COUNCIL OF EUROPE/EUROPEAN CENTRE ON PREVENTION AND FORECASTING OF EARTHQUAKES (ECPFE)
EARTHQUAKE PLANNING AND PROTECTION ORGANIZATION (EPPO)
ATHENS, APRIL 12/2013

ECPFE

WORKSHOP: Implementation of EC8 part 3:2005. Assessment and interventions on buildings in earthquake prone regions

Differences in the design of interventions according to EC8 part 3 and the Greek CSI

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Retrofitting of Buildings

✓ **Interfaces** between existing – new elements ← Greek Code

✓ **Retrofitting** (strengthening) **of existing elements**

- Greek Code
- Eurocode

✓ **Retrofitting** (of the whole structure) **by adding new elements**

Greek Code

CONTEXT STRUCTURE (CONCEPT)

EUROCODE

Specific techniques are adopted → Types of strengthening offered (in flexure, shear, ductility)

GREEK CODE

Specific deficiencies are diagnosed and purpose of intervention is decided → Alternative and appropriate techniques are proposed

Moreover, Greek Code a much more detailed document

GCSI: **INTERFACES**

BASIC DESIGN CONSIDERATIONS

Repaired/Strengthened Element

↓

Multi – Phased Element

↓

Composite Element

↓

Influence of Interface Connection

VERIFICATION OF A SUFFICIENT CONNECTION BETWEEN CONTACT SURFACES

$$S_d \leq R_d$$

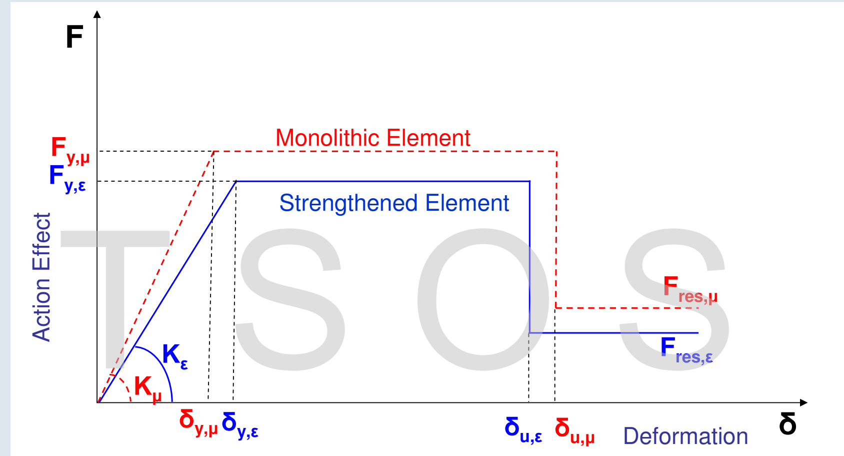
$$V_{Sd}^{interface} \leq V_{Rd}^{interface}$$

Interface Shear Force $\leq$ Interface Shear Resistance

Under specific construction conditions (measures), verification may not be necessary

INFLUENCE OF INTERFACES

CAPACITY CURVES



$$K_\kappa = \frac{K_\varepsilon}{K_\mu} \qquad K_r = \frac{F_{y,\varepsilon}}{F_{y,\mu}} \qquad K_{\delta y} = \frac{\delta_{y,\varepsilon}}{\delta_{y,\mu}} \qquad K_{\delta u} = \frac{\delta_{u,\varepsilon}}{\delta_{u,\mu}}$$

MONOLITHIC BEHAVIOUR FACTORS

- **For the Stiffness:**

$$k_k = \frac{\text{the stiffness of the strengthened element}}{\text{the stiffness of the monolithic element}}$$

- **For the Resistance:**

$$k_r = \frac{\text{the strength of the strengthened element}}{\text{the strength of the monolithic element}}$$

