Investigating the accuracy of fabricated rebar and rebar's placement in beams, and their impact in weight and cost of a building

Boralda Bendaj

Site Engineer Representative of Kontakt Ltd

ABSTRACT

The inspection of rebar in different structural elements has the goal to ensure that contract documents between investitor and contractor, rebar placing drawings, and technical specification of building codes are followed. The quality – control programs also ensure structural safety and architectural aesthetic compliance. Inspection procedure consists of material inspections and quality during construction. Regarding these, the engineer's site representative verify if the test report by the material producer meet the requirements of the structural project. Reinforcing bar inspection is achieved by the contractor's inspectors and the field supervisors mandated by the investitor.

This paper introduces the rebar inspection procedures in beams of the residential building "Dorado", part of the residential complex "Magnet " in Tirana. Reports from a testing laboratory state the grade of steel, tensile properties, chemical composition of the material used in this structure. The in – place inspection of rebar consisted in visually check bar diameter and shape, measure of bar lengths, measure of hook lengths, measure of spacing between rebar, the number of ties and stirrups and their spacing, measure of lap splices and their location in conjuction with the structural drawings. Also is checked the tying of the rebar, that assure the remain in their specified position.

The data from the in place inspection and measurements of rebar are compared with the tolerances given in ACI standards and European standards (Eurocodes). This comparison has been used for the purpose of estimating the accuracy of the fabricating rebar and the placing operation by the ironworkers in this building. Their degree of accuracy has a direct impact on the cost of the structure. As the result of rebar's greater lengths, greater number of ties and stirrups , is calculated the increase in the weight of the structure resulting in increased cost of the building.

Keywords: *rebar inspection in beams, rebar fabricated, rebar placement*

INTRODUCTION

During the construction of the object " Dorado ", the rebar inspection has been carried out from the inspector mandated by the owner, with the goal to ensure that the quality of the product meets the established criteria. Inspections by the material producer and supplier assure that products meet material specifications. Inspectors should be familiar with the project contract documents and building code requirements, and have access to material standards and references, codes and industry manual or reports. Approved placing drawings should be available for review and study by field – placing personnel and the inspector at least one day before the actual placing of rebar.

All construction work has tolerances to allow for inherent variances in construction materials and workmanship skills. Tolerances should be discussed to identify those which are critical, the method of measurement, and the basis for rejection or acceptance. In this study, measurements of rebar of beams in object "Dorado " have been recorded to know the accuracy of the rebar in-placement and the quantity of deviation based on the tolerances given in the applicable ACI and European codes.

Figure 1. Object "Dorado" during construction Figure 2. Beams of 7th floor

To achieve this, the followings have been carried out:

I. Material Inspection

II. Reinforcing bar inspection

III. Comparing the measurements with the approved placing drawings

IV. Comparing the value of the measurements with the specified Standard tolerances

V. Additional weight and additional cost of the object

I. MATERIAL INSPECTION

In – place inspection of rebar is supplemented by a report from an independent testing laboratory. Reports state grade of steel, tensile properties, chemical composition and spacing and height of deformations. According to the test results given in the figure 3. the material is not radioactive, and complies with the order contract. Natural radiation Back Ground BG rate at the place of testing is 0,1 µSv/h. Good was radiological controlled. Results dose rates are less then 0,2µSv/h. Weldability is determined by two characteristics: carbon equivalent and limitation on the content of certain elements. According to the European codes, the maximum values of individual elements and the carbon equivalent shall not exceed the values given in Table.1. The carbon equivalent value *C*eq shall be calculated using the following formula (1):

$$Ceq = C + Mn/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15 \quad (1)$$

where the symbols of the chemical elements indicate their content in % by mass.

The specified values for the tensile properties (*R*e, *R*m/*R*e, *A*gt, and where relevant *R*e,act./*R*e,nom.) shall be the corresponding specified characteristic value with p = 0,95 for *R*e, and p = 0,90 for *A*gt, *R*m/*R*e, and *R*e,act./*R*e,nom. For yield strength (*R*e) the upper yield strength (*R*eH) shall apply. If a yield phenomenon is not present, the 0,2 % proof strength (*R*p0,2) shall be determined.

