Benchmark Example No. 47

Pushover Analysis: SAC LA9 Building

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VERiFiCATiON
BE47 Pushover Analysis: SAC LA9 Building

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Front Cover

6th Street Viaduct, Los Angeles Photo: Tobias Petschke

Overview	
Element Type(s):	B3D
Analysis Type(s):	MNL
Procedure(s):	EIGE
Topic(s):	EQKE
Module(s):	ASE, SOFiLOAD
Input file(s):	pushover_sac_la9.dat

1 Problem Description

In this example a pushover analysis of a moment resisting frame structure is performed. The pushover curve is identified and compared to the reference solution, as described in Chopra [1].

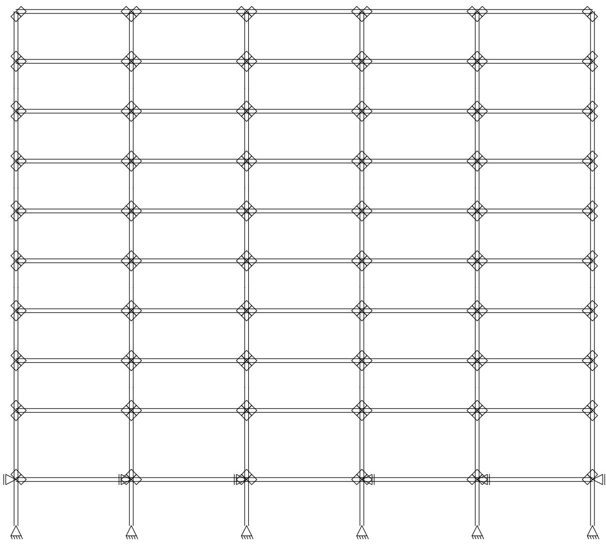


Figure 1: Problem Description

2 Reference Solution

In this Benchmark the interest is focused in the retrieval of the pushover curve. The steps involved in this process are described schematically in Figure 2. Important is the definition of the pushover lateral load case pattern. The pushover analysis is performed by subjecting the structure to this monotonically increasing load pattern of lateral forces. Here the first three eigenmodes of the structure will be used. Choosing the characteristic force and displacement of the structure, a so called *pushover curve* of the multi-degree-of-freedom (MDOF) system can be obtained. The force, here denoted as V_b, is usually *base-shear*, while the displacement is a displacement of the characteristic point on the structure u_{cnod}, also called the *roof displacement* and the *control node displacement*.

3 Model and Results

The properties of the model are presented in Table 1 and Figure 3. The model utilised in this Benchmark consists of the benchmark structure for the SAC project, as has been described by Gupta and Krawinkler [2], Chopra and Goel [1] and FEMA [3].

“The 9-story structure, was designed by Brandow & Johnston Associates for the SAC2 Phase II Steel Project. Although not actually constructed, this structure meets seismic code and represents typical