- **For the Displacement:**

$$k_{\delta y} = \frac{\text{the displacement at yield of the strengthened element}}{\text{the displacement at yield of the monolithic element}}$$

$$k_{\delta y} = \frac{\text{the ultimate displacement of the strengthened element}}{\text{the ultimate displacement of the monolithic element}}$$

$$(EI)_{strengthened} = k_k \,(EI)_M$$

$$R_{strengthened} = k_r \, R_M$$

$$\delta_{i,strengthened} = k_{\delta i} \, \delta_{i,M}$$

GREEK CSI: STRENGHTENING THE WHOLE STRUCTURE

- **Infilling Frames**
  - Addition of simple "infills" (Reinforced or unreinforced concrete walls, reinforced or unreinforced masonries)
  - Conversion of frames to shear walls — Reinforced concrete walls and jackets
  - Strengthening of existing masonry infills (Shotcreting reinforced layers)
  - Addition of bracing. Conversion of frames to vertical trusses (By steel or RC elements)
- **Construction of new lateral shear walls**

GCSI: Adding Simple Infills

- Addition of walls from: a) Unreinforced or reinforced concrete (cast in situ or prefabricated)
  b) Unreinforced or reinforced masonry
- No specific requirement to connect infill to the existing frame
- Modelling of infills by diagonal strut
- Low ductility of infill. Recommended m ≤ 1,5

<u>WARNING</u>

Additional shear forces are induced in the columns and beams of the frame

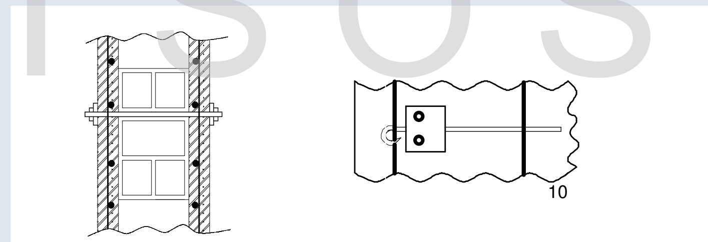
GCSI: Strengthening of existing masonry infills

- Reinforced shotcrete layers applied to both sides of the wall
  - Minimum concrete thickness 50 mm
  - Minimum reinforcement ratio $\rho_{vertical} = \rho_{horizontal} = 0{,}005$

Essential to connect both sides by bolting through the wall

No need to connect to the existing frame as it is an infill

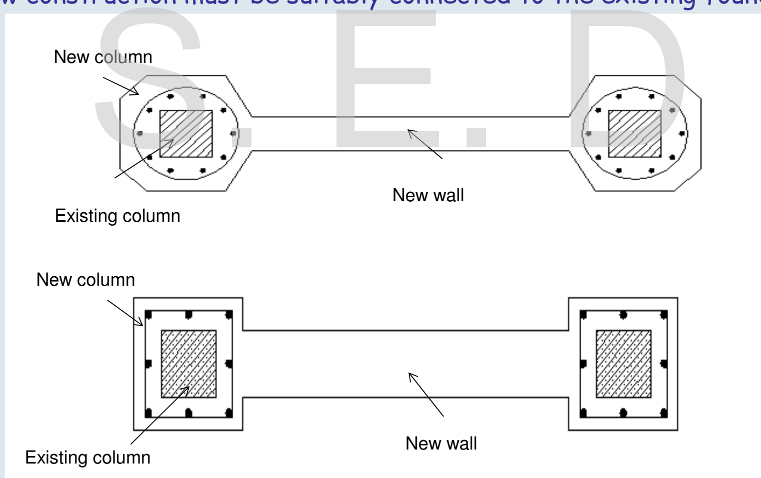
All new construction must be suitably connected to the existing foundation



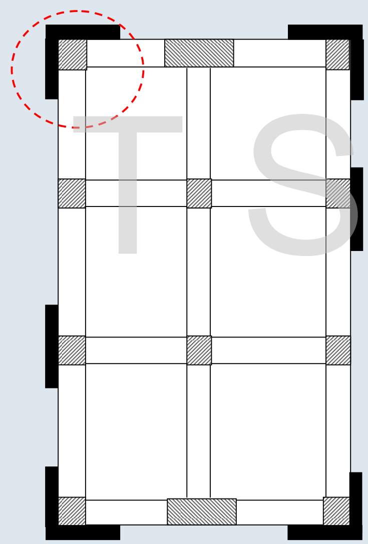
GCSI: Frame Encasement

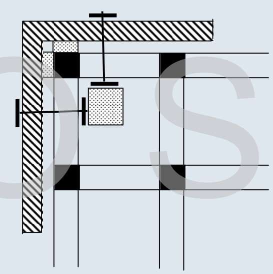
conversion of frames to shear walls

Reinforced walls are constructed from one column to another enclosing the frame (including the beam) with jackets placed around the columns. Note, all new construction must be suitably connected to the existing foundation