Table 1. Chemical composition (% by mass)

	Carbon [a] max.	Sulphur max.	Phosphorus max.	Nitrogen [b] max.	Copper max.	Carbon equivalent value [a] max.
Cast analysis	0,22	0,050	0,050	0,012	0,80	0,50
Product analysis	0,24	0,055	0,055	0,014	0,85	0,52

[a] It is permitted to exceed the maximum values for carbon by 0,03 % by mass, provided that the carbon equivalent value is decreased by 0,02 % by mass.

[b] Higher nitrogen contents are permissible if sufficient quantities of nitrogen binding elements are present.

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STS-06/117 REG2-0004-03-ZGPro-1306

UVJERENJE O PREGLEDU br 1558/2015
INSPECTION CERTIFICATE ACCORDING TO
EN 10204 3.1 /2004

Naš znak :
Our sign : 57 03 22 02
Datum:
Date: 2015. 12.29.
List/Page: 1/3

KUPAC: IKONA SHPK
CUSTOMER: Pusi i Mezinit-Soda,Zona Industriale,Kushtrimi
9400 VLORA
ALBANIA

UGOVOR Br:
CONTRACT No : AL/IK-2015
OC 623010151

PREDMET:
SUBJECT: DEFORMED REINFORCED BARS IN QUALITY B500B AS PER EN 10080

TEŽINA :
WEIGHT : Ø8 - Ø22mm 786,050 TO

STANDARD : EN10080/2005,EN 1992-1-1:2004,
SPECIFICATION : TU-4-14

HEMIJSKA ANALIZA TALINE - CAST CHEMICAL ANALYSIS

Talina br. Cast No.	Kvalitet Quality	C %	Mn %	P %	S %	N %	Cu %	Cekv %
225457	B500B	0,17	0,50	0,044	0,019	0,007	0,07	0,26
225456	"	0,18	0,47	0,021	0,016	0,007	0,08	0,27
225463	"	0,19	0,53	0,029	0,016	0,007	0,08	0,29
225462	"	0,18	0,52	0,032	0,013	0,008	0,08	0,28
225455	"	0,19	0,50	0,023	0,016	0,008	0,08	0,29
225458	"	0,18	0,51	0,032	0,014	0,007	0,07	0,28
225464	"	0,20	0,54	0,025	0,014	0,007	0,08	0,30
122404	"	0,18	0,52	0,046	0,034	0,007	0,07	0,28
225453	"	0,20	0,51	0,036	0,016	0,007	0,08	0,30
225422	"	0,17	0,55	0,035	0,016	0,007	0,07	0,28
225465	"	0,20	0,52	0,022	0,011	0,007	0,07	0,30

MEHANIČKE OSOBINE - MECHANIC AL PROPERTIES

Talina br. Cast No.	Dimenzija Dimension (mm)	Dužina Length (m)	Napon tečenja Yield stress R_{eH} (N/mm^2)	Rm/Re	Re act/Re nom	Ukupno izduženje kod max. sile A_{gt}(%) Percentage total elongation at max. frce	Relativna površina rebra Relative rib area (f_R)	Povratno Savijanje Rebend test
225457	ϕ 8	12	559	1,15	1,12	11,2	0,069	Dobro/good
225456	"	"	573	1,14	1,15	10,1	0,066	"
225463	"	"	573	1,15	1,15	9,5	0,051	"
225462	"	"	588	1,14	1,18	9,0	0,040	"
225455	"	"	578	1,14	1,16	10,2	0,061	"
225458	"	"	508	1,19	1,02	13,2	0,069	"
225464	"	"	602	1,16	1,20	8,9	0,047	"
122404	ϕ 10	"	567	1,17	1,13	11,0	0,074	"
225453	"	"	571	1,13	1,14	11,1	0,071	"
225422	ϕ 12	"	569	1,14	1,14	11,6	0,065	"
225465	"	"	556	1,16	1,11	11,5	0,063	"

Materijal nije radioaktivan. The material is not radioactive.
Ovim se potvrđuje da je isporučeni materijal ispitan i da je u skladu sa zahtjevom narudžbe.
We hereby certify, that the material described above has been tested and complies with the terms of the order contract.
Identifikaciona oznaka proizvođača 9-45 I AMZ logo se nalaze na proizvodu. Manufacturer's identification mark 9-45 are applied on the product.

