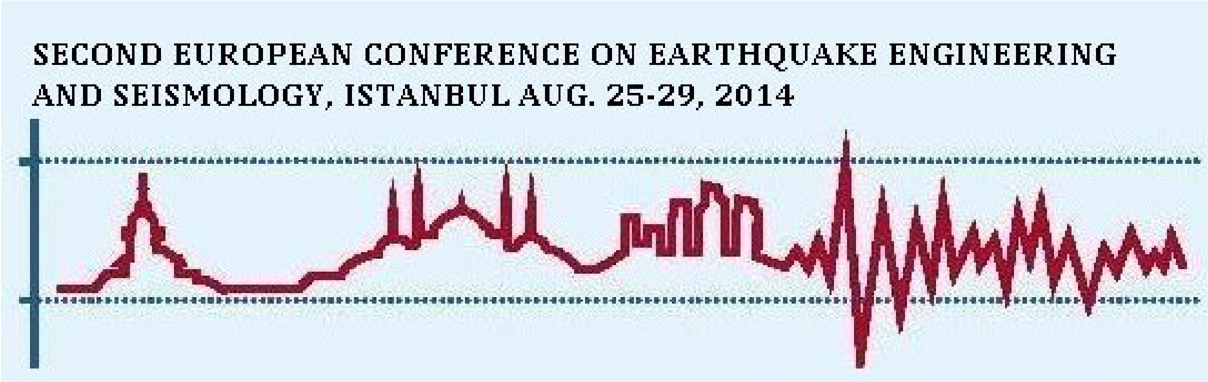

MONOLITHICITY FACTORS FOR THE DESIGN OF R/C COLUMNS STRENGTHENED WITH R/C JACKETS

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ABSTRACT

An extended parametric study of substandard reinforced concrete (R/C) members, which were retrofitted by the addition of R/C jackets was performed using an analytical model that takes into account slip at the interface. Apart from the cross section geometry and the thickness of the jacket, parameters of the investigation were the material properties of the core (existing) cross section and the jacket, as well as the percentage of longitudinal reinforcement of the jacket and the percentage of dowels placed to connect the existing member to the outer shell (jacket). Eight groups of composite members were set up. The sensitivity of the monolithicity factors (ratios of resistance of the jacketed section to that of an identical monolithic one) to the various parameters of investigation for levels of dimensionless axial load ranging from 0 to 30% was studied. Conclusions were drawn regarding the influence of each parameter on the monolithicity factors. Moreover, the experimental values of the monolithicity factors were defined and compared with the values adopted by EC8-Part 3 (2005) and the Greek Code for Structural Interventions (KANEPE 2013).

INTRODUCTION

Reinforced concrete jacketing of substandard R/C columns is one of the most appropriate intervention methods for strengthening existing non-conforming R/C buildings. It can accommodate vertical irregularities while controlling the lateral deflection profile of the building by the addition of lateral stiffness and strength uniformly distributed throughout the plan of the building. A key issue related to the response of the strengthened member is the interaction between the existing cross section and the outer shell (jacket). Experimental evidence (e.g. Rodriguez and Park 2004, Vandoros and Dritsos 2006a, Boussias et al. 2007) has shown that despite any connection measures taken between the jacket and the core cross section to ensure full composite action between the two parts, this is not feasible since slip takes place at the interface between the existing member and the jacket.

To simplify the design procedure, design codes adopt the “monolithicity factor” approach, according to which the mechanical characteristics of the strengthened members are obtained by applying adequate modifiers (monolithicity factors) to the properties of the monolithic members with identical geometry and reinforcement. Both Eurocode 8, Part 1.3 (2005) and the Greek Code for Structural Interventions (KANEPE 2013) suggest monolithicity factors for shear strength, K_v, stiffness, K_k, moment at yield K_{My}, rotation at yield and ultimate, $K_{\theta y}$ and $K_{\theta u}$, subject to specific assumptions.

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The values adopted by the codes are empirical, mainly due to the limited understanding of the influence of shear resistance mechanisms mobilized by slip at the interface. To this purpose an analytical model was developed for predicting the response of R/C jacketed members taking into account slip at the interface between the existing member and the jacket under both monotonic and cyclic loading conditions, the validity of which was checked against test results (Thermou et al. 2007, 2011, 2012).

An extended parametric study of substandard R/C members retrofitted by the addition of R/C jackets was performed utilising the proposed analytical model. Apart from the cross section geometry and the thickness of the jacket, parameters investigated were the material properties of the core (existing) cross section and the jacket, as well as the percentage of longitudinal reinforcement of the jacket and the percentage of dowels placed to connect the existing member to the outer shell (jacket). Eight groups of composite members were set up. The sensitivity of the monolithicity factors to the various parameters of the investigation for levels of dimensionless axial load ranging from 0 to 30% was studied. Conclusions were drawn regarding the influence of each parameter of the investigation on the calculated monolithicity factors. Moreover, the experimental values of the monolithicity factors were defined and compared with the values adopted by EC8-Part 3 (2005) and the Greek Code for Structural Interventions (KANEPE 2013).

BRIEF DESCRIPTION OF THE ANALYTICAL MODEL ADOPTED FOR DESCRIBING THE BEHAVIOUR OF R/C JACKETED MEMBERS

The proposed analytical model for predicting the flexural response of existing R/C members strengthened with concrete jacketing under monotonic and cyclic loading conditions introduces a degree of freedom allowing the relative slip at the interface between the existing member and the jacket (Thermou et al. 2007, 2011, 2012). Slip along the member length is attributed to the difference in normal strains at the contact interfaces (Fig. 1). For flexural analysis, the cross-section is divided into three layers which bend with the same curvature, φ (Fig. 1). The two external layers represent the contribution of the jacket, whereas the internal one represents both the core (existing cross section) and the web of the jacket shell. Slip at the interface mobilizes the shear transfer mechanisms such as aggregate interlock, friction generated by clamping action of the bars, and dowel action provided by the stirrup legs of the jacket and by the dowels placed at the interface between the core and the jacket in case that such a connection measure is taken.

