SOFiSTiK

Benchmark Example No. 36

Pushover Analysis: Performance Point Calculation by ATC-40 Procedure

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VERiFiCATiON
BE36 Pushover Analysis: Performance Point Calculation by ATC-40 Procedure

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Front Cover

Volkstheater, Munich Photo: Florian Schreiber

Overview	
Element Type(s):	
Analysis Type(s):	
Procedure(s):	
Topic(s):	EQKE
Module(s):	SOFiLOAD
Input file(s):	pushover-pp-atc.dat

1 Problem Description

The following example is intended to verify the ATC-40 procedure for the calculation of the performance point (illustrated schematically in Fig. 1), as implemented in SOFiSTiK. The elastic demand and capacity diagrams are assumed to be know.

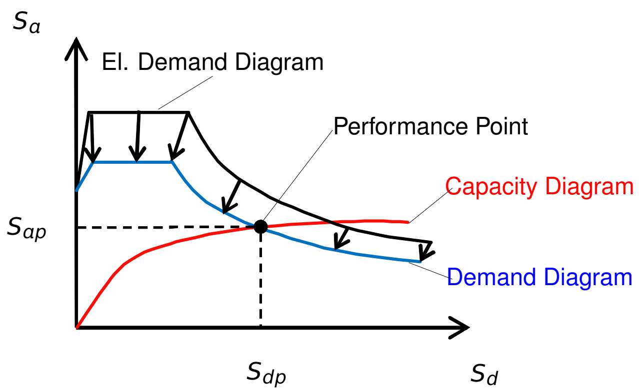

Figure 1: Determination of the performance point PP (S_{dp}, S_{ap})

2 Reference Solution

The reference solution is provided in [1], 8.3.3.3 "Performance Point Calculation by Capacity Spectrum Method - Procedure A".

Assuming that the elastic demand diagram (5% elastic response spectrum in ADRS format[1]) and the capacity diagram are known, it is possible to determine the performance point PP (S_{dp}, S_{ap}) (Fig. 1). The procedure comprises of a series of trial calculations (trial performance points PP_t $(S_{dp,t}, S_{ap,t})$), in which the equivalent *inelastic* single degree of freedom system (SDOF), represented by the capacity diagram, is transformed to an equivalent *elastic* SDOF system whose response in form of the performance point PP is then calculated from the reduced elastic response spectrum (demand diagram). The computation stops when the performance point PP is within a tolerance of a trial performance point PP_t. The ATC-40 Procedure A is a semi-analytical procedure since it involves graphical bilinear idealization of the capacity diagram. Detailed description of this step-by-step procedure can be found in [1].

3 Model and Results

In order to verify the analysis procedure for the determination of the performance point, a test case has been set up in such a way that it comprises of a SDOF with a unit mass and a non-linear spring element. It is obvious that for such an element the quantities governing the transformation from the original system

[1]ADRS = Spectral Acceleration S_a - Spectral Displacement S_d format

to the equivalent inelastic SDOF system must be equal to one, i.e.

$$\phi_{cnod} = 1 \quad ; \quad \Gamma = 1 \quad ; \quad m = 1 \,, \tag{1}$$

where ϕ_{cnod} is the eigenvector value at control node, Γ is the modal participation factor and m is the generalized modal mass. Writing now the equations which govern the conversion of the pushover curve to capacity diagram, we obtain [2]

$$S_d = \frac{u_{cnod}}{\phi_{cnod} \cdot \Gamma} = u_{cnod} \,, \tag{2a}$$

$$S_a = \frac{V_b}{\Gamma^2 \cdot m} = V_b \,, \tag{2b}$$

where V_b is the base shear and u_{cnod} is the control node displacement.

Since the original system is a SDOF system, V_b and u_{cnod} are nothing else but the force in spring P and the displacement of the unit mass u, respectively. It follows further that the force-displacement work law assigned to the spring element corresponds to the capacity diagram in ADRS format, with the force P and displacement u equal to S_a and S_d, respectively.

The capacity diagram used in the reference example is defined by four points, whose coordinates are listed in the Table 1. According to the analysis above, these points can be used to define the force-displacement work law $P - u$ of the non-linear spring element (Fig.2).

