SO-Foundation

Version 2.3.8598.1

Verification Manual

This software is developed by Soil Office Software Group and is aimed at the bearing capacity of shallow footings considering both shear failure criterion and allowable settlement.

Soil Office

July 2023

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1 Introduction

This manual is to validate SO-Foundation using some practical examples presented in geotechnical engineering references and a means to introduce software menus and capabilities. Final results are compared in each case and the differences are investigated.

Note: Full descriptions regarding calculation theories and the list of symbols are accessible through the scientific manual downloadable at:

www.soiloffice.com

2 Examples

SO-Foundation calculates bearing capacity of shallow foundations considering both “shear failure” and “settlement”. Note that only one of the mentioned criteria is investigated in each of the validated examples. Thus, the available data are directly used and other parameters are assumed, which are not necessarily consistent with the others; these assumptions together with the cells having no effect on the final results, are hatched.

Whole manual and the verified examples are in “SI” units.

2-1 Bearing capacity considering shear failure – Terzaghi's equation

<u>Example 3.1 – reference no.01:</u> A square foundation is 2 [m] × 2 [m] in plan. Soil properties are as below. Determine the allowable gross pressure on the foundation with a factor of safety of 3. Assume that the depth of the foundation is 1.5 [m] and that general shear failure occurs in the soil.

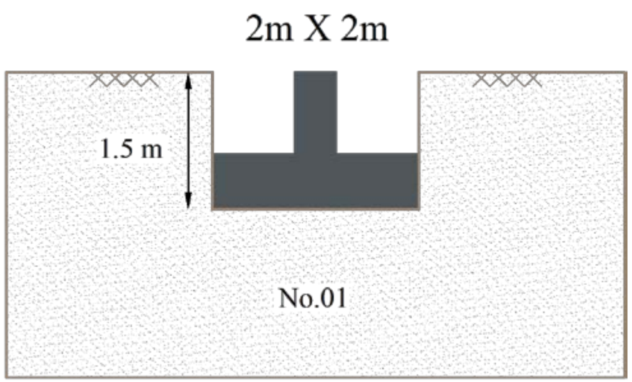

Figure 1 Problem geometry

No.	USCS	Bounds [m]	γ [kN/m^3]	ϕ [deg.]	c [kPa]	E_s [kPa]	ν	Consolidation	C_c	C_s	e_0	Auto	Sublayers
01		0.0 – 1000.0	16.5	25.0	20.0								

General	g [m/s^2]

T [m]	D [m]	D_w [m]
1.5	1.5	-

Footing type	B [m]	L/B
Spread	2.0	1.0

Shear failure	Method	Failure type	F.S.	RF_ϕ	RF_c
	Terzaghi	General	3.0		

Water effect

Large footing effect
False

As can be seen in the above tables:

- **General settings:** Footing is of spread type and according to the extension of the failure surface from the footing base to the ground surface, T and D are considered equal. Water table is not encountered in the project.
- **Shear failure:** Terzaghi's equation is used. General shear failure is assumed to occur and the factor of safety is 3. Large footing effect is also ignored.
- **Settlement:** These settings are not important.

By accessing "Results" section and afterwards "Shear failure & Settlement" tab, bearing capacity is presented by each of the criteria. Table 1 compares the software results with the reference. The reason for the difference lies within the equation used for N_γ which slightly differs from the values reported by Terzaghi.

Table 1

Parameter	Reference	Software	Difference
q_{all-sh}	359.5 [kPa]	363.2 [kPa]	1.0 [%]

2-2 Bearing capacity considering shear failure – Vesic's equation

<u>Example 6.3 – reference no.02:</u> Compute the ultimate bearing capacity of a 1.5 [m] thick mat foundation, according to the given soil layers and properties, by the use of Vesic's equation.

