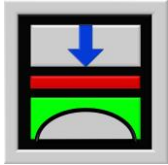


Examples to verify and illustrate *ELPLA*



Determining
contact pressures, settlements, moments
and shear forces of slab foundations by the
method of finite elements

Version 2010

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Contents

	Page
Introduction	- 3 -
1 Verifying stress on soil under a rectangular loaded area	- 24 -
2 Verifying stress on soil under a circular loaded area	- 27 -
3 Verifying immediate settlement under a loaded area on Isotropic elastic half-space medium	- 30 -
4 Verifying immediate settlement under a rectangular loaded area on layered subsoil	- 33 -
5 Verifying immediate settlement under a circular tank on layered subsoil	- 37 -
6 Verifying consolidation settlement under a rectangular raft	- 42 -
7 Verifying consolidation settlement under a circular footing	- 45 -
8 Verifying rigid square raft on Isotropic elastic half-space medium	- 51 -
9 Verifying rigid circular raft on Isotropic elastic half-space medium	- 54 -
10 Verifying flexible foundation and rigid raft on layered subsoil	- 57 -
11 Verifying ultimate bearing capacity for a footing on layered subsoil	- 60 -
12 Verifying simple assumption model for irregular raft	- 67 -
13 Verifying main modulus of subgrade reaction k_{sm}	- 71 -
14 Verifying beam foundation on elastic springs	- 76 -
15 Verifying grid foundation on elastic springs	- 78 -
16 Verifying elastic raft on Isotropic elastic half-space soil medium	- 81 -
17 Verifying <i>Winkler's</i> model and Isotropic elastic half-space soil medium	- 84 -
18 Verifying simply supported slab	- 86 -
19 Evaluation of iteration methods	- 89 -
20 Examination of influence of overburden pressure	- 95 -

Examples to verify and illustrate *ELPLA*

	Page
21 Examination of influence of load geometry	-100-
22 Settlement calculation under flexible foundation of an ore heap	-113-
23 Settlement calculation for a rigid raft subjected to an eccentric load	-118-
24 Verifying deflection of a thin cantilever beam	-122-
25 Verifying forces in piles of a pile group	-125-
26 Verifying continuous beam	-130-
27 Verifying moments in an unsymmetrical closed frame	-132-
28 Verifying plane truss	-134-
29 Influence of <i>Poisson</i> 's ratio ν_s	-136-
References	-138-

Introduction

Purpose of the examples

This book presents analysis of many foundation examples. These examples are presented in order to

- verify the mathematical models used in the program *ELPLA* by comparing *ELPLA* results with closed form or another published results
- illustrate how to use *ELPLA* for analyzing foundation by different subsoil models

The examples discussed in this chapter cover many practical problems. For each example discussed in this book, data files and some computed files are included in *ELPLA* software package. The file names, contents and short description of examples are listed below. Besides, a key figure of each problem that contains the main data concerning the foundation shape, loads and subsoil is also shown.

Examples can be run again by *ELPLA* to examine the details of the analysis or to see how the problem was defined or computed and to display, print or plot the results.

When ordering package *ELPLA*, a CD is delivered. It contains the programs and 29 project data files for test purposes, which are described in this book. Data are stored in 67 files. These data introduce some possibilities to analyze slab foundations by *ELPLA*.

Firstly, the numerical examples were carried out completely to show the influence of different subsoil models on the results. Furthermore, different calculation methods for the same subsoil model are applied to judge the computation basis and the accuracy of results. In some cases the influences of geological reloading, soil layers and also the structure rigidity are considered in the analysis. In addition, for applying *ELPLA* in the practice, typical problems are analyzed as follows:

- Stress in soil or plane stress
- Immediate settlement
- Final consolidation
- Ultimate bearing capacity of the soil
- Modulus of subgrade reaction
- Analysis of beams, grids or frames by FE method
- Floor slabs
- Soil settlement due to surcharge fills
- Flexible, elastic and rigid rafts

For this purpose, the following numerical examples introduce some possibilities to analyze foundations. Many different foundations are chosen, which are considered as some practical cases may be happened in practice. All analyses of foundations were carried out by *ELPLA*, which was developed by *M. El Gendy / A. El Gendy*.

