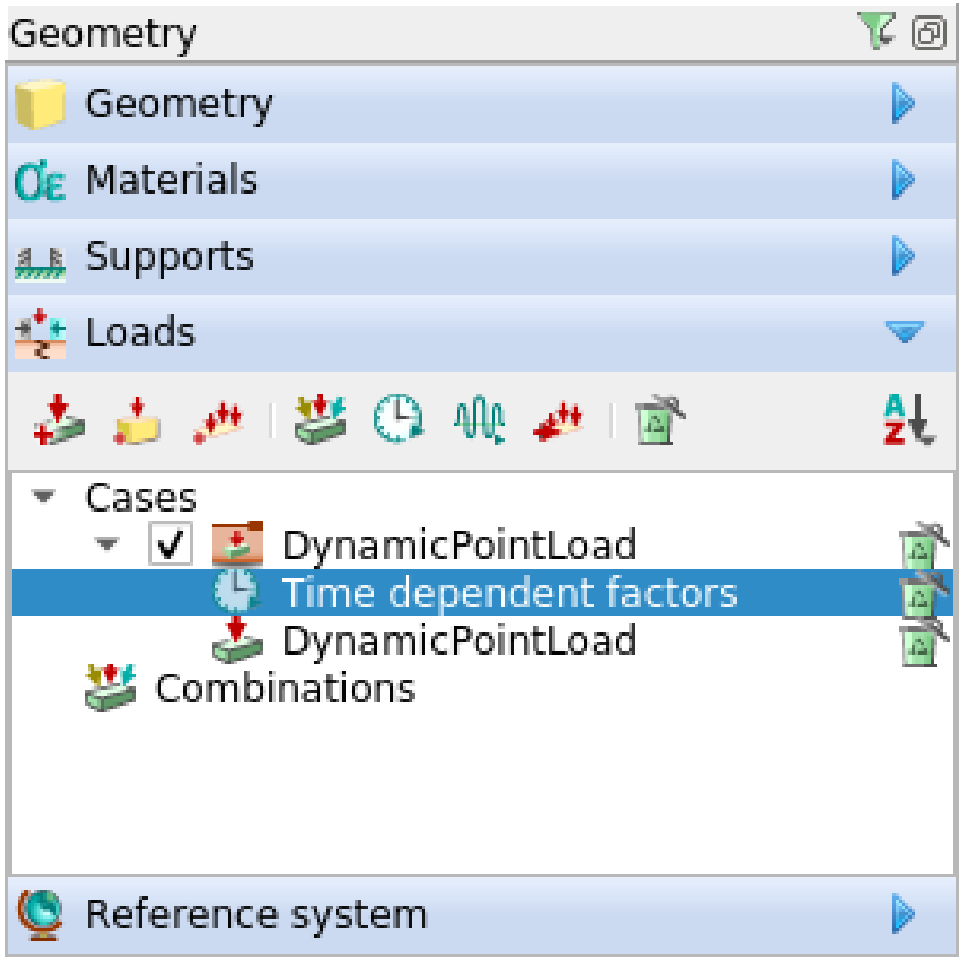

Figure 6: Geometry browser - time dependent load factors

2.2 Fixed Boundary Condition

We now assign supports in global X and Y direction to the curved edge as shown in Figure 8 to create fixed boundary conditions and generate the mesh.

DianaIE

Main menu → Geometry → Assign → Add supports [Fig. 8]
Main menu → Geometry → Generate mesh [Fig. 9]

