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APPLICATION OF N2 METHOD IN DESIGN

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Abstract: The N2 method is simple nonlinear method for the seismic performance evaluation of structures. The method combines the nonlinear static (pushover) analysis and the response spectrum approach. The method yields results of reasonable accuracy if the structure oscillates predominantly in the first mode By reversing the analysis process, the method can be used as a tool for the implementation of the direct displacement-based design approach.

Keywords: seismic demand, direct displacement based design, performance evaluation, inelastic behavior, etc.

Introduction

The concept of design "Direct Displacement Based design- DDBD" is an alternative "philosophy" of the seismic design. Input parameter to this method is the maximum allowable displacement. Though, a seismic design is oriented in such a way that structural limit state is expressed by acceptable maximum deformation (displacement).N2 method is used for the assessment of existing buildings, by reversing of N2 method we can use as e tool for the implementing the direct displacement based design. To demonstrate the N2 method in design we have chosen the four story buildings, three story building and eight story buildings, the later one we compare with the Direct displacement based design according to Priestley.

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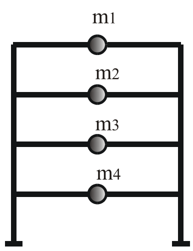
I. Summary of the N2 method [3,5-19]

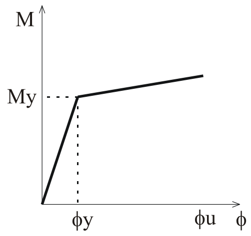
I. Data

a) Structure

b) Moment-curvature relationship

c) Elastic spectra of accelerations





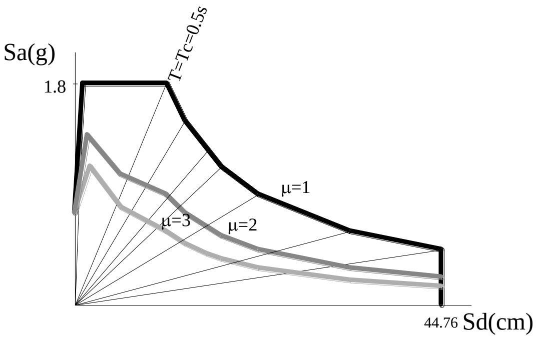
II. Seismic demands on format AD

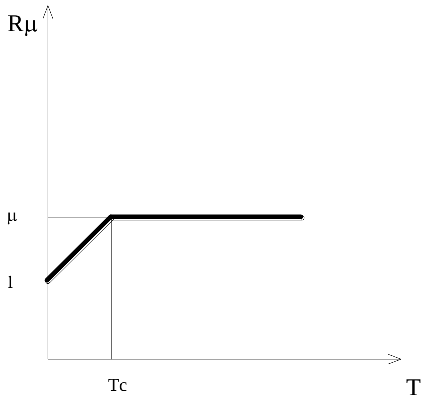
a) Define elastic spectra in AD format

$$S_{de} = \frac{T^2}{4\pi^2} S_{ae}$$

b) Define the inelastic spectra for constant ductility

$$S_a = \frac{S_{ae}}{R_\mu}, S_d = \frac{\mu}{R_\mu} S_{de}$$





$R_\mu = \mu$ for $T^* \geq T_C$,

$R_\mu = (\mu - 1)\dfrac{T^*}{T_C} + 1$ for $T^* < T_C$

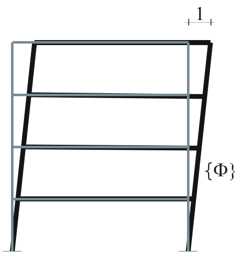
III. ''Pushover'' analysis

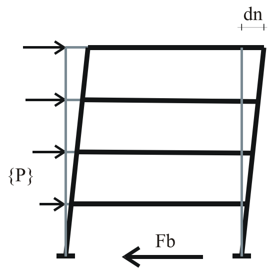
a) Assume the form of displacement $\{\Phi\}$

b) Determine the vertical distribution of lateral force

$$\{P\} = [M]\{\Phi\}, \quad P_i = p m_i \Phi_i$$

c) Determine the "based shear force – top displacement relationship".





IV. Equivalent model with single degree of freedom.

a) Define the mass m^*

$$m^* = \sum_{i=1}^{n} m_i \Phi_i$$

b) Transform quantities (Q) of system with multi degrees of freedom in quantities (Q^*) of the system with single degree of freedom

$$Q^* = \frac{Q}{\Gamma}, \qquad \Gamma = \frac{m^*}{\sum_{i=1}^{n} m_i \Phi_i^2}$$

c) Determine the approximate relationship elastic-plastic force-displacement

d) Determine the strength F_y^*, yield displacement d_y and period T^*.