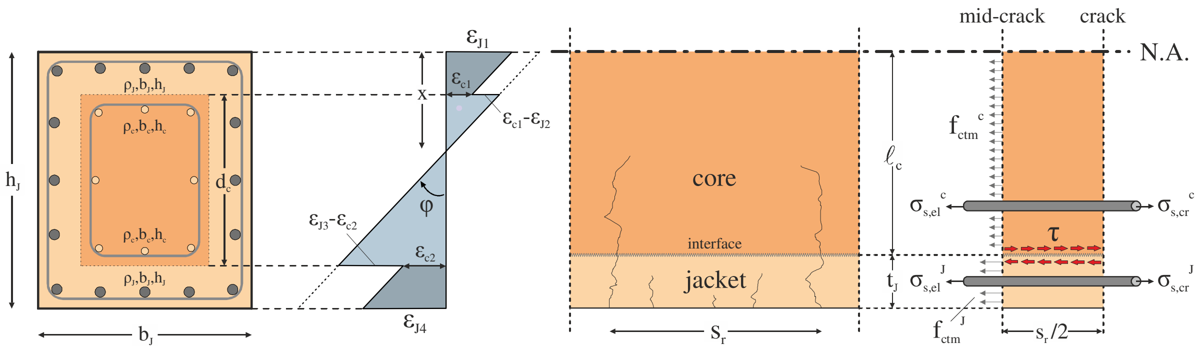

Figure 1. Strain profile of the jacketed cross section. : Crack spacing, s_r, and free body equilibrium in the tension zone of the composite section.

According to the analytical model of Thermou et al. (2007, 2011, 2012) for R/C jacketed members, shear transfer at the interface between the existing member and the jacket takes place between half-crack intervals along the length of the jacketed member, as commonly considered in bond analysis. At the initial stages of loading, cracks form only at the external layers (jacket) increasing in number with increasing load, up to crack stabilization (Fig. 1).

Shear stress demand at the interfaces, $\tau_{d,i}$, is determined by examining the cross section along the height and along a member length equal to the distance between successive cracks (Fig. 1). The layer force resultant ΣF_i (sum of concrete and steel forces at each layer), for the externally applied axial load, N_{ext} (considered to be applied to the jacketed section), is used to calculate the vertical shear stress demand in the member, $\tau_{d,i}$. With the assumption that the shear flow, q, reversal takes place at length equal to $s_r/2$ (where s_r is the crack spacing), the average stress demand $\tau_{d,i}$ is equal to:

$$\tau_{d,i} = \frac{\Sigma F_i}{0.5\, s_r\, b_J} \tag{1}$$

where ΣF_i is the layer force resultant and b_J is the width of the jacketed cross section; s_r is the crack spacing length which is defined as follows:

$$s_r = \frac{0.64 \cdot b_J\, \ell_c\, f_{ctm,c}}{n_c\, D_{b,c}\, f_{b,c} + n_J\, D_{b,J}\, f_{b,J}} \tag{2}$$

where b_J is the width of the jacketed cross section, ℓ_c is the height of the tension zone in the core of the composite cross section, $f_{ctm,c}$ is the tensile strength of core concrete, n_c, n_J are the number of bars in the tension steel layer of the core and the jacket, respectively, $D_{b,c}$, $D_{b,J}$ are the bar diameter of the core and jacket longitudinal reinforcement, respectively, and $f_{b,c}$, $f_{b,J}$ are the average bond stress of the core and the jacket reinforcement layer, respectively.

The objective of the calculation algorithm at each loading step is twofold; simultaneous establishment of equilibrium between the shear stress capacity and demand at the interfaces for relative slip, s, and force equilibrium at the cross section. An iterative procedure is followed and equilibrium is established until convergence is achieved. Due to the complexity of the proposed solution algorithm, a computer program had to be developed, using the fibre approach. The program was utilised herein for performing the analyses of the parametric study. The derived moment – curvature response curves were further processed to obtain the necessary response parameters for the definition of the monolithicity factors utilised herein.

DEFINITION OF THE MONOLITHICITY FACTORS

The use of monolithicity factors simplifies substantially design calculations and is applicable to various structural members (slabs, beams, columns, walls, foundation elements) and various intervention methods (e.g. R/C jacketing, R/C infill walls). These reduction factors are used to obtain the strength and deformation indices of the jacketed members and are applied to the respective properties of monolithic members with identical geometry. The monolithicity factors are defined as follows:

$$K = \frac{Response\ index\ of\ the\ composite\ member}{Response\ index\ of\ the\ monolithic\ member\ with\ identical\ geometry} \tag{3}$$

The various monolithicity factors usually used in design and adopted in the current study are:
(i) The monolithicity factors that refer to the deformation capacity indices such as the rotations at yield and ultimate, which are defined as:

$$\text{Rotation at yield: } K_{\theta y} = \frac{\theta_{y,J}}{\theta_{y,M}}\text{; Rotation at ultimate: } K_{\theta u} = \frac{\theta_{u,J}}{\theta_{u,M}} \tag{4}$$

(ii) The strength related monolithicity factors:

$$\text{Shear strength: } K_v = \frac{V_{J,max}}{V_{M,max}}\text{; Moment at yield: } K_{My} = \frac{M_{y,J}}{M_{y,M}} \tag{5}$$

(iii) The stiffness monolithicity factor:

$$\text{Stiffness at yield: } K_k = \frac{K_{y,J}}{K_{y,M}} \tag{6}$$

where the subscripts J and M correspond to the composite (jacketed) cross section and to the identical monolithic cross section, θ_y, θ_u are the rotations at yield and ultimate, V_{max} is the maximum strength of the cross section, M_y is the yield moment, and K_y is the secant flexural stiffness at yield, defined as the ratio of the yield moment (M_y) to the yield curvature (φ_y).