Kontrolor:
Controler: Beganović Emira BE

Za:
Odobrio: Direktor Departmenta Kontrole kvaliteta
Approved by: Quality Control Department Director
Fuad Babić, dipl.inž.

Figure 3 . Report test from an independent testing result

Comparing the test results with the European Standards, is evident that the products meet the material specifications.

II. REINFORCING BAR INSPECTION

During the rebar inspection is proceeded as followed: -
Visually it has been checked bar diameter and the shape (if bent),

-Rebar tying requirements

Reinforcing bars are tied together to form a rigid mat for slabs. A rigid cage is formed when beam or column longitudinal are tied to the stirrups and ties. Ironworkers usually tie a minimum number of rebar intersections. If the specifications are not precise about the number of tied intersections, the work should be accepted unless it is apparent the mats or cages of reinforcing steel will be displaced from their inspected position during concreting.

Quantity	Pos.	ϕ	L (cm) Project LP	L (cm) Measured LM	Dif . LM - LP (cm)	Number Project	Number In-Place
1	1	16	524	527	3	1	1
1	1	16	529	528	-1	1	1
1	1	16	534	534	0	1	1
1	1	16	539	539	0	1	1
1	2	16	460	458	-2	4	4
1	3	16	680	680	0	1	1
1	3	16	685	685	0	1	1
1	3	16	690	690	0	1	1
1	3	16	695	695	0	1	1
1	4	16	321	322	1	4	4
1	5	16	435	435	0	1	1
1	6	16	188	184	-4	3	3
1	7	16	300	300	0	2	2
1	8	16	205	217	12	3	3

Table 2. As – Built , Beam “RC” of 7th Floor

- Measurements of rebar

The goal of measurements is to confirm the compliance of the approved structural drawings, to define the accuracy of the in-place work based on the tolerances given in the Codes(European and American Standards), to define the additional weight of steel placed in the beams and as result the additional cost.

All measurements are summarized in tabular form. For every beam in every floor of the object, it has been filled in a table which shows the measurement lengths for every bar and the verification of elements number placed, and the difference according to the project.

The measurements done are showed below: 1. Measurements of bar lengths and spacing of rebar and the verification of the number of bars places. It is important to confirm the meet of the number and the lengths of rebar and their spacing with those given in the structural drawings and rebar placing drawings. If the bar length is shorter it affects the capacity of the element. If the length is bigger it may increase the rigidity, it may change the dynamic behaviour of the structure in nodes or in special elements. This also causes an additional weight and cost. The process of measuring has consisted in measuring : the straight bar length, the hooks length.

Figure 4 Measurement of bar length

2. Measurements of lap splices length and the verification of their location. Lap splices of rebar in beams are important because they provide the transmission of tension forces that arises in bar section. So, it is important to apply correctly their lengths. The length of lap splice specified in the structural project of the object is 60 φ. Regarding this are measured: 1.Lap splices for tension bars 2. Lap splices for compression bars For every beam it has been filled in a table, which shows the lap length of every couple of bars that overlap.

Table 3. Length of Lap splices in Beam "RC" of 7th floor

Beam	Pos. bar nr.1	Pos. bar nr.2	Length Lap project (cm)	Length Lap Measured (cm)	Dif. LLM-LLP (cm)	Nr.of overlapping bars
	1	2	96	94	-2	4
	3	4	96	100	4	4

Figure 5. Measurement of length of lap splices

3. Verification of the number of stirrups placed and their spacing. It is necessary that the number of stirrups placed meets the requirement of the project. Otherwise are expected negative effects. So if the number of stirrups placed is bigger than in the project (smaller spacing) increases the shear forces and can cause an amorf behaviour of the reinforced concrete. A smaller number (bigger spacing of stirrups) does not ensure the shear capacity of the section. The inspection of stirrups placed consisted in: -Measuring the number of the stirrups according to their types given in the project. -Verifying the dimensions of spacing between them. All this is summarized for every beam in tabular form where it is defined the difference in weight comparing to that one given in the project, as is showed in table 4.

