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ProtaStructure Design Guide

Calculation Target Displacement for Pushover Analysis(FEMA 356)

Version 1.0 21 April 2022

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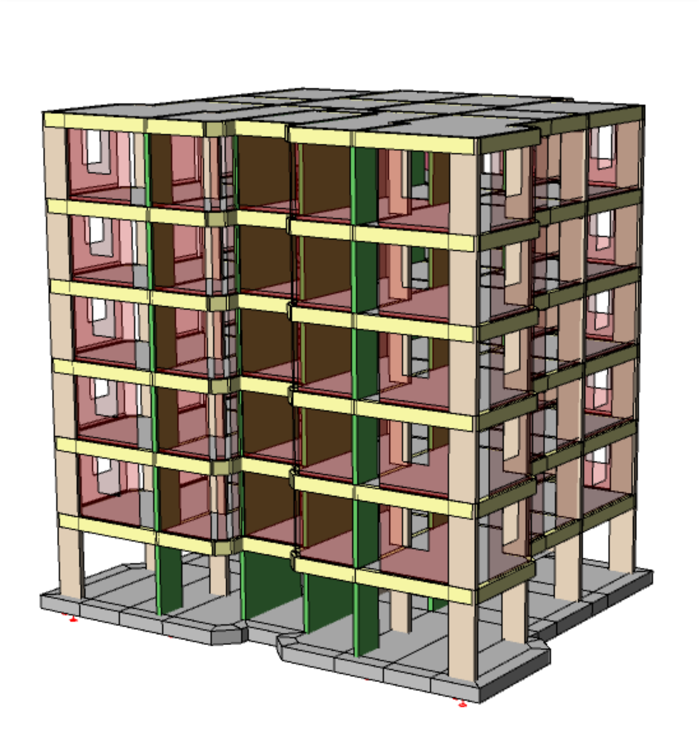
Introduction

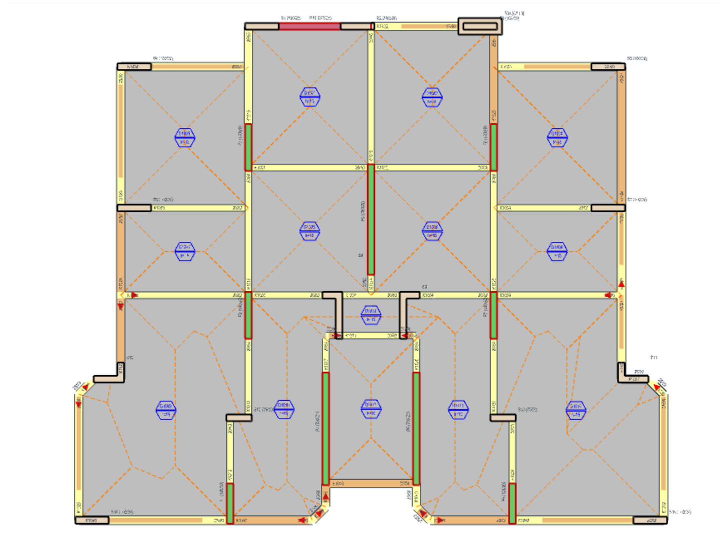
The “Nonlinear Analysis” feature in ProtaStructure enables the user to perform nonlinear analysis methods such as Pushover Analysis and Time-History Analysis.

In this document, target displacement calculation for nonlinear pushover analysis according **to FEMA 356 3.3.3.3.2** will be explained in detail and verified with the hand calculation.

Building Model

The building model consists of 7 regular floors. 3D and typical story plan views are shown below.

