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Effect of Relative Humidity on Creep and Shrinkage of Concrete According to the European Code for Calculation of Slender Columns

M. Sc. Diana Lluka[1]
Departament of Building Constructions and Transport Infrastructure, Faculty of Civil Engineering, Polytechnic University of Tirana,
Albania.

M. Sc. Merita Guri[2]
Departament of Applied and Human Science,
Faculty of Architecture and Design,
Polis University,
Tirana, Albania

Assc. Prof. Hektor Cullufi[2]
Departament of Mechanic of Structures,
Faculty of Civil Engineering,
Polytechnic University of Tirana,
Albania

***Abstract*—The paper gives a short description of mechanism for creep and shrinkage of concrete accorting to Europen Normative Eurocode 2. It is focused on effect of relative humidity and cement class on creep and shrinkage parameters calculated for slender reinforced concrete columns. Two main methods will be presented, the method based on nominal stiffness and the method based on nominal curvature for calculation of slender columns. Columns with rectangular section with uniform distribution of the reinforcement are studied and some parameters like relative humidity of enviroment and cement class will be changed in order to study the influence of creep and shrinkage in second order effects. The resultants are given in tables and graphs.**

***Keywords*—Creep, shrinkage, relative humidity, slenderness, bending stiffnes, Eurocode 2**

I. INTRODUCTION

Columns are structural elements used to support compressive loads. A slender column is a column in which the ulimate load is governed not only by the strength of materials and the dimensions of the cross section but also by the slenderness. The second-order parameters in design of slender columns are very important and the effects of creep and shrinkage of concrete must be analyzed. The relative humidity of enviroment, the class of cement in the composition of concrete are some of the parameters that have influence in calculation of creep and shrinkage of concrete and the second-order parameters in the calculations of slender columns.

II. CREEP AND SHRINKAGE OF CONCRETE

A. Shrinkage of concrete.

Shrinkage is the decrease of concrete with the time.The causes of shrinkage are:

a) Loss of water on drying.
b) Change volume on carbonation.

The early age of volume changes are typically ignored in design of concrete structures. Shrinkage can be separated into two stages. The early age shrinkage occurs in the first 24 hours and the long term shrinkage cccurs after the first 24 hours.

The early age shrinkage is autogenous, drying and thermal. The long term shrinkage is carbonation, thermal, chemical and autogenous.

Autogenous shrinkage is the decrease of concrete volume that occurs without moisture being transferred to the exterior enviroment.

Drying shrinkage is the decrease of concrete volume that occurs due to a physical loss of water from the concrete to the exterior environment during the curing process.

Thermal shrinkage is the change of volume in concrete when the temeperature fluctuates. As in most materials concrete will expand when temperature rises and it will contract when cooled. At early ages the concrete temperature rises due to hydration process.

Carbonation shrinkage is the reduction of concrete volume that cccurs due to the reaction between the products of the hydration process and carbon dioxide in atmosphere. In this process CO_2 from atmosphere acting chemically with calcium hydroxide and the product is the transformation of calcium hydrocide into calcium carbonate C_aCO_3 in concrete.

$$CO_2 + C_a(OH)_2 \rightarrow C_aCO_3 + H_2O$$

According Ferreira, 2004 the rate of carbonation in concrete is low for relative air humidity below 30% and above 75% and high when the realtive air humidity is 40%-70%.

The chemical shrinkage is product of the hydration process. The reactions below describe the basic reactions of cement clinker that occur during the cement-water interaction:

$2C_3S+6H \rightarrow C_3S_2H_3+3CH$
$2C_2S+4H \rightarrow C_3S_2H_3+CH$

B. Creep of concrete.

Creep is the increase of concrete strain under constant stress.

In concrete, creep deformations are generally larger than elastic deformation and thus creep represents an important factor affecting the deformation behaviour. Concrete under stress undergoes a gradual increase of strain with time. The final creep strain may be several times as large as the initial elastic strain.

Time depend deformation, that occurs when concrete is loaded in a sealed condition and the moisure, cannot escape. It is called basic creep and is primarily influenced by the material property.

The drying creep is the creep of the concrete when moisture exchange is permitted.