In the case of Eurocode 8, Part-3 (§A.4.2, 2005) and under the assumptions of: (i) full composite action between old and new concrete, (ii) application of full axial load to the jacketed member, and (iii) application of the concrete properties of the jacket over the full section of the element, monolithicity factors are equal to K_V=0.9 for shear strength, K_{My}=1.0 for yield moment, $K_{\theta u}$=1.0 for the rotation at ultimate, whereas for the yield rotation, the value $K_{\theta y}$=1.05 applies in case that measures for roughening of the interface have been taken and $K_{\theta y}$=1.20 applies for the rest of the measures taken for the connection of the jacket to the existing member or when no particular measures are taken. The Greek Code for Structural Interventions (§8.2.1, KANEPE 2013), which is a document compatible with EC8-3, suggests monolithicity factors for shear strength K_V=0.9, for stiffness, K_K=0.8, and rotation at yield and ultimate $K_{\theta y}$=1.25 and $K_{\theta u}$=0.80, respectively.

It is noted that the monolithicity factors design approach as proposed by the Greek Code for Structural Interventions (KANEPE 2013) is subject to certain limitations, i.e. that the target strength increase of the jacketed member should not exceed twice that of the original. On the other hand, considering the code minima regarding the percentage of longitudinal reinforcement of the jacket, but also of the entire composite cross section (equal to 1%), and the pertinent detailing rules (minimum thickness of the jacket is 70 mm), it is seen that the strength of the strengthened member far exceeds twice its original strength. In the case of EC8-Part 1.3 (2005), there is no restriction related to the increase of resistance of the R/C member due to jacketing.

EXPERIMENTAL VALUES OF THE MONOLITHICITY FACTORS

Despite the fact that R/C jacketing is a popular intervention method for the seismic retrofitting of existing substandard columns, the experimental studies carried out are limited. In an effort to gather all the existing information on the behaviour of R/C jacketed columns an experimental database was created which includes 44 specimens from 11 experimental studies (Thermou et al. 2011). The database includes specimens where various connection measures were taken between the existing member and the jacket, whereas the jacket construction was done using shotcrete or cast-in-place concrete. After processing of the experimental envelope curves, the experimental values of the monolithicity factors were defined and appear in Table 1.

The code suggested monolithicity factors are compared with the experimental values for monolithicity factors in Fig. 2. The red and blue coloured horizontal dashed lines correspond to the monolithicity values of EC8 – Part 3 (2005) and KANEPE (2013), respectively. It is clear that there is large dispersion in the case of monolithicity factors $K_{\theta y}$, $K_{\theta u}$ and K_k. This observation has to be further assessed by considering the limited range of parameters of the experimental database. One should also note that deformation and stiffness values are difficult to measure experimentally and 'ultimate' conditions are not defined in a uniform way in all tests.

Table 1. Experimental values of the monolithicity factors

Reference	$K_{\theta y}$	$K_{\theta u}$	K_{My}	K_v	K_k
Gomes & Appleton (1998)	0.84	0.73, 1.07	0.99, 1.00	0.99, 1.00	1.18, 1.20
Ilki et al. (1998)	0.77, 1.00	0.72, 0.92	0.57, 0.79	0.62, 0.70	0.74, 0.79
Vandoros & Dritsos (2006a, 2006b, 2008)	1.49~4.54	0.75~1.26	0.78~0.99	0.82~0.98	0.22~0.64
Júlio et al. (2005)	-	-	0.96~1.32	-	-
Bousias et al. (2007a, 2007b, 2008)	0.26~1.41	0.88~1.21	0.79~1.06	0.76~1.02	0.64~3.65
Júlio & Branco (2008)	0.71~1.53	0.97~1.41	0.98~1.13	0.98~1.17	0.72~1.56
min/max	0.26/4.54	0.72/1.41	0.57/1.32	0.62/1.17	0.22/3.65
Mean*	1.09	1.03	0.93	0.94	1.06

*Specimens with $K_{\theta y} > 2.5$ were excluded from the estimation of the mean