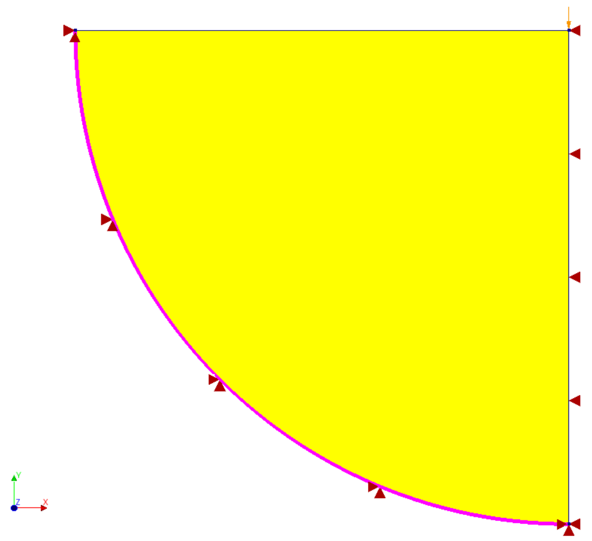

Figure 7: View of model - fixed boundary condition

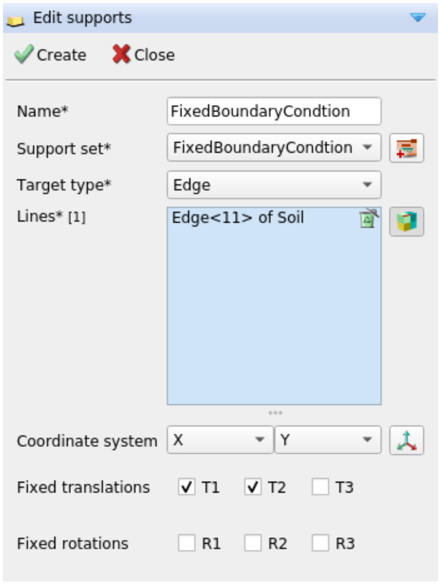

Figure 8: Fixed boundary condition

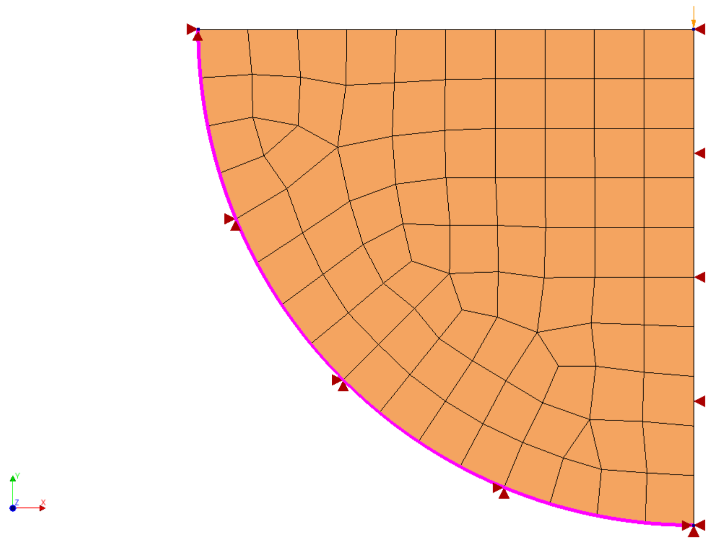

Figure 9: Finite element mesh

Further, we set up the analysis. In the *Analysis browser* we add a new analysis and rename it to *Nonlin_Dynamic* and add a *Structural nonlinear* command to it. Next we delete the load block *new execute block* [Fig. 10] and add a new time block [Fig. 11]. We edit the time steps and specify 500 steps of 0.005 s [Fig. 12].

DianaIE

Main menu → Analysis → Add analysis
Analysis browser → Analysis1 → Rename → NonlinDynamic
Analysis browser → NonlinDynamic → Add command → Structural nonlinear
Analysis browser → NonlinDynamic → Structural nonlinear → new execute block → Remove [Fig. 10]
Analysis browser → NonlinDynamic → Structural nonlinear → Add... → Execute steps - Time steps [Fig. 11]
Analysis browser → NonlinDynamic → Structural nonlinear → new execute block 2 → Time steps → Edit properties [Fig. 12]