The real situation might be the combination of two phenomena, sometimes, one being the dominating factor. Creep deformation contains three regions:

1. Primary creep, that is initial increase in deformation.
2. Secondary creep that is relatively a steady deformation region.
3. Tertiary creep that leads to creep fracture.

The total strain of concrete may be decomposed as:

$\varepsilon_c(t)=\varepsilon_{el}+\varepsilon_{sh}+(\varepsilon_{bc}+\varepsilon_{dc})$
$\varepsilon_c(t)$- total strain at time t
ε_{el}- elastic strain
ε_{sh}-shrinkage strain (no stress)
ε_{bc}-basic creep
ε_{dc}-drying creep
$\varepsilon_{bc}+\varepsilon_{dc}= \varepsilon_{cc}(\infty,t_0)$ is called total creep

The factors affecting drying shrinkage and creep of concrete are:

- Aggregate content
- Cement content and water/cement ratio.
- Humidity
- Geometry of the concrete element
- Temperature
- Age of loading

The macroscopic factor affecting creep can be devide into two categories, intrinsic factor and extrinsic factor.

The instrinsic factors are water/cement ratio, water content, cement type, aggregate content.

The extrinsic factors are geometry of concrete element, relative humidity of the environment, stress level, when the load is first applied, the duration and magnitude of the loading, and temperature.

Water is present in concrete in different forms: Water vapour, capillary water, absorbed water, interlay water and chimical combined water.

Concrete is made up of pores of different size and the water moves from smaller to larger pores at different levels. The movement of capillary water is rapid and reversible. The absorbed water moves gradually and the movement is reversible. The interlayer water moves slower than the absorbed and capillary water.

The source of shrinkage and creep is the hydrated cement paste. The factor that influence the drying shrinkage also influence the creep in concrete.The magnitute of creep and shrinkage strains cannot ignored in structural design.

The creep coefficient of concrete $\varepsilon cc(\infty,t_0)$ according EC2-2004 is $\varphi(t,t_0)$ is releted to E_c, where:

$$E_c=1.05\ E_{cm.}$$

The creep deformation of concrete $\varepsilon_{cc}(\infty,t_0)$ at time $t=\infty$ for a constant compressive stress at the concrete age t_0 is:

$$\varepsilon_{cc}(\infty,t_0)= \varphi(\infty,t_0)\cdot(\sigma c/Ec)$$

When $\sigma c>0.45fck(t_0)$ then creep non-linearity should be considered.

Some creep graph are included in Euro Code2 for inside condition with RH=50% and outside condition RH=80% and notional size h_0.

The values are valid for ambient temperature between -40^0C and $+40^0C$ and a relative humidity between RH=40% and RH=100%.

$\varphi(\infty,t_0)$- is the final creep coefficient
t_0-is the age of concrete at time of loading in days
$h_0=2Ac/u$, where Ac is concrete cross sectional area and u is the perimeter of the part which is exposed to drying.
S- is Class S for slowly hardening cements
N- is Class S for normal hardening cements
R- is Class S for rapid hardening cements

The creep coeficient $\varphi(t,t_0)$ can be calculate:

$$\varphi(t,t_0)= \varphi_0\cdot\beta_c(t,t_0)$$

where:

$$\varphi_0=\varphi_{RH}\cdot\beta(f_{cm28})\cdot\ \beta(t_0)$$

t_0 – the age of cocnrete in the moment of loading.
$\varphi_{RH}=f(RH)$
RH – Relative humidity in %.

$$\varphi_{RH}=\begin{cases} 1+\left[\dfrac{1-\frac{RH}{100}}{0.1\cdot\sqrt[3]{h}}\right] & for\ \ \mathrm{fcm28}<35MPa \\ 1+\left[\dfrac{1-\frac{RH}{100}}{0.1\cdot\sqrt[3]{h}}\cdot\alpha 1\right]\cdot\alpha 2 & for\ \ \mathrm{fcm28}<35MPa \end{cases}$$