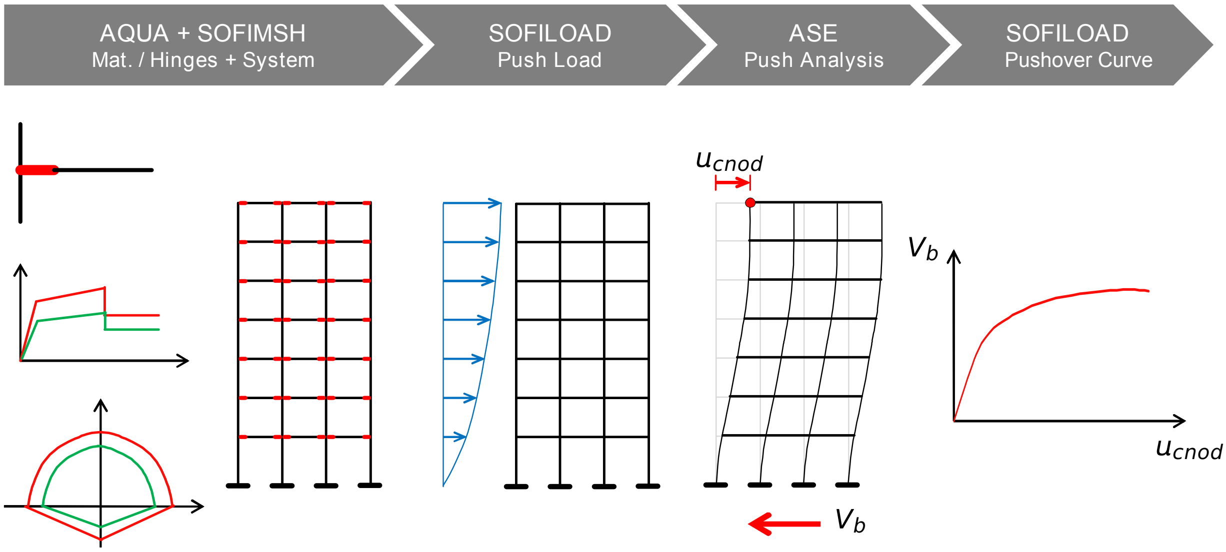


Figure 2: Pushover curve determination workflow

medium-rise buildings designed for the Los Angeles, California, region. The building is square in plan and rises nine floors above ground in elevation. The bays are $9.15\ m$ on center, in both directions, with five bays each in the north-south (N-S) and east-west (E-W) directions. The buildingâ€™s lateral load-resisting system is composed of steel perimeter moment-resisting frames (MRFS) with simple (simple hinged connection) framing on the farthest south E-W frame. The columns are steel wide-flange sections. The levels of the 9-story building are numbered with respect to the ground level, with the ninth level being the roof. The building has a basement level, denoted B-1. The column lines employ two-tier construction, i.e., monolithic column pieces are connected every two levels beginning with the first level. Column splices, which are seismic (tension) splices to carry bending and uplift forces, are located on the first, third, fifth, and seventh levels at $h_s = 1.83\ m$ above the center-line of the beam to column joint. The column bases are modeled as pinned and secured to the ground (B-1). Concrete foundation walls and surrounding soil are assumed to restrain the structure at the ground level from horizontal displacement. The floor system is composed of steel wide-flange beams in acting composite action with the floor slab. Each frame resists one half of the seismic mass associated with the entire structure. The seismic mass of the structure is due to various components of the structure. The model is based on centerline dimensions of the bare frame in which beams and columns extend from centerline to centerline. The strength, dimension, and shear distortion of panel zones are neglected.” [1]

“Shear deformations in beam and column elements are neglected. Plastic zones in beams and columns are modeled as point hinges. The hysteretic behavior at plastic hinge locations is described by a bilinear moment-rotation diagram. All elements have 3% strain hardening. Expected rather than nominal yield strength values are used ($49.2\ ksi$ for $A\ 36$ steel and $57.6\ ksi$ for $A\ 50$ steel). Viscous damping 2% is used in first mode and at $T = 0.2\ sec$.” [3]

Table 1: Model Properties

Material	Geometry
$A\ 50$	$l = 9.15\,m$
$A\ 36$	$h_b = 3.65\,m$, $h_g = 5.49\,m$
	$h_f = 3.96\,m$, $h_s = 1.83\,m$

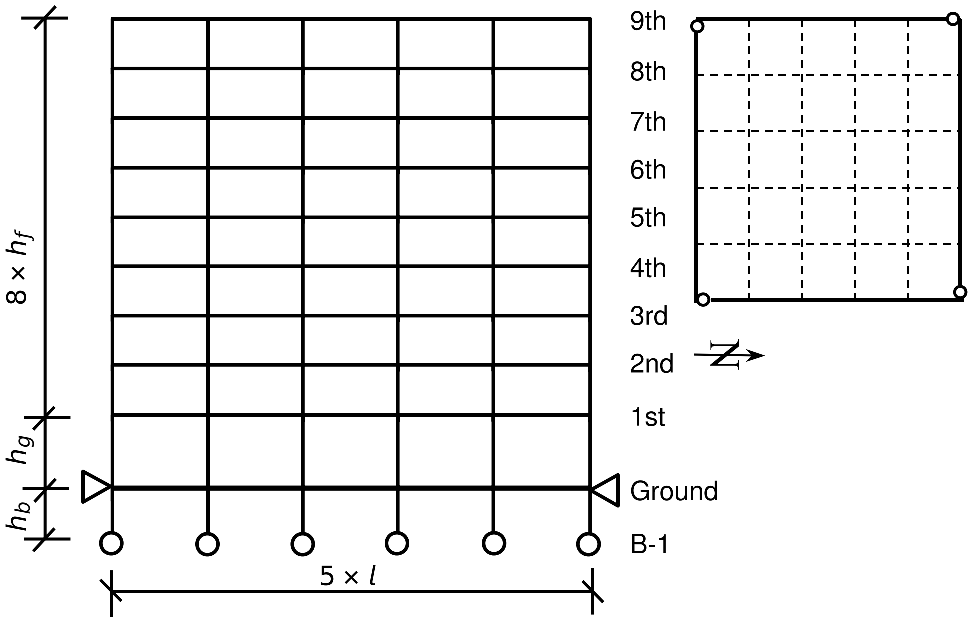
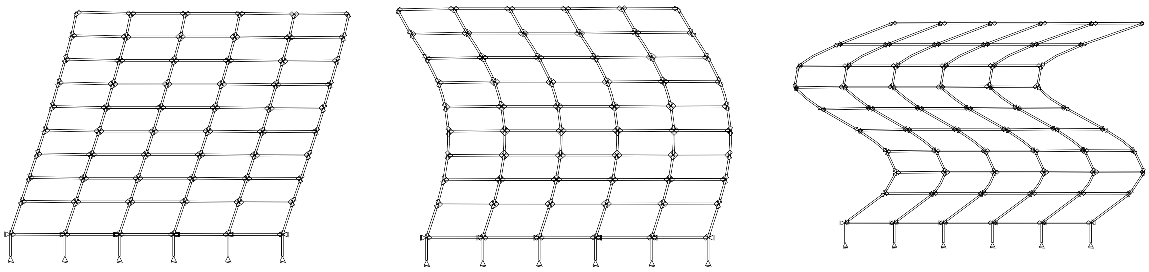