GCSI: Addition of New External Walls





Schematic arrangement of connections between existing building and new wall

GCSI: Addition of a Bracing System

OBJECTIVES			GREEK CODE (2012) DESIGN OF INTERVENTIONS	EC 8-PART 3 (2005) CAPACITY MODELS FOR STRENGTHENING
Interfaces	1	Verification of the interface connection	Yes	No
Strengthening of elements	2	Interventions in critical regions of linear structural members	Yes	Yes
	3	Interventions to frame joints	Yes	No
	4	Interventions on shear walls	Yes	No
	5	Interventions on foundation elements	Yes	No
Retrofitting whole structure	6	Frame encasement	Yes	No
	7	Construction of external new shear walls	Yes	No

Interventions in Critical Regions of Linear Structural Members

GREEK CSI (2012)		EC 8 PART 3 (2005)	
8.2.1.1	Local repair of a damaged member region	-	-
8.2.1.2	Restoration of insufficient lap splice length of the reinforcement	A.4.3.3 A.4.4.4	Clamping of lap-splices by FRP wrapping
8.2.1.3 8.2.1.4	Interventions to strengthen the tension or compression zone against flexure with axial force	-	-
8.2.1.5	Column jackets with the objective of simultaneous strengthening in the tension and compression zone	A.4.2.2	Enhancement of strength, stiffness and deformation capacity by concrete jackets
8.2.2.1 8.2.2.2	Interventions to increase the shear capacity a) inadequacy of the compression struts b) inadequacy of transverse reinforcement	A.4.3.2 A 4.4.2	Enhancement of shear strength (inadequacy of transverse reinforcement) by steel or FRP wrapping
8.2.3	Interventions to increase local ductility	A.4.2.2 A.4.4.3	Enhancement of strength, stiffness and deformation capacity by concrete jackets Confinement action by FRP wrapping
8.2.4	Interventions to increase the stiffness	A.4.2.2	Enhancement of strength, stiffness and deformation capacity by concrete jackets

EC 8-3

ANNEX A (informative): REINFORCED CONCRETE STRUCTURES

CAPACITY MODELS FOR STRENGTHENING

- Concrete Jacketing
- Steel Jacketing
- FRP Plating and Wrapping

EC 8-3

- Concrete Jacketing

Proposed to enhance the strength stiffness and deformation capacity

Correlation with a monolithic equivalent

$$V_R^* = 0,9\, V_R \qquad M_y^* = M_y$$

$$\theta_y^* = 1,05\ \theta_y \quad \text{or} \quad 1,20\,\theta_y \qquad \theta_u^* = \theta_u$$

if roughened — if not

EC8-3

- Steel Jacketing

to: (a) Increase shear strength
(in case of inadequate shear reinforcement)

(b) Prevent lap-splice failure
Only construction detailing

EC8-3

- FRP Plating and Wrapping
(more extended part - 6 pages out of 9)

to: (a) Increase shear strength

(b) Increase ductility of critical regions

(c) Prevent lap-splice failure

NECESSARY AMOUNT OF CONFINEMENT for a target curvature ductility $\mu_{\phi,tar}$

EC8-3: First choice

Applied to circular and rectangular cross sections

Confinement pressure ➡ $f_\ell = 0,4\, I_x^2\, f_c \dfrac{\varepsilon_{cu}^2}{\varepsilon_{ju}^{1,5}}$ (A.34) $\quad I_x = \dfrac{\mu_{\phi,tar}}{\mu_{\phi,o}}$

$$f_\ell = \frac{1}{2}\rho_f\, E_f\, \varepsilon_{ju} = \frac{1}{2}\rho_f\, f_j = \frac{1}{2}\frac{4t_f}{D}\frac{f_j}{f_c} = \frac{2\,t_f}{D}\, f_j \qquad f'_\ell = k_s\, f_\ell$$

$$\frac{f'_\ell}{f_c} = k_s \frac{2\,t_f}{D}\frac{f_j}{f_c} = 0,5\, k_s \omega_w \xrightarrow{(A.34)} \left(\frac{\mu_{\phi,tar}}{\mu_{ave}}\right)^2 = 1,25\,\frac{\varepsilon_{ju}^{1,5}}{\varepsilon_{cu}^2}\, k_s \omega_w$$