Table 1: Model Properties [1]

Capacity Diagram		Elastic Demand
Point	$(S_d[mm],\ S_a[m/s^2])$	UBC 5% Elastic Response Spectrum.
A	$(\ 48.77,\ 2.49)$	Seismic Zone 4, ZEN = 0.40.
B	$(\ 71.37,\ 3.03)$	No near-fault effects.
C	$(\ 96.01,\ 3.39)$	Soil Profile:
D	$(199.14,\ 3.73)$	- Type S_B: $C_A = 0.40, C_V = 0.40$
		- Type S_D: $C_A = 0.44, C_V = 0.64$

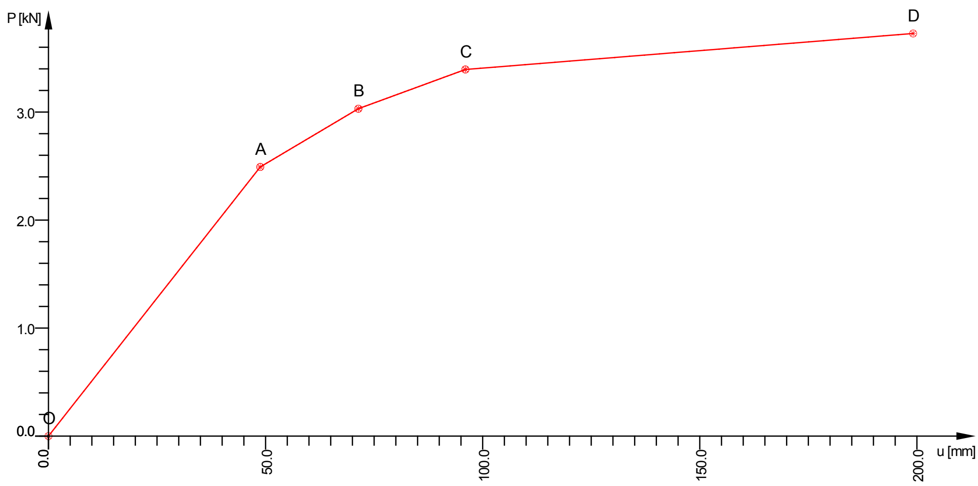

Figure 2: Force-displacement work law of the non-linear spring

The elastic demand is an UBC 5% damped elastic response spectrum, whose properties are summarized in Table 1. Two soil profile types are considered - soil profile type S_B and S_D.

The outcome of the analysis is shown in Figures 3 and 4.

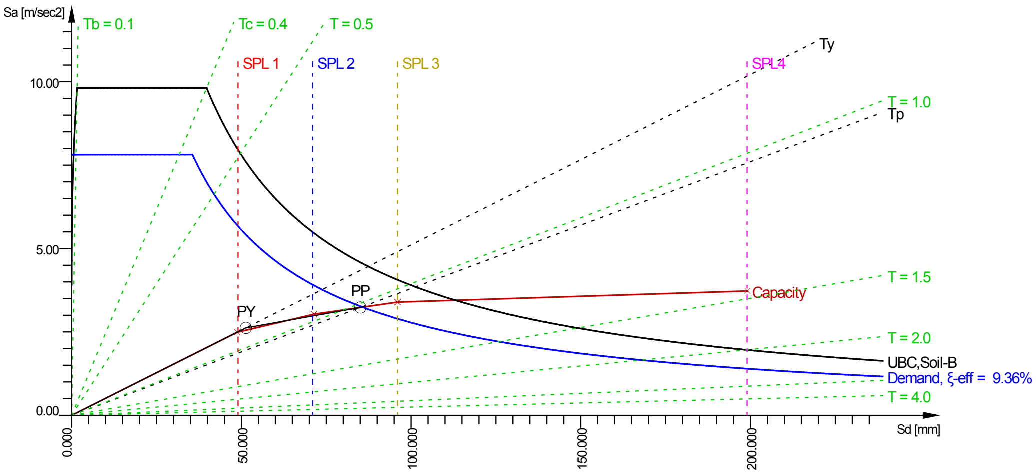

Figure 3: Capacity-Demand-Diagram (Soil Profile Type S_B)