Figure 3: Model Description



(a) Mode 1

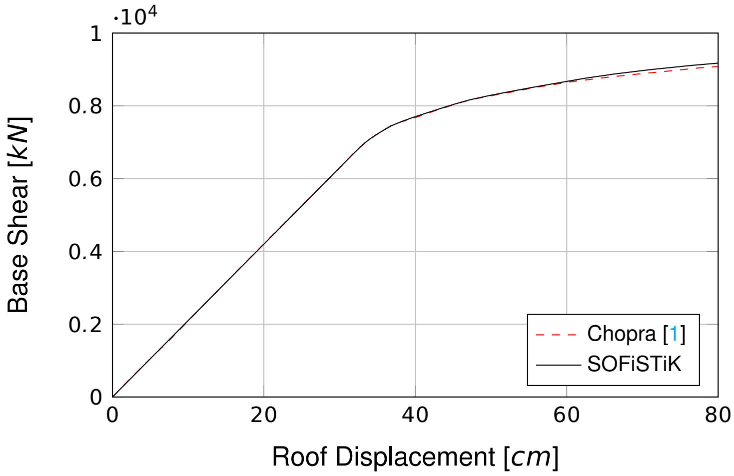
(b) Mode 2

(c) Mode 3

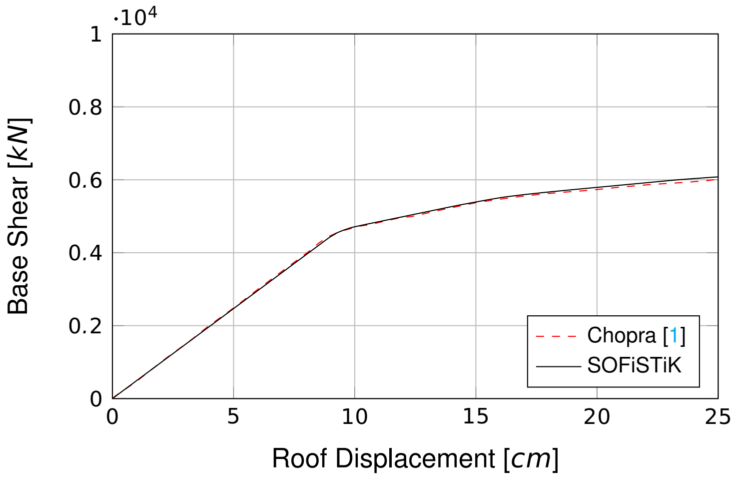
Figure 4: Eigenmodes

Table 2: First three natural-vibration periods

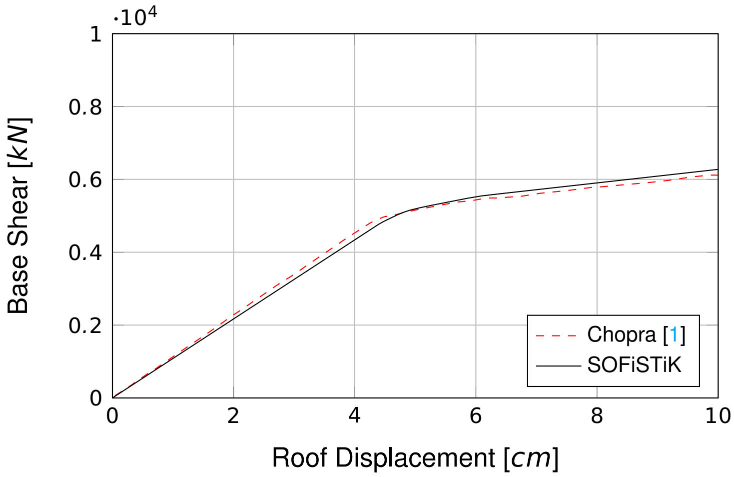
Periods	Ref. [1]	SOF.
T_1	2.27	2.26
T_2	0.85	0.85
T_3	0.49	0.49