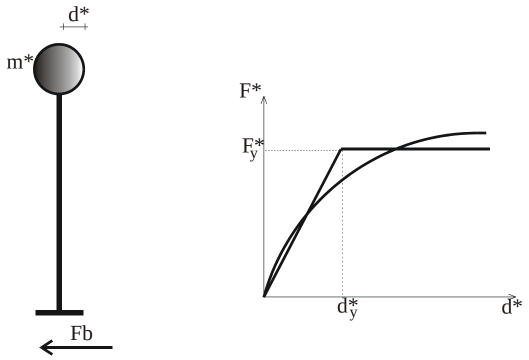
$$T^* = 2\pi\sqrt{\frac{m^* d_y^*}{F_y^*}}, \qquad k^* = F_y^* / d_y^*$$

4.18

e) Determine the diagram of capacity (acceleration versus displacement)

$$S_a = \frac{F^*}{m^*}$$

V. Seismic demand for the model with single degree of freedom.



a) Define reducing factor R_μ

$$R_\mu = \frac{S_{ae}}{S_{ay}}$$

b) Define displacement demand

$d^* = S_d = \dfrac{S_{de}}{R_\mu}\left(1 + (R_\mu - 1)\dfrac{T_C}{T^*}\right)$ for $T^* < T_C$

$d^* = S_d = S_{de}$, for $T^* \geq T_C$

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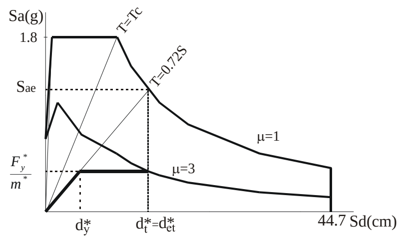
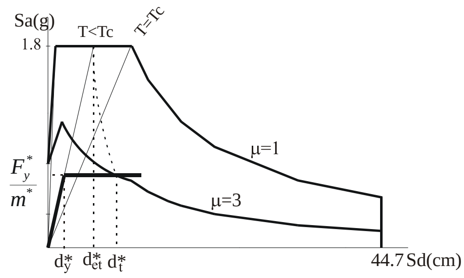




VI. Global seismic demand for the model with many degrees of freedom.

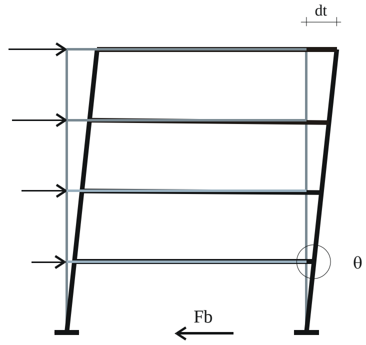
a) Transform the displacement demand of the system with single degree of freedom to the top displacement of multi degrees of freedom model.

$$d_t = \Gamma d^*$$

VII. Local seismic demand

a) Apply the analysis "pushover" in the model with multi degrees of freedom (MDOF) until reaching the displacement in d_t

b) Determine local quantities (relative displacement of floors, rotation of joints etc.), corresponding to dt



VIII. Performance Assesment

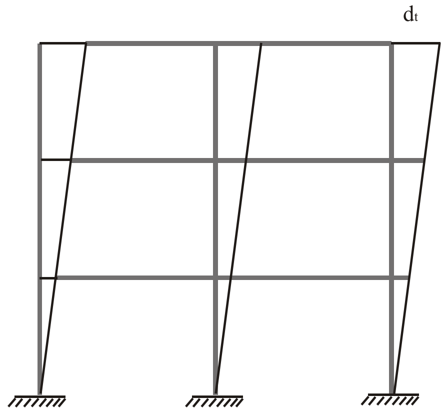
a) Compare local and global seismic demand with capacity to the required level of performance.

2. N2 METHOD IN DESIGN[2-3]

With the inversion of procedure of method N2 used for assessment of the performance, can be developed a design methodology based directly on the displacement. Practically will be done this way:

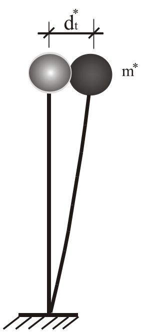
1st Step.

For the required performance (defined) is given the displacement $d_{t(n)}$, which represents the displacement on the roof of the system with many degrees of freedom.



2nd Step.

Determining the displacement of the system with single degree of freedom



$$d_t^* = S_d^* = \frac{d_t}{\Gamma}$$

where $\Gamma \cong \frac{3n}{2n+1}$ or $\Gamma = \frac{m^*}{\sum_{i=1}^{n} m_i \Phi_i^2}$,

where n-number of floors, $m^* = \sum_{i=1}^{n} m_i \Phi_i$,

Φ_i - linear form of vibration (first form of vibration).

3^{rd} Step.