$\alpha 1=[35/f_{cm28}]^{0.7}$ and $\alpha 2=[35/f_{cm28}]^{0.2}$
$\beta(f_{cm28})=16.8/\sqrt{}(f_{cm})$ and $\beta(t_0)=1/[0.1+(t_o)^{0.2}]$

The development of creep with time after loading is taken into consideration with $\beta_c(t,t_0)$.

$$\beta_c(t,t_0) =[(t-t_0)/(\beta_H+t-t_0)]^{03}$$

where:

$\beta_{H=}1.5[1+(0.012RH)^{18}]\cdot h+250$ for $f_{cm}\leq 35Mpa$
$\beta_{H=}1.5[1+(0.012RH)^{18}]\cdot h+250\alpha_3$ for $f_{cm}\leq 35Mpa$
and $\alpha_3=(35/f_{cm28})^{0.5}$

III. THE EFFECT OF CREEP IN SECOND-ORDER ANALYSES.

A. Slenderness criterion for isolated members

The second order effects may be ignored if the slenderness

$\boldsymbol{\lambda= l_0 / i < \lambda_{lim}}$

l_0 is effective length
i is the radiusof gyration of the uncracked concrete section

According EC2 [2004] a general definition of the effective length for isolate members with constant cross section are given:

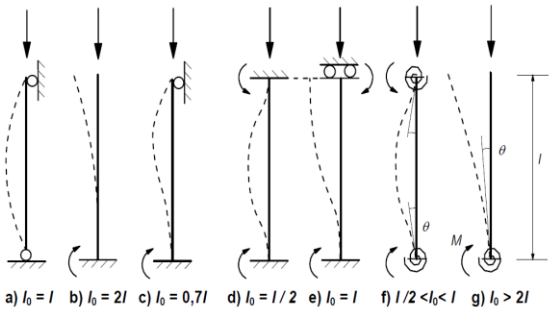


Fig. 1. Effective length for isolate members.

For calculation of λ_{lim} the recommended value are:

$\lambda_{lim} = 20\ A\ B\ C/\sqrt{n}$

where:

$A = 1/(1 + 0.2\ \varphi_{ef})$

$B = \sqrt{1 + 2\omega}$

$C = 1.7 - r_m$

$n = N_{Ed}/(A_c\ \ f_{cd})$

$\omega = A_s\ \ f_{yd}/(A_c\ \ f_{cd})$

$r_m = M_{01}/M_{02}$

φ_{ef} is the effective creep ratio

The effect of creep shall be taken into account in second-order analysis with due consideration of both the general conditions for creep and the duration of different loads in the load combination considered.

The effective creep ratio is:

$$\varphi_{ef} = \varphi(\infty,t_0)\cdot M_{0Eqp}/M_{0Ed}$$

Where: $\varphi(\infty,t_0)$ is the final creep coefficient

M_{0Eqp} is the first order bending moment in quasi-permanent load combination.

M_{0Ed} is the first order bending moment in design load combination.

The effect of creep may be ignored $\varphi_{ef} = 0$ if three conditions are:

$\varphi(\infty,t_0) \leq 2$

$\lambda \leq 75$

$M_{0Ed}/N_{Ed} \geq h$

M_{0Ed} is the first order moment and his the cross section depth in the corresponding direction.

N_{Ed} is the design value of the applied axial force

h is the heigh of cross section

B. The simlified methods of analyses for calculation of slender columns.

Two are the simplified methods for calculation of slender columns according EC2.

a) Nominal stiffness (NS)

b) Nominal curvature (NC)

Method (a) may be used for both isolated members and whole structures.

Method (b) is suitable for isolated members.

a) Nominal Stiffness Method (N.S.)

This method based on nominal stiffness (NS) of slender compression members with arbitrary cross section:

$$EI = K_c \cdot E_{cd} \cdot I_c + K_s \cdot E_s \cdot I_s$$

$E_{cd} = E_{cm}/\gamma_{cE}$ is the design value of modulus of elasticity of concrete and $\gamma_{cE} = 1.2$]

I_c–is moment of inertia of concrete cross section

E_s–is the design value of modulus of elasticity of reinforcement

I_s–is the second moment of area of reinforcement about the centre of area of the concrete.