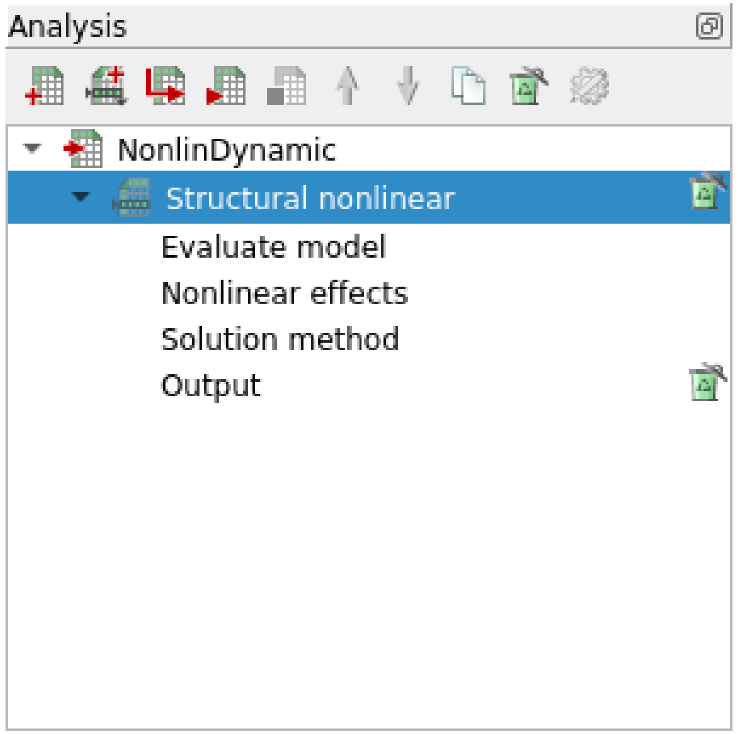

Figure 10: Analysis browser - after deleting default load block

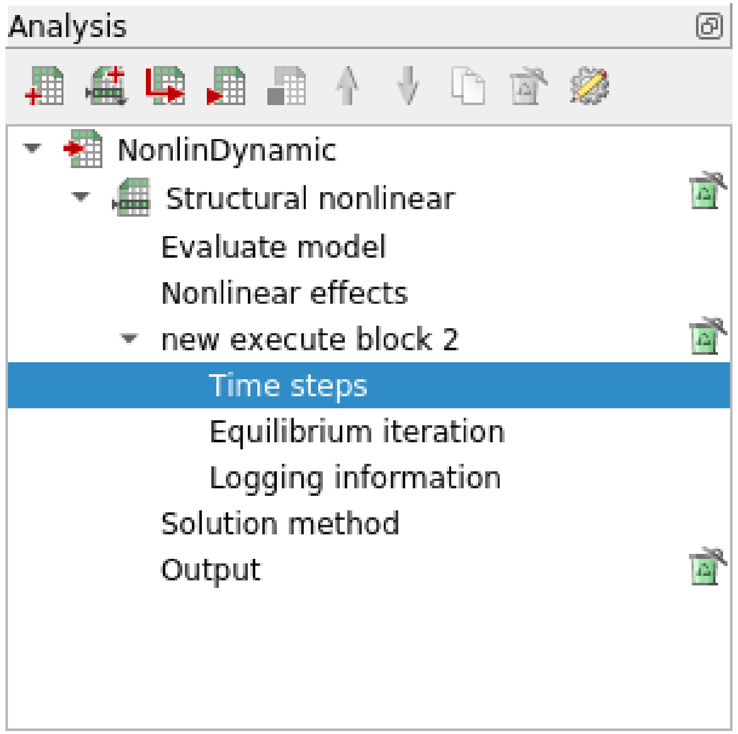

Figure 11: Analysis browser - after adding time block

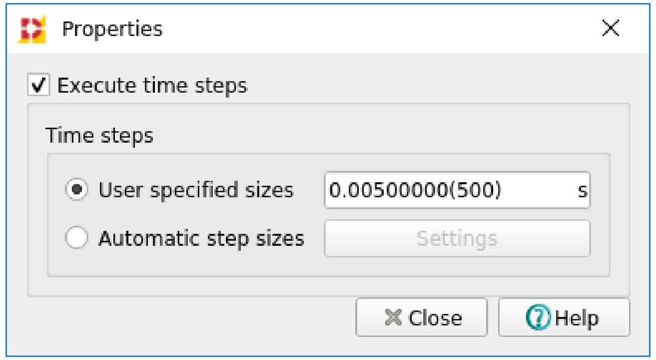

Figure 12: Edit time steps properties

Since we have not specified any physical nonlinearities in our model, we can uncheck *Physically nonlinear* in *Nonlinear effects* [Fig. 13]. In order to consider the dynamic behavior of the soil, we check on *Transient effects*. In the settings for *Dynamic effects* we include the *Damping matrix* [Fig. 14]. Since we have not specified any damping in the material itself, the *Damping matrix* will only be set up for the bounding elements when we assign the absorbing boundary condition in the following section. For now, we run the analysis and investigate the results for the fixed boundary condition.