Examples to verify and illustrate *ELPLA*

Description of the calculation methods

A general computerized mathematical solution based upon the finite elements-method was developed to represent an analysis for foundations on the real subsoil model, and it is capable of analyzing foundations of arbitrarily shape considering holes within the slabs and the interaction of external foundations. The developed computer program is also capable of analyzing different types of subsoil models, especially a three dimensional continuum model that considers any number of irregular layers. Additionally, the program can be used to represent the effect of structural rigidity on the soil foundation system and the influence of temperature change on the slab. In *ELPLA*, there are 9 different numerical methods considered for the analysis of slab foundations as follows:

1. Linear contact pressure
2. Constant modulus of subgrade reaction
3. Variable modulus of subgrade reaction
4. Modification of modulus of subgrade reaction by iteration
5. Modulus of compressibility method for elastic raft on half-space soil medium
6. Modulus of compressibility method for elastic raft (Iteration)
7. Modulus of compressibility method for elastic raft (Elimination)
8. Modulus of compressibility method for rigid raft
9. Modulus of compressibility method for flexible foundation

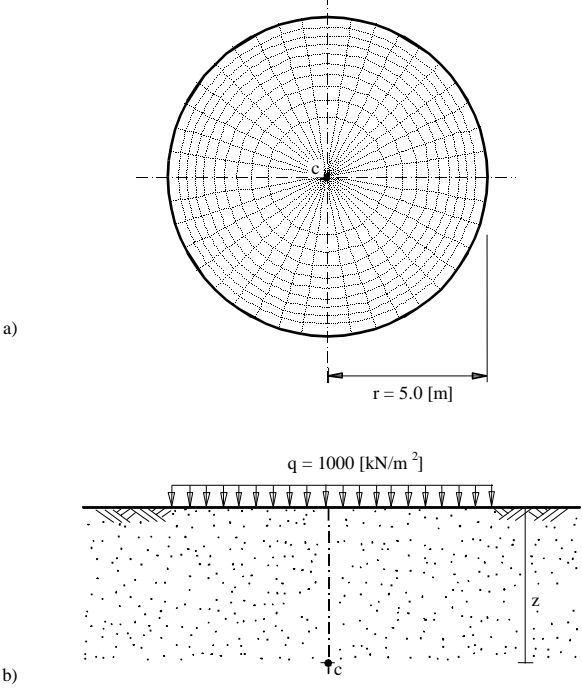
Besides the above 9 main methods, *ELPLA* can also be used to analyze

- System of flexible, elastic or rigid foundations
- Floor slabs, beams, grids, plane trusses, plane frames and plane stress

File names, contents and short description of examples

File	Content	Foundation shape, loads, subsoil, ... etc.
str	Stress on soil	<p>a)</p> <p>b)</p>
<p>Example 1: Verifying stress on soil under a rectangular loaded area</p>		