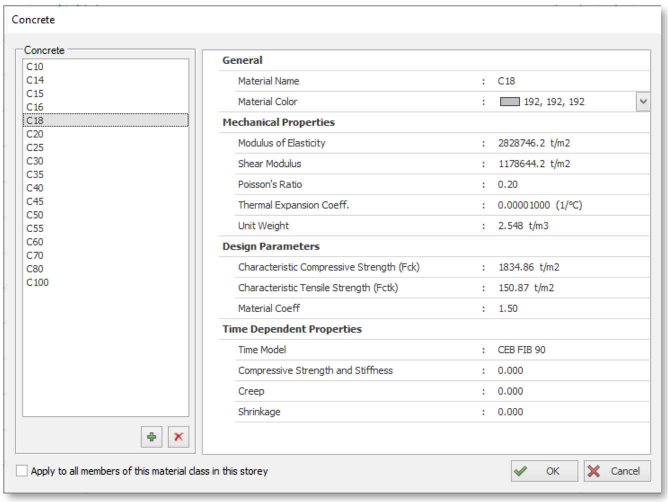




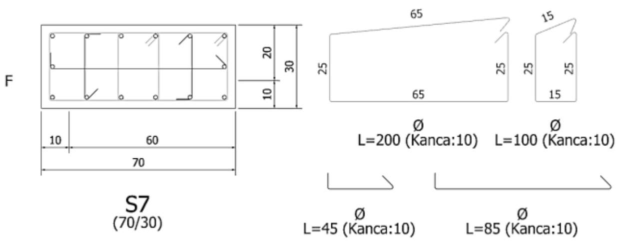
3D and Typical Plan View of Building Model

Material And Section Details

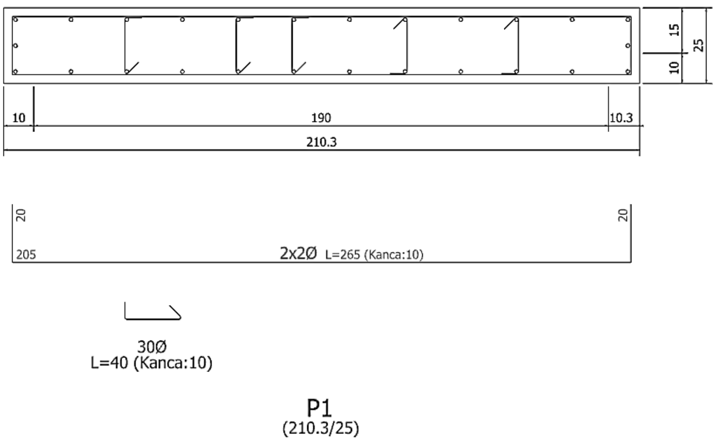
<u>Concrete Material Details:</u>



<u>Typical Column Section Details:</u>



<u>Typical Wall Section Details:</u>



Estimated rebar ratios are used for beam members. Estimated rebar details are given below;

Calculation Details

According to **FEMA 356 3.3.3.3.2**, "The target displacement, δ_t, at each floor level shall be calculated following Equation (3-15) and as specified in Section 3.3.3.3.1.

$$\delta = C_0 C_1 C_2 C_3 S_a \frac{{T_e}^2}{4\pi^2} g \qquad (3-15)$$

C_0 : Modification factor to relate spectral displacement of an equivalent SDOF system to the roof displacement of the building MDOF system

C_1 : Modification factor to relate expected maximum inelastic displacements to displacements calculated for linear elastic response

C_2 : Modification factor to represent the effect of pinched hysteretic shape, stiffness degradation and strength deterioration on maximum displacement response

C_3 : Modification factor to represent increased displacements due to dynamic P-Δ effects.

S_a : Response spectrum acceleration at the effective fundamental period and damping the ratio of the building in the direction under consideration, g, as calculated in Sections 1.6.1.5 and 1.6.2.1.