$k_s = 1,0$ circular

$k_s = \dfrac{2R_c}{D}$ rectangular

In practice $k_s = 0.2 - 0.35$

EC8-3: Second choice
Applied only to rectangular cross sections

$$\theta_{um} = \frac{1}{\gamma_{el}} \times 0,016 \times 0,3^{v} \times f_c^{0,225} \times \left(\frac{L_s}{h}\right)^{0,35} \times 25^{\alpha \rho_f \frac{f_{f,e}}{f_c}}$$ **where** $$f_{f,e} = f_u (1 - 0,7 f_u \frac{\rho_f}{f_c})$$

$$\theta_{um} = \frac{1}{\gamma_{el}} \times 0,016 \times 0,3^{v} \times f_c^{0,225} \times \left(\frac{L_s}{h}\right)^{0,35} \times 25^{\alpha\omega_{wx}}$$ **where** $$\alpha\omega_{wx} = \frac{\alpha\omega_w}{2}(1 - 0,35\omega_w)$$

$$\theta_{u,}\ \theta_y \rightarrow \mu_\theta = \frac{\theta_u}{\theta_y} \rightarrow \mu_\phi = f(\mu_\theta) = f(\theta_u)$$

$$\frac{\mu_\theta - 1}{\mu_\phi - 1} = 3\lambda_{p\ell}(1 - 0.5\lambda_{p\ell})$$

e.g. $$\text{for } \lambda_{p\ell} = \frac{L_{p\ell}}{L_s} \approx 0.10 \rightarrow \mu_\phi = 3.5\mu_\theta - 2.5$$

$$\text{for } \lambda_{p\ell} = \frac{L_{p\ell}}{L_s} \approx 0.20 \rightarrow \mu_\phi \approx 2\mu_\theta - 1$$

GREEK CODE

Approximate procedure

$$\mu_\phi = \frac{\varepsilon_{cu,c}}{2,2\,\varepsilon_{sy}\,v}$$

CFRP: $$\varepsilon_{cu,c} = 0,0035\left(\frac{f_{cc}}{f_c}\right)^2 = 0,0035\,(1,125 + 1,25\,a\omega_w)^2$$

$$\varepsilon_{sy} = \frac{f_y}{E_s}$$ **Yield strain**

$$v = \frac{N}{b\,h\,f_c}$$ **Normalized axial load**

In all Expressions

Therefore, $$\mu_\phi = f\,(a\omega_w)$$

However, quite different relationships are proposed with different influences from crucial parameters.

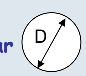
$$\mu_\phi = (\ldots)\sqrt{a\omega_w}$$ **EC8-3**

$$\mu_\phi = (\ldots)\,25^{\frac{\alpha\omega_w}{2}(1 - 0.35\,\omega_w)}$$ **EC8-3**

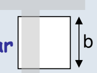
$$\mu_\phi = (\ldots)(\kappa + \lambda\,\alpha\,\omega_w)^2$$ **GCSI**

Volumetric Confinement Ratio ω_w

$$\max a\omega_w = ?$$

circular 

$$\omega_w = \frac{V_j}{V_{con}}\frac{f_j}{f_c} = \frac{\pi D t}{(\pi D^2/4)}\frac{f_j}{f_c} = \frac{4t}{D}\frac{f_j}{f_c}$$

rectangular 

$$\omega_w = \frac{4t}{b}\frac{f_j}{f_c}$$ **Collars or stirrups** $$\frac{A_\kappa}{S} = t$$ A_κ = **collar cross section area**

Assume Φ8/100 stirrups in a 300x300 mm cross section or circular D = 300 mm, f_{ck} = 14-16 MPa, f_{cm} = 20 MPa