Determining the ductility or stiffness (rigidity) of the structure. To define the ductility, initially should be determined the yield displacement for the system.

$$d_{yt}^* = \frac{d_{yt}}{\Gamma}$$

Ductility will be

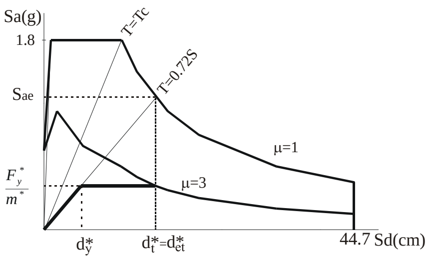
$$\mu = \frac{d_t^*}{d_{yt}^*}$$

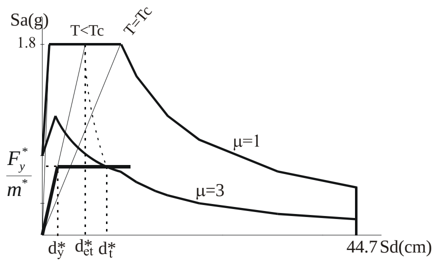
4^{th} Step.

For the defined quantity d_t^* appreciate S_{ae} and T^*. Further apply the following expressions:

$$R_\mu = \mu \text{ for } T^* \geq T_C,$$

$$R_\mu = (\mu - 1)\frac{T^*}{T_C} + 1 \text{ for } T^* < T_C$$





$$S_{ay} = \frac{S_{ae}}{R_\mu}$$

Thus, base shear force of the system with single degree of freedom will be: 4.15

$$S_{ay} = \frac{F_y^*}{m^*} \Rightarrow F_y^*$$

5^{th} Step.

Determine the base shear force for the system with multi degree of freedom. $F_b = F_y^* \cdot \Gamma$

6^{th} Step.

The distribution in the height of the structure of horizontal load adapting assumed displacement profile:

$$F_i = \frac{\Phi_i m_i}{\sum_{i=1}^{n} \Phi_i m_i} F_b$$

According to the DDBD- N2 method based on Fajfar,

First Case :For the defined performance $d_{t(n)} = 24cm$ and seismic demand, EC8,B , a) $a_g = 0.4g$ and b) $a_g = 0.5g$ determine the base shear force for the four story buildings

$$\Gamma = 1.33$$

$$m^* = 200 \text{ ton}$$

$$d_t^* = 18cm$$

$$d_{yt} = 0.5 \cdot 0.002 \cdot \frac{600}{50} \cdot 1600 = 19.2cm$$

$$d_{yt}^* = 14.4cm$$

$$\mu = 1.25$$

a) From design spectra we can read

$$S_{ae} = 0.49g \quad \text{dhe} \quad T^* = 1.2$$

Per $T^* > 0.5s \quad R_\mu = \mu$

$$S_{ay} = \frac{S_{ae}}{R_\mu} = 0.39g$$

$$F_y^* = 780.85kN$$

$$F_b = 1041.1kN$$

b) From design spectra we can read

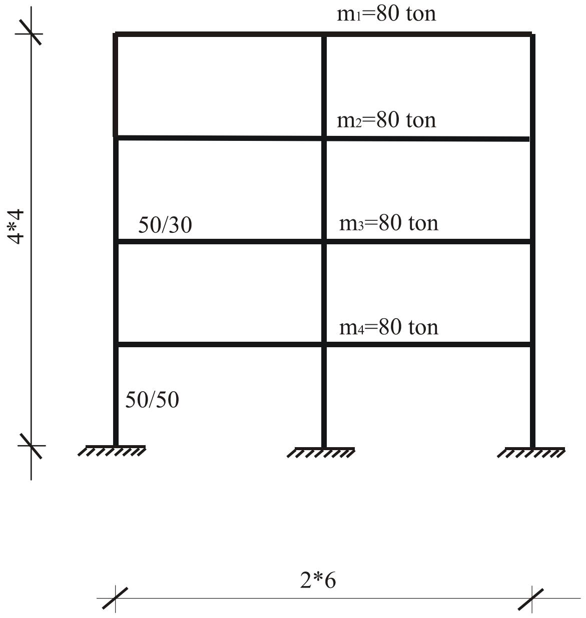
$$S_{ae} = 0.77g \quad \text{dhe} \quad T^* = 0.96$$

for $T^* > 0.5s \quad R_\mu = \mu$

$$S_{ay} = \frac{S_{ae}}{R_\mu}$$

$$F_y^* = 1220.81kN$$

$$F_b = 1626.7kN$$



Second Case [3 For the defined performance dt =15 cm and seismic demand, ag=0.3g,0.4g,0.5g and 0.6g to be determined the base shear force