K_c – is a factor for effects of creep, cracking etc.

K_s – is a factor for contribution of reinforcement.

When $\rho \geq 0.01$, where $\rho = As/Ac$,

as a simplified alternative $K_s = 0$, $K_c = 0.3/(1 + 0.5\varphi_{ef})$

φ_{ef} - is the effective creep ratio.

And the stiffness should be based on an effective concrete modulus $E_{cd,\,eff} = E_{cd}/(1 + \varphi_{ef})$

The total design moment, including second order moment is:

$M_{Ed} = M_{0Ed}[1 + \beta/\{(N_B/N_{Ed}) - 1]\}$

M_{0Ed} - is the first order moment

$\beta = \pi^2/c_0$ - is a factor which depends on distribution of first and second order moments and c_0 is a coefficient which depends on the distribution of first order moment.

N_{Ed} - is the design value of axial load

N_B - is the buckling load based on nominal stiffness.

b) Nominal Curvature Method (NC)

This method gives a nominal second order moment based on a deflection.

The moment design is:

$$M_{Ed} = M_{0Ed} + M_2$$

M_{0ED} –is the first order moment

M_2 – is the nominal second-order moment

$M_2 = NEd \cdot e_2$

The deflection $e_2 = (1/r)\ l_0^2/c$; $1/r$ -is the curvature;

l_0 is the effective length and $c = 10 = \pi^2$ is a factor depending on curvature distribution for constant symmetrical sections.

The curvature is $1/r = K_r \cdot K_\varphi \cdot 1/r_0$

$Kr = (n_u - n)/(n_u - n_{bal})$ is a correction factor depending on axial load.

$K_\varphi = 1 + \beta \cdot \varphi_{ef} \geq 1$ is a factor for taking account of creep, and $\beta = 0.35 + f_{ck}/200 - \lambda/150$

The influence of some factors that infuences in the creep effective ratio φ_{ef} in the calculation of slender compression elements, with both methods NS and NC according EC2, is given in the next section for isolated members.

IV. PARAMETER STUDY

One of the most importatnt factors for both shrinkage and creep is the relative humidity of the medium surrounding the concrete element.

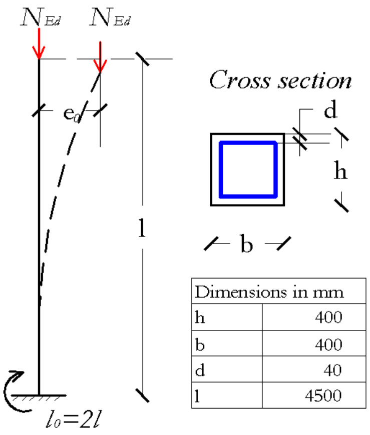
A colomn with rectangular cross section, dimensions 400x400mm with reinforcement laid uniformly is analysed. XC3 with moderate humidity is chosen for the enviromental condition according to Table 4.1 EN 1992-1-1:2004.

Concrete class is C30/37 and the concrete cover is 40mm. The first load application is for t_0=28days.

The axial force is N_{Ed}=2025(kN), the heigh of column is 4.5m and $l_0=2\cdot4.5=9$m.

For each calculation some parameters will be changed in order to study their influence in effective creep ratio, concrete creep coeficient and second order effects.

These parameters are humidity of the environment and cement class. The humidity of the environment will be changed from 45% -80% and the cement class is R, N, S for each calculation. Other parameters like the applied load (N_{Ed}=2025kN), concrete class C30/37 and reinforcement are kept constant. “Fig. 1” gives the column in compression and the dimensions of high, depth and width of cross section and concrete cover.



Dimensions in mm	
h	400
b	400
d	40
l	4500

Fig. 2.Slender column with concstant cross section.

The analyses are made with NS and NC method and the effective creep ratio, concrete creep coeficient, bending stiffness of compression members are calculated for each case.

a) The effect of cement class and relative humidity in concrete creep coefficient $\varphi(\infty,t_0)$.