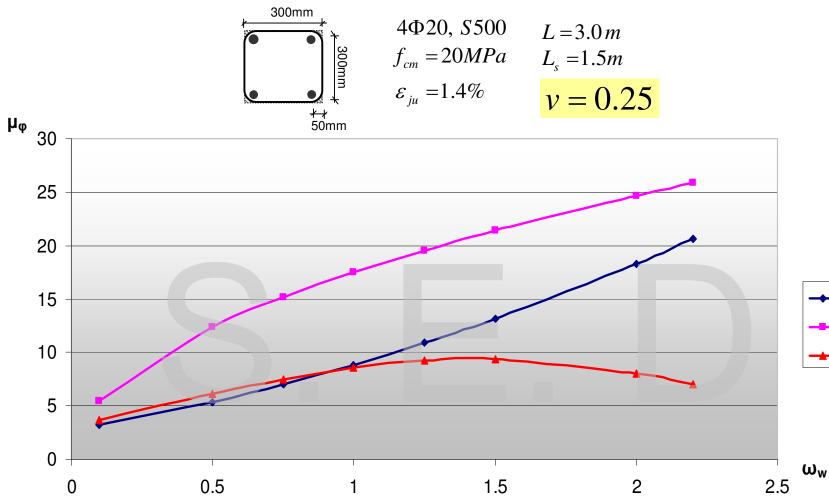
$$\frac{A_\kappa}{S} = t_{eq} = \frac{50}{100} = 0,5\text{mm}$$ $$\omega_w = \frac{4 \times 0,5}{300}\frac{500}{20} = \frac{10}{6} \cong 0,2$$

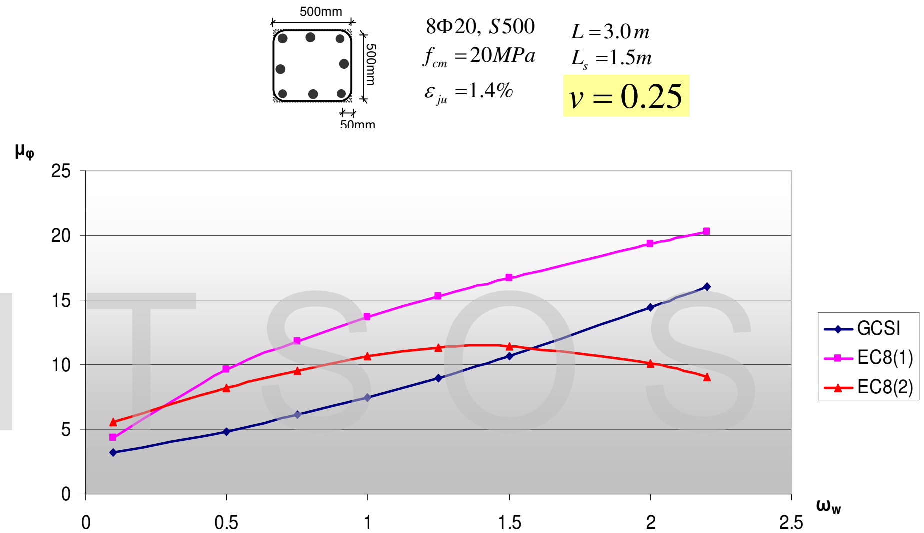
If $\Phi 10/75 \rightarrow \omega_w \cong 0,4$

For an CFRP jacket t = 1 mm

$$\varepsilon_j = 0,015 \rightarrow f_j = E_j\,\varepsilon_j = 200.000 \times 0,015 = 3000\text{MPa}$$

$$\omega_w = \frac{4}{300}\frac{3000}{20} = 2$$


300mm
300mm
50mm
4Φ20, S500
$f_{cm} = 20MPa$
$\varepsilon_{ju} = 1.4\%$
$L = 3.0m$
$L_s = 1.5m$
$v = 0.25$
μ_φ
ω_w
GCSI
EC8(1)
EC8(2)
0
5
10
15
20
25
30
0
0.5
1
1.5
2
2.5


