COMPDYN 2019
7th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics
and Earthquake Engineering
Crete, Greece, 24–26 June 2019

An Approximate Method to Assess the Seismic Capacity of Existing RC Buildings

Michaela V. Vasileiadi, M.Sc. Civil Engineer
Stephanos E. Dritsos, Emeritus Professor
University of Patras, Department of Civil Engineering

Introduction

- Engineers are not interested <u>when</u> a strong earthquake may occur.
  - They are interested to build safe structures to withstand a strong earthquake, whenever it may occur.
- Increase knowledge —influence→ modern design —influence→ new regulations

  New regulations —resulting→ (In general) safer new buildings
- What about old buildings (before the implementation of the new seismic codes e.g. in Greece 1995)?
- About 80% of the existing buildings stock could be considered as old.
  - Which of them can be considered safe? → Need of assessment

Tools: EC8-3, KANEPE, KADET

- The most accurate procedure

However,

- Need of high level earthquake engineering background
- Time consuming procedure - cost

Any other solution?

Approximate procedures for a gross evaluation of safety.

The Approximate Method

Advantages

- Very quick procedure for an estimation of the seismic vulnerability degree, of R.C. Structures
- Very useful tool when the goal is to identify the most vulnerable structures in a target building stock. Create a ranking order in a number of buildings, according to their vulnerability degree e.g. as in the second level procedure for pre- earthquake assessment of existing buildings, is requested.
- It is based on very simple calculations.
- Ability for a row estimation of the capacity of buildings possibly even when reinforcement details are unknown.

Disadvantages

- The approximation of the method.

Scope of the work

↓

Examine the accuracy of the method

How?

By comparing results with respective ones obtained from more accurate analytical procedures.

In the present work the static inelastic (push-over) analytical procedure is used.

The Approximate Method

Main Steps of the Method

1. Determination of the seismic demand in terms of base shear (V_{req})

2. Estimation of the seismic resistance of the whole structure (V_R)

3. Determination of a global failure index $\lambda = V_{req}/V_R$

1st Step: Seismic Demand V_{req}

$$V_{req} = M\, S_d(T)$$

where, M is the mass of the building

S_d is the design acceleration, based on the design spectrum of the current seismic code

where q is the behavior factor for the examined direction and performance level obtained by KANEPE

Values of behavior factor q' for performance level B (Severe Damage) according to KANEPE
For Level A values are multiplied by 0.6 (accepted into the range 1-1.5) and for level C values are multiplied by 1.4

Standards applied for design (and construction)	Favorable presence or absence of infill walls (1)		Generally unfavourable presence of infill walls (1)	
	Substantial damage in primary elements		Substantial damage in primary elements	
	No	Yes	No	Yes
1995<...	3.0	2.3	2.3	1.7
1985<...<1995(2)	2.3	1.7	1.7	1.3
...<1985	1.7	1.3	1.3	1.1

(1) On the role and effect of infill walls see §5.9 και §7.4.
(2) For buildings of this period, the values of the Table are valid provided that the check for non-formation of plastic hinges in column ends is made according to §9.3.3 (by satisfying $\Sigma M_{Rc} \geq 1.3 \Sigma M_{Rb}$).
For torsionally sensitive structures, or for those with at least 50% of the mass concentrated in the upper 1/3 of their height (inverted pendula), the values of the Table are multiplied by 2/3 but can not be lower than 1.0.

The Approximate Method

2nd Step: Seismic Resistance V_R

The seismic resistance, of the whole structure, V_R is estimated as: $V_R = \beta\, V_{R0}$

where, β is the reduction factor based on the 13 criteria of the method

V_{R0} is the basic seismic resistance

$$V_{R0} = a_1 \sum V_{Ri}^{columns} + a_2 \sum V_{Ri}^{walls} + a_3 \sum V_{Ri}^{short\ columns}$$

α_1= 0.5	α_2= 0.7	α_3= 0.9	in structures with columns, walls and short columns
α_1= 0.7	α_2= 0.9		in structures with columns and walls but without short columns
α_1= 0.7		α_3= 0.9	in frame structures without walls, and with short columns
α_1= 0.8			in frame structures without walls and short columns