“Tab.1.” represent the value of concrete creep coefficient $\varphi(\infty,t_0)$ for concrete class C30/37 with three types of cement class R, N, S and in the following graphs in “Fig.3.” the vertical axis represent concrete creep coefficient $\varphi(\infty,t_0)$ and the horizontal axis the relative humidity RH in (%).

Concrete creep coefficient $\varphi(\infty,t_0)$			
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	2.41	2.47	2.55
50	2.31	2.37	2.44
55	2.2	2.26	2.33
60	2.1	2.16	2.22
65	2	2.05	2.11
70	1.89	1.94	2
75	1.79	1.84	1.89
80	1.69	1.73	1.78

Tab.1. The concrete creep coefficient $\varphi(\infty,t_0)$ *and RH.*

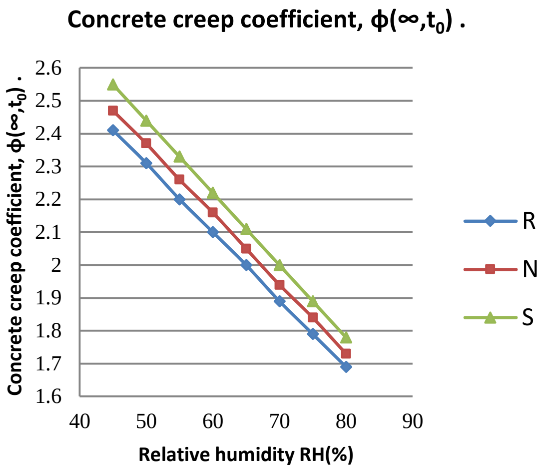


Fig. 3. The concrete creep coefficient $\varphi(\infty,t_0)$

For concrete with class S of cement, the value of concrete creep coeficient $\varphi(\infty,t_0)$ is bigger than the value of concrete creep coefficient $\varphi(\infty,t_0)$ for concrete with cement class N and S. The effect of concrete creep coefficient reduced when concrete is composed with cement class R then N and S. When the relative humidity increases the effect of creep decreases.

b) The effect of cement class and relative humidity in effective creep ratio φ_{ef}.

“Tab.2.” gives the value of creep effective factor φ_{ef} and relative humidity in (%) for concrete class C30/37 with three types of cement class R, N, S. In the following graphs in “Fig. 4.”, the vertical axis represent concrete creep coefficient φ_{ef} and the horizontal axis the relative humidity RH in (%) for cement type R, N, S.

$$\varphi_{ef} = \varphi(\infty,t_0)\cdot M_{0Eqp}/M_{0Ed}$$

Creep effective factor φef			
	Cement class.		
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	1.79	1.83	1.89
50	1.71	1.75	1.81
55	1.63	1.67	1.72
60	1.56	1.6	1.64
65	1.48	1.52	1.56
70	1.4	1.44	1.48
75	1.33	1.36	1.4
80	1.25	1.28	1.32

Tab.2. The creep effective factor φef *and relative humidity RH.*

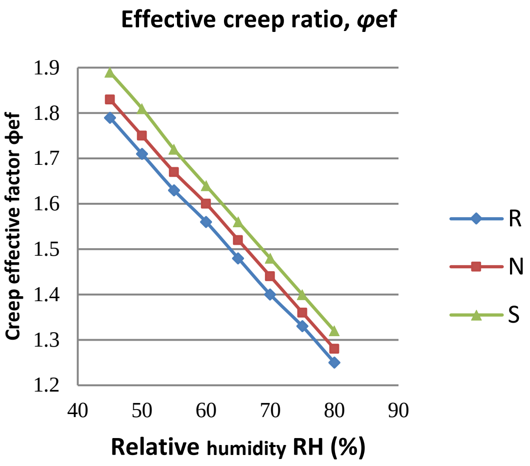


Fig. 4. The effective creep ratio, φ_{ef}. *and relative humidity RH.*

For concrete with class S of cement the value of creep effective factor ϕ_{ef} is bigger than the value of creep effective factor ϕ_{ef} for concrete that contains cement class N and S. The effect of effective creep ratio reduced when concrete is composed with cement class R then N and S. When the relative humidity increases the value of effective creep ratio decreases.

c) The effect of cement class and relative humidity in slendernes λ_{lim}.