T_e : Effective fundamental period of the building in the direction under consideration, sec.

g : acceleration of gravity

Determination of C_0

According to the C_0 definition, which is given in **FEMA 356 3.3.3.3.2**, there is more than one procedure to determine the factor,

- The first modal participation factor at the level of the control node
- The modal participation factor at the level of the control node is calculated using a shape vector corresponding to the deflected shape of the building at the target displacement. This procedure shall be used if the adaptive load pattern defined in paragraph 2.2 of Section 3.3.3.2.3 is used
- The appropriate value from Table 3-2

ProtaStructure uses the first modal participation factor at the level of the control node as the C_0 factor. ProtaStructure follows the calculation procedure given in **FEMA 274** (Seismic Rehabilitation Commentary).

$$C_0 = \phi_{1,r} \frac{\sum_1^N m_i \phi_{1,n}}{\sum_1^N m_i {\phi_{1,n}}^2} \qquad FEMA\ 274\ (C3-4)$$

Determination of C_1

According to the **C_1** definition, which is given in **FEMA 356 3.3.3.3.2**, the calculation procedure is given as follows:

=1.0 for $T_e \geq T_S$

=$[1.0 + (R-1)\,T_S/T_e]/R$ for $T_e \geq T_S$

But not greater than the values given in Section 3.3.1.3 nor less than 1.0.

Determination of C_2

According to the **C_2** definition which is given in **FEMA 356 3.3.3.3.2**, "C_2 = 1.0 shall be permitted for nonlinear procedures.". There C_2 is taken as 1.0 by ProtaStructure.

Determination of C_3

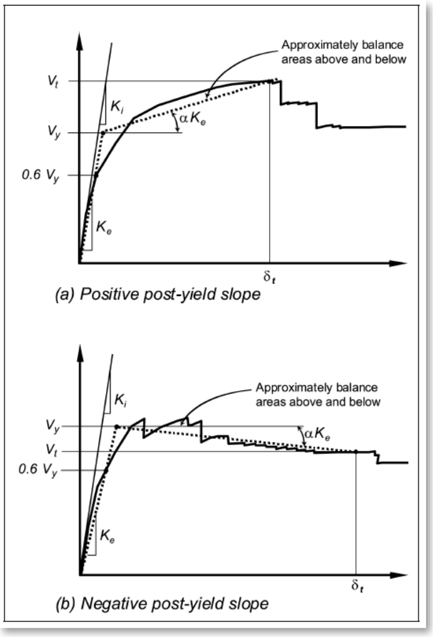
According to the **C_3** definition, which is given in **FEMA 356 3.3.3.3.2**, "values of C_3 shall be calculated using Equation (3-17)."

$$C_3 = 1.0 + \frac{|\alpha|(R-1)^{3/2}}{T_e} \qquad (3-17)$$

T_e : Effective fundamental period of the building in the direction under consideration, sec.
α : Ratio of post-yield stiffness to effective elastic stiffness, where the nonlinear force-displacement relation shall be characterized by a bilinear relation as shown in Figure 3-1
R : Ratio of elastic strength demand to calculated yield strength coefficient calculated by **Equation (3-16)**

$$R = \frac{S_a}{V_y/W} C_m \qquad (3-16)$$

Idealized Force-Displacement Curve and Determination of T_e



According to **FEMA 356 3.3.3.2.4**, " The nonlinear force-displacement relationship between base shear and displacement of the control node shall be replaced with an idealized relationship to calculate the

effective lateral stiffness, K_e, and effective yield strength, V_y, of the building as shown in Figure 3-1.
This relationship shall be bilinear, with initial slope Ke and post-yield slope α. Line segments on the idealized force-displacement curve shall be located using an iterative graphical procedure that balances the area above and below the curve.
The effective lateral stiffness shall be taken as the secant stiffness calculated at a base shear force equal to 60% of the effective yield strength of the structure. The post-yield slope, α, shall be determined by a line segment that passes through the actual curve at the calculated target displacement."