500mm
500mm
50mm
8Φ20, S500
$f_{cm} = 20MPa$
$\varepsilon_{ju} = 1.4\%$
$L = 3.0m$
$L_s = 1.5m$
$v = 0.25$
μ_φ
ω_w
GCSI
EC8(1)
EC8(2)
0
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25
0
0.5
1
1.5
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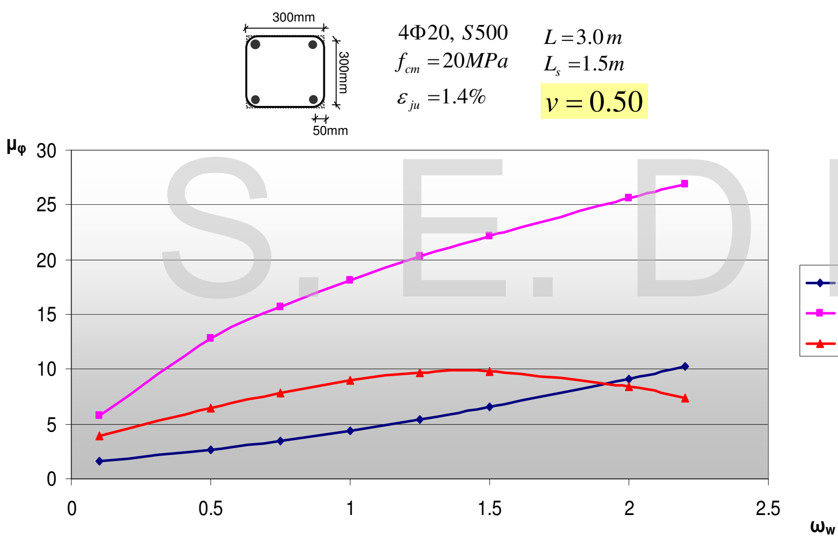
2.5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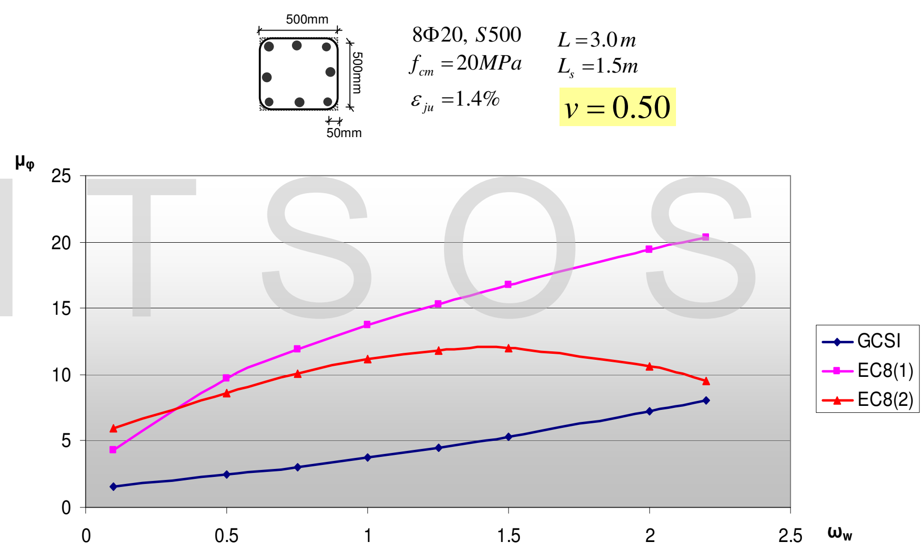
500mm
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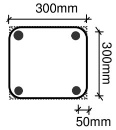
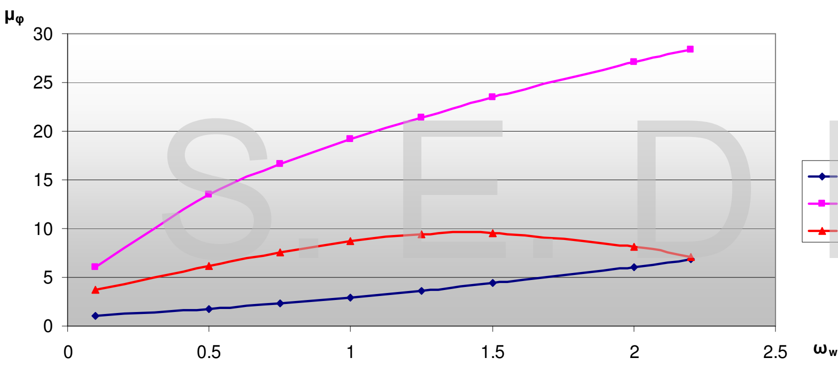
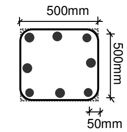


