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DESIGN REINFORCED AREAS OF CONCRETE BEAM DEPEND ON THE CONCRETE TABLE

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ABSTRACT

The traditional method of reinforced concrete beam design that using the table depend on the concrete and strength of the steel. There are many strenght steel in market and concrete, so many tables are also needed. A simpler method namely the new method where is using table depend on the concrete is needed. All the equilibrium equation variable change into ξ=c/d, so only one type table is needed. In this study, only concrete table should be provided. Principle calculation in the traditonal method and the new method is samed. The strenght of steel is used later. From the example can be concluded that the new method can be used as a method of designing reinforced concrete beam.

Keywords: variable ξ=c/d and concrete table

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1. INTRODUCTION

1.1. The traditional method

1.1.1. Singly reinforcement.

1.1.1.1. Compression of concrete

$$C_c = 0.85 f_c' ab \tag{1}$$

1.1.1.2. Tension of steel

$$T_s = A_s f_y = \rho b d f_y \tag{2}$$

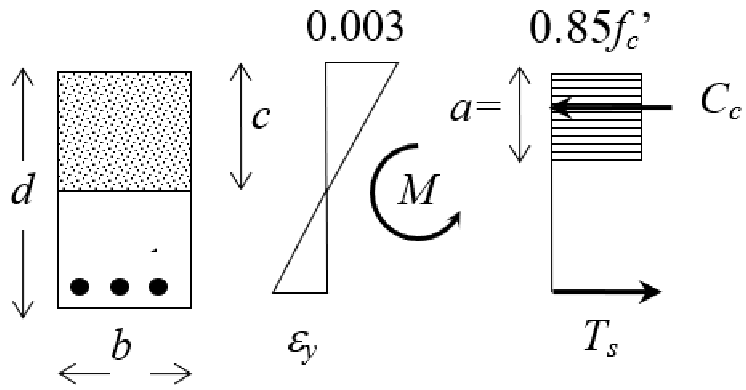

Figure 1 Singly reinforcement section

1.1.1.3. Forces equilibrium

$$\sum F = 0$$
$$0.85f_c'ab - A_sf_y = 0$$
$$0.85f_c'ab = A_sf_y$$
$$a = \frac{\rho d f_y}{0.85f_c'} \quad (3)$$

1.1.1.4. Moment equilibrium

$$\sum M = 0$$
$$M - \emptyset A_sf_y\left(d - \frac{1}{2}a\right) = 0$$
$$M = \emptyset\rho bdf_y\left(d - \frac{1}{2}a\right) \quad (4)$$
$$M = 0.9\rho bd^2f_y\left(1 - \frac{\rho f_y}{1.7f_c'}\right) \quad (5)$$
$$\frac{M}{bd^2} = 0.9\rho f_y\left(1 - \frac{\rho f_y}{1.7f_c'}\right)$$

If :n

$$R_u = \frac{M}{bd^2} \quad (6)$$
$$\emptyset = 0.9 \text{ (reduction factor)} \quad (7)$$
$$\frac{0.9}{1.7}\frac{f_y^2}{f_c'}\rho^2 - 0.9f_y\rho + R_u = 0 \quad (8)$$
$$\rho = 0.85\frac{f_c'}{f_y}\left(1 - \sqrt{1 - \frac{R_u}{0.3825f_c'}}\right) \quad (9)$$

So, in the traditional method ρ directly calculated from R_u, strength of steel f_y and behavior of concrete namely β_1 and f_c' and

$$A_s = \rho bd \quad (10)$$

1.1.1.5. Control

$\rho_{min} < \rho < \rho_{max}$ → for singly reinforcement.