Table 4. Measurement of number of stirrups in Beam "RC" in 7 th floor.

Quantity	Pos.	ϕ	L (cm) Project	L (cm) In - Place	Diff. LIP - LP (cm)	Number Project	Number In - Place	L Total (m) Project	L Total (m) In - Place	W(sp) kg/m	W diff . (PF-PP)
1	s	8	192	192	0	60	64	115.2	122.88	0.395	3.03
1	s1	8	88	88	0	60	64	52.8	56.32	0.395	1.39
										W.TOT DIF	4.42

Figure 6. In – Placement of stirrups

Figure 7. Measurement of spacing between stirrups

III. COMPARING THE MEASUREMENTS WITH THE APPROVED PLACING DRAWINGS

The comparison between the in - place and the approved structural project consists in the topics below:

Comparing the lengths of rebar in beams and the number of stirrups placed

The differences in lengths of bars between the project and the in place are summarized in tabular and graphical form. First it is computed a table which shows the difference of lengths and the differences of number of stirrups, and the corresponding weight difference for every beam, for example for Beam RC is showed in table 5. Than a second table where it is reflected every difference in bar length and its frequency. This procedure has been executed for all the beams in a floor, and in the end for all the beams in the object as showed in figure 8.

Table 6. As – Built quantity book for RC beam in 7th floor

Quantity	Pos.	ϕ	LP (cm)	LM (cm)	LM - LP (cm)	Nr Project	Nr. In - Place	L Tot (m) Project	L Tot (m) In - Place	W (sp) kg/m	W diff (WM-WP) (kg)
1	1 mes	16	524	527	3	1	1	5.24	5.27	1.57	0.05
1	1 mes	16	529	528	-1	1	1	5.29	5.28	1.57	-0.02
1	1 mes	16	534	534	0	1	1	5.34	5.34	1.57	0.00
1	1 mes	16	539	539	0	1	1	5.39	5.39	1.57	0.00
1	2	16	460	458	-2	4	4	18.4	18.32	1.57	-0.13
1	3 mes	16	680	680	0	1	1	6.8	6.8	1.57	0.00
1	3 mes	16	685	685	0	1	1	6.85	6.85	1.57	0.00
1	3 mes	16	690	690	0	1	1	6.9	6.9	1.57	0.00
1	3 mes	16	695	695	0	1	1	6.95	6.95	1.57	0.00
1	4	16	321	322	1	4	4	12.84	12.88	1.57	0.06
1	5	16	435	435	0	1	1	4.35	4.35	1.57	0.00
1	6	16	188	184	-4	3	3	5.64	5.52	1.57	-0.19
1	7	16	300	300	0	2	2	6	6	1.57	0.00
1	8	16	205	217	12	3	3	6.15	6.51	1.57	0.57
1	s	8	192	192	0	60	64	115.2	122.88	0.39	3.03
1	s1	8	88	88	0	60	64	52.8	56.32	0.39	1.39
										DIF.	4.77