(a) Mode 1 Pushover Curve



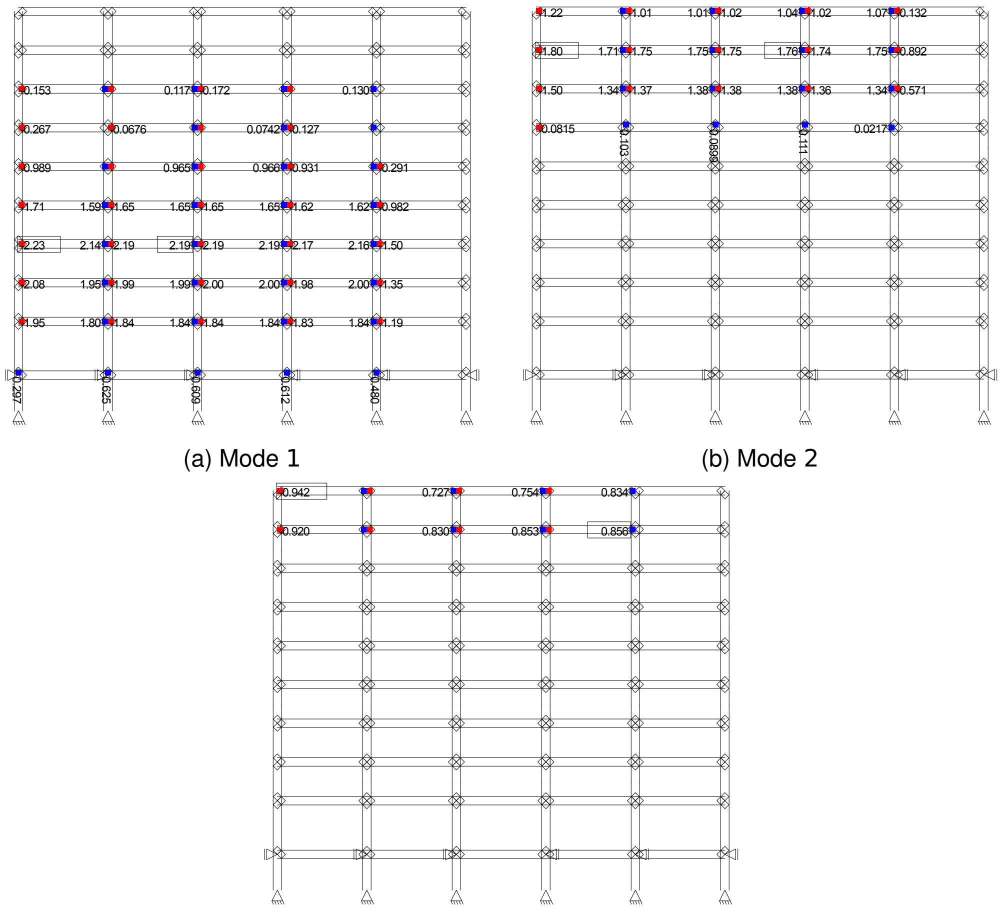
(b) Mode 2 Pushover Curve



(c) Mode 3 Pushover Curve

Figure 5: Pushover Curves

The first three vibration modes and periods of the building for linearly elastic vibration are shown in Figure 4. The vibration periods are 2.26, 0.85, and 0.49 sec, respectively. The force distributions of these first three modes are used in the pushover analysis in order to retrieve the pushover curves. The pushover curves for the first three eigenmodes, are presented in Figures 5. The hinge formation distribution for each pushover analysis, corresponding to approximatelly the last load case depicted in each pushover curve, is presented in Figures 6.



(a) Mode 1 (b) Mode 2

(c) Mode 3

Figure 6: Hinge distribution

4 Conclusion

This example adresses the determination of the pushover curve for a benchmark structure. It has been shown that the results obtained are in a good agreement with the reference given by Chopra [1].

5 Literature

[1] A.K. Chopra and R. K. Goel. *A Modal Pushover Analysis Procedure to Estimate Seismic Demands for Buildings: Theory and Preliminary Evaluation*. Tech. rep. PEER Report 2001/03. Pacific Earthquake Engineering Research Center - University of California Berkeley, 2001.

[2] A. Gupta and H. Krawinkler. *Seismic Demands for Performance Evaluation of Steel Moment Resisting Frame Structures*. Tech. rep. Report No. 132. The John A. Blume Earthquake Engineering Center, 1999.

[3] Prepared for the SAC Joint Venture Partnership by Helmut Krawinkler. *State of the Art Report on Systems Performance of Steel Moment Frames Subject to Earthquake Ground Shaking*. Tech. rep. FEMA-355C. Federal Emergency Management Agency (FEMA), 2000.