International Balkans Conference on Challenges of Civil Engineering, BCCCE,
19-21 May 2011, EPOKA University, Tirana, ALBANIA.

Code Calibration for Reinforced Concrete Structures in Bosnia and Herzegovina using CodeCal

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ABSTRACT

One of the most important tasks for the civil engineers is designing structures. Designing structures is conducted according to the technical regulations of the country.
Safety and reliability of those structures will mostly depend upon safety and reliability of those regulations.
Therefore it is very important to give attention to the safety and reliability of the structures during making of the regulations.

Bosnia and Herzegovina (B&H) is in the process of adjusting its technical regulations to the regulations adopted in the EU, which implies definition of the safety format for the B&H regulations based on recommended values given in EC 0 – EN 1990:2002.
Therefore it is necessary to conduct careful safety analysis of the regulations, that is their calibration with values of resistance and loads from our country.

This paper examines is it possible to directly accept proposed safety format from EUROCODE in new structural design codes for reinforced concrete structures in B&H by using CodeCal, a Microsoft Excel © based program that can be obtained for free at the webpage of the Joint Committee on Structural Safety (JCSS).
This analysis was conducted for the reinforced concrete structures, based on values of resistance and loads from B&H and safety format from the EUROCODE.

Analysis showed that even do the reliability of concrete compressive strength in B&H is less than in the European countries it is possible to directly accept proposed safety format from EUROCODE, and still have high level of safety for the concrete structures.

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Keywords: *Code Calibration, Safety of structures, Reliability index*

INTRODUCTION

The basic function of all bearing structures is to withstand the load acting on it. Bearing structures, and their individual elements, must be calculated, constructed and maintained in a manner that during the planned lifespan, with the appropriate degree of reliability and cost-effective manner they:

- remain eligible for use regardless of expected actions (serviceability limit state)
- withstand all extreme and cyclical actions, which may occur during construction and operation of the facilities (ultimate limit state)
- will not be excessively damaged in cases such as floods, landslides, fire, explosion, impacts or consequences of human error (structural integrity demand)

In order to meet the above requirements, it is necessary to know the characteristics of actions that may affect the bearing structure and properties of the structure.
Properties of the structure are pre-determined in the design stage, primarily, based on the actions, that we believe can affect the structure in the planned lifespan.

However, no one can say with certainty that the structure will have same characteristics after construction, or that the values of actions will be as predicted.
Therefore, there is always a possibility that the resistance of structure will be less than designed one, or that the values of actions will be greater than predicted.
To solve this problem, the safety factors are introduced in the design process in order to cover uncertainty in defining the structural resistance and the value of actions on the structure.
The values of these safety factors were initially determined based on experience and assumptions.

Today, the safety factors are determined by probabilistic method of second order for the chosen format of regulations and required reliability index β, and this whole process is often called "code calibration".

BASIC VARIABLES

Structural resistance and loads are functions of several different values that we called basic variables. Basic variables can be divided in three groups: mechanical properties of structural materials, geometrical properties of structural elements and extreme values of loads.

All basic variables are, by their nature, random variables and with different probability of occurrence. Accordingly, the resistance values in general and effects that are functions of basic variables are also random variables.

For code calibration for reinforced concrete structures in B&H in this paper the following basic variables were used:

- Concrete compressive strength and self weight, defined in [1]
- Live load and yield strength of reinforcement, used in [2]
- Snow load, defined in [3]

Determination of statistical parameters for concrete compressive strength and self weight, conducted in [1], was based on testing results from laboratories in B&H, and the results are shown in Tables 1 and 2.

Table 1 Results for concrete compressive strength

Concrete class	Average (MPa)	Standard deviation (MPa)	Coefficient of variation (%)
MB30	38,99	9,02	23,1
MB40	45,21	6,70	14,83
Total	40,96	8,74	21,34

Lognormal distribution was chosen to represent analyzed results, same as in [2] were on the other hand the coefficient of variation was 10%.

Table 2 Results for concrete self weight

Average (kN/m^3)	Standard deviation (kN/m^3)	Coefficient of variation (%)
24,91	0,57	2,3

Since the values of live loads in buildings are independent on the building location, it is possible to use results of research from other countries for code calibration in B&H. In this paper the results from several European countries and from USA, used also in [2], were chosen. These results are given in Table 3.

Table 3 Live load used in [2]

Building	Average (N/m^2)	Standard deviation (N/m^2)	Coefficient of variation (%)	Average room area (m^2)	Source
Residential	271	98	36	63	[4]
Residential	285	80	28	50	[5]
Hotel	244	53	22	47	[4]
Hotel	157	59	38	23	[5]
Hospital	252	74	29	20	[6]
Hospital	392	118	30	-	[4]
Office	570	245	43	20	[7]
Office	465	211	45	22	[7]
Office	622	426	68	14	[8]
Office	613	345	56	31	[8]
Office	589	302	51	58	[8]
School	551	166	30	38	[6]

Snow load is classified as the natural load and therefore strongly depends on geographical location. To determine the snow load you definitely need a long observation in the field and statistical analysis of those results.