T_i : Elastic fundamental period (in seconds) in the direction under consideration calculated by elastic dynamic analysis
K_i : Elastic lateral stiffness of the building in the direction under consideration
K_e : Effective lateral stiffness of the building in the direction under consideration

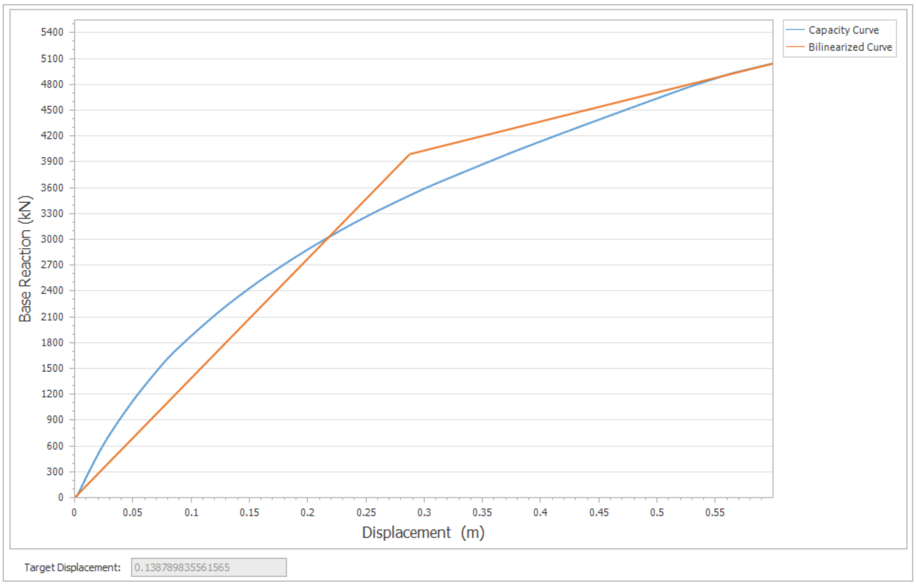
Period Determination;

According to **FEMA 356 3.3.3.2.5,**" The effective fundamental period in the direction under consideration shall be based on the idealized force-displacement curve defined in **Section 3.3.3.2.4**. The effective fundamental period, T_e, shall be calculated per Equation (3-14):

$$T_e = T_i \sqrt{\frac{K_i}{K_e}} \qquad (3-14)$$

Verification of the ProtaStructure Target Displacement Results

ProtaStructure performs idealization of Force-Displacement Curve according to **FEMA 356 3.3.3.2.4;**



Elastic Lateral Stiffness	Ki: 27902.03 kN/m
Effective Lateral Stiffness	Ke: 13874.22 kN/m
Fundamental Period of the Building	Ti : 1.1676 s
Effective Fundamental Period of the Building	Te : 1.6559 s (According to **FEMA 356 Equation 3-14**)
Edge Period of the Target Spectrum	T_S : 0.2438 s

Yield Strength	Vy : 3990.0723 kN
Effective Seismic Weight	W : 25165.9756 kN
Effecticve Mass Factor	Cm : 1.0000
Strength Ratio	R : 1.0000

C_0 = 1.4015 (According to **FEMA 274 C3-4**)
C_1 = 1.00 (Since $T_e > T_s$,C_1 is taken as 1.00 according to **FEMA 356 3.3.3.3.2**)
C_2 = 1.00 (Since C_2 is used for nonlinear procedures, C_2 = 1 according to **FEMA 356 3.3.3.3.2**)
C_3 = 1.00 (Since the post-yield stiffness of the force-displacement curve is positive, C_3 = 1 according to **FEMA 356 3.3.3.3.2**)

Response Spectrum Acceleretaion, Sa: 0.1453 (According to **FEMA 356 Equation 3-16**)

Determination Of Target Displacement:

$$\delta = C_0 C_1 C_2 C_3 S_a \frac{T_e^{\,2}}{4\pi^2} g$$

$$\delta = (1.4015)(1)\,(1)\,(1)\,(0.1453\,)\frac{(1.6559)^2}{4\pi^2} g$$

$$\delta = 13.8\ cm$$

Summary

In this document, calculation details of target displacement according to FEMA 356 3.3.3.3.2 are explained. Results of the ProtaStructure are verified with hand calculations.

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