Where :

$$\rho_{min} = \frac{\sqrt{f'_c}}{4f_y} \tag{11}$$

Or :

$$\rho_{min} = \frac{1.4}{f_y} \tag{12}$$

ρ_{max} is taken :

$$\frac{c}{d} = \frac{\varepsilon'_{cu}}{\varepsilon'_{cu}+\varepsilon_y} = \frac{0.003}{0.003+\frac{f_y}{E_s}} = \frac{0.003}{0.003+\frac{f_y}{200000}} \tag{13}$$

$$\frac{c}{d} = \frac{600}{600+f_y} \tag{14}$$

$$c = \frac{600}{600+f_y}\, d \tag{15}$$

$$\sum H = 0$$
$$C_c - T_s = 0$$
$$0.85 f_c' ab - A_s f_y = 0$$
$$0.85 f_c' \beta_1 cb - \rho_b b d f_y = 0$$
$$0.85 f_c' \beta_1 c - \rho_b d f_y = 0$$
$$0.85 f_c' \beta_1 \frac{600}{600+f_y} d - \rho_b d f_y = 0$$
$$0.85 f_c' \beta_1 \frac{600}{600+f_y} - \rho_b f_y = 0$$

$$\rho_b = 0.85 \frac{f_c'}{f_y} \beta_1 \frac{600}{600+f_y} \tag{16}$$

For structure under reinforced, ratio maximum is taken:

$$\rho_{max} = 0.75\rho_b = 0.75 \times 0.85 \frac{f_c'}{f_y} \beta_1 \frac{600}{600+f_y} = 0.6375 \frac{f_c'}{f_y} \beta_1 \frac{600}{600+f_y} \tag{17}$$

2. DOUBLY REINFORCEMENT

If more slender beam is needed in design for aesthetic, so maybe $\xi > \xi_{max}$. In this case compression steel is needed

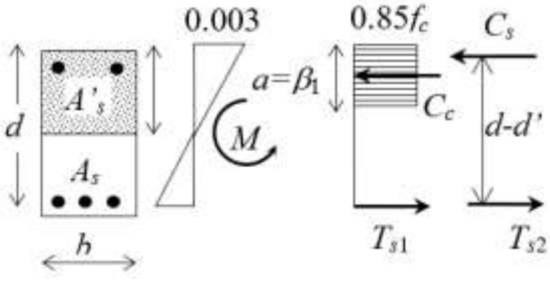

Figure 3 Doubly reinforcement sestion

All the formula assumed $f'_s = f_y$. So M is needed to devide two segment M_{u1} dan M_{u2}

Where :

M_{u1} is a bending moment related ρ_{max} and

$$z = \left(d - \tfrac{1}{2}a\right) \tag{18}$$

Tensile steel is :

$$A_{s1} = \rho_{max} bd \tag{19}$$

$$M_{u1} = \emptyset\, \rho_{max} bd \left(d - \frac{1}{2}a\right)$$

$$M_{u1} = 0.9\rho_{max} bd^2 f_y \left(1 - \frac{\rho f_y}{1.7 f_c'}\right) \tag{20}$$

M_{u2} is the remaining moment against by the same tensile steel and compresssion steel. The arm bending moment is $z = d - d'$

The total added steel $A_{s2} = A'_s$:

$$A_{s2} = A'_s = \frac{M_u - M_{u1}}{\emptyset f_y (d - d')} \tag{21}$$

Total A_s :

$$A_s = A_{s1} + A_{s2}$$

$$= \rho_{max} bd + \frac{M_u - M_{u1}}{\emptyset f_y (d - d')} \tag{22}$$

2. METHODOLOGY

2.1. The New method

2.1.1. Singly reinforcement

In this study all the equilibrium equation, is converted to $\xi = \left(\frac{c}{d}\right)$ as variable :

Moment equilibrium :

$$\sum M = 0$$

$$M - \emptyset A_s f_y \left(d - \frac{1}{2}a\right) = 0$$

$$M = 0.9 \times 0.85 f_c' ab\left(d - \tfrac{1}{2}a\right)$$

$$M = 0.765 f_c' bd^2 \left\{\frac{a}{d} - \frac{1}{2}\left(\frac{a}{d}\right)^2\right\}$$

$$\frac{M}{bd^2} = 0.765\beta_1 f_c' \left\{\frac{c}{d} - \frac{1}{2}\beta_1 \left(\frac{c}{d}\right)^2\right\}$$

$$R_u = \frac{M}{bd^2}$$

$$\xi = \left(\frac{c}{d}\right) \tag{23}$$

$$0.3825\beta_1^2\, f_c'\xi^2 - 0.765\beta_1\, f_c'\xi + R_u = 0 \quad (24)$$

$$\xi = \frac{1}{\beta_1}\left(1 - \sqrt{1 - \frac{R_u}{0.3835 f_c'}}\right) \quad (25)$$