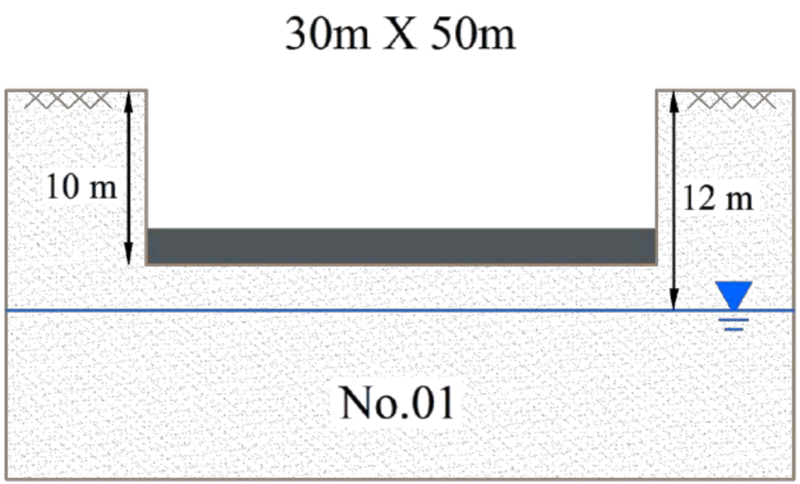

Figure 2 Problem geometry

No.	USCS	Bounds [m]	γ [kN/m^3]	ϕ [deg.]	c [kPa]	E_s [kPa]	ν	Consolidation	C_c	C_s	e_0	Auto	Sublayers
01		0.0 – 1000.0	18.5	30.0	0.0								

General	g [m/s^2]
	9.8

T [m]	D [m]	D_w [m]
1.5	10.0	12.0

Footing type	B [m]	L/B
Mat	30.0	1.667

Shear failure	Method	Failure type	F.S.	RF_ϕ	RF_c
	Vesic	General	1.0		

Water effect
Das

Large footing effect
False

- **General settings:** T and D are 1.5 and 10, respectively. Depth to water table measured from the ground surface (D_w) is 12 and the gravitational acceleration is 9.8 [m/s^2].
- **Shear failure:** Water effect is modified by Das's method. Despite the dimensions, large footing effect is not applied. Finally, by setting F.S. to 1, the allowable and ultimate bearing capacity would be the same.
- **Settlement:** These settings are not important.

The ultimate bearing capacity might be accessed by referring to "Results" section and afterwards "Shear failure & Settlement" tab. The software result is compared with the reference. It can be seen that rounding the values before using them in the bearing capacity equation, has caused a slight error in the reference.

Table 2

Parameter	Reference	Software	Difference
q_{ult-sh}	7455 [kPa]	7413.1 [kPa]	0.6 [%]

2-3 Stress increase due to footing load – Boussinesq’s method

<u>Example 5.3 – reference no.03:</u> A 800 [kN] load is applied to a square footing 2 [m] × 2 [m] in plan. Find the stress beneath the center (point O) at the depths of 0, 1, 2, 3 and 4 [m] using Boussinesq’s method.

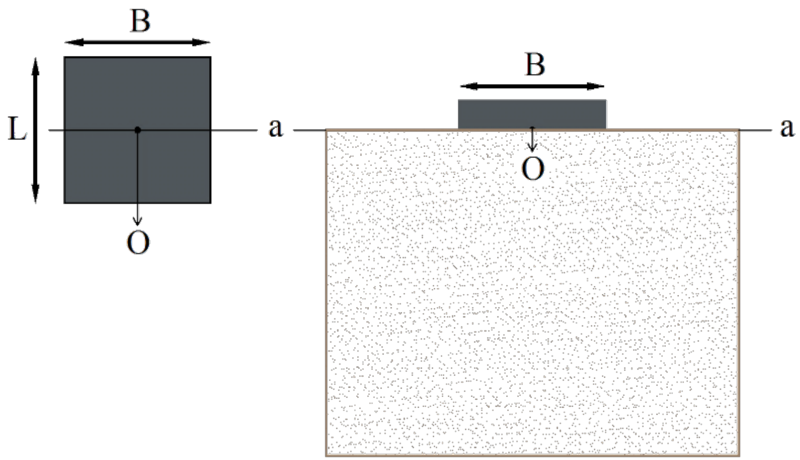

Figure 3 Location of pressure isobars beneath a footing

Pressure isobars are generated beneath line “a” (refer to Figure 3). These lines present the stress increase due to the footing load. The first step is to define the geometry of the problem, where in this case only the footing dimensions are important. Other parameters and inputs do not affect the output. By choosing Boussinesq’s method and the footing dimensions in the pressure isobars section, the stress distribution contours are generated beneath the footing. Finally, by clicking on various points, the coordinates and the corresponding stress increase due to the footing load (I [%]) are presented. Table 3 shows the consistency of the results.

Note that by choosing the effective stratum depth as a multiple of footing width and wisely meshing, calculations can be performed on all of the desired points and coordinates. For instance, Figure 4 shows the value of I at a depth of 4 [m] below the footing center.