Examples to verify and illustrate *ELPLA*

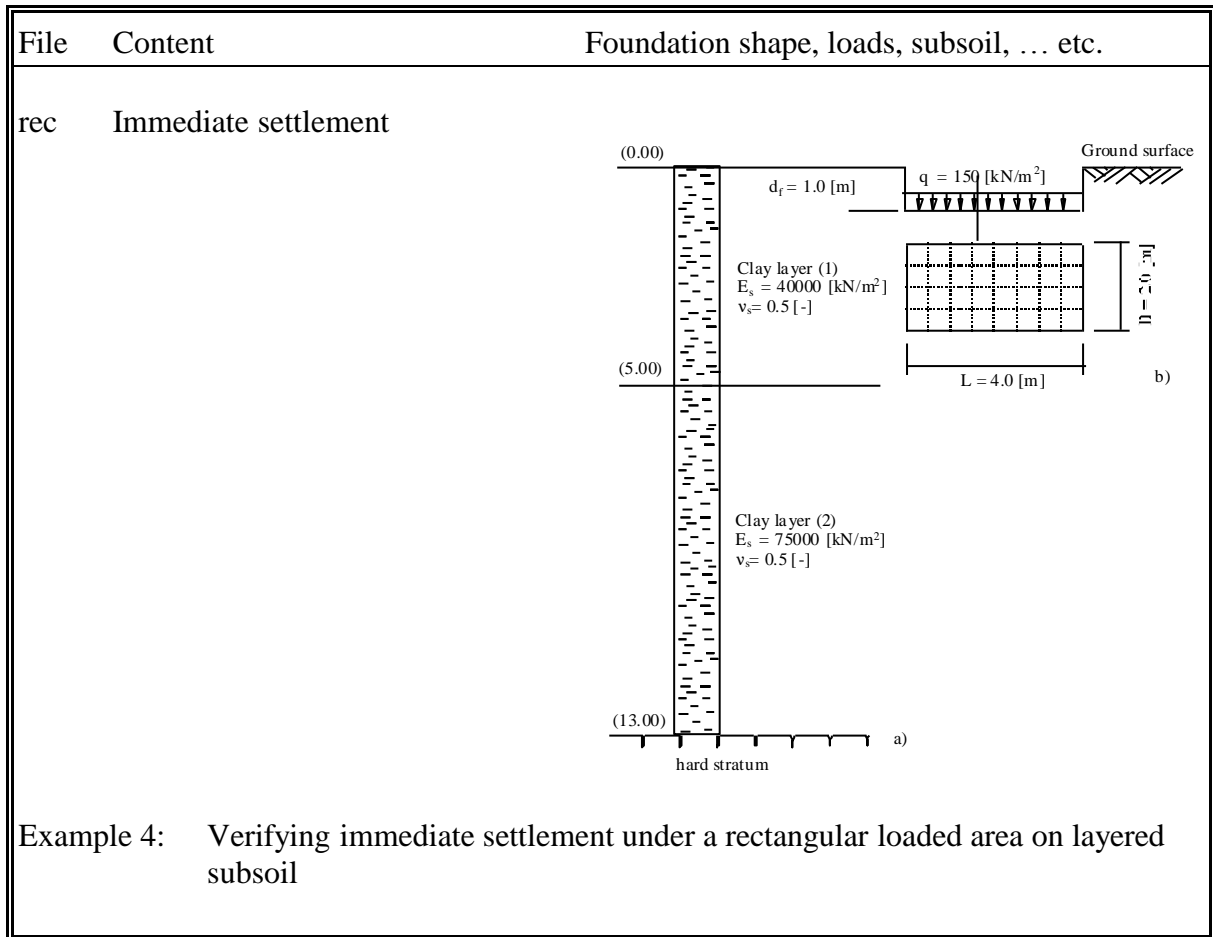
File	Content	Foundation shape, loads, subsoil, ... etc.
cir	Stress on soil	 <p>a)</p> <p>b)</p> <p>$q = 1000 \text{ [kN/m}^2\text{]}$</p> <p>$r = 5.0 \text{ [m]}$</p> <p>$z$</p> <p>$c$</p>

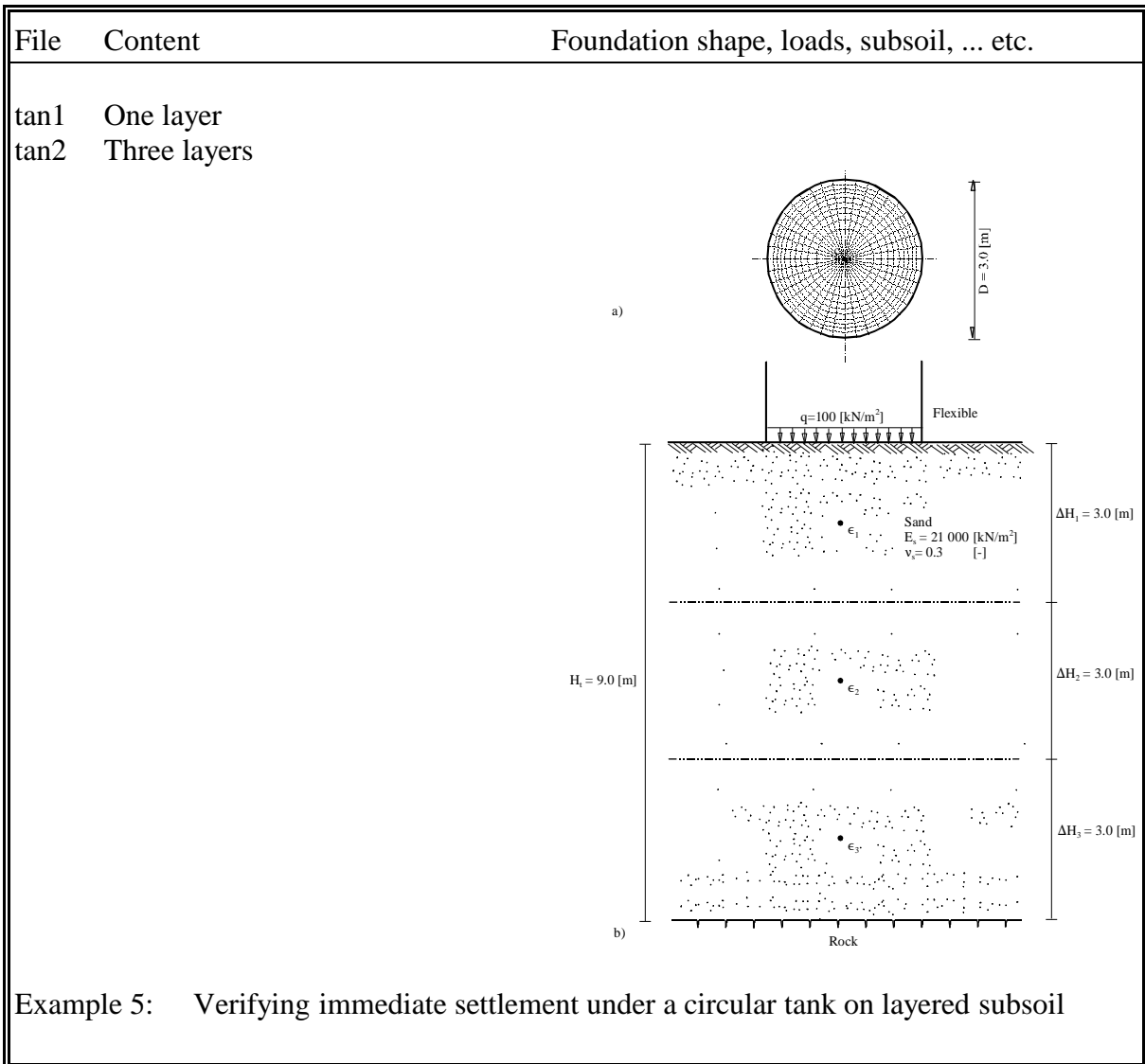
Example 2: Verifying stress on soil under a circular loaded area