The strength of the vertical members, V_{Ri}, is obtained as: $V_{Ri} = \min[(V_{Rd,s}, V_{R,max}), V_M]$

where ➡ $V_{Rd,s}$ and $V_{R,max}$ are the shear resistances, from concrete design formulas or from KANEPE (similar to EC8-3)

(Reinforcement detailing data is considered under tolerable reliability level according to KANEPE or by limited knowledge level according to EC8-3)

➡ $V_M = M_R/L_s$ is the flexural capacity of the member, where

L_s is the shear length obtained according to KANEPE, as $L_s = L_k/2$

for columns L_k is the clear length in the critical floor

for walls L_k is the length of the wall measuring from the base cross-section up to the top of the building

Approximate Method – Vulnerability Criteria

Table of Criteria

		Criteria	Morfology factor β_i: 0 max	1	2	3	4	5 min	Weight factor σ_i
1	Over-critical	Existing structural damage							0.10
2	Over-critical	Reinforcement corrosion							0.10
3	Over-critical	Normalized axial load							0.05
4		Regularity in plan							0.05
5		Stiffness distribution in plan – torsion							0.10
6		Regularity in elevation							0.05
7		Stiffness distribution in elevation							0.15
8		Mass distribution in elevation							0.05
9		Short columns							0.15
10		Vertical discontinuities							0.05
11		Force transfer							0.05
12		Pounding with adjacent buildings							0.05
13		Faulty workmanship or non-structural damage that has occurred either during or after construction							0.05

$$\beta = \Sigma \frac{\sigma_i\, \beta_i}{5}$$

where, β_i is a morfology factor ($0 \le \beta_i \le 5$)

σ_i is a weight factor ($0 \le \beta_i \le 5$)

Analytical Inelastic (Pushover) Procedure

Definition of Resistance

In the present work two alternatives ways are used to determine the seismic resistance of the whole structure

Local Resistance Definition

When one vertical element reaches first its max. acceptable deformation (δ_{max}) for the examined performance level.

δ_{max} as follows:
where δ_y and δ_u are the yield and failure deformations of the element.

Global Resistance Definition

When the whole structure reaches its max. acceptable deformation (δ_{max}) for the examined performance level.

δ_{max} as follows:
where δ_y and δ_u are the yield and failure deformations obtained according to KANEPE (or EC8-3) from the capacity curve of the whole structure.

A: $\delta_{max} = \delta_y$

B: $\delta_{max} = [0.5(\delta_y + \delta_u)]/\gamma_{Rd}$

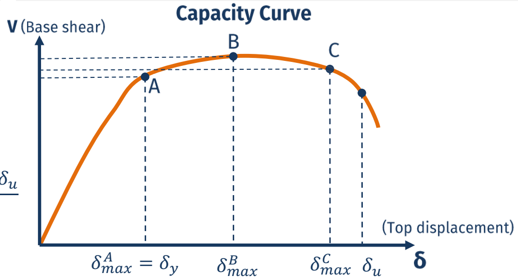
C: $\delta_{max} = \delta_u/\gamma_{Rd}$

(KANEPE 2017)

$$\delta_{max}^B = \frac{\delta_y + \delta_u}{2\,\gamma_{Rd}} = \frac{\delta_y + \delta_u}{3}$$

$$\delta_{max}^C = \frac{\delta_u}{1.5}$$

Capacity Curve



Failure Index

Approximate Method

In terms of base shear

$$\lambda = \frac{V_{req}}{V_R} = \frac{V_{req}}{\beta\, V_{R0}} = \frac{\lambda_0}{\beta}$$

Inelastic (pushover) Analysis

In terms of base shear

- Force Local Values (FLV)
- Force Global Values (FGV)

$$\lambda_V = \frac{V_{req}}{V_R}$$

In terms of displacement

- Displacement Local Values (DLV)
- Displacement Global Values (DGV)

$$\lambda_\delta = \frac{\delta_t}{\delta_{max}}$$

δ_t is the target displacement

The Case Study

- Performance level B (main investigation) but also A and C

- Seismic Demand $V_{req} = M\, S_d(T)$

  considering: a) $T = T_{empirical}$

  b) $T = T_{analysis}$

  to investigate the influence of T

- Seismic Resistance V_R

  considering: a) Known reinforcement amounts (minimum)

  b) Ignoring the presence of reinforcement amounts

  to investigate the influence of the reinforcement

The Case Study

- 5-storey RC building, constructed in 1988
- Square-shaped floor plan: 15 x 15 m
- Ground floor height : 5.50 m
- Remaining floor heights : 3.50 m
- Seismic zone II, (ground acceleration 0.24 g), soil type B