Table 3

Parameter	Z [m]	Reference	Software	Difference
I	0	100.0 [%]	100.0 [%]	0.0 [%]
	1	70.0 [%]	70.1 [%]	0.1 [%]
	2	33.6 [%]	33.6 [%]	0.0 [%]
	3	18.0 [%]	17.9 [%]	0.6 [%]
	4	10.8 [%]	10.8 [%]	0.0 [%]

The value of I is also requested in the corner of the footing, but is ignored due to the current inability of the software to draw 3D contours.

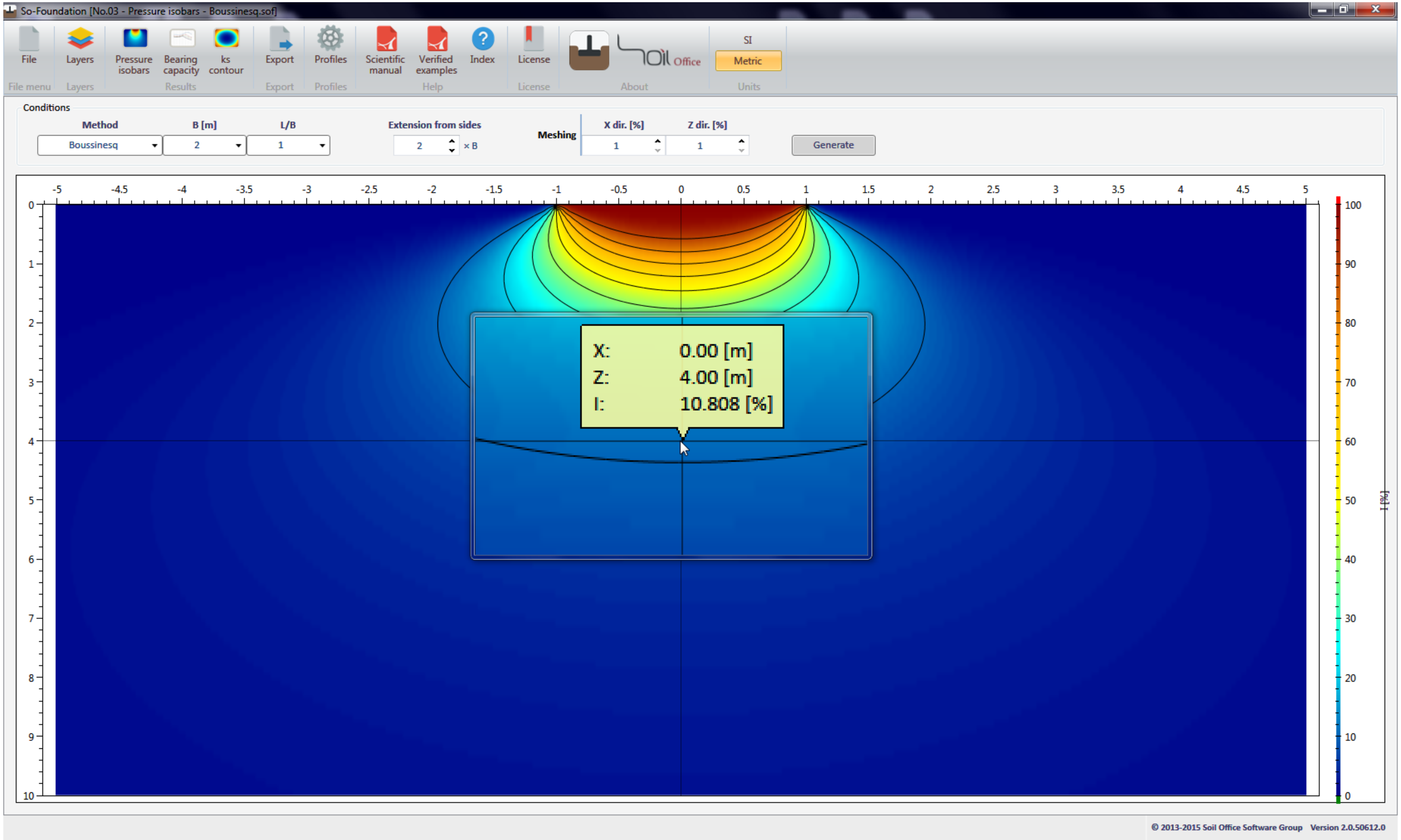

Figure 4 The value of I at a depth of 4 [m] beneath the footing center

2-4 Elastic settlement of a mat footing – Steinbrenner's method

Example 5.7 – reference no.03: Estimate the settlement of the raft (or mat) foundation for the "Savings Bank Building" given by Kay and Cavagnaro (1983) by the given data. The measured settlement is about 18 [mm].