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
circ	Circular area	<p>The diagrams illustrate three foundation shapes: <ul style="list-style-type: none"> 1: A square foundation with side length 10.0 [m]. 2: A circular foundation with a diameter of 10.0 [m]. 3: A rectangular foundation with length $L = 20.0 \text{ [m]}$ and width $B = 10.0 \text{ [m]}$. </p>
rec	Rectangular area	
squ	Square area	
<p>Example 3: Verifying immediate settlement under a loaded area on Isotropic elastic half-space medium</p>		

Examples to verify and illustrate *ELPLA*





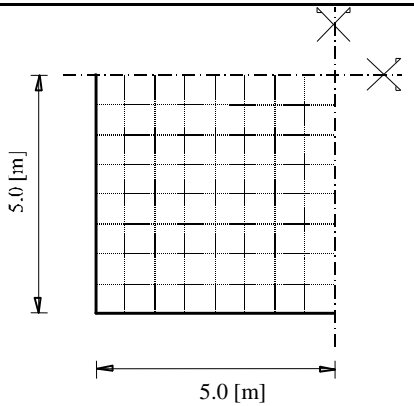
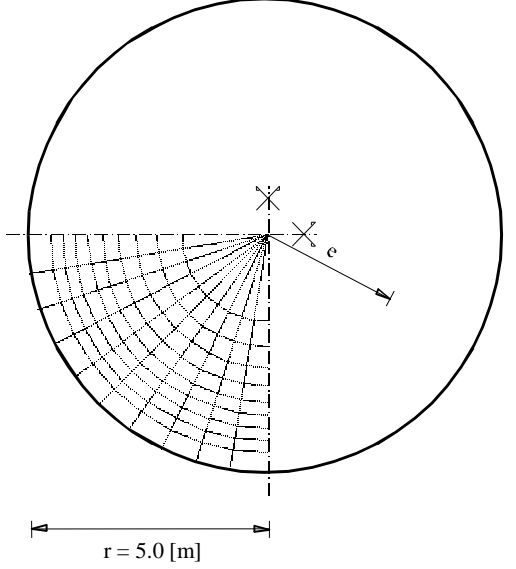
Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
Cons	Consolidation settlement	<p>a)</p> <p>b)</p>