$$\Gamma = 1.28$$

$$m^* = 141\text{ton}$$

$$d_t^* = 11.71cm$$

$$d_{yt} = 0.5 \cdot 0.002 \cdot \frac{600}{50} \cdot 1200 = 14.4cm$$

$$\pm 10\% \cong 13cm$$

$$d_{yt}^* = 10.15cm$$

$$\mu = 1.15$$

From the design spectra can be obtained (read):

$$S_{ae} = 0.43g \quad \text{and} \quad T^* = 1.04$$

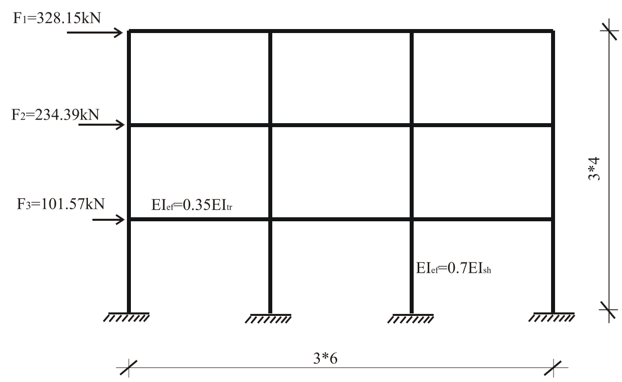
$$S_{ay} = \frac{S_{ae}}{R_\mu} = 0.37g\,,\ F_y^* = 518.28kN$$

$$F_b = 664.12kN$$

$$F_1 = 328.15kN$$

$$F_2 = 234.39kN$$

$$F_3 = 101.57kN$$



For performance $d_{t(n)} = 15cm$ we have results for four seismic demand, the results are presented below in tabular form

	0.3g	0.4g	0.5g	0.6g
m^* (ton)	141	141	141	141
Γ	1.28	1.28	1.28	1.28
d_t (cm)	**15**	**15**	**15**	**15**
d_t^* (cm)	11.71	11.71	11.71	11.71
d_{yt} (cm)	13	13	13	13
d_{yt}^* (cm)	10.15	10.15	10.15	10.15
μ	1.15	1.15	1.15	1.15
$S_{ae}\ (m/s^2)$	0.43g	0.76g	1.195	1.49g
T^* (s)	1.04	0.78	0.627	0.52

R_μ	1.15	1.15	1.15	1.15
$S_{ay}\left(m/s^2\right)$	0.37g	0.66g	1.035g	1.49g
F_y^* (kN)	518.28	921.37	1439.64	2073.09
Fb(kN)	664.12	1180.65	1844.78	2656.48

For another performance $d_{t(n)} = 24cm$ **,we have results as below**

	0.3g	0.4g	0.5g	0.6g
m^* (ton)	141	141	141	141
Γ	1.28	1.28	1.28	1.28
d_t (cm)	**24**	**24**	**24**	**24**
d_t^* (cm)	18.72	18.72	18.72	11.71
d_{yt} (cm)	13	13	13	13
d_{yt}^* (cm)	10.15	10.15	10.15	10.15
μ	1.84	1.84	1.84	1.84
$S_{ae}\left(m/s^2\right)$	0.26g	0.47g	0.74g	1.07g
T^* (s)	1.67	1.25	1.0	0.83
R_μ	1.84	1.84	1.84	1.84
$S_{ay}\left(m/s^2\right)$	0.145g	0.258g	0.4g	0.58g
F_y^* (kN)	202.45	359.91	562.36	809.8
Fb(kN)	259.42	461.19	720.61	1037.68

Third case: For the defined performance $d_{t(n)} = 49cm$ and seismic demand, based on EC8,B ,ag=0.6g , determine the base shear force for eight story buildings

a) based on DDBD- Priestley and Kowalsky

b) Based on DDBD- Fajfar

a)		*b)*	
d_t (cm)	**49**	**d_t (cm)**	**49**
d_t^* (cm)	31.5	Γ	1.36
m_e (ton)	648.47	m^* (ton)	475.66
h_e (m)		d_t^* (cm)	31.5
d_{yt}^* (cm)	20.11	d_{yt}^* (cm)	21.5
μ	1.56	μ	1.45
ξ_e %	12.65	$S_{ae}\left(m/s^2\right)$	0.44
T_e (s)	2.24	T^* (s)	1.68
Fb(kN)	1600.3	Fb(kN)	1943.2

Conclusions

N2 method can be used both for the seismic performance evaluation of newly designed or existing structures. Furthermore, by reversing the analysis process, the method can be used as a tool for the implementation of direct displacement-based design approach, in which design starts from a predetermined target displacement. We have demonstrated the method in three example. In third case we have compare with another DDBD according to Priestley. We shown that we have the discrepancy in results for base share force. It must be recognized ,however, that more research is needed to clarify these discrepancy.

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