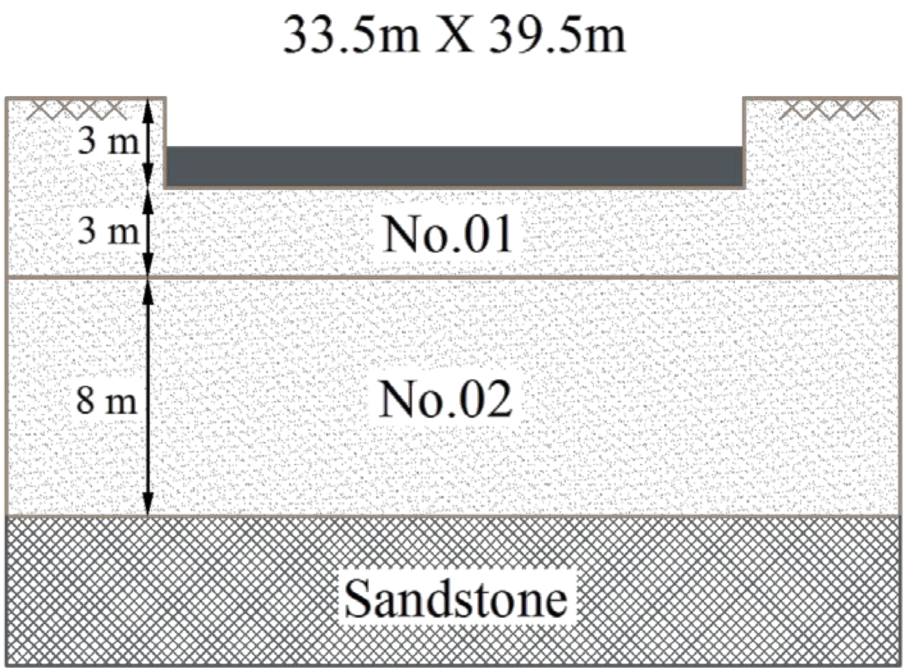

Figure 5 Problem geometry

No.	USCS	Bounds [m]	γ [kN/m^3]	ϕ [deg.]	c [kPa]	E_s [kPa]	ν	Consolidation	C_c	C_s	e_0	Auto	Sublayers
01	CL	0.0 – 6.0				42,500	0.35	False	-	-	-	-	1
02	CL	6.0 – 14.0				60,000	0.35	False	-	-	-	-	1
03	Rigid												

General

g [m/s^2]

T [m]	D [m]	D_w [m]
1.0	3.0	-

Footing type	B [m]	L/B
Mat	33.5	1.179104

Settlement

Basic

Allowable settlement [m]
0.0165

Effective stratum depth	Criteria	Method	Value [%]
	Pressure isobars	Approximate 2V:1H	0.01

Elastic

Es method	Excavation effect	
Weighted average	Er/Es	1.0

Influence factor	Rigidity	Criteria
Steinbrenner	Flexible	Center

Consolidation

P′c method	Loading effects	

α_{cons}	Excavation effect

- ❖ **General settings:** T and D are 1 and 3, respectively. Considering the mat footing type, footing thickness (T) does not affect the bearing capacity (based on shear failure criterion). Water table is not encountered.
- ❖ **Shear failure:** These settings are not important.
- ❖ **Settlement:** The following tips are essential:

  - SO-Foundation calculates bearing capacity considering the user-defined allowable settlement. Therefore, the resulting settlement in the reference (16.5 [mm]) is assumed as the allowable settlement and the corresponding bearing capacity is compared with the initial exerted pressure (134 [kPa]).
  - Using different options, the effective stratum depth should be equal to 11 [m] – the thickness of the compressible layer as defined by the problem. The following two methods can be employed:

    a. Defining a Rigid layer and setting the effective stratum depth criterion to the extent that exceeds the rigid layer and is not critical (same as the above table).
    b. Choosing the Approximate 2V:1H method in the pressure isobars criterion for the effective stratum depth, in a way that the effective depth equals the desired value:

$$I = \frac{B \times L}{(B + Z) \times (L + Z)} \rightarrow I = \frac{33.5 \times 39.5}{(33.5 + 11) \times (39.5 + 11)} = 58.883\ [\%]$$

- Referring to the problem, modulus of elasticity is defined by the “weighted average” method.
- Excavation effect is not taken into account, therefore $E_r/E_s = 1$. Using this option forces the modulus of elasticity to be the same in both static and reloading state.
- Footing is of flexible type and Steinbrenner’s method is applied.

