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Reliability Index for Post-Tensioned Prestressed Concrete Girders in Flexure Based on IS: 1343-1980 Provisions

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***Abstract* – The reliability analysis of a post tensioned Girder in different limit states will help to formulate the reliability based design criteria, which will ensure the satisfactory performance of a structural element. The LRFD Format is used in foreign countries, enough research has not been done in the Indian conditions. This paper presents the methodology for generation of resistance statistics of post-tensioned Girders in the limit state of flexure. The equation for the ultimate flexural strength is taken from Indian Standard Code IS: 1343-1980. Statistics of basic design variables are taken from available literature. Monte Carlo Simulation is used to generate the data. Partial safety factors are computed for target reliability index β_0, using AFOSM method. A sample calculation for partial safety factors for the design variables for a Target Reliability Index 4.0 are worked out.**

***Keywords* – Ultimate Limit State, Simulation, Reliability Index, Partial Safety Factors, LRFD.**

I. Introduction

Design formats are undergoing many changes in the light of probabilistic studies. Ultimately structural design codes are established for the purpose of providing a simple, safe and economically efficient basis for the design of structures under normal loading, operational and environmental conditions. Design codes take basis in design equations from which the reliability verification of a given design may be easily performed by a simple comparison of resistances and loads or load effects. Load and resistance are treated as random variables.

Over the years different approaches for establishing design values for resistances and loads have been applied in many countries. However, all design codes have adopted Load and Resistance Factors Design Format (LRFD). Different versions of the LRFD format exists in the codes, CIRIA, CEB, Eurocodes, AASHTO, LRFD and OHBDC, but they are essentially based on the same principles [12, 14, 15]. In the Indian Scenario, there is a need to calibrate the code towards more rational method like LRFD. The following methodology is used. A number of representative sections are designed using a suitable algorithm like the one suggested by Prasad Rao [1], that employs minimum concrete area and hence employs minimum pre-stressing force, leading to a minimum cost design [1, 4, 5, 6, 8, 9, 10].

The sections designed for different combinations of loads, spans and class of the structural components are used to generate the resistance statistics as per IS: 1343-1980 provisions [2]. The Reliability Index β is computed by AFOSM method. The Monte Carlo Simulation technique is used to generate random data on resistance for each of the design situations and a suitable resistance model is developed for flexural strength. Code calibration is attempted by selecting values of target reliability β_0 which would reflect the average reliability implicit in current designs. The partial safety factors for the loads and the strength random variables that can be used as a basis for developing design requirements are worked out. LRFD format is proposed for the design of PSC Bridge Girders in limit state of flexure. The values of resistance factors ϕ and load factors γ_D and γ_L are determined through a calibration process that limits the probability of failure P_f to a small target value.

In an LRFD code, the basic design formula is

$$\Sigma \gamma_i X_i < \phi R_n \qquad \ldots(1)$$

Here X_i = nominal (design) load component i, γ_i = load factor i; R_n = nominal (design) resistance; and ϕ = resistance factor. The objective of calibration is to determine load and resistance factors so that the safety of bridges designed according to the code will be at the pre-selected target level [19]. Sensitivity analysis is performed for load and resistance parameters.

II. The IS: 1343-1980 Provisions

The theoretical model for the ultimate moment of resistance of the flanged section is obtained from the expression [2],

$$M_u = f_{pu} A_{pw} (d\text{-}0.42 X_u) + 0.675 f_{ck} (b\text{-}bw) D_f (d\text{-}0.5 D_f).$$

The governing equation for calculating the resistance statistics is,

$$R = \mu f_{pu} * \mu A_{pw} (\mu_d - 0.42 \mu X_u) + 0.675 \mu f_{ck} (\mu b - \mu bw) \mu D_f (\mu d - 0.5 \mu D_f) \qquad \ldots(2)$$

2.1. Monte Carlo Simulation Method

Using the Monte Carlo technique, random deviates of various variables are generated and then using the same in prediction equation, sample values of R is generated [11, 17, 18].

Generally, the value of R are normalized with its corresponding nominal value R_n, so that the statistics of R of different design can be compared. R_n is obtained by substituting the nominal values of the variables in the prediction equation. It is to be noted that R_n is deterministic and is constant for a particular value of

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design. The histograms of the generated data well fits the log normal distribution, based on Kolmogorove Smirnov (K.S) Test. Fifteen representative sections are chosen, 40,000 data sets were randomly generated for each cross-section, and each data set varied randomly as a function of statistical models for the variables involved bias ([mean/nominal], coefficient of variation [COV = standard deviation/mean], and distribution type). The variables included in the study are dimensions, material properties, loads and uncertainty of the analysis model. The statistical models used in this study were determined after a review of the literature, which is summarized in Table 1.

Table 1: Statistics of the basic variables

Variable	Bias (Mean / Nominal)	COV (%)	Distribution Type
Dimensions (D, d, b)	1.00-1.03	3.0-7.0	Normal
Area of Steel (A_p)	1.00-1.03	1.0-4.0	Normal
Concrete Strength (f_{pu})	1.00-1.04	2.0	Normal
Model Uncertainty (α)	1.01-1.10	4.5	Normal
Uncertainty of Girder DF(η)	0.89-1.02	9.0-14.0	Normal
Wearing Surface Loads (WS)	1.00-1.10	8.0-20.0	Normal
Dead Load (D)	1.00-1.05	9.0-10.0	Lognormal
Live Load (L)	1.25-1.35	18.0	Lognormal

The resistance statistics, bias factor and reliability index for the fifteen representative design sections are presented in Table 2. These statistical parameters are referred to in the literature as the resistance model [11, 17, 18]. A MATLAB program was developed to calculate Reliability Index. The reliability index is non-normal[20].