Columns and Walls cross sections

- 0.60 x 0.60 m (Ground floor)
- 0.50 x 0.50 m (1^{st} and 2^{nd} floor)
- 0.40 x 0.40 m (3^{rd} and 4^{th} floor)
- Π-shaped shear wall 3.00 x 3.00 x 0.25 m

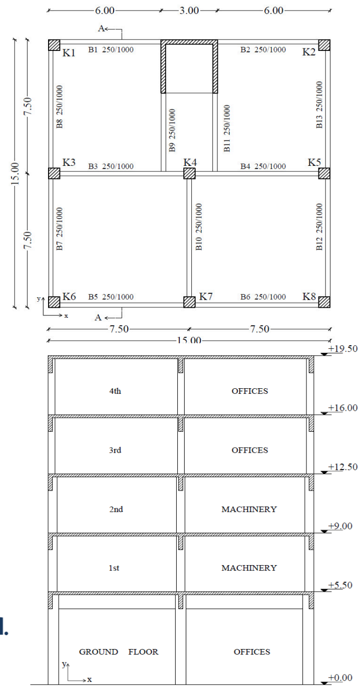
Beams

- 0.25 x 1.00 m

Materials

- Concrete: C16/20
- Reinforcing steel : S500

❑ In the present work, the **infills of the structure are ignored.**



Dynamic Characteristics

Empirical Period

According to the approximate equation of EC8:

$T = C_t\, H^{\frac{3}{4}} = 0.464\ sec$ where

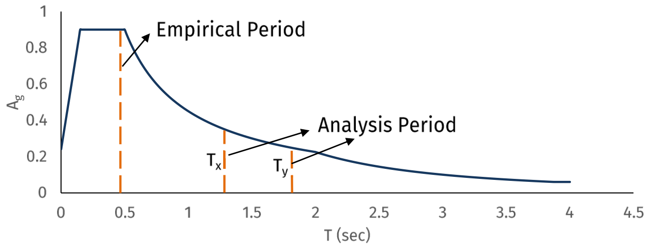
- C_t is equal to 0.05
- H is the height of the building starting from the foundation

Analysis Period

It resulted for each direction from modal analysis using the effective stiffness (according to KANEPE) for all the members, which was determined by section analysis.

$$T_x = 1.82\ sec$$
$$T_y = 1.27\ sec$$

Design Spectrum

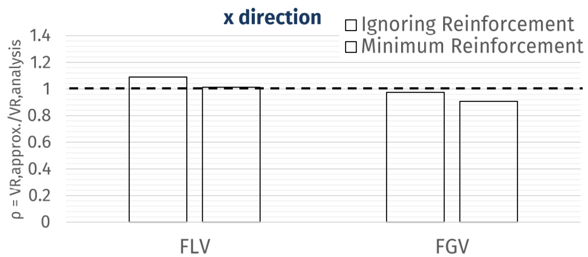


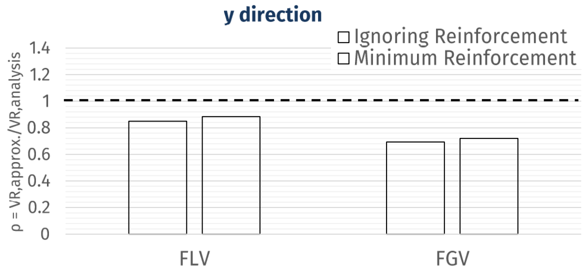
Seismic Resistances Comparison

$$\rho = \frac{V_{R,approximate}}{V_{R,analysis}}$$

where **FLV:** Force Local Values

FGV: Force Global Values





Conclusions

- There is a quite good agreement in the results of both methods, as the ratio ρ is quite close to unity.
- Higher accuracy is achieved for FLV case, and much higher when the reinforcement amounts are taken into account.
- Using the local values, the approximate method is more conservative.