From of this equation, ξ directly calculated, only depend on R_u and behavior of concrete namely β_1 and f_c', so it become easier. And A_s =

$$\sum F = 0$$

$$C_c - T_s = 0$$

$$0.85 f_c' ab - A_s f_y = 0$$

$$A_s = 0.85\frac{f_c'}{f_y}ab = 0.85\left(\frac{a}{d}\right)\frac{f_c'}{f_y}bd = 0.85\beta_1\left(\frac{c}{d}\right)\frac{f_c'}{f_y}bd$$

$$A_s = 0{,}85\,\beta_1\xi\frac{f_c'}{f_y}bd \quad (26)$$

The strenght of steel is used later

$$\rho = 0.85\beta_1\xi\frac{f_c'}{f_y} \quad (27)$$

$$\rho_b = 0.85\beta_1\xi_b\frac{f_c'}{f_y}$$

$$\rho_{max} = 0.75 \times \rho_b = 0.75 \times 0.85\beta_1\xi_b\frac{f_c'}{f_y}$$

$$\xi_{max} = 0.75 \times \frac{600}{600+f_y} \quad 28)$$

3. DOUBLY REINFORCEMENT

Where :

M_{u1} is the bending moment related ξ_{max}. Tensile steel is

$$A_{s1} = \rho_{max}bd = 0.75 \times 0.85\beta_1\xi_b\frac{f_c'}{f_y}bd = 0.85\beta_1\xi_{max}\frac{f_c'}{f_y}bd \quad (29)$$

$$M_{u1} = 0.9\rho_{max}bd^2 f_y\left(1 - \frac{\rho f_y}{1.7 f_c'}\right)$$

$$M_{u1} = 0.765\beta_1 f_c' bd^2\xi_{max}\left\{1 - \tfrac{1}{2}\beta_1\xi_{max}\right\} \quad (30)$$

M_{u2} is the remaining momen against by the same tensile steel and compresssion steel. The arm bending moment is

$$z = d - d' \quad (31)$$

The total added steel $A_{s2} = A'_s$:

$$A_{s2} = A'_s = \frac{M_u - M_{u1}}{\emptyset f_y(d - d')}$$

Total A_s :

$$A_s = A_{s1} + A_{s2}$$

$$= 0.85\beta_1\xi_{max}\frac{f_c'}{f_y}bd + \frac{M_u - M_{u1}}{\emptyset f_y(d-d')} \quad (32)$$

4. BORDER FOR TABLE

4.1. R_u border :

$$D \geq 0 \quad (33)$$

$$(0.765 \times \beta_1 f_c')^2 - 4 \times 0.3825\beta_1^2 f_c' R_u \geq 0$$

$$R_u \leq 0.3825 f_c' \quad (34)$$

4.2. ξ border

For simplication :

$$\xi_{max} = 0.75 \times \frac{600}{600 + f_y}$$

$$\text{Where : } f_{ymin} = 280 \text{ MPa} \quad (35)$$

$$\text{So : } \xi_{max} = 0.511 \quad (36)$$

For simplication :

$$\xi_{min} = \frac{1.4}{f_y}$$

$$\text{Where : } f_{ymax} = 550 \text{ MPa} \quad (37)$$

$$\text{So : } \xi_{min} = 0.0026 \quad (38)$$

Or :

$$\xi_{min} = \frac{1}{0.85\beta_1}\frac{f_y}{f_c'} = \frac{1}{0.85\beta_1}\frac{f_y}{f_c'} \times \frac{\sqrt{f_c'}}{4f_y} = \frac{1}{3.4\beta_1\sqrt{f_c'}} \quad (39)$$

Table 1 ξ_{min}

f'_c	β_1	ξ_{min}	ξ_{min}
17	0,850	0,0026	0,084
20	0,850	0,0026	0,077
25	0,850	0,0026	0,069
30	0,836	0,0026	0,064
35	0,800	0,0026	0,062
40	0,764	0,0026	0,061

5. CASE STUDY

5.1. The traditional method.

b = 0.4 *d* = 0.5 *m* f'_c = 35 MPa f_y = 400 MPa

M_u = 850 kNm

$$R_u = \frac{M_u}{bd^2} = 8500\ \mathrm{kN/m^2} = 8.5\ \mathrm{MPa}$$

$$\rho = 0.85\frac{f_c'}{f_y}\left(1-\sqrt{1-\frac{R_u}{0.3825f_c'}}\right) = 0.029 > 0.02678 \rightarrow \text{Doubly reinforcement}$$