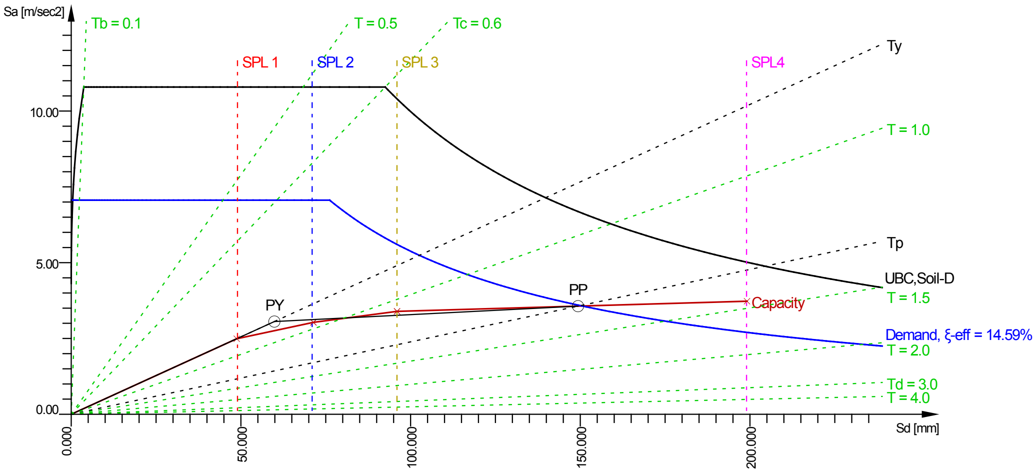

Figure 4: Capacity-Demand-Diagram (Soil Profile Type S_D)

The results of the SOFiSTiK calculation and the comparison with the reference solution are summarized in Table 2.

Table 2: Results

Soil type		ξ_{eff} [%]	SR_a [−]	SR_v [−]	S_{dy} [mm]	S_{ay} [m/s^2]	S_{dp} [mm]	S_{ap} [m/s^2]
S_B	SOF.	9.4	0.80	0.84	51.30	2.62	85.04	3.23
	Ref. [1]	9.2	0.80	0.85	53.34	2.65	83.36	3.24
	|e| [%]	2.2	0.0	1.2	3.8	1.1	2.0	0.3
	SOF.	14.6	0.65	0.73	59.86	3.06	149.34	3.57

Table 2: (continued)

Soil type		ξ_{eff} [%]	SR_a [−]	SR_v [−]	S_{dy} [mm]	S_{ay} [m/s²]	S_{dp} [mm]	S_{ap} [m/s²]
S_D	Ref. [1]	14.2	0.66	0.74	58.42	3.04	149.86	3.63
	$\lvert e \rvert$ [%]	2.8	1.5	1.4	2.5	0.7	0.3	1.7

ξ_{eff} effective viscous damping of the equivalent linear SDOF system
SR_a, SR_v spectral reduction factors in constant acceleration and constant velocity range of spectrum
S_{dy}, S_{ay} spectral displacement and spectral acceleration at yielding point
S_{dp}, S_{ap} spectral displacement and spectral acceleration at performance point

The results are in excellent agreement with the reference solution. Small differences can mainly be attributed to the approximate nature of the graphical procedure for the bilinear idealization of the capacity used in the reference solution, while the procedure implemented in SOFiLOAD is refrained from such approximation and computes the hysteretic energy directly from the area underneath the capacity curve and the coordinates of the performance point [2]. Apart from that, the performance point displacement tolerance used in SOFiLOAD is lower than the one used in the reference solution (1% compared to 5%).

4 Conclusion

Excellent agreement between the reference and the results computed by SOFiSTiK verifies that the procedure for the calculation of the performance point according to ATC-40 is adequately implemented.

5 Literature

[1] ATC-40. *Seismic Evaluation and Retrofit of Concrete Buildings*. Applied Technology Council. Redwood City, CA, 1996.

[2] *SOFiLOAD Manual: Loads and Load Functions*. Version 2018-0. SOFiSTiK AG. Oberschleißheim, Germany, 2017.