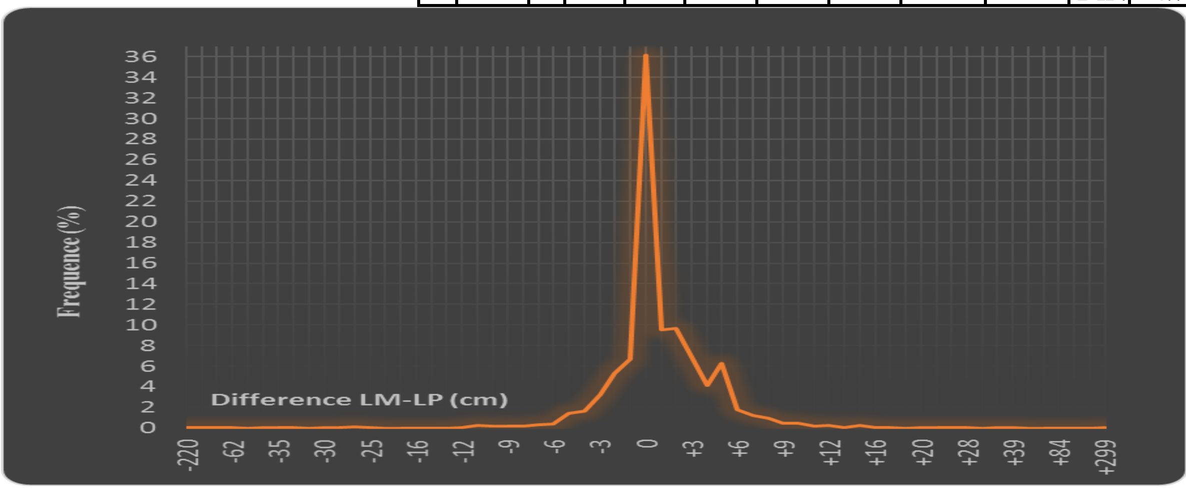


Figure 8. The graph of frequencies of length differences in beams of the object

Full compliance in beams of object "Dorado" is 36 %. 21 % of rebar lengths are smaller than the lengths in project, and 43 % are greater. It seems in this graphic differences in the interval lengths [-3 cm ; +6 cm] are most frequent.

Comparing the lap splices lengths of rebar in beams

Table 7. Frequency of lap

LLM-LLP (cm)	Nr .of cases	Frequency (%)

lengths differences

The differences in lap lengths of bars between the project and the in place are summarized in tabular and graphical form. First it is computed a table where it is reflected every difference in bar lap length and its frequency. With these data it has been plotted the graph that shows the differences of lap lengths and their frequencies (figure 9). This procedure has been executed for all the beams in every floor, and in the end for all the beams in the object (Table 7).

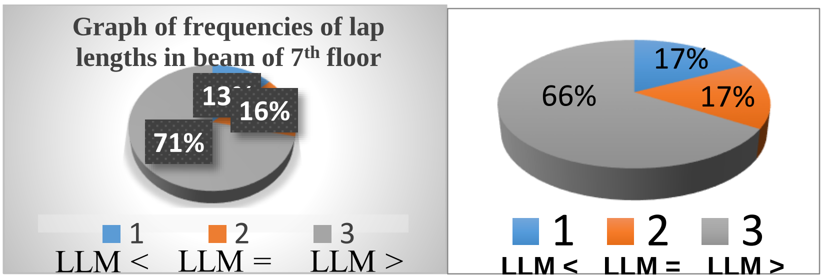


Figure 9. Graph of frequencies of lap length in beams of the 7th floor and in all beams of the object

Comparing the weights of the steel between the weight calculated from the project and the weight of in-placed steel .

The Project steel weight is calculated referring the nominal mass per meter. The values for the nominal mass per meter are calculated from the values of the nominal cross – sectional area using a density value of 7.85 kg/dm^3 . The measured steel weight is the weight refered in the test report by the material producer. The difference is as result of the difference in the mass per metre of the producer and the teorical mass per metre and as result of the difference in the length of the bars.

Table 8. Comparison Project Steel Weight – Measured Steel Weight for the Beam C in 7th floor

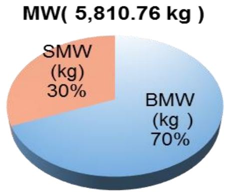
DORADO	Measured Weight MW(kg)	Project Weight PW(kg)	Difference MW - PW	%
"R - C"	232.27	227.50	4.77	102.10

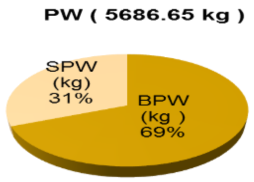
Table 9. Comparison Project Steel Weight – Measured Steel Weight for the 7th floor Beam