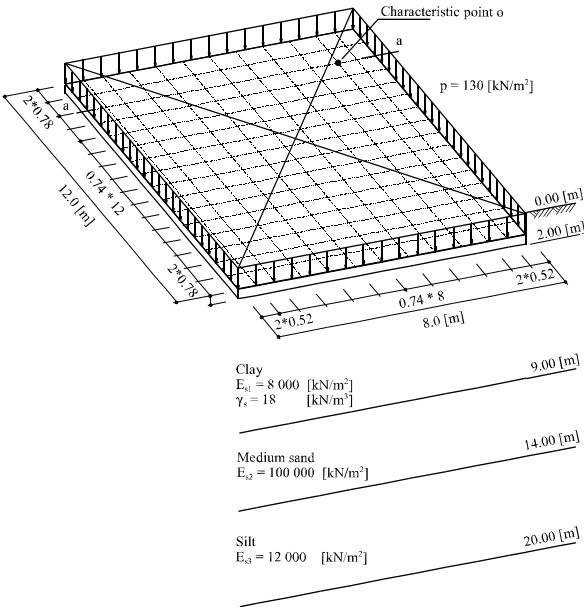
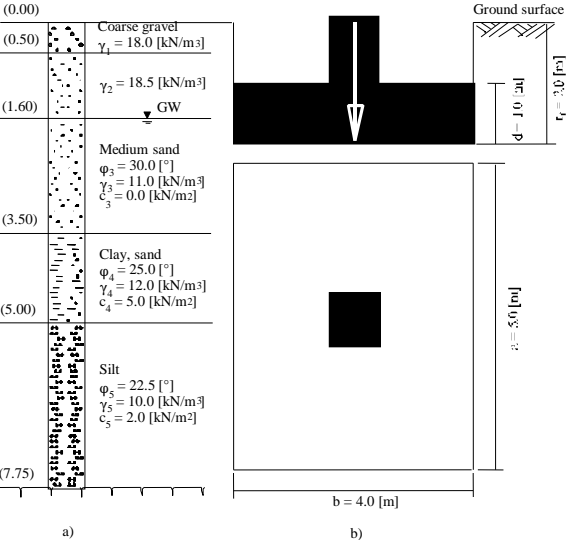
Example 6: Verifying consolidation settlement under a rectangular raft

File	Content	Foundation shape, loads, subsoil, ... etc.
scc	Consolidation settlement	<p>The diagram illustrates a circular footing with a diameter of $2b = 2.0$ [m] and a load $q = 150$ [kN/m²]. The soil profile consists of a sand layer (1.0 m thick, $\gamma = 17$ [kN/m³]) and a normally consolidated clay layer (5.0 m thick, $\gamma_{sat} = 9.19$ [kN/m³]). The clay layer is divided into four 1.0 m segments, each with a thickness $\Delta H_i = 1.0$ [m]. The groundwater table (GW) is located at a depth of 0.5 m. The vertical axis is labeled z and the total height of the clay layer is $H_c = 5.0$ [m]. The diagram also shows a mesh for settlement calculation and a vertical z-axis.</p>
Example 7: Verifying consolidation settlement under a circular footing		

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
<p>rf2 Raft with 2 * 2 net rf4 Raft with 4 * 4 net rf6 Raft with 6 * 6 net rf8 Raft with 8 * 8 net rf12 Raft with 12 * 12 net rf16 Raft with 16 * 16 net rf20 Raft with 20 * 20 net rf24 Raft with 24 * 24 net rf32 Raft with 32 * 32 net rf48 Raft with 48 * 48 net</p>		 <p>Example 8: Verifying rigid square raft on Isotropic elastic half-space medium</p>
rig	Rigid raft	 <p>Example 9: Verifying rigid circular raft on Isotropic elastic half-space medium</p>