DianaIE

Analysis browser → NonlinDynamic → Structural nonlinear → Nonlinear effects → Edit properties [Fig. 13]
Nonlinear effects → Transient effects → Settings [Fig. 14]
Main menu → Analysis → Run analysis

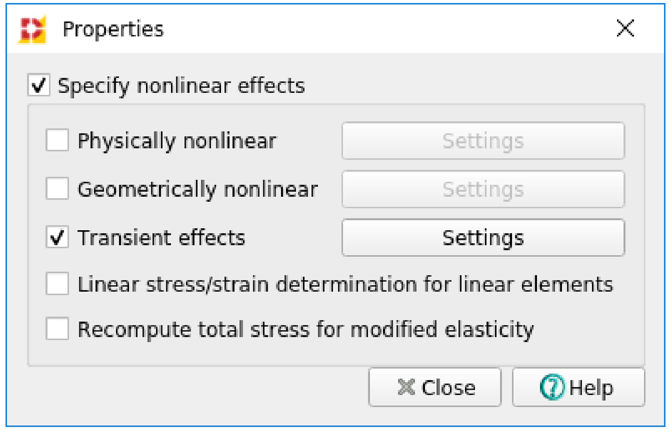

Figure 13: Nonlinear effects

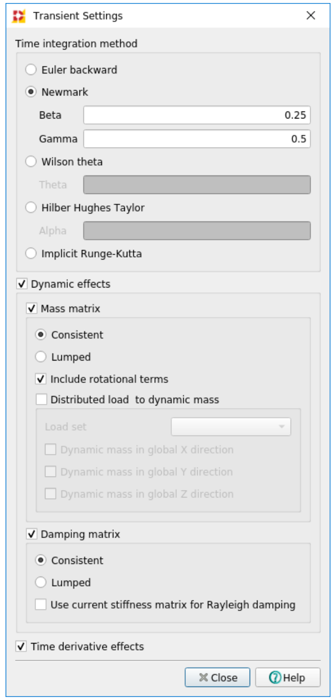

Figure 14: Transient effects - Settings

In order to visualize the response of the soil, we select a set of nodes with an increasing distance from the source [Fig. 15]. Next, in the results browser we right-click on TDtY and select *Show table*.

DianaIE

Main menu → Viewer → Selection mode → Node selection [Fig. 15]
Results browser → Output → Nodal results → Displacements → TDtY → Show table [Fig. 17]