	Measured Weight MW(kg)		Project Weight PW(kg)		Difference MW - PW		% of Difference MW - PW	
Beam 7th Floor	5,810.76		5686.65		124.11		2.18	
	Straight Bars weight BMW (kg)	Stirrups Weight SMW (kg)	Straight Bars weight BPW (kg)	Stirrups Weight SPW (kg)	BMW-BPW	SMW-SPW	% BMW-BPW	% SMW-SPW

-28	3	0.118
-24	4	0.158
-23	3	0.118
-21	8	0.316
-20	3	0.118
-15	6	0.237
-14	2	0.079
-12	5	0.197
-11	7	0.276
-10	6	0.237
-8	3	0.118
-7	6	0.237
-6	59	2.329
-5	23	0.908
-4	36	1.421
-3	32	1.263
-2	77	3.040
-1	154	6.080
0	424	16.739
+1	141	5.567
+2	294	11.607
+3	217	8.567
+4	341	13.462
+5	95	3.750
+6	49	1.934
+7	56	2.211
+8	56	2.211
+9	89	3.514
+10	53	2.092
+11	18	0.711
+12	17	0.671
+13	18	0.711
+14	61	2.408
+15	8	0.316
+16	18	0.711
+17	7	0.276
+18	11	0.434
+19	25	0.987
+20	9	0.355
+21	14	0.553
+22	2	0.079
+24	30	1.184
+26	9	0.355
+28	4	0.158
+30	4	0.158
+31	4	0.158
+37	6	0.237
+38	4	0.158
+43	2	0.079
+47	2	0.079
+48	2	0.079
+50	6	0.237
Total	2533	100.000

	4,042.59	1,768.17	3,927.28	1759.37	115.31	8.81	2.03	0.15
%	69.57	30.43	69.06	30.94	30.39	69.61	97.82	





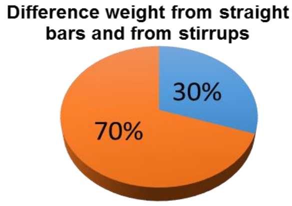


Figure 10. Comparison Weight Project – Measured for the rebar of beams in 7th floor

Table 10. Comparison Project Steel Weight – Measured Steel Weight for "Dorado" Beams

D	Measured Weight MW(kg)		Project Weight PW(kg)		Difference MW - PW		% of Difference MW - PW	
BEAMS	75,952.05		73,454.60		2,497.45		3.40	
	BMW (kg)	SMW (kg)	BPW (kg)	SPW (kg)	BMW-BPW	SMW-SPW	% BMW-BPW	% SMW-SPW
	53,055.22	22,896.83	51,410.29	22,044.31	1,644.93	852.52	2.24	1.16
%	69.85	30.15	69.99	30.01	65.86	34.14	96.60	

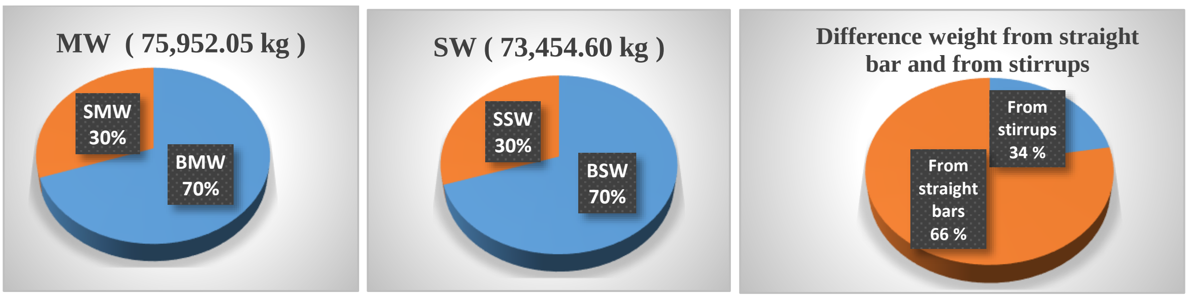


Figure 11. Graphic of comparison Weight Project – Measured for the beams of the object

IV. COMPARING THE VALUE OF THE MEASUREMENTS WITH THE SPECIFIED STANDARD TOLERANCES

Different standards recognize the imprecise nature of the placing operations and allow deviation criteria. Also deviation criteria are allowed for the tensile and chemical properties and for the mechanical properties. Placing tolerances are necessary to verify the quality during the construction. So we have chosen the European Standard EN 10080:2005 and the American Standard ACI 117.