Such an investigation was conducted in [3] where the meteorological snow loads were obtained on the basis of the parameters of height and density of snow from the meteorological data from 15 measuring sites in B&H. After statistical analysis the Gumbel's distribution was chosen, and the results are shown in the Table 4.

Table 4 Results for snow load defined in [3]

Location	Altitude (m)	Average kN/m^2	Standard deviation kN/m^2	Coefficient of variation (%)
Mostar	99	0,175	0,178	1,017
Doboj	146	0,430	0,280	0,651
Banja luka	153	0,530	0,290	0,547
Sanski most	158	0,490	0,340	0,694
Bihać	246	0,750	0,400	0,533
Tuzla	305	0,770	0,640	0,831
Zenica	344	0,310	0,194	0,626
Goražde	345	0,450	0,320	0,711
Drvar	485	0,790	0,630	0,797
Bugojno	562	0,580	0,290	0,500
Sarajevo	630	0,540	0,370	0,685
Livno	730	0,390	0,320	0,821
Ivan sedlo	860	1,370	0,640	0,467
Sokolac	872	0,960	0,510	0,531
Čemerno	1306	2,680	1,460	0,545

Statistical parameters obtained from results of testing yield strength of reinforcement given in [2] were also used in this paper since these results are very similar with the results in B&H, because the steel is produced in controlled environment according to international licenses.

Based on all these results, the basic variables for code calibration for reinforced concrete structures in B&H was chosen, and shown in Table 5.

Table 5 Basic variables for code calibration

Basic Variables		Coefficient of variation (%)	Distribution
Action	Self weight	2,3	Normal
	Other permanent load	10,0	Normal
	Live load	20,0	Gumbel's
	Snow load	60,0	Gumbel's
Resistance	Concrete compressive strength	20,0	Log-normal
	Yield strength of reinforcement	5,0	Log-normal
	Model uncertainties	5,0	Normal

Model uncertainties, covers differences in cross section geometry and variations of conversion factor, i.e. ratio between concrete strength in the structure and potential strength obtained by test specimens.

The value of coefficient of variation for model uncertainties was also taken from [2].

CODE CALIBRATION

Code calibration can be implemented by judgment, optimization, "fitting" or by combination of these methods. The method of code calibration by judgment was the main method of about 15 to 25 years ago, and it was based on historical experience and judgment of code creators. When creating a completely new technical regulations it is necessary to carry out their optimization, which consists of the following steps:

- You chose a set of representative structures
- You chose a target index of reliability
- You chose a code format with the values of safety factors
- Representative structures are then designed according to chosen code format
- The reliability indexes are calculated for the designed structures
- The value $Y = \sum w_i (\beta_i - \beta_{target})^2$ is calculated
- Procedure is repeated until the smallest value of Y is obtained

Optimum values of safety factors are the one for which the calculated reliability index is closest to target value.

The method of "fitting" safety factors can be used when the code format needs to be changed, which is the case in B&H.

Therefore, the task in B&H is to chose a code format, according to EC 0 – EN 1990:2002, in the way that the structures designed according to new codes have same, or greater, level of safety as existing structures, designed according to old codes, having in mind that increasing level of safety can have negative financial consequences.

Thus, the most important thing is to determine the reliability index of existing structures. This was performed in [1] by comparing results of the design according to existing codes with the results of design according to EC2 for the same structure and load.

Since these results were almost the same, it is possible to chose target reliability index as recommended in EC with the value of 3,8.

The next step in code calibration, for this case, was to determine the value of reliability index, for code format and values of safety factors given in EC 0 – EN 1990:2002, and for the values of loads and material properties from B&H given in Table 5.

Ideal tool for this problem is a Microsoft Excel © based program called CodeCal which can be obtained for free at the webpage of the Joint Committee on Structural Safety (JCSS) at www.jcss.ethz.ch, and whose theory is given in [9].

This program uses design equation from EC 0 – EN 1990:2002, and can consider up to three different materials, and up to three different loads (self weight and two live loads).

Beside the statistical parameters given in Table 5, for calculation of the reliability index, it is necessary to input values of safety factors, values of factors for combinations of actions and fractiles for characteristic values of self weight and strength.

Listed input data together with design equations make code format, which implies that the reliability index, determined for these input data, would be the same as the reliability index of real structure, since the same input data would be used.

Reliability index in real structures also depends on ratio between dead and live load, as well as on ratio between two live loads, in case when more than one live load is present.

Therefore, the program calculates reliability index for all ratios between 0 and 1, as shown in Figure 1, and Table 6.