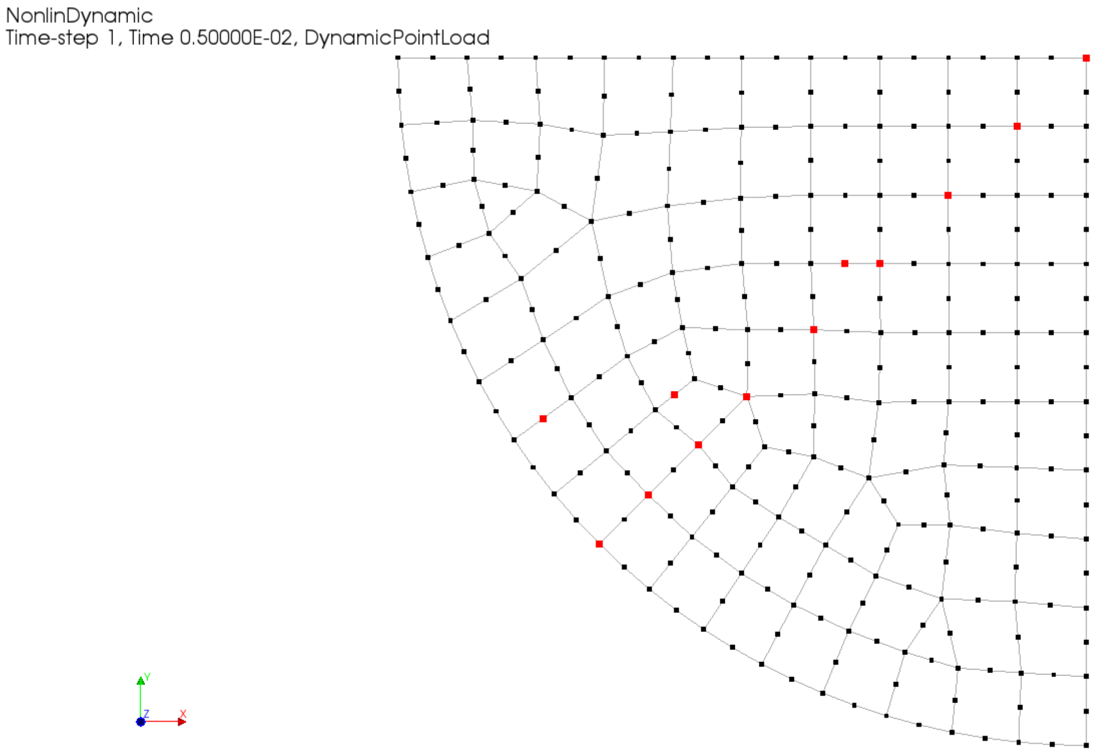

Figure 15: Nodes for checking time response

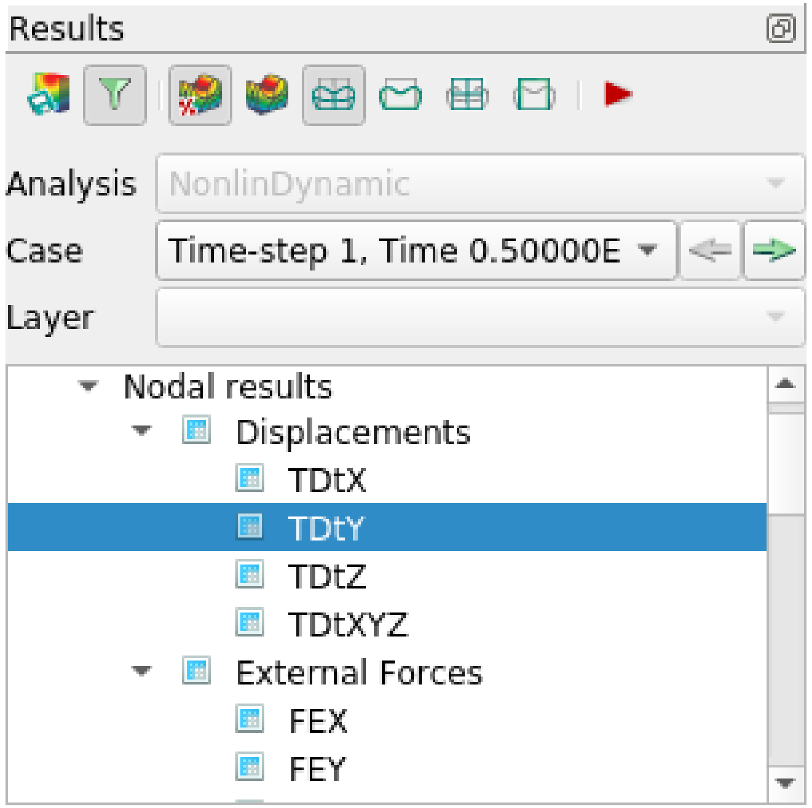

Figure 16: Results browser - TDtY

The response, as seen in Figure 17, shows a pattern of sine waves. The amplitude of the waves is highest at the source and lowest near the boundary. Through the single sine squared pulse, we input energy only in the downward direction. This causes a net residual static displacement in the system after the end of application of the pulse. This is reflected back from the fixed boundary in the upward direction. This, in turn, is reflected back from the free surface towards the boundary in a downward direction. Since we have selected a set nodes with an increasing distance from the source, this lasting sine pattern indicates a back and forth reflection of the waves from free surface where the source is located to the fixed boundary. Further, no damping is considered in the material meaning that the reflection pattern goes on indefinitely. This defies our intuition of an infinite wave transmitting medium.