$4\Phi 20,\ S500$ $\quad L = 3.0\,m$

$f_{cm} = 20MPa$ $\quad L_s = 1.5m$

$\varepsilon_{ju} = 1.4\%$ $\quad \nu = 0.75$





$8\Phi 20,\ S500$ $\quad L = 3.0\,m$

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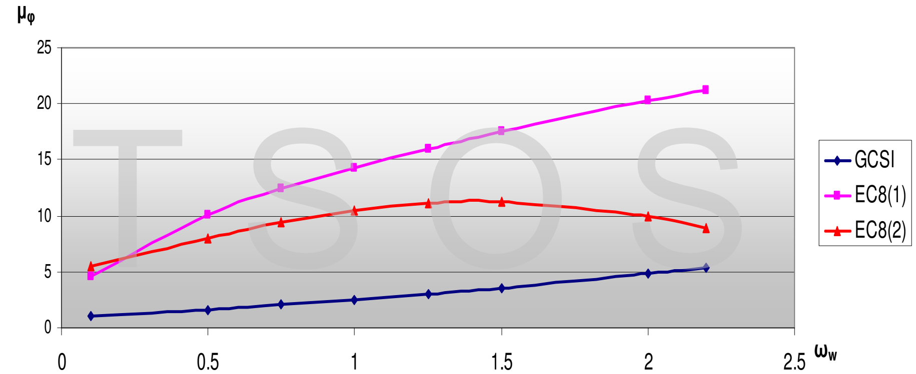
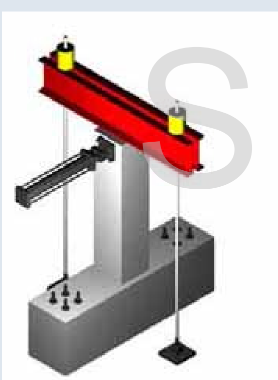
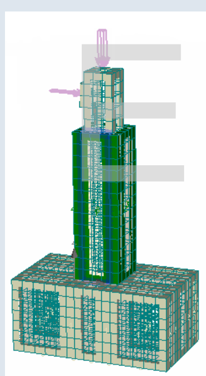
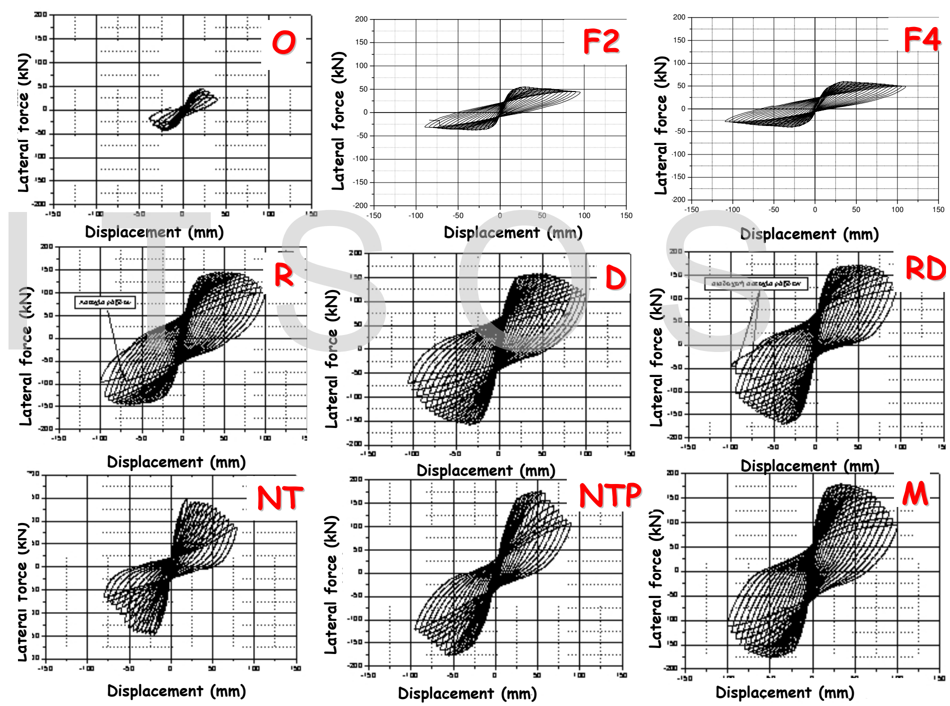