Actually the traditional method provides the table for calculation but here used hand calculation.

$$\rho_{max} = 0.6375\frac{f_c'}{f_y}\beta_1\frac{600}{600+f_y} = 0.02678$$

$$\rho_{min} = \frac{\sqrt{f'_c}}{4f_y} = 0.0037$$

$$\rho_{min} = \frac{1.4}{f_y} = 0.0035$$

$$M_{u1} = 0.9\rho_{max}bd^2f_y\left(1-\frac{\rho_{max}f_y}{1.7f_c'}\right)$$

$$= 0.9\times 0.027\times 0{,}4\times 0{,}5^2\times 400\left(1-\frac{0.02678\times 400}{1.7\times 35}\right) = 797.04\ \mathrm{kNm}$$

$$A_{s1} = \rho_{max}bd = 0.02678\times 40\times 50 = 53.56\ \mathrm{cm^2}$$

$$A_s = A_{s1} + A_{s2}$$

$$= \rho_{max}bd + \frac{M_u - M_{u1}}{\emptyset f_y(d-d')} = 53.56 + \frac{850-797.04}{0.9\times 400(50-5)} = 53.56 + 0.003$$

$$= 53.563\ \mathrm{cm^2}$$

5.2. The new method.

From the table(attachement), founded :

$$R_u = \frac{M_u}{bd^2} = 8500\ \mathrm{MPa} = 8.5\ \mathrm{MPa} < Ru = 0.3825\times 35 = 13{,}3875$$

$$\xi_{max} = 0.75\times\frac{600}{600+400} = 0.45 < \xi = 0.495 \rightarrow \text{Doubly reinforcement}$$

$$A_{s1} = 0.85\beta_1\xi_{max}\frac{f_c'}{f_y}bd = 0.85\times 0.8\times 0.45\times\frac{35}{400}\times 40\times 50 = 53.55\ \mathrm{cm}^{\,2}$$

$$M_{u1} = 0.765\beta_1 f_c' bd^2\xi_{max}\left\{1-\tfrac{1}{2}\beta_1\xi_{max}\right\} = 0.765\times 0.8\times 35\times 0.4\times 0.5^2\times 0.45\times\left(1-\frac{1}{2}0.8\times 0.45\right) = 790.4\ \mathrm{kNm}$$

Total A_s :

$$A_s = A_{s1} + A_{s2}$$

$$= 0.85\beta_1\xi_{max}\frac{f_c'}{f_y}bd + \frac{M_u - M_{u1}}{\emptyset f_y(d-d')} = 53.55 + \frac{850-790.4}{0.9\times 400(50-5)} = 53.55 + 0.004 = 53.554\ \mathrm{cm^2}$$

6. CONCLUSION

From the case study obtained the new method is same with the result from the traditional method, namely A_s = 53,554 cm^2 $\cong$ 53.563 cm^2. This indicates that the new method can be used as method of designing reinforced concrete beam.

REFERENCES

[1] Badan Standarisasi Nasional (BSN) SNI 2487-2013, Persyaratan beton struktural untuk bangunan gedung, Jakarta, 2013. (*Indonesian concrete code same as ACI*)

[2] Mac Gregor, James G., Reinforced concrete (Mechanics and design), Third edition, Prentice-Hall International, Inc,1988.

[3] Park, R,. and T. Paulay, 1975. Reinforced Concrete Structures, Department of Civil Engineering University of Canterbury New Zealand, John Wiley & Sons, New York.

[4] Vis, W. C. dan Kusuma, Gideon, 1993, Grafik dan tabel perhitungan beton bertulang (Seri beton 4), Penerbit Erlangga, Jakarta. (*Vis, W. C. (Dutchman) and Kusuma*, *Gideon*, *1993" Graph and table for reinforced concrete calculation"* (*Concrete series 4*), *Erlangga Publisher, Jakarta*).