The results would be:

Table 4

Parameter	Reference	Software	Difference
q_{set}	134 [kPa]	139.5 [kPa]	4.1 [%]

The reason for the difference in results lies within the approximate calculation of I_s and I_F in the reference.

Note: As an alternative to validate the software calculations, one can access the “q_{user}” mode in the “Load-Settlement” tab, input the pressure (134 [kPa]) and compare the resulting settlement with the reference.

2-5 Elastic and consolidation settlement of a spread footing

Example 3.15 – reference no.04: Estimate the total settlement of the foundation.

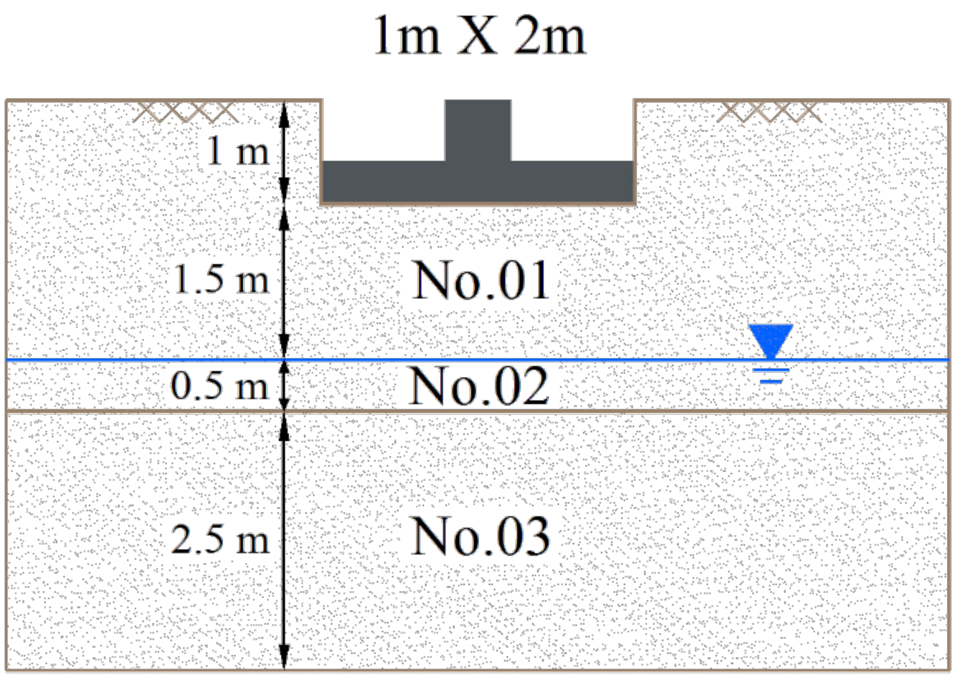

Figure 6 Problem geometry

No.	USCS	Bounds [m]	γ [kN/m^3]	ϕ [deg.]	c [kPa]	E_s [kPa]	ν	Consolidation	C_c	C_s	e_0	OCR	Sublayers
01	SP	0.0 – 2.5	16.5			10,000	0.3	False	-	-	-	1	1
02	SP	2.5 – 3.0	17.5			10,000	0.3	False	-	-	-	1	1
03	CL	3.0 – 1000.0	16.0			10,000	0.3	True	0.32	0.09	0.8	1	1

General

g [m/s^2]
9.81

T [m]	D [m]	D_w [m]
1.0	1.0	2.5

Footing type	B [m]	L/B
Spread	1.0	2.0

Settlement

Basic

Allowable settlement [m]
0.06328

Effective stratum depth	Criteria	Method	Value [%]
	Pressure isobars	Approximate 2V:1H	5.594

Elastic

Es method	Excavation effect	
Weighted average	Er/Es	1.0

Influence factor	Rigidity
Das	Rigid

Consolidation

P'c method	Loading effects	
OCR	Approximate 2V:1H	(T+4M+B)/6

α_{cons}	Excavation effect
1	False

- **General settings:** Both T and D are 1 [m]. Water table is located 2.5 [m] below the ground surface.
- **Shear failure:** These settings are not important.
- **Settlement:** The following tips are essential:

  - The same method described in section 2-4 is used in this example. The total settlement in the problem (63.28 [mm]) is assumed as the allowable settlement and the corresponding bearing capacity is compared with the initial exerted pressure (150 [kPa]).
  - Thickness of the compressible layer is 4.5 [m] and according to section 2-4, two approaches are available:

    a. Defining a Rigid layer and setting the effective stratum depth criterion to the extent that exceeds the rigid layer and is not critical.

    b. Choosing the Approximate 2V:1H method in the pressure isobars criterion for the effective stratum depth, in a way that the effective depth equals the desired value (same as the above table):

$$I = \frac{B \times L}{(B+Z)\times(L+Z)} \rightarrow I = \frac{1.0 \times 2.0}{(1.0+4.5)\times(2.0+4.5)} = 5.594\ [\%]$$

- Elastic settlement is calculated by using sand layer's properties. Considering the software's procedure to use the weighted average of the elastic parameters, sand layer's elastic properties (E_s and ν) have to be assigned to the whole problem.
- Excavation effect is ignored in the elastic settlement, thus $E_r/E_s = 1$.
- Footing is considered rigid and Das's influence factor is used.
- Soil layer is normally consolidated, therefore $OCR = 1$.
- Approximate 2v:1H method and the Simpson's rule are used for the calculation of stress increase due to the footing load.

$$\Delta q = {}^{1}/_{6}\left(\Delta q_{top} + 4\Delta q_{middle} + \Delta q_{bottom}\right)$$

- Initial effective overburden pressure (P_0') is calculated from the ground surface, therefore excavation effect is ignored in consolidation settlement.
- Consolidation settlement is completely considered in the calculations, therefore $\alpha_{cons} = 1$.

Final results are:

Table 5

Parameter	Reference	Software	Difference
q_{set}	150 [kPa]	149.6 [kPa]	0.3 [%]

The slight difference is originated from the value of α_r derived from the graph.

Note: As an alternative same as the previous example, the input of 150 [kPa] in the "q_{user}" mode of the "Load-Settlement" tab, results in a settlement close to 63.28 [mm].

2-6 Modulus of subgrade reaction across the footing

Example 10.2 – reference no.03: Calculate the modulus of subgrade reaction in a mat footing as below:

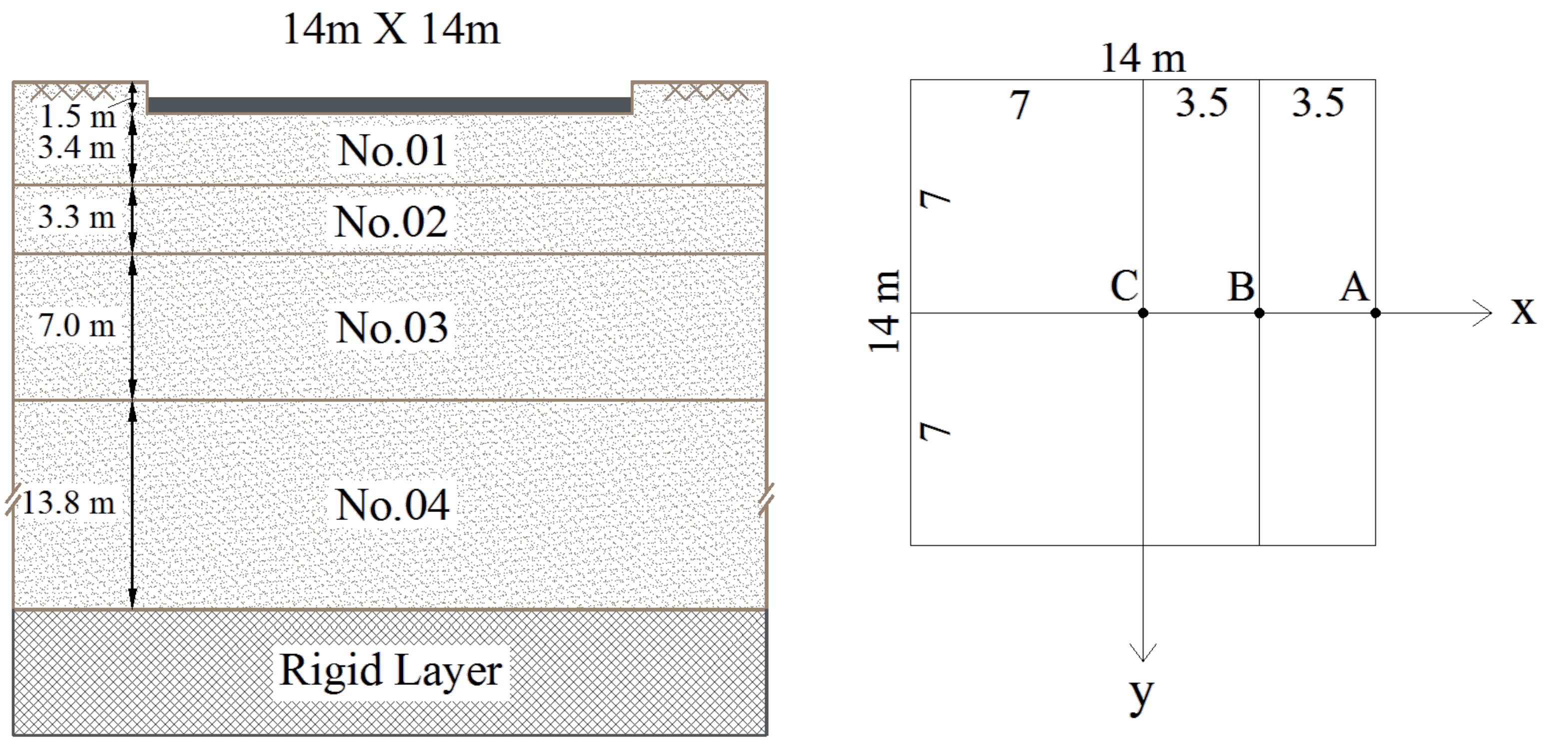

Figure 7 Problem geometry

No.	USCS	Bounds [m]	γ [kN/m³]	ϕ [deg.]	c [kPa]	E_s [kPa]	ν	Consolidation	C_c	C_s	e_0	Auto	Sublayers
01	CL-ML	0 – 4.9				150,000	0.3	False	-	-	-	-	1
02	SW	4.9 – 8.2				18,950	0.3	False	-	-	-	-	1
03	SW	8.2 -15.2				22,000	0.3	False	-	-	-	-	1
04	SW	15.2 -29.0				32,900	0.3	False	-	-	-	-	1
05	Rigid												

General	g [m/s²]	T [m]	D [m]	D_w [m]	Footing type	B [m]	L/B
		1.5	1.5	-	Mat	14.0	1.0

Settlement						
Basic	Allowable settlement [m]		Effective stratum depth	Criteria: Pressure isobars	Method: Approximate 2V:1H	Value [%]: 0.01
Elastic	Es method: Weighted average	Excavation effect: Er/Es 1.0		Influence factor: Steinbrenner	Rigidity: Flexible	Criteria: Center
Consolidation	P′c method	Loading effects		α_{cons}	Excavation effect	

- **General settings:** T and D are both 1.5 [m] and water table is not encountered.
- **Shear failure:** Taking into account that no consolidation settlement occurs, the modulus of subgrade reaction does not depend on these settings.
- **Settlement:** The following tips are essential:

  - This problem is in continuation of example 10-1 of the same reference and since no consolidation settlement occurs, modulus of subgrade reaction is independent of the allowable settlement.
  - Referring to the previous descriptions (sections 2-4 and 2-5), the 27.5 [m] effective stratum depth is applied by defining a rigid layer.
  - Excavation effect is ignored in the elastic settlement, thus $E_r/E_s = 1$.
  - Footing is considered flexible and Steinbrenner’s influence factor is used.

Modulus of subgrade reaction is a single value in a rigid footing but varies across the base of a flexible one. Therefore calculations are performed in various points in flexible footings and the result is presented as contours. By clicking on any arbitrary point within the generated shadings, the corresponding coordinates and the modulus of subgrade reaction are presented. Figure 8 shows the value of K_s in point *B*, for instance.

Final results are compared below:

Table 6

Parameter	Location	Reference	Software	Difference
k_s	A	6887 [kN/m^3]	6906.0 [kN/m^3]	0.3 [%]
	B	4445 [kN/m^3]	4428.1 [kN/m^3]	0.4 [%]
	C	4167 [kN/m^3]	4132.5 [kN/m^3]	0.8 [%]

The approximate calculation of I_s and I_F in the reference has led to slight differences which may be ignored.