"Tab.3." represent the value of slenderness limit λ_{lim} and relative humidity in (%) for concrete class C30/37 with three types of cement class R, N, S calculate with Nominal Stiffness Method (N.S.) for slender columns. In the following graphs in "Fig.5", the vertical axis represent concrete slenderness limit and the horizontal axis the relative humidity RH in (%) for each cement class.

Method nominal stiffness N.S.			
	λlim		
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	20.91	20.77	20.61
50	21.15	21.01	20.85
55	21.4	21.26	21.1
60	21.64	21.51	21.36
65	21.9	21.77	21.62
70	22.16	22.04	21.89
75	22.43	22.31	22.17
80	22.7	22.59	22.45

Tab.3. The slenderness limit *λlim and relative humidity RH.*

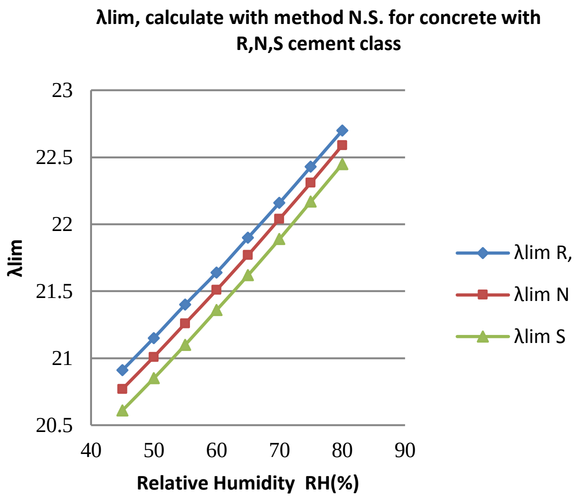


Fig. 5. The slenderness limit *λlim and relative humidity RH.*

"Tab.4." represent the value of slenderness limit λ_{lim} and relative humidity in (%) for concrete class C30/37 with three types of cement class R, N, S calculate with Nominal Curvature Method (N.C.) for slender columns. In the following graphs "Fig.6", the vertical axis represent concrete slenderness limit and the horizontal axis the relative humidity RH in (%) for each cement class.

Method nominal curvature N.C.			
	λlim		
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	22.96	22.8	22.62
50	23.22	23.07	22.89
55	23.49	23.34	23.17
60	23.76	23.62	23.45
65	24.04	23.9	23.74
70	24.33	24.19	24.03
75	24.62	24.49	24.33
80	24.92	24.79	24.64

Tab.4. The slenderness limit *λlim and relative humidity RH.*

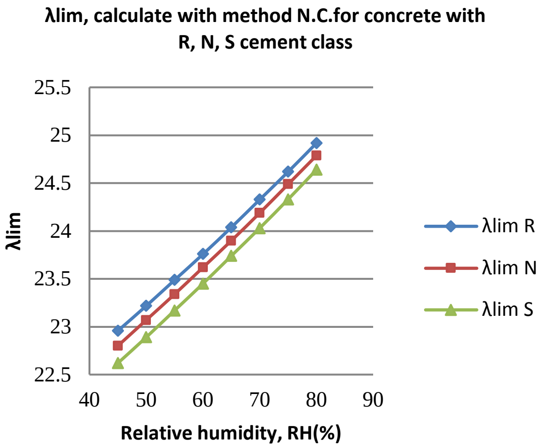


Fig. 6. The slenderness limit *λlim and relative humidity RH.*

For concrete with class R of cement the value of slenderness λ_{lim} is bigger than the value of slenderness λ_{lim} for concrete that contains cement class N and S calculate with both methods N.S. and N.C..

The value of slenderness λ_{lim} increases with increasing of relative humidity.

e) The effect of cement class and relative humidity in bending stiffness of compression members calculate with Nominal Stiffness Method (N.S.)

“Tab.5.” represent the value of bending stiffness EI and relative humidity in (%) for concrete class C30/37 with three types of cement class R, N, S calculate with Nominal Stiffness Method (N.S.) for slender columns. The graphs in “Fig.7” represent in the vertical axis EI and the horizontal axis the relative humidity RH in (%) for each cement class.