ATTACHEMENT

f'_c	**17**	f'_c	**20**	f'_c	**25**
β_1	0,850	β_1	0,850	β_1	0,850
M_u/bd^2	**ξ**	**M_u/bd^2**	**ξ**	**M_u/bd^2**	**ξ**
4,42	0,511	5,20	0,511	6,50	0,511
4,40	0,507	5,10	0,497	6,40	0,500
4,30	0,492	5,00	0,484	6,30	0,489
4,20	0,476	4,90	0,471	6,20	0,479
4,20	0,476	4,80	0,458	6,10	0,469
4,10	0,461	4,70	0,446	6,00	0,458
4,00	0,447	4,60	0,434	5,90	0,448
3,90	0,432	4,50	0,422	5,80	0,439
3,80	0,418	4,40	0,410	5,70	0,429
3,70	0,404	4,30	0,398	5,60	0,419
3,60	0,390	4,20	0,386	5,50	0,410
3,50	0,377	4,10	0,375	5,40	0,400
3,40	0,364	4,00	0,364	5,30	0,391
3,30	0,351	3,90	0,353	5,20	0,382
3,20	0,338	3,80	0,342	5,10	0,373
3,10	0,325	3,70	0,331	5,00	0,364
3,00	0,313	3,60	0,320	4,90	0,355
2,90	0,301	3,50	0,310	4,80	0,346
2,80	0,289	3,40	0,300	4,70	0,338
2,70	0,277	3,30	0,289	4,60	0,329
2,60	0,265	3,20	0,279	4,50	0,320
2,50	0,253	3,10	0,269	4,40	0,312
2,40	0,242	3,00	0,259	4,30	0,304
2,30	0,231	2,90	0,249	4,20	0,295
2,20	0,219	2,80	0,240	4,10	0,287
2,10	0,208	2,70	0,230	4,00	0,279
2,00	0,198	2,60	0,221	3,90	0,271

f'$_c$	**17**	f'$_c$	**20**	f'$_c$	**25**
β_1	0,850	β_1	0,850	β_1	0,850
M_u/bd^2	**ξ**	**M_u/bd^2**	**ξ**	**M_u/bd^2**	**ξ**
1,90	0,187	2,50	0,211	3,80	0,263
1,80	0,176	2,40	0,202	3,70	0,255
1,70	0,165	2,30	0,193	3,60	0,247
1,60	0,155	2,20	0,183	3,50	0,240
1,50	0,145	2,10	0,174	3,40	0,232
1,40	0,134	2,00	0,165	3,30	0,224
1,30	0,124	1,90	0,157	3,20	0,217
1,20	0,114	1,80	0,148	3,10	0,209
1,10	0,104	1,70	0,139	3,00	0,202
1,00	0,094	1,60	0,130	2,90	0,194
0,90	0,084	1,50	0,122	2,80	0,187
		1,40	0,113	2,70	0,180
		1,30	0,105	2,60	0,173
		1,20	0,096	2,50	0,165
		1,10	0,088	2,40	0,158
		1,00	0,080	2,30	0,151
				2,20	0,144
				2,10	0,137
				2,00	0,130
				1,90	0,123
				1,80	0,116
				1,70	0,110
				1,60	0,103
				1,50	0,096
				1,40	0,090
				1,30	0,083
				1,20	0,076
				1,10	0,070

f'$_c$	**30**	f'$_c$	**35**	f'$_c$	**40**
β_1	0,836	β_1	0,800	β_1	0,764
M_u/bd^2	**ξ**	**M_u/bd^2**	**ξ**	**M_u/bd^2**	**ξ**
7,70	0,510	8,70	0,510	9,60	0,510
7,60	0,501	8,60	0,502	9,50	0,503
7,50	0,492	8,50	0,495	9,40	0,496
7,40	0,483	8,40	0,487	9,30	0,489
7,30	0,475	8,30	0,479	9,20	0,482
7,20	0,466	8,20	0,472	9,10	0,476
7,10	0,458	8,10	0,464	9,00	0,469
7,00	0,449	8,00	0,457	8,90	0,462