Standard tolerances for the length of straight bars and for the bars with hook

According to the EN 10080:2005 the tolerance for the length of straight bars and for the bars with hooks is ±2.5 cm.

According to the ACI 117 the tolerance for the length of bars with one hook or double hooks in both sides is ±1 inch. These two standards recognize the same deviation criteria for the length of rebar.

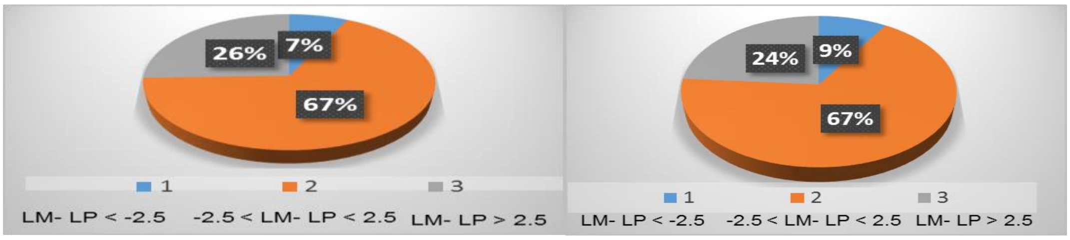


Figure 12. Accuracy in length bars according EN and ACI for beams in 7th floor and for beams of the object

All the data recorded during the inspections for every floor level are summarized in a graphical form, plotting a Gauss curve to interpret the results. So based on the relationship between the deviation of measurement and its frequency for all the length rebar of the beams we obtain a discrete graph. This one can be transformed in a Gauss curve using the technique of the nonlinear regression. Finally, doing this, the Gauss curve for the relationship studied is obtained. In Figure 13 is shown the discrete graph for the accuracy of rebar lengths and the Gauss curve for this relationship.

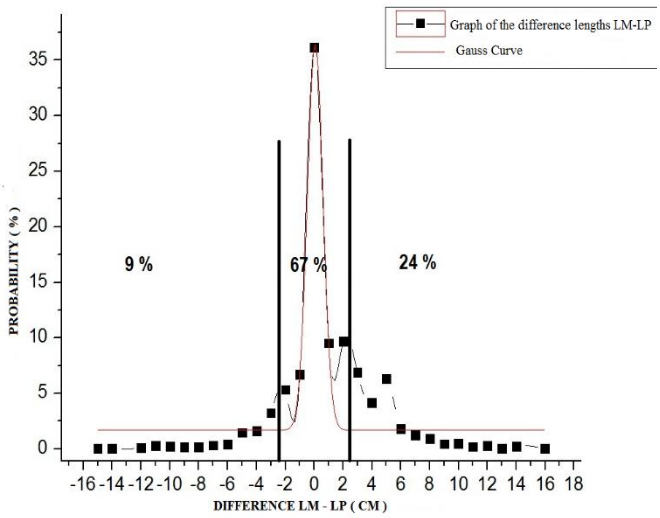


Figure 13. Gauss curve for the deviation of length bars

Standard tolerances for the length of lap splices

This tolerance according to EN 10080:2005 is ±2.5 cm, according to the ACI 117 is ±1 inch.

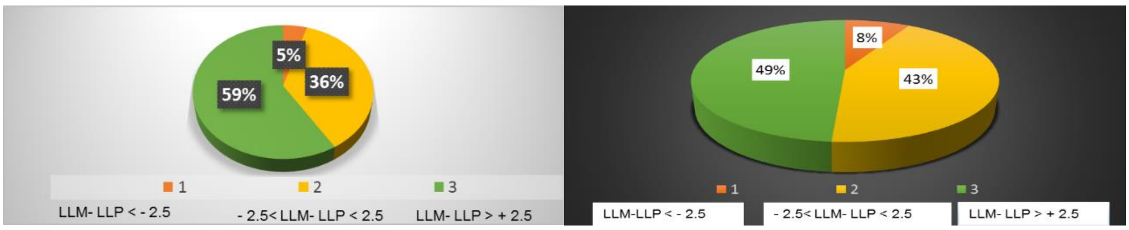


Figure 14. Accuracy in lap length bars according EN and ACI for beams in 7th floor and for beams in object "Dorado"

Standard tolerances for the weight of rebar

According to the EN 10080:2005 the permissible mass per meter shall not be more than ±4.5 % on nominal diameters above 8 mm and ±6 % on nominal diameters 8 mm .