Examples to verify and illustrate *ELPLA*

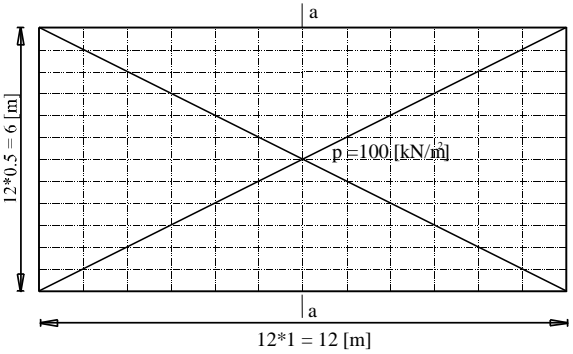
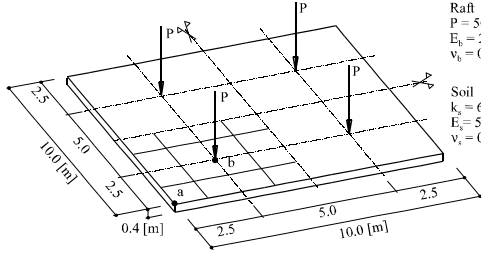
File	Content	Foundation shape, loads, subsoil, ... etc.
fle rig	Flexible raft Rigid raft	 <p>Clay $E_{s1} = 8\ 000$ [kN/m²] $\gamma_s = 18$ [kN/m³]</p> <p>Medium sand $E_{s2} = 100\ 000$ [kN/m²]</p> <p>Silt $E_{s3} = 12\ 000$ [kN/m²]</p>
Example 10: Verifying flexible foundation and rigid raft on layered subsoil		
bea	Ultimate bearing capacity	 <p>Coarse gravel $\gamma_1 = 18.0$ [kN/m³]</p> <p>Medium sand $\phi_3 = 30.0$ [°] $\gamma_3 = 11.0$ [kN/m³] $c_3 = 0.0$ [kN/m²]</p> <p>Clay, sand $\phi_4 = 25.0$ [°] $\gamma_4 = 12.0$ [kN/m³] $c_4 = 5.0$ [kN/m²]</p> <p>Silt $\phi_5 = 22.5$ [°] $\gamma_5 = 10.0$ [kN/m³] $c_5 = 2.0$ [kN/m²]</p>
Example 11: Verifying ultimate bearing capacity for a footing on layered subsoil		

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
lin	Simple assumption model	
Example 12: Verifying simple assumption model for irregular raft		
be1	Modulus of subgrade reaction	
Example 13: Verifying main modulus of subgrade reaction k_{sm}		

File	Content	Foundation shape, loads, subsoil, ... etc.
bea	Beam foundation	<p>Concrete C30/37</p> <p>$P = 1000 \text{ [kN/m]}$</p> <p>0.50 [m]</p> <p>$d = 0.60 \text{ [m]}$</p> <p>$k_s = 50\,000 \text{ [kN/m]}$</p> <p>$L = 5.0 \text{ [m]}$</p>
Example 14: Verifying beam foundation on elastic springs		
gri	grid foundation	<p>10 [m]</p> <p>P</p> <p>$p_l = 500 \text{ [kN/m]}$</p> <p>$P = 500 \text{ [kN]}$</p> <p>10 [m]</p> <p>1.25 1.25 1.25 2.50 1.25 1.25 1.25</p>
Example 15: Verifying grid foundation on elastic springs		

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
ma1	$k_B = \pi/30, d = 18.5$ [cm]	
ma2	$k_B = \pi/10, d = 26.7$ [cm]	
ma3	$k_B = \pi/3, d = 40$ [cm]	
<p>Example 16: Verifying elastic raft on Isotropic elastic half-space soil medium</p>		
win	<i>Winkler's model</i>	
iso	Half-space soil medium	
<p>Example 17: Verifying <i>Winkler's model</i> and Isotropic elastic half-space soil medium</p>		

File	Content	Foundation shape, loads, subsoil, ... etc.
ne1	Slab with 1 element	
ne4	Slab with 4 elements	
ne9	Slab with 9 elements	
ne16	Slab with 16 elements	
Example 18: Verifying simply supported slab		

au1	Method 4	
au2	Method 6	
au3	Method 7	
Example 19: Evaluation of iteration methods		