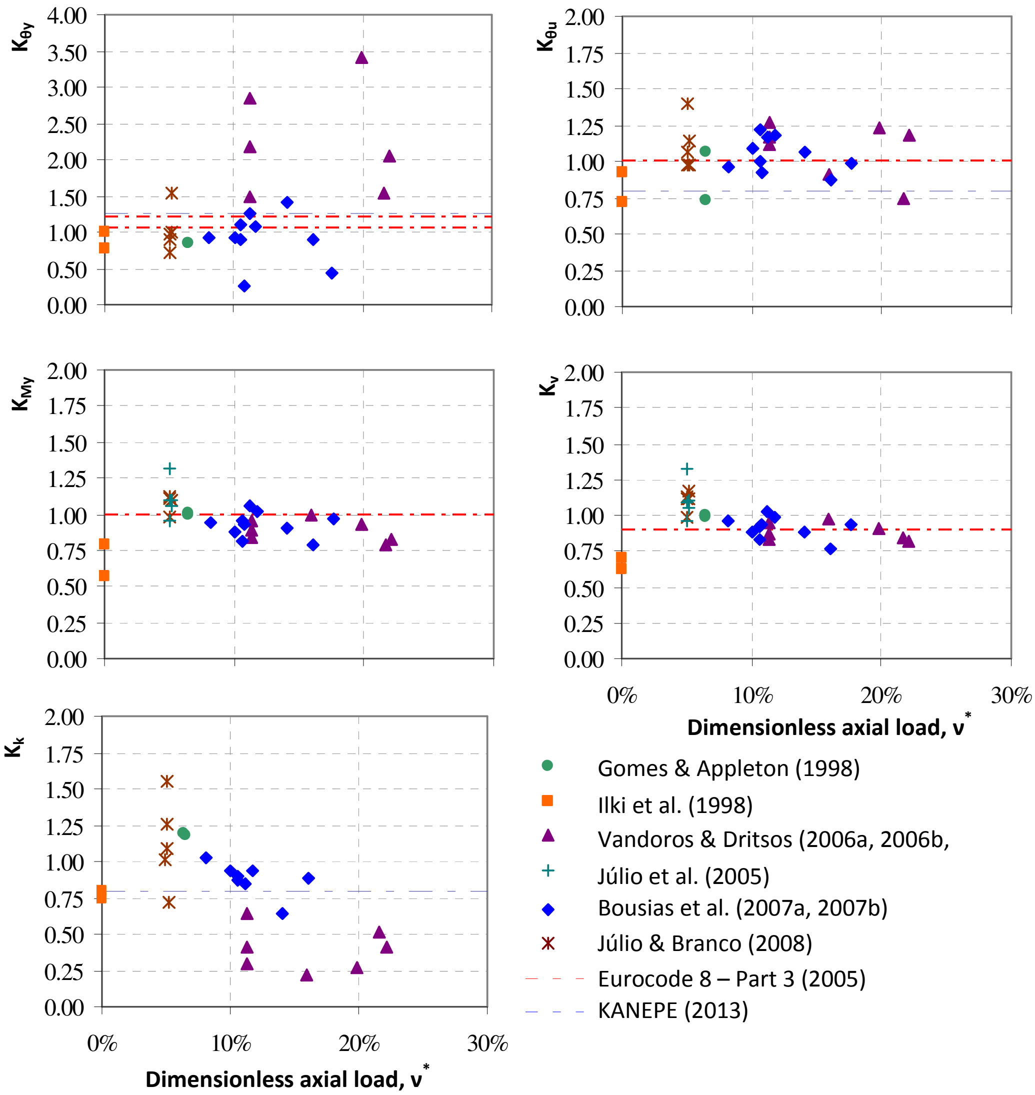

Figure 2. Comparison between the experimental values of the monolithicity values and the EC8-Part 3 (2005) and KANEPE (2013) suggested values

PARAMETRIC STUDY

The parametric investigation was performed for 250 mm square and 300×400 mm rectangular core cross sections. Reinforcement detailing and material properties are representative of the construction practice influenced by older generation codes, specifically of the 60s and 70s. The percentage of the longitudinal reinforcement was ρ_c=1% and open stirrups ∅6/300 were utilized. St I (mean f_y≈250 MPa) and St III (mean f_y≈480 MPa) were the steel grades used for smooth and ribbed longitudinal reinforcement, respectively, whereas St I was used for stirrups. For the core of the jacketed cross section the concrete grades selected were B160, B225 (older generation of codes, grade based on average cube strength) and C20/25 (close to B300). The thickness of the jacket assumed values equal to 75, 100 and 125 mm. The percentage of the longitudinal reinforcement of the jacket ($\rho_{J*}=A_J/(b_Jh_J-b_ch_c)$) ranged between 1% and 4%, whereas the stirrups placed were ∅8/200. The concrete grades selected for the jacket were C25/30 and C50/60, whereas B500C ribbed bars were used for the longitudinal and transverse reinforcement. Another parameter of investigation was the dimensionless axial load, $v^*(=N/[(b_J \cdot h_J - b_c \cdot h_c) \cdot f_{c,J} + b_c \cdot h_c \cdot f_{c,c}]$, which was considered to be applied to the jacketed cross section and ranged between 0 and 30%. Moreover, the influence of the dowels placed at the interfaces was studied as a connection measure between the existing member and the jacket. The minimum percentage defined by the Greek code for structural interventions (KANEPE 2013) equal to $\rho_{d.min}=0.20f_{ctm}/f_{yk}\geq 0.12\%$ (1Ø16/600 mm) and twice that value was considered ($\rho_d=2\rho_{d.min}=0.24\%$, *1Ø16/300 mm*). All the groups defined for the needs of current parametric study appear in Table 2.

Table 2 Groups of the parametric study

Parameters	**Groups of parametric study**							
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
B160 (f_{cm}=10 MPa)	√							
B225 (f_{cm}=16 MPa)		√	√	√	√			√
C20/25(f_{cm}=28 MPa)						√	√	
C25/30 (f_{cm}=33 MPa	√	√	√	√		√		
C50/60 (f_{cm}=58 MPa)					√		√	√
St I (f_{ym}=250 MPa)	√	√	√	√	√	√	√	√
St III (f_{ym}=480 MPa)		√	√	√	√	√	√	√
B500C (f_y=500 MPa)	√	√	√	√	√	√	√	√
ρ_{J*}=1%~2%						√	√	
ρ_{J*}=1%~4%	√	√	√	√	√			√
ρ_d=0, 0.12%, 0.24%			√					
t_r= 75 mm	√	√			√	√	√	√
t_r= 100 mm			√					
t_r= 125 mm				√				

Due to the section thickness increase caused by the jacket, the shear span ratio was reduced. The reduction of the shear span ratio ranged from 6 to 3 (considering the case of the jacket thickness 125 mm) and from 3.8 to 2.8 (for jacket thickness 75 mm) for the square and the rectangular cross section, respectively. The study of short (captive) columns (initially or after the retrofit) was not studied herein.