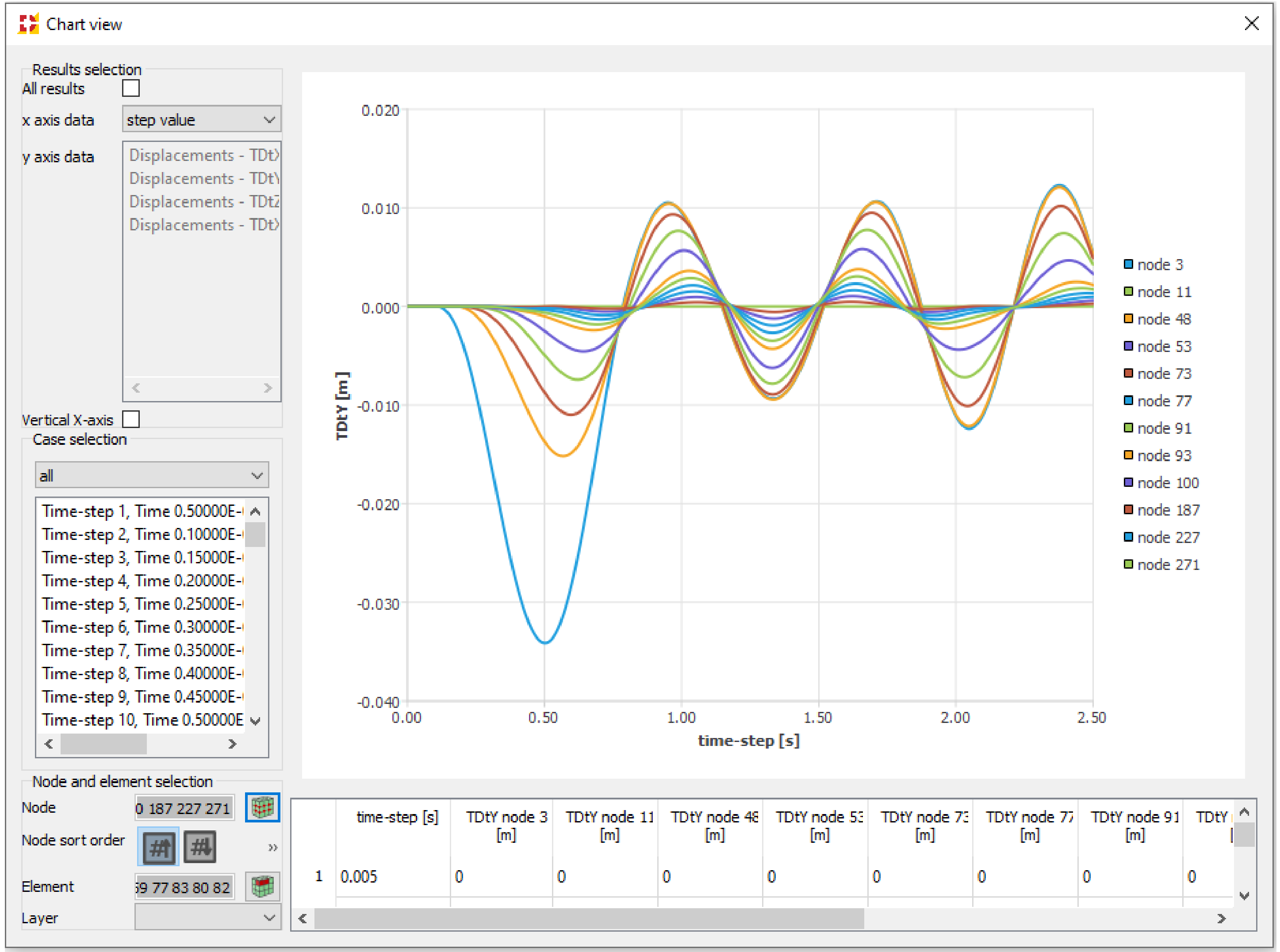

Figure 17: Time response - fixed boundary condition

2.3 Absorbing Boundary Condition

To try to overcome the limitation posed by the fixed boundary condition, we define the absorbing boundary condition in the curved edge. First, we remove the support from the fixed boundary condition and assign an absorbing boundary [Fig. 19]. DianaIE derives the damping properties as described by Lysmer and Kuhlemeyer (1969) [1] for the bounding elements used for the absorbing boundary condition from the material properties of the adjacent soil elements. Therefore, for this assignment, we do not have to specify any additional properties for the