Failure Indices Results

Approximate Method: $T = T_{emp}$, $q = q_{KANEPE}$, $V_R = V_{R,approx.}$

Analytical Method: $T = T_{anal}$, $q = q_{anal}$, $V_R = V_{R,anal}$, $\delta_i = \delta_{anal}$

P.L.	Seismic Direction	Approximate Method (Empirical Period)		Non-linear Static Analysis (Analysis Period)			
		Ignoring Reinforcement	Minimum Reinforcement	Local		Global	
				λ_V	λ_δ	λ_V	λ_δ
A	x	8.34	8.98	2.73	4.72	2.45	3.75
	y	5.08	4.88	2.40	2.44	2.03	1.80
B	x	5.01	5.38	1.40	3.12	1.26	2.32
	y	3.05	2.93	0.99	1.70	0.81	0.91
C	x	3.58	3.85	0.75	1.92	0.69	1.46
	y	2.18	2.09	0.54	1.20	0.43	0.55

Great differences in the values because:

- $T_{empirical} = 0.464$ sec << $T_x = 1.82$ sec, $T_y = 1.27$ sec -> $V_{req,appr}$ >> $V_{req,anal}$
- In the present work, the infills of the structure are ignored.

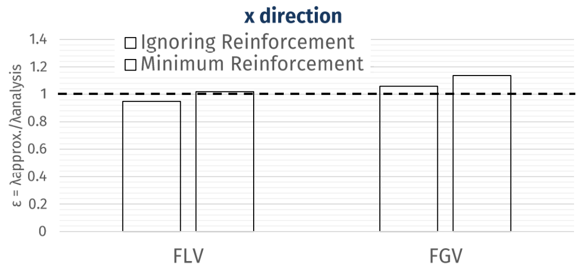
If the infills are taken into account, the overall stiffness increases and the analysis period decreases, which resulted equal to $T_x = 1.40$ sec, $T_y = 0.75$ sec, and is much closer to the empirical period. **Thus, the results of both methods would be closer.**

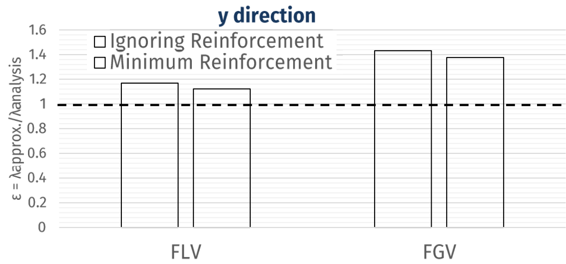
Failure Indices Comparison – For V_{req} ($T = T_{empirical} = 0.464$ sec) Performance Level B

$$\varepsilon = \frac{\lambda_{approximate}}{\lambda_{V,analysis}}$$ where

FLV: Force Local Values

FGV: Force Global Values





Conclusions

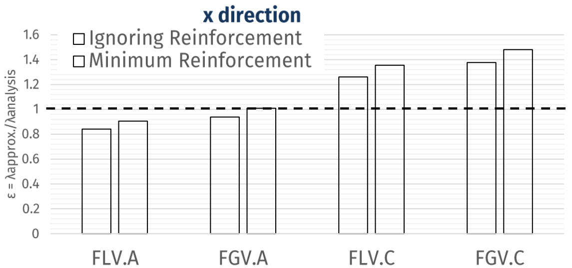
- The ratio ε is always > 1.
- The approximate method is conservative for performance level B.
- The deviations between the two methods are not very high, with the highest one being around 40%.
- Global values are more conservative than local ones.

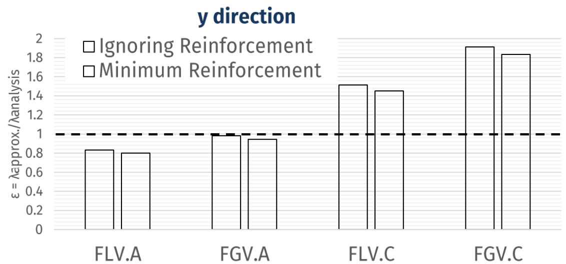
Failure Indices Comparison – For V_{req} ($T = T_{empirical} = 0.464$ sec) Performance Levels A & C

$$\varepsilon = \frac{\lambda_{approximate}}{\lambda_{V,analysis}}$$ where

FLV: Force Local Values

FGV: Force Global Values





Conclusions

- The approximate method is conservative for performance level C, but not for level A.
- The global values are more conservative than local ones.