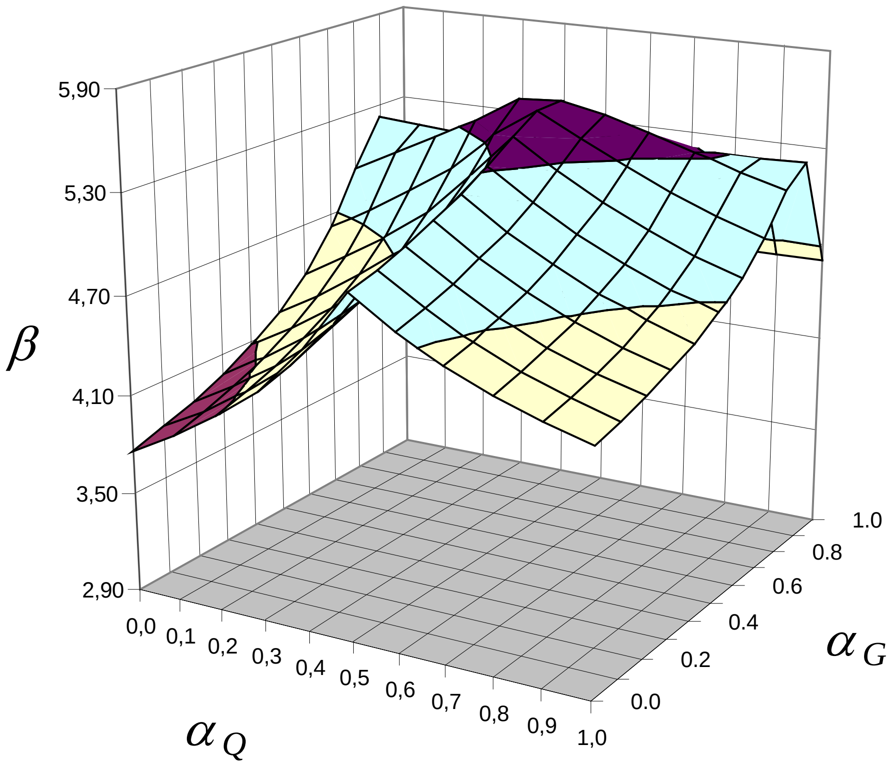

Figure 1 Reliability index for concrete structures based on Table 5

Values α_G and α_Q represent ratio between dead load and total load, and live load and total live load, respectively.

Table 6 Reliability index for concrete structures based on Table 5

β	α_Q										
α_G	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
0,0	3,76	3,91	4,08	4,28	4,57	4,94	4,76	4,62	4,51	4,42	4,34
0,1	3,82	3,97	4,14	4,34	4,63	4,99	4,81	4,67	4,56	4,46	4,38
0,2	3,89	4,04	4,21	4,41	4,70	5,06	4,88	4,73	4,61	4,51	4,43
0,3	3,97	4,13	4,30	4,50	4,78	5,13	4,95	4,80	4,68	4,58	4,49
0,4	4,08	4,23	4,40	4,60	4,88	5,22	5,04	4,89	4,76	4,65	4,56
0,5	4,21	4,36	4,54	4,74	5,01	5,33	5,14	4,99	4,86	4,75	4,66
0,6	4,38	4,54	4,71	4,90	5,16	5,44	5,27	5,12	4,99	4,88	4,78
0,7	4,62	4,77	4,93	5,11	5,35	5,55	5,40	5,27	5,15	5,05	4,95
0,8	4,95	5,08	5,22	5,36	5,53	5,54	5,49	5,41	5,33	5,25	5,17
0,9	5,22	5,20	5,18	5,15	5,14	5,18	5,22	5,24	5,26	5,27	5,27
1,0	4,60	4,60	4,60	4,60	4,60	4,60	4,60	4,60	4,60	4,60	4,60
β_{max} =	5,55										
β_{min} =	3,76										
Pf_{max} =	8,4E-05										
Pf_{min} =	1,5E-08										

CONCLUSION

In this paper, a simple code calibration procedure for reinforced concrete structures in Bosnia and Herzegovina using CodeCal is given.

The basic idea was to analyze a possibility of direct application of code format given in EC 0 – EN 1990:2002 in Bosnia and Herzegovina, without making any changes to values of safety factors or any other. The main goal was to see weather the code format from EC 0 – EN 1990:2002 combined with the loads and material properties from Bosnia and Herzegovina will give the satisfactory reliability index.

The fastest way was to use CodeCal, a simple program which gives accurate and reliable results. The results show that, although, the coefficient of variation for concrete compressive strength is higher in Bosnia and Herzegovina than in European countries, the reliability index is larger or equal to target value of 3,8 which is given in EC.

This comes from the fact that the values of safety factors for self weight and yield strength of reinforcement given in EC are overestimated, which causes increase of the reliability index since the program, as well as codes, uses the set of safety factors together.

The most important conclusion, in this paper, is that the first step in adjusting code format with EC 0 – EN 1990:2002 should be simple analysis using CodeCal, which gives information about expected reliability indexes in structures, for values and safety concept given in EC 0 – EN 1990:2002.

Naturally, this analysis should be performed for all types of structures in the same way, using same statistical parameters for live loads.

If the resulting indexes of reliability are equal to target values, no changes in values of safety factors given in EC 0 – EN 1990:2002 should be made.

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