EI(kN*m^2) calculate with Method N.S.			
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	21027.1	20945.9	20853
50	21168.1	21085.9	20991.8
55	21317.2	21234.1	21138.8
60	21475.3	21391.2	21294.8
65	21643.1	21558.1	21460.6
70	21821.5	21735.6	21637.1
75	22011.6	21925	21825.6
80	22214.7	22127.4	22027

Tab.5. The bending stiffness EI *and relative humidity RH.*

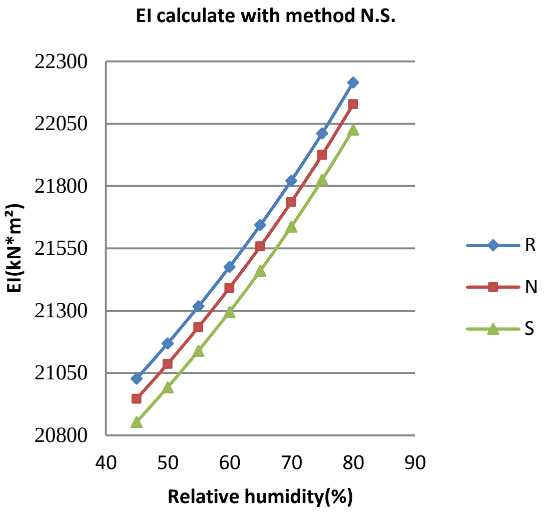


Fig. 7. The bending stiffness EI *and relative humidity RH.*

For concrete with class R of cement the value of bending stiffness EI is bigger than the value EI for concrete that contains cement class N and S.

f) The effect of cement class and relative humidity in second-order moment of compression members calculate with Nominal Stiffness Method (N.S.)

“Tab.6.” gives the value of second-order moment M_{Ed} in slender columns and relative humidity RH(%) for concrete class C30/37 with three types of cement class R, N, S. In the following graphs “Fig.8.”, the vertical axis represent second order moment M_{Ed}(kN*m) and in the horizontal axis is the relative humidity RH (%) for each cement class.

M_{Ed}(kN*m) calculate with Method nominal stiffness N.S.			
	*M_{Ed} (kN*m)*		
RH(%)	*Cement class R*	*Cement class N*	*Cement class S*
45	242.77	246.52	250.98
50	236.58	240.14	244.38
55	230.43	233.81	237.83
60	224.33	227.52	231.33
65	218.27	221.29	224.88
70	212.26	215.1	218.48
75	206.29	208.95	212.13
80	200.36	202.86	205.82

Tab.6. The second- order moment M_{Ed} *and relative humidity RH.*

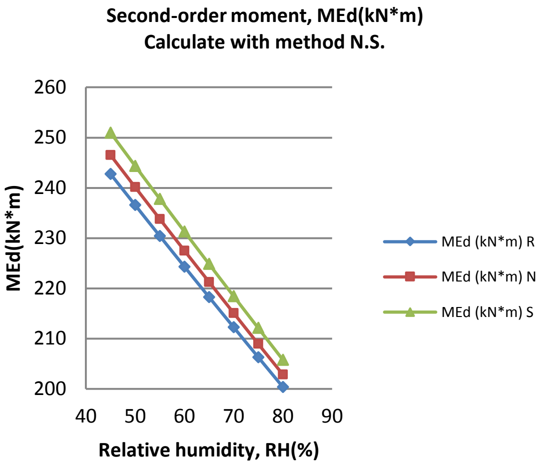


Fig. 8. The second -order moment M_{Ed} *and relative humidity RH.*

For concrete C30/37 with cement of class R the value of second-order moment of the slender column is bigger than the same column with the concrete C30/37 that contains cement class N and S.

V. CONCLUSION

1. The effect of creep-shrinkage decreases with increasing of relative humidity.
2. The limit slenderness λ_{lim} for slender columns increases with increasing of relative humidity.
3. The bending stiffness of slender copmression elements calculate with nominal stiffness method increases with increasing of relative humidity.
4. The second-order moment of slender compression elements decreases with increasing of relative humidity.

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