f'$_c$	**30**	f'$_c$	**35**	f'$_c$	**40**
β_1	0,836	β_1	0,800	β_1	0,764
M_u/bd^2	**ξ**	**M_u/bd^2**	**ξ**	**M_u/bd^2**	**ξ**
6,90	0,441	7,90	0,450	8,80	0,456
6,80	0,433	7,80	0,442	8,70	0,449
6,70	0,425	7,70	0,435	8,60	0,443
6,60	0,417	7,60	0,428	8,50	0,436
6,50	0,409	7,50	0,421	8,40	0,430
6,40	0,401	7,40	0,414	8,30	0,424
6,30	0,393	7,30	0,407	8,20	0,417
6,20	0,385	7,20	0,400	8,10	0,411
6,10	0,378	7,10	0,393	8,00	0,405
6,00	0,370	7,00	0,387	7,90	0,399
5,90	0,362	6,90	0,380	7,80	0,392
5,80	0,355	6,80	0,373	7,70	0,386
5,70	0,348	6,70	0,367	7,60	0,380
5,60	0,340	6,60	0,360	7,50	0,374
5,50	0,333	6,50	0,353	7,40	0,368
5,40	0,326	6,40	0,347	7,30	0,362
5,30	0,319	6,30	0,340	7,20	0,357
5,20	0,312	6,20	0,334	7,10	0,351
5,10	0,305	6,10	0,328	7,00	0,345
5,00	0,298	6,00	0,321	6,90	0,339
4,90	0,291	5,90	0,315	6,80	0,333
4,80	0,284	5,80	0,309	6,70	0,328
4,70	0,277	5,70	0,303	6,60	0,322
4,60	0,270	5,60	0,297	6,50	0,316
4,50	0,264	5,50	0,291	6,40	0,311
4,40	0,257	5,40	0,284	6,30	0,305
4,30	0,250	5,30	0,278	6,20	0,299
4,20	0,244	5,20	0,272	6,10	0,294
4,10	0,237	5,10	0,267	6,00	0,288
4,00	0,231	5,00	0,261	5,90	0,283
3,90	0,224	4,90	0,255	5,80	0,278
3,80	0,218	4,80	0,249	5,70	0,272
3,70	0,212	4,70	0,243	5,60	0,267
3,60	0,205	4,60	0,237	5,50	0,261
3,50	0,199	4,50	0,232	5,40	0,256
3,40	0,193	4,40	0,226	5,30	0,251
3,30	0,187	4,30	0,220	5,20	0,245
3,20	0,180	4,20	0,214	5,10	0,240
3,10	0,174	4,10	0,209	5,00	0,235
3,00	0,168	4,00	0,203	4,90	0,230
2,90	0,162	3,90	0,198	4,80	0,225

f'c	**30**	f'c	**35**	f'c	**40**
β_1	0,836	β_1	0,800	β_1	0,764
M_u/bd^2	**ξ**	**M_u/bd^2**	**ξ**	**M_u/bd^2**	**ξ**
2,80	0,156	3,80	0,192	4,70	0,219
2,70	0,150	3,70	0,187	4,60	0,214
2,60	0,144	3,60	0,181	4,50	0,209
2,50	0,138	3,50	0,176	4,40	0,204
2,40	0,132	3,40	0,170	4,30	0,199
2,30	0,127	3,30	0,165	4,20	0,194
2,20	0,121	3,20	0,160	4,10	0,189
2,10	0,115	3,10	0,154	4,00	0,184
2,00	0,109	3,00	0,149	3,90	0,179
1,90	0,104	2,90	0,144	3,80	0,174
1,80	0,098	2,80	0,138	3,70	0,169
1,70	0,092	2,70	0,133	3,60	0,164
1,60	0,087	2,60	0,128	3,50	0,159
1,50	0,081	2,50	0,123	3,40	0,155
1,40	0,075	2,40	0,118	3,30	0,150
1,30	0,070	2,30	0,112	3,20	0,145
1,20	0,064	2,20	0,107	3,10	0,140
		2,10	0,102	3,00	0,135
		2,00	0,097	2,90	0,131
		1,90	0,092	2,80	0,126
		1,80	0,087	2,70	0,121
		1,70	0,082	2,60	0,116
		1,60	0,077	2,50	0,112
		1,50	0,072	2,40	0,107
		1,40	0,067	2,30	0,102
		1,30	0,062	2,20	0,098
				2,10	0,093
				2,00	0,089
				1,90	0,084
				1,80	0,079
				1,70	0,075
				1,60	0,070
				1,50	0,066
				1,40	0,061