Failure Indices Comparison – For V_{req} ($T = T_{analysis}$, $T_x = 1.82$ sec, $T_y = 1.27$ sec) Performance Level B

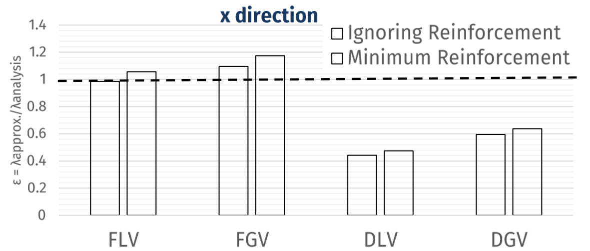
$$\varepsilon = \frac{\lambda_{approximate}}{\lambda_{analysis}}$$ where

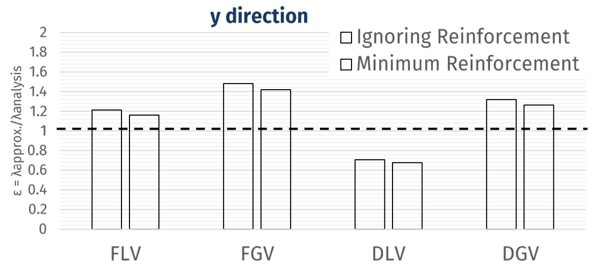
FLV: Force Local Values

FGV: Force Global Values

DLV: Displacement Local Values

DGV: Displacement Global Values





Conclusions

- Great differences when the results are based on forces and on displacements.
- Higher accuracy is achieved when using forces.
- The approximate method is not conservative when using displacements.
- Higher accuracy is achieved for local values when using forces.

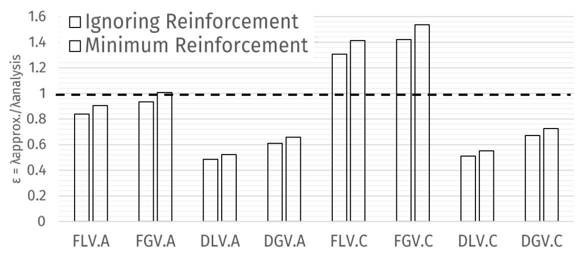
Failure Indices Comparison – For V_{req} ($T = T_{analysis}$, $T_x = 1.82$ sec, $T_y = 1.27$ sec) Performance Levels A & C

$$\varepsilon = \frac{\lambda_{approximate}}{\lambda_{analysis}}$$

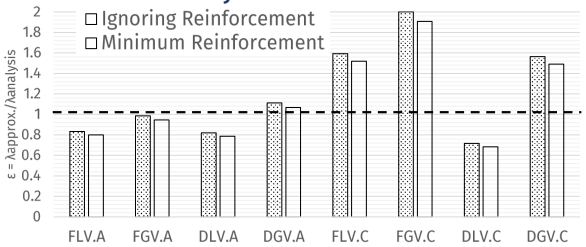
where

FLV: Force Local Values
FGV: Force Global Values
DLV: Displacement Local Values
DGV: Displacement Global Values

x direction



y direction



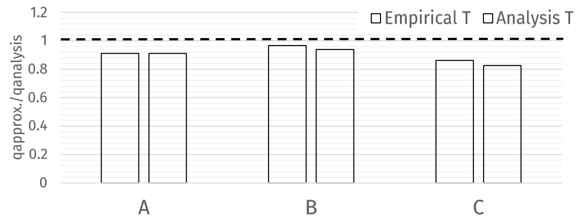
Conclusions

- Great differences when the results are based on forces and on displacements.
- The approximate method is not conservative when using displacements.
- The approximate method is conservative for performance level C, but not for level A.
- The global values are more conservative than local ones.