boundary. We generate the mesh again, re-run the analysis and follow the same procedure to investigate the results as in the previous section.

DianaIE

Geometry browser → Supports → FixedBoundaryCondition → Remove
Main menu → Geometry → Assign → Add connection [Fig. 19]
Main menu → Geometry → Generate mesh
Main menu → Analysis → Run analysis

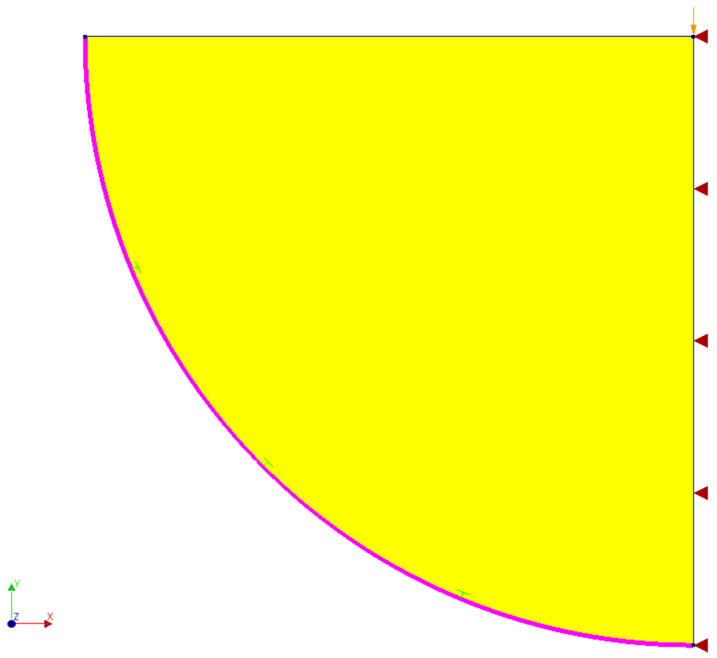

Figure 18: View of model - Absorbing boundary condition

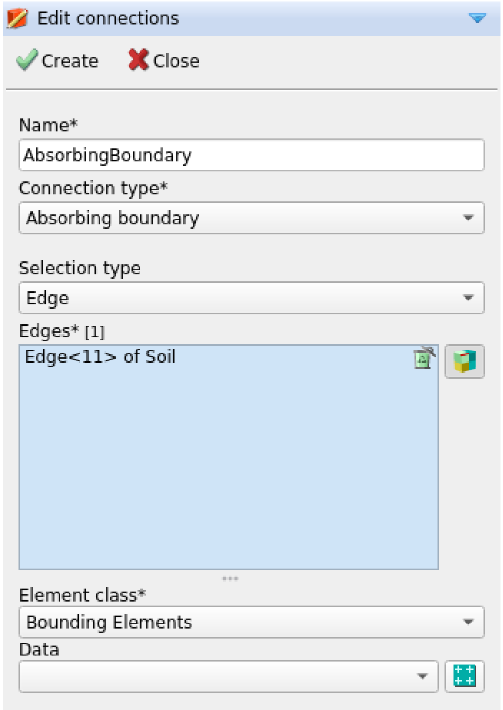

Figure 19: Absorbing boundary condition

Main menu → Viewer → Selection mode → Node selection [Fig. 15]
Results browser → Output → Nodal results → Displacements → TDtY → Show table [Fig. 20]