- Rotation at yielding and ultimate

The cross section is considered to have attained a state of flexural yielding when the extreme layer of tensile reinforcement reaches first its yield strain ε_{sy} or alternatively when the concrete strain at the extreme compression fiber exceeds the limit value of ε_c=1.5‰ (*fib* 2003). Definition of an ultimate state is also adopted so as to allow comparisons between the monolithic and the detailed analytical approach. The total inelastic rotation, $\theta_{u,J}$, is defined as:

$$\theta_{u,J} = \theta_{u,J}^{flex} + \theta_{u,J}^{slip} + \theta_{u}^{interf,slip} \qquad (7)$$

where $\theta_{u,J}^{flex}$ is the inelastic rotation at ultimate due to flexural deformation, $\theta_{u,J}^{slip}$ is the ultimate rotation due to slippage of the longitudinal reinforcement of the jacket and $\theta_{u,J}^{interf.slip}$ is the ultimate rotation due to slippage of the interfaces. The component of the ultimate rotation that corresponds to shear deformation has been ignored. However, it was checked if the element continues to have a flexure-dominated response after the application of the jacket and the ensuing decrease in the shear span ratio. The terms that appear in Eq. (7) can be estimated as follows:

- Ultimate rotation due to flexural deformation:

$$\theta_{u,J}^{flex} = \theta_{y,J}^{flex} + \theta_{p,J}^{flex}\ ;\ \theta_{y,J}^{flex} = \frac{\varphi_{y,J} L_V}{3}\ ;\theta_{p,J}^{flex} = \frac{(\varphi_{u,J} - \varphi_{y,J})L_P(L_V - 0.5L_p)}{L_V} \qquad (8)$$

where $\theta_{y,J}^{flex}$, $\theta_{p,J}^{flex}$ are the elastic rotation at yield and the plastic rotation, respectively, $\varphi_{y,J}$ and $\varphi_{u,J}$ are the curvatures at yield and ultimate, respectively, L_V is the shear span of the member and L_p is the length of the plastic hinge region.

- Ultimate rotation due to slippage of the longitudinal reinforcement of the jacket, $\theta_{u,J}^{slip}$:

$$\theta_{u,J}^{slip} = \theta_{y,J}^{slip} + \theta_{p,J}^{slip} \qquad (9)$$

$$\theta_{y,J}^{slip} = \frac{\varphi_{y,J} L_{b,y}}{2} \;;\; L_{b,y} = \frac{d_b}{4}\frac{f_y}{f_{by}} \;;\; \theta_{p,J}^{slip} = \left(\varphi_{u,J} - \varphi_{y,J}\right)\frac{(f_u - f_y)}{f_u} L_{bu} \;;\; L_{bu} = \frac{d_b}{4}\frac{f_u}{f_{bu}} \;;\; f_{bu} = 0.8 \cdot f_{by} \quad (10)$$

$\varphi_{y,J}$ and $\varphi_{u,J}$ are the curvatures at yield and ultimate, respectively, $L_{b,y}$ and $L_{b,u}$ are the anchorage lengths at yield and ultimate, respectively, L_V is the shear span of the member, d_b is the diameter of the longitudinal reinforcement, f_y, f_u are the yield and ultimate steel strengths, respectively, f_{by}, f_{bu} are the bond stresses at yield and ultimate, respectively.

- Ultimate rotation due to slippage of the interfaces, $\theta_{u,J}^{inter.slip}$

$$\theta_{u,J}^{int\,erf,slip} = \frac{\left(s_{1u} + s_{2u}\right)}{h_c} \quad (11)$$

where s_{1u}, s_{2u} are the slip values at the upper and bottom interfaces, and h_c is the height of the core of the composite cross section. For estimating the rotation at yield due to slippage at the interfaces, $\theta_{y,J}^{inter,slip}$, Eq. (11) can be used provided that the slip values at the upper and bottom interface will correspond to yielding of the composite cross section.

For proper comparison of the response of the R/C jacketed member considering the monolithic and analytical approach, the equivalent monolithic curvature is estimated by considering equal deformations at ultimate for the two analysis cases. Hence:

$$\varphi_{u,M}^{eq} = \frac{\left[\theta_{u,J} - \frac{\varphi_{y,M} L_V}{3} - \frac{\varphi_{y,M} L_{b,y}}{2} + \frac{\varphi_{y,M} L_{SP}\left(L_V - 0.5L_P\right)}{L_V} + \frac{\varphi_{y,M}\left(f_u - f_y\right)L_{b,u}}{f_u}\right]}{\left[\frac{L_{SP}\left(L_V - 0.5L_P\right)}{L_V} + \frac{\left(f_u - f_y\right)L_{b,u}}{f_u}\right]} \quad (12)$$

where the various parameters have been defined previously.

The analytical model was utilised for the derivation of moment – curvature (M – φ) curves for monotonic loading with or without the presence of slip at the interface between the existing cross section (core) and the jacket. The response curves were bi-linearized using BILIN (Panagopoulos and Kappos 2009) a program developed at the Laboratory of Reinforced Concrete and Masonry Structures of the Aristotle University. The response curve was converted to a bilinear curve according to the following rules: (i) the bilinear curve provided an equal area to that under the experimental curve (equal energy absorption); (ii) the linear branch of the bilinear curve intersected the experimental curve at 60% of the yield load; (iii) the ultimate displacement corresponded to 20% drop in the peak load; (iv) hardening in the post-elastic branch was limited in the range between 0 and 10%.