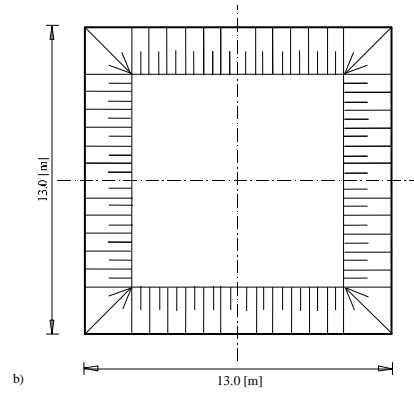
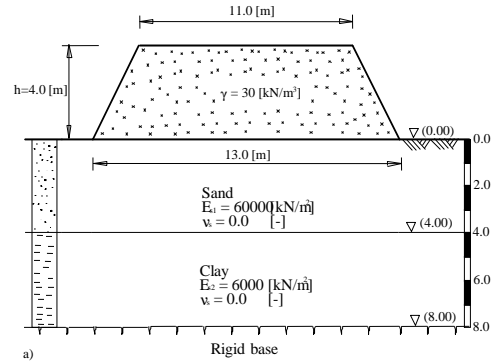
Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
vo1	$W_s = E_s$	<p style="text-align: center;"> $\nabla (0.00)$ $\nabla (2.50)$ $\nabla (7.50)$ Rigid base GW=(1.70) Silt $\gamma_{s1} = 19$ [kN/m³] $\gamma_{s2} = 9.5$ [kN/m³] $E_s = 4149$ [kN/m²] $W_s = 1244$ [kN/m] $\nu = 0.3$ [-] </p>
vo2	$W_s = 900\,000\,000$ [kN/m ²]	
vo3	$W_s = 3 * E_s$	
<p>Example 20: Examination of influence of overburden pressure</p>		
<p>Load geometry a</p> <p>qa1 Linear contact pressure method qa2 Modulus of subgrade reaction method qa3 Isotropic elastic half-space qa4 Modulus of compressibility method qa5 Rigid slab</p>		<p style="text-align: center;"> $B=12*0.833=10.0$ [m] $L=12*0.833=10.0$ [m] </p>
<p>Load geometry b</p> <p>qb1 Linear contact pressure method qb2 Modulus of subgrade reaction method qb3 Isotropic elastic half-space qb4 Modulus of compressibility method qb5 Rigid slab</p>		
<p>Load geometry c</p> <p>qc1 Linear contact pressure method qc2 Modulus of subgrade reaction method qc3 Isotropic elastic half-space qc4 Modulus of compressibility method qc5 Rigid slab</p>		<p style="text-align: center;"> $d = 0.4$ [m] $E_s = 10000$ [kN/m²] = W_s $k_s = 2000$ [kN/m³] $\nu_s = 0.2$ [-] </p> <p style="text-align: center;"> $z = 10.0$ [m] zusammendrückbare Schicht fester Untergrund </p>
<p>Load geometry d</p> <p>qd1 Linear contact pressure method qd2 Modulus of subgrade reaction method qd3 Isotropic elastic half-space qd4 Modulus of compressibility method qd5 Rigid slab</p>		

Example 21: Examination of influence of load geometry

File	Content	Foundation shape, loads, subsoil, ... etc.
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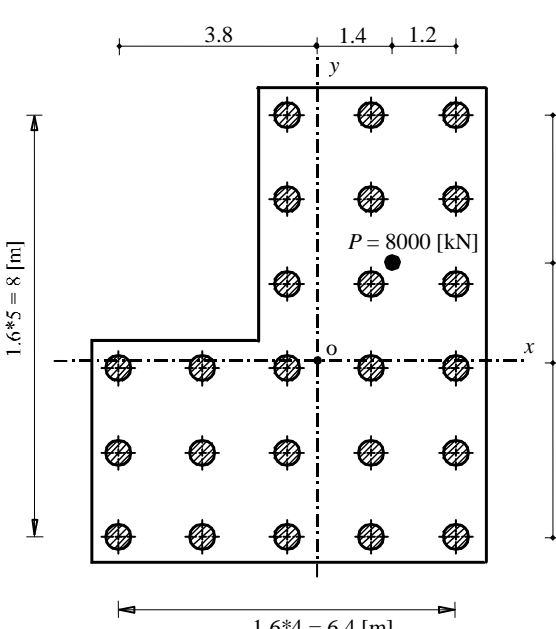
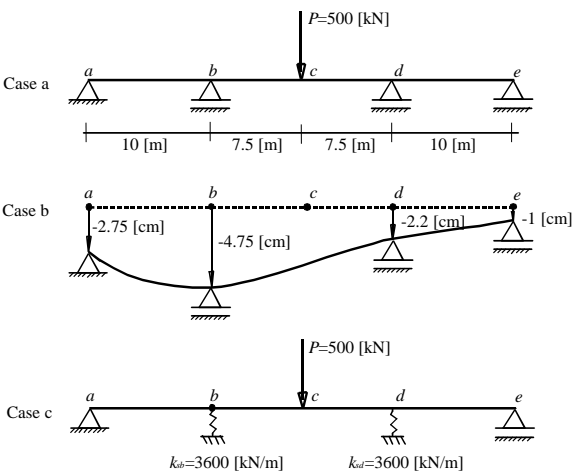
flex	Settlement calculation	
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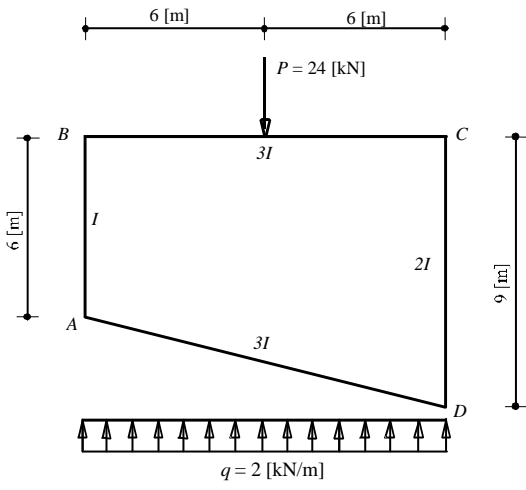
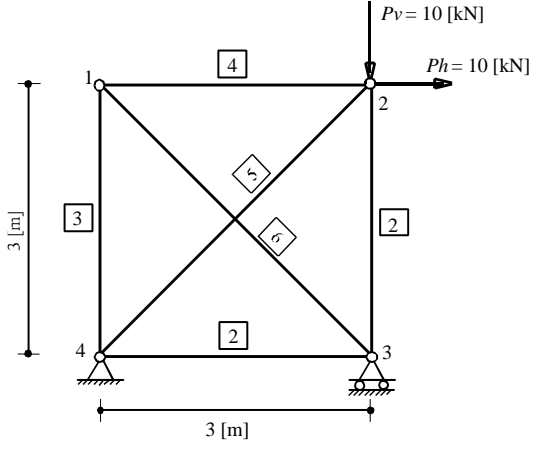
Example 22: Settlement calculation under flexible foundation of an ore heap