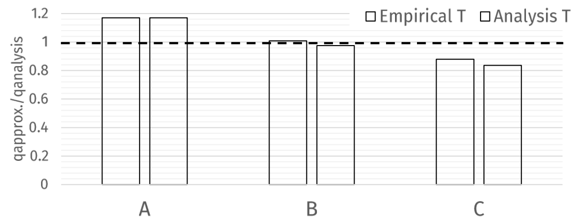
Behavior Factor q Comparison

Method		Seismic Direction	Performance Level A	B	C
Approximate (KANEPE)		x	1.02	1.70	2.38
		y	1.38	2.30	3.22
Inelastic (pushover) analysis	Empirical T	x	1.12	1.76	2.76
		y	1.18	2.28	3.66
	Analysis T	x	1.12	1.81	2.88
		y	1.18	2.36	3.85

x direction



y direction



The graphs present the ratio of α

$$\alpha = \frac{q_{approximate}}{q_{analysis}}$$

Conclusions

- The approximate method is conservative for all performance levels, except level A for the y direction.
- Higher accuracy is achieved for performance level B. Values are almost the same.

Conclusions

From the examined case study the following conclusions can be derived:

- **The approximate evaluation of the Seismic Resistance V_R**

$$V_{R0} = a_1 \sum V_{Ri}^{columns} + a_2 \sum V_{Ri}^{walls} + a_3 \sum V_{Ri}^{short\ columns}$$

Examined in the form $V_R = \beta\, V_{R0} = \beta\left(0.7 \sum V_{Ri}^{columns} + 0.9 \sum V_{Ri}^{walls}\right)$

(Case study with vertical elements: columns and shear walls)

was found in quite good agreement, with analytical results especially when comparing with Local Values.

- **Approximate Values of q factor from KANEPE** (used in the approximate method)

In high agreement, with the analytical values. The KANEPE being conservative for almost all performance levels.

- <u>Failure indices λ_v</u>

✓ **Comparison of Approximate ($T = T_{approx.}$, $q = q_{KANEPE}$) and Analytical (T and q from Analysis) Procedures**

$\lambda_{approx.} = \dfrac{V_{req(T)}}{V_{R,approx.}}$ compared with $\lambda_{V,anal.} = \dfrac{V_{req(T)}}{V_{R,anal.}}$ and $\lambda_{\delta,anal.} = \dfrac{\delta_t}{\delta_{max}}$

$$\lambda_{approx.} : \lambda_{V,anal.} : \lambda_{\delta,anal.} \approx 5:3:2$$

Conclusions

✓ **Comparison of Approximate and Analytical λ_v Values in terms of base shear where**

$\lambda_{approx.} = \dfrac{V_{req(T)}}{V_{R,approx.}}$ $\lambda_{V,anal.} = \dfrac{V_{req(T)}}{V_{R,anal.}}$

- Very good accuracy for B Level. The highest when comparing with global values
- Conservative for C Level
- Not always safe for A Level

✓ **Comparison of Approximate and Analytical λ_δ Values where**

$\lambda_{approx.} = \dfrac{V_{req(T)}}{V_{R,approx.}}$ $\lambda_{\delta,anal.} = \dfrac{\delta_t}{\delta_{max}}$ (in terms of displacement) $> \lambda_{V,anal.} = \dfrac{V_{req(T)}}{V_{R,anal.}}$

$\lambda_{approx.} < \lambda_{\delta,anal.}$ ➡ **Approximate not safe**

Conclusions

- In conclusion, the use of different fundamental period affects the seismic demand $V_{req.}$ Thus, the use of an exact value of the fundamental period is very crucial for a reliable determination of the failure index. The approximate method would be highly improved if accurate fundamental periods are used.
- In all cases, the global values are more conservative than the local ones.
- Ignoring or taking into consideration the reinforcement amounts, there is no great difference in the comparison of failure indices results (5-10%).
- More research is needed (it is in progress), in order to obtain more general concrete conclusions.

Relative Website

ΕΠΙΣΚΕΥΕΣ & ΕΝΙΣΧΥΣΕΙΣ ΚΑΤΑΣΚΕΥΩΝ - ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

REPAIR & STRENGTHENING OF STRUCTURES - UNIVERSITY OF PATRAS

www.episkeves.civil.upatras.gr

Thank you for your attention