Yielding was defined on the basis of the bilinear response curves. The ultimate point was defined: (i) in case of monolithic response as the point where the compressive strength of the confined concrete was reduced to 0.85f_c and (ii) in the case where slip was allowed at the interfaces of the composite cross section when either the upper or the lower interface reached a slip value equal to 2 mm (Tassios and Vintzileou 1987, Vintzileou and Tassios 1986, 1987). The curvature values at yielding and ultimate were transformed to rotation values according to Eqs. (7-11).

- Results of the parametric study

The moment – curvature response curves according to the monolithic (i.e. no slip at the interface is considered) and analytical approach (i.e. according to the analytical model describe in previously) were derived for all the specimens of the eight groups of the parametric study presented in Table 2 (Fig. 3). These data were further processed and the monolithicity factors were defined according to the definitions provided in the preceding section. Some representative results are shown in Figs. 4-6.

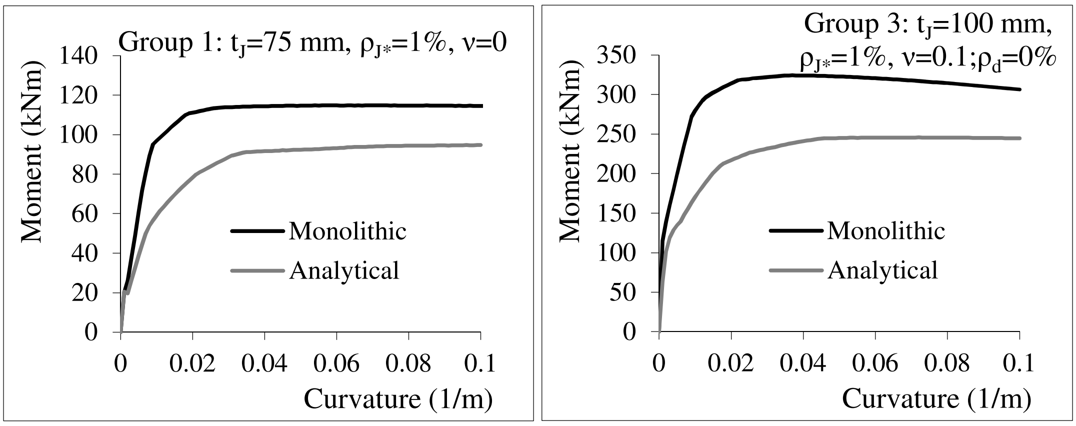

Figure 3. Moment – curvature response curves for a column of Group 1 and Group 3.

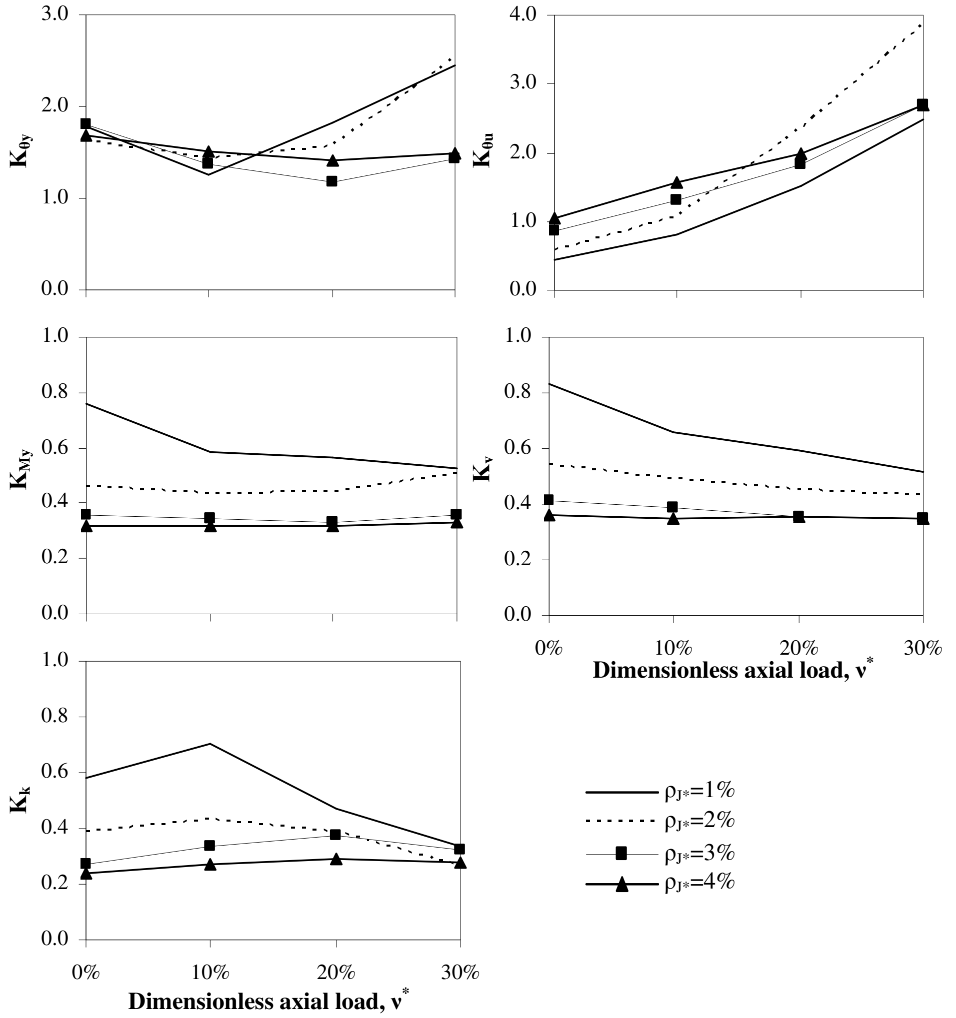

Figure 4. Monolithicity factors for the 1st group of the parametric study.