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
sta	Rigid raft	
Example 23: Settlement calculation for a rigid raft subjected to an eccentric load		
<p>Plane Stress 10 10</p> <p>Plane Stress 15 15</p> <p>Plane Stress 20 20</p> <p>Plane Stress 30 30</p>	<p>Mesh size 10 * 10 [cm²]</p> <p>Mesh size 15 * 15 [cm²]</p> <p>Mesh size 20 * 20 [cm²]</p> <p>Mesh size 30 * 30 [cm²]</p>	
Example 24: Verifying deflection of a thin cantilever beam		

File	Content	Foundation shape, loads, subsoil, ... etc.
Forces in piles	Pile group	
<p>Example 25: Verifying forces in piles of a pile group</p>		
Case a Case b Case c	Case a Case b Case c	
<p>Example 26: Verifying continuous beam</p>		

Examples to verify and illustrate *ELPLA*

File	Content	Foundation shape, loads, subsoil, ... etc.
Frame	Closed frame	 <p>Diagram of an unsymmetrical closed frame. The frame consists of nodes A, B, C, and D. The horizontal span is 12 m, divided into two 6 m segments. The vertical height is 9 m. The frame is supported by a uniformly distributed load $q = 2 \text{ [kN/m]}$ along the bottom edge AD. A vertical point load $P = 24 \text{ [kN]}$ is applied at the midpoint of the top edge BC. The frame members have different moments of inertia: I for member AB, $2I$ for members BC and CD, and $3I$ for members BA and AD.</p>
<p>Example 27: Verifying moments in an unsymmetrical closed frame</p>		
Plane Truss	Plane Truss	 <p>Diagram of a square plane truss. The truss has four nodes: 1 (top-left), 2 (top-right), 3 (bottom-right), and 4 (bottom-left). The truss is 3 m wide and 3 m high. It is supported by a pin support at node 4 and a roller support at node 3. A vertical load $P_v = 10 \text{ [kN]}$ and a horizontal load $P_h = 10 \text{ [kN]}$ are applied at node 2. The truss members are numbered: 2 (top horizontal), 3 (left vertical), 4 (top horizontal), 5 (diagonal from 1 to 3), 6 (diagonal from 2 to 4), and 2 (right vertical).</p>
<p>Example 28: Verifying plane truss</p>		

File	Content	Foundation shape, loads, subsoil, ... etc.
poi	Settlement calculation	<p>The diagram shows a square foundation divided into four quadrants by a vertical dashed line (line 3) and a horizontal dashed line (line 2). Each quadrant contains a central point load labeled $P = 500$. The corners of the square are marked with circled numbers: 1 at the top-left and bottom-right, and 2 at the top-right and bottom-left.</p>
Example 29: Influence of <i>Poisson's</i> ratio		