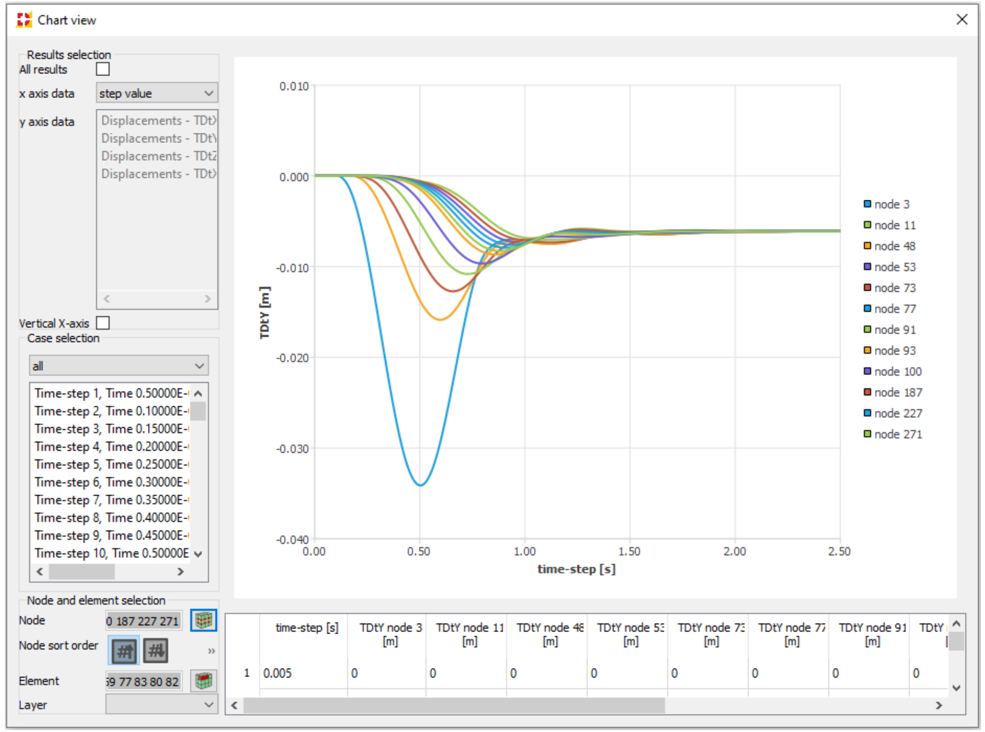

Figure 20: Time response - absorbing boundary condition

A drastically different response is obtained with the absorbing boundary condition [Fig. 19]. One major peak is seen for all points with decreasing amplitude as we move away from the source. Secondary minor peaks are obtained for a few nodes between time 1.2 s and 1.9 s, which indicates some reflection of waves from the boundary. Although, all minor peaks are much less severe than the fixed boundary response and are in a range of less than 5% of the maximum amplitude. Further, they get damped out within 0.5 s. A uniform downward displacement of approximately 6 mm is observed in the soil at the end of 2.5 s, which is in line with the intuition of an infinite wave transmitting medium.

Appendix A Additional Information

Folder: Tutorials/AbsorbingBoundaries

Number of elements ≈ 450

Keywords:
ANALYS: dynami nonlin transi.
CONSTR: suppor.
ELEMEN: boundi cl6tb cq16e ct12e pstrai.
LOAD: force node time.
MATERI: elasti isotro.
OPTION: direct newmar newton regula units.
POST: binary ndiana.
PRE: dianai.
RESULT: cauchy displa extern force green reacti strain stress total.

References:

[1] J. Lysmer and R. L. Kuhlemeyer. Finite dynamic model for infinite media. *J. Eng. Mech., ASCE*, 95(4):859–877, 1969.

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