The analyses conducted for the different composite sections indicated the sensitivity of the monolithicity factors to both the construction material of the existing cross section (core) and the percentage of longitudinal reinforcement of the jacket for increasing axial load.

The range of the estimated values for the monolithicity factors are summarised in the following:

- Groups 1-2, 5-7: existing cross section ***250 mm-square***, jacket thickness ***75 mm***: $K_{\theta y}$=1.17~2.86, $K_{\theta u}$=0.45~1.87, K_{My}=0.32~0.99, K_r=0.35~1.02 and K_k=0.24~0.95.
- Group 3: existing cross section ***250 mm-square***, jacket thickness ***100 mm:*** (i) no additional dowels: $K_{\theta y}$=1.63~3.30, $K_{\theta u}$=0.63~3.71, K_{My}=0.41~0.87, K_r=0.42~0.88 and K_k=0.24~0.73, (ii) minimum percentage of dowels according to KANEPE (2013): $K_{\theta y}$=1.63~4.85, $K_{\theta u}$=0.72~4.05, K_{My}=0.43~0.87, K_r=0.45~0.88 and K_k=0.22~0.73, (iii) two times the minimum percentage: $K_{\theta y}$=1.39~4.81, $K_{\theta u}$=0.53~4.01, K_{My}=0.48~0.93, K_r=0.50~0.95 and K_k=0.23~0.82
- Group 4: existing cross section ***250 mm-square***, jacket thickness ***125 mm***: $K_{\theta y}$=1.78~3.94, $K_{\theta u}$=0.69~4.13, K_{My}=0.39~0.85, K_r=0.37~0.85 and K_k=0.19~0.70.
- Group 8: existing cross rectangular ***300×400* mm**, jacket thickness **75 mm**: $K_{\theta y}$=1.49~2.64, $K_{\theta u}$=0.81~3.73, K_{My}=0.42~0.90, K_r=0.45~0.91 and K_k=0.38~0.82.

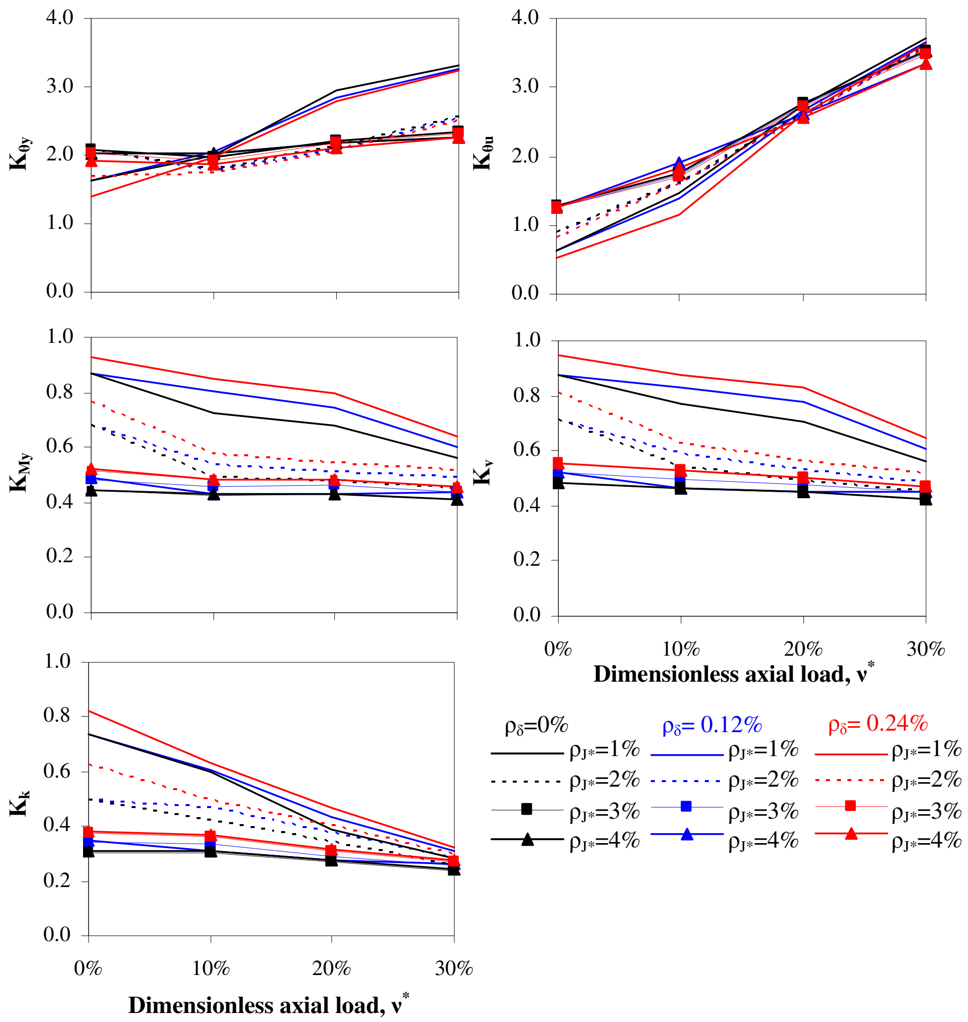

Figure 5. Monolithicity factors for the 3rd group of the parametric study.

The very low values obtained for the strength and stiffness monolithicity factors, K_V, K_{My} and K_k, correspond to a percentage of the longitudinal reinforcement of the jacket equal to 3% and 4%, which is not common in practice. Furthermore, the minimum number of dowels at the interface between existing member and the jacket does not have any visible influence, whereas the influence of twice the minimum number of dowels is small. It is recalled that in all cases the stirrup legs act as dowels.