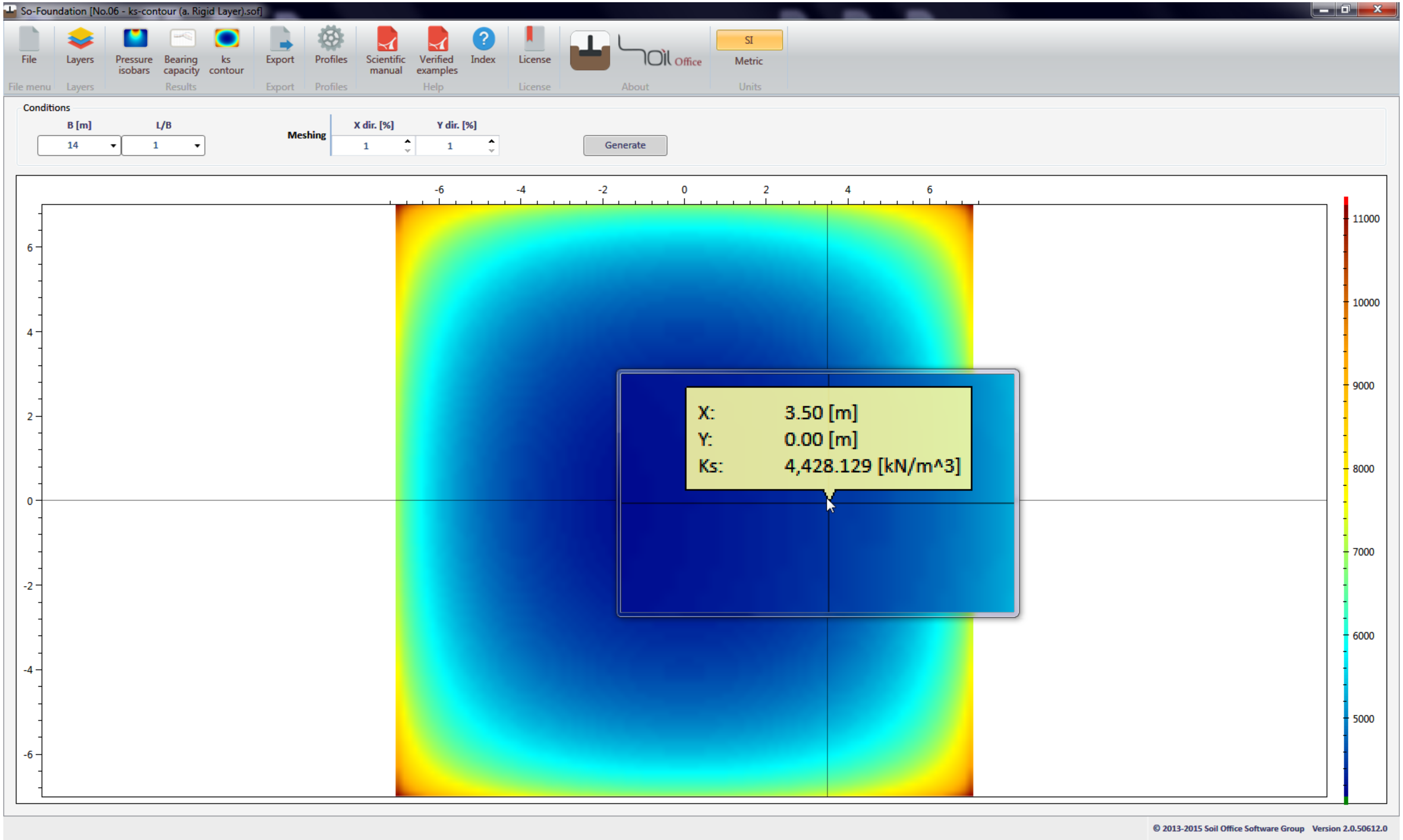

Figure 8 Modulus of subgrade reaction at point B of the footing base

REFERENCES

[1] B. M. Das, Principles of Foundation Engineering, 7th ed., Stamford: Cengage Learning, 2010.

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[3] J. E. Bowles, Foundation Analysis and Design, 5th ed., New York: McGrow-Hill, 1997.

[4] ب. ام. داس، اصول مهندسی ژئوتکنیک، ویرایش دوم، جلد ۲، تهران: موسسه انتشارات پارس آئین، ۱۳۸۳.