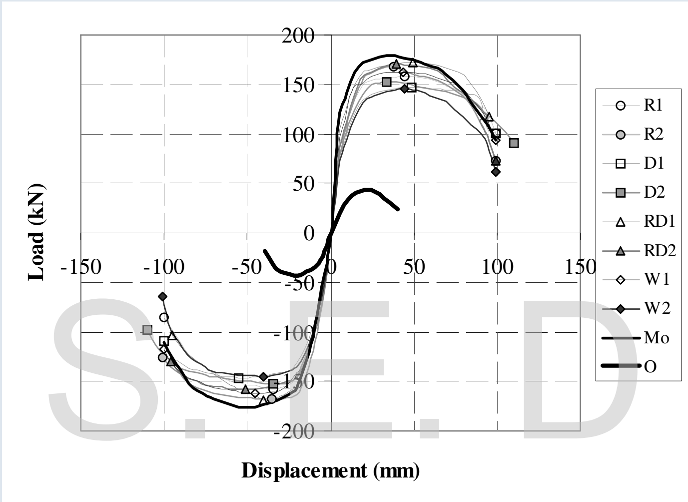
EXPERIMENTAL DATA FOR CONCRETE JACKETING

(UNIVERSITY OF PATRAS)









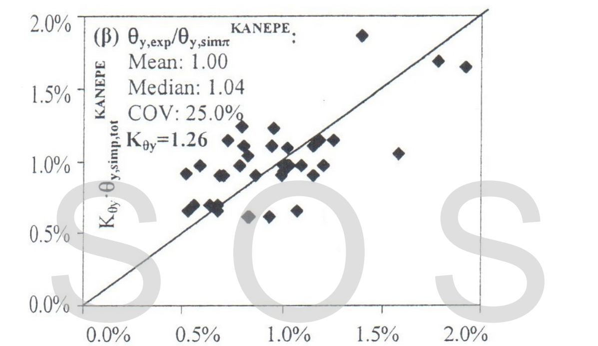
Load Against Displacement Envelope Curves for All Tested Specimens

(Bousias et al. 2004, Vandoros and Dritsos, 2006b, Vandoros and Dritsos, 2006c)

$\theta_{y,GCSI}$? $\theta_{y,exp}$

Total data (42 specimens)

$k_{\theta=}$? if $\bar{\theta}_{y,exp} = \bar{\theta}_{y_{GCSI}}$



(Kappos et al, EPPO report 2012)

$k_{\theta y=}1.26$

GCSI: $k_{\theta y=}1.25$

EC8-3: $k_{\theta y=}1.05$ or 1.20

RECENT PROJECTS FUNDED BY EPPO

On the specific subject of Ch. 8 of GCSI: Design of Interventions (Budget 150.000 Euro)

1. Investigation of the behaviour of old type RC columns strengthened by concrete jackets. (Aristotle University of Thessaloniki).
2. Investigation of the behaviour of RC columns after restoring insufficient reinforcement lap splice lengths. (Aristotle University of Thessaloniki).
3. Experimental investigation of shear strengthening of beams in their support areas, under seismic actions. (Aristotle University of Thessaloniki).
4. Experimental investigation of the behaviour or RC frames strengthened by infilling with new concrete walls. (Thessali University)
5. Experimental investigation of 4-floor RC frames strengthened by infilling with new concrete walls. (University of Patras)

Also, 5 more projects funded (Budget 150.000 Euro) on the topic of strengthening RC buildings with one or more soft storeys.

CONCLUDING REMARKS

- **EC8-3 and the GCSI deal with the crucial issue of the seismic risk of existing buildings and try to give guidance for assessment and retrofitting**
- **However, when specifically looking at the design of interventions, two crucial differences can be identified**
  - ✓ **Concept**
  - ✓ **Detail and topics covered**

- **From the three main parts of the Greek Code: a) verification of force transfer at interfaces, b) strengthening of elements, c) strengthening of the whole structure, only b is considered by EC8-3.**
- **Even when common objectives, different analytical expressions are provided leading to different outcomes.**
- **In the specific objective of "interventions to increase local ductility", the GCSI is found to be more conservative in comparison to EC8-3 and is drastically influenced by the normalized axial load.**
- **More research is needed not only in the objectives where the two Codes are contradictory but also in the areas that EC8-3 does not touch while the GCSI attempts to provide guidance, however with extremely limited experimental existing data.**