The implementation of the equations describing these two resistance mechanisms to the cases of the parametric study indicated that the friction resistance contributes the major part of the total interface resistance. Thus, the capacity of the interface is controlled by the lower concrete compressive strength of the two bodies in contact, which is usually that of the core cross section (e.g. in the 1st group of the parametric analyses, where a low concrete grade, B160, was used). When the concrete compressive strength of the core is significant (e.g. groups 6, 7, see Table 2), the response of the composite cross section is close to the response of the corresponding monolithic section, especially for percentages of longitudinal reinforcement of the jacket equal to 2% and for dimensionless axial load up to 20%.

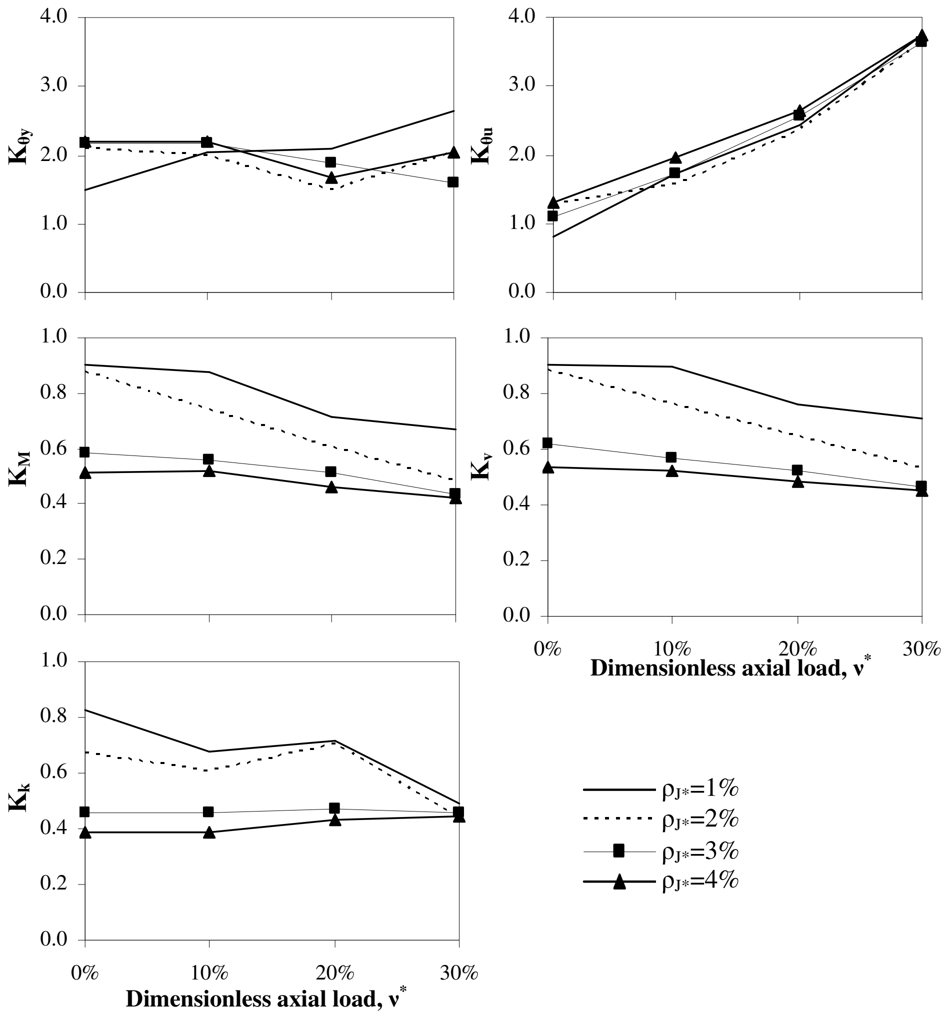

Figure 6. Monolithicity factors for the 8th group of the parametric study.

CONCLUSIONS

The main conclusions drawn from the parametric study conducted using the developed model for jacketed members are:

1. The sensitivity of the monolithicity factors to the construction materials of the existing cross section (core) and the jacket, as well as to the percentage of longitudinal reinforcement of the

jacket for increasing axial load was highlighted. For the range of parameters considered in the present study the lower and upper limits for the monolithicity factors were found to be: $K_{\theta y}$=1.17~4.85, $K_{\theta u}$=0.45~4.13, K_{My}=0.32~0.99, K_r=0.35~1.02 and K_k=0.19~0.95.

2. The need for further investigation of the response of R/C jacketed columns with low concrete compressive strength of the core was identified. An experimental programme wherein jacketed members with low concrete compressive strength of the core will be tested would lead to safer conclusions regarding the applicability (or otherwise) of the monolithicity factors adopted by EC8-Part 3 (2005) and KANEPE (2013). Moreover, the response of interfaces with significant difference in the concrete compressive strength between the substrate and the newly cast concrete, which is the usual case in practice, need be further investigated.
3. The proposed values for the monolithicity factors to be used in EC8-Part 3 (2005) and KANEPE (2013) apply for specific properties of the construction materials and level of applied axial load. These limits are defined by the experimental data as follows:
   (i) Percentage of the longitudinal reinforcement of the existing cross section 0.81 ~ 2.01%
   (ii) Percentage of the longitudinal reinforcement of the jacket 0.75 to 1.64%
   (iii) Concrete compressive strength of the existing cross section 23 to 56 MPa
   (iv) Concrete compressive strength of the jacket 18 to 69 MPa
   (v) Dimensionless axial load (with the assumption that it is applied to the jacketed cross section) 0 to 0.23.

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