According to the ACI 117 the tolerance on mass per meter is ±6 %.

So the total weight of reinforced steel placed in object differs from the weight calculated from the technical drawings. The additional weight of rebar in beams of object "Dorado " (2497.45 kg) is +**3. 40 %.**It is within permissible tolerances given by the two codes above

V. ADDITIONAL WEIGHT AND ADDITIONAL COST OF THE OBJECT

All deviations during the in-placement of rebar of the beams affect directly into the weight calculated from the approved structural project and as a result in an additional cost. Three main factors depend on the amount of the additional weight: 1. Greater rebar lengths, 2.Greater number of stirrups placed, 3.Greater mass per meter of the producer material

Processing the data recorded during the inspections, first the deviation in weight for every single beam is calculated. Then the deviation of weight for beams in every floor is calculated and the total additional weight is obtained in the end. The additional weights are shown in Table 11.The additional weight for the steel of the beams of the object "Dorado "is 2,497.45 kg , resulting with a additional cost **1374 Euro**.

Table 11. Additional weight

Floor	Weight of rebar (kg)	Additional Weight (kg)
-1	9,618.97	389.56
+1	10,162.47	396.46
+2	10,286.71	391.42
+3	10,321.87	389.67
+4	10,321.87	362.26
+5	5,686.65	178.90
+6	5,686.65	145.54
+7	5,686.65	124.11
+8	5,682.76	119.53
Total	73,454.60	2,497.45
%		**+ 3.40**

If we consider this percentage of additional in weight for all the structural elements, will result that the additional weight for the steel of all reinforcement structure of the object "Dorado " (326 ton) will be **11,084 kg** , resulting with a additional cost **6097 Euro.**
The additional cost for every square meter **is 0.88 Euro / m^2** (GFA – Dorado = 6945 m^2).

CONCLUSIONS

1. The tolerances are intended to maintain the integrity, quality, and function of the material or work involved. Tolerances used should be fully discussed at the preconstruction conferences and documented in the construction records.
2. Reports from testing laboratory that states the properties of materials, usually don't have problems meeting the recommended tolerances.
3. Deviations in rebar lengths do not cause a considerable difference in weight, but they impact significantly in the length of lap splices.
4. From the measurements we have 24% of rebar with lengths that are greater than in the structural project and 9 % are shorter, resulting in unchanged capacity of elements, but it may change the dynamic behavior of certain elements.
5. Regarding to lap splices, 75 % of lengths of lap splices are within the European tolerance, 7% are smaller than tolerance and 18 % bigger than tolerance.
6. The difference in number of stirrups placed results in considerable additional weight (66%)
7. The weight difference is within the permissible value given by the EN and ACI Codes.
8. Engineer or a representative should be present during the measurement of weight of reinforcing steel to be supplied to match it with that calculated from the quantity book.

REFERENCES

[1] European Standard (January 2005) Final draft prEN 10080

[2] ACI Detailing Manual (1988) ACI ,Includes Details of concrete (ACI 318 – 89)

[3] Standard Specifications for Tolerances for Concrete Constructions and Materials (ACI 117-90), American Concrete Institute (ACI)

[4] Placing Reinforcing Bars 6th edition CRSI ,(1992)

[5] Rebar Inspection CRSI's Engineering Data Report No. 36

[6] Structural Welding Code—Reinforcing Steel (ANSI/AWS D1.4-92), American Welding Society, Miami, 1992.

[7] Placing Reinforcing Bars, 6th ed.,CRSI, 1992.