Table 2: Results of Monte Carlo Simulations (Moments in KN-m)

Design Case	M_L/M_D	R_n Nominal Value	R Mean Value	Bias	COV	Reliability Index β
PS1	0.68	4.4 E+08	4.92 E+08	1.12	9.52	5.18
PS2	0.66	4.95 E+08	5.55 E+09	1.12	9.65	5.28
PS3	0.64	5.51 E+08	6.18 E+08	1.12	9.81	5.28
PS4	0.62	6.39 E+08	7.16 E+08	1.12	9.76	5.70
PS5	0.61	7.19 E+08	8.06 E+08	1.12	9.61	5.90
PS6	0.73	9.09 E+08	1.02 E+09	1.13	9.97	4.95
PS7	0.72	1.01 E+09	1.14 E+09	1.13	10.06	5.14
PS8	0.70	1.13 E+09	1.27 E+09	1.13	10.03	5.30
PS9	0.68	1.26 E+09	1.42 E+09	1.13	9.99	5.46
PS10	0.67	1.40 E+09	1.58 E+09	1.13	10.13	5.70
PS11	0.73	1.40 E+09	1.57 E+09	1.13	10.28	5.67
PS12	0.72	1.94 E+09	2.17 E+09	1.12	9.43	5.69
PS13	0.70	2.34 E+09	2.61 E+09	1.12	9.50	6.03
PS14	0.68	2.55 E+09	2.85 E+09	1.12	9.58	6.20
PS15	0.67	2.78 E+09	3.11 E+09	1.12	9.55	6.33

III. Limit States

The available reliability methods are presented in several books [17, 18]. Reliability analysis can be performed using iterative procedures, by Monte Carlo Simulations or using special sampling techniques. Limit States are the boundaries between safety and failure. There are three types of limit states. Ultimate Limit States (ULS) are mostly related to the bending capacity, shear capacity and stability. Serviceability Limit States (SLS) are related to gradual deterioration users comfort or maintenance costs. The third type of limit state is fatigue. This paper is focused on the ultimate limit state of the moment carrying capacity [13].

IV. Reliability Index

A traditional notion of the safety limit is associated with the ultimate limit states. For example, a beam fails if the moment due to loads exceed the moment carrying capacity. Let R represent resistance (moment carrying capacity) and S represent the load effect (total moment applied to the considered beam). Then the corresponding limit state function, g, can be written,

$$G = R - S \qquad \ldots(3)$$

The g > 0, the structure is safe, otherwise it fails. The probability of failure, P_f, is equal to,

$$P_f = \text{Prob}\,(R - S < 0) = \text{Prob}\,(g < 0) \qquad \ldots(4)$$

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Let the probability density function (PDF) of R be f_R and PDF of S be f_S. Then, let Z = R – S. Z is also a random variable and it represents the safety margin.

In general, the limit state function can be a function of many variables (load components, influence factors, resistance parameters, material properties, dimensions, analysis factors). A direct calculation of P_f may be very difficult, if not impossible. Therefore, it is convenient to measure structural safety in terms of a reliability index, β. Reliability index is directly related to the probability of failure:

$$\beta = -\phi^{-1}(P_f) \qquad \ldots(5)$$

Where ϕ^{-1} = inverse standard normal distribution function. There are various procedures available for calculation of β. These procedures vary with regard to accuracy, required input data and computing costs and they are described in [17].

4.1. Advanced First Order Second Moment Method:

To over come short comings in the FOSM methods, an advanced First order second moment method is adopted in which the limit state in the variables are first transferred to reduced variables with zero mean and unit variance, in the space of reduced coordinates Zi, the limit state is, $g(Z_1, Z_2 \ldots Z_n) = 0$. An algorithm proposed by Fissler (1980) is used with reduced variables and gives the values of β after only one set of iterations. The procedure is as follows.

The formulation equation for moment of resistance is given as, g (x) = R – S, where the resistance,

$$R = f_{pu}\, A_{pw}\,(d - 0.42\, X_u) + 0.675\, f_{ck}\,(b - bw)\, D_f\,(d - 0.5\, D_f) \qquad \ldots(6)$$

Where,

$A_p = A_{pw} + A_{pf}$, and

$$A_{pf} = 0.675\, f_{CK}\,(b - bw)\,(D_f / F_p) \qquad \ldots(7)$$

and the Action

$$S = \frac{W_d L^2}{8} + \frac{W_L L^2}{8} \qquad \ldots(8)$$

$$x = \mu\, A_{pf} = 0.675\, \mu\, f_{ck}\,(\mu b - \mu bw)\,(\mu D_f / \mu\, f_p) \qquad \ldots(9)$$

$$\sigma A_{p_f} = \sqrt{\left(\frac{\partial x}{\partial f_{ck}}\sigma_{f_{ck}}\right)^2 + \left(\frac{\partial x}{\partial f_p}\sigma_{f_b}\right)^2 + \left(\frac{\partial x}{\partial b_w}\sigma_{b_w}\right)^2 + \left(\frac{\partial x}{\partial D_f}\sigma_{D_f}\right)^2 + \left(\frac{\partial x}{\partial f_p}\sigma_{f_b}\right)^2} \qquad \ldots(10)$$

Then, $y = \mu\, A_{pw} = \mu\, A_p - \mu\, A_{pf}$ …(11)

$$\sigma A_{p_w} = \sqrt{\left(\frac{\partial y}{\partial A_p}\sigma_{A_p}\right)^2 + \left(\frac{\partial y}{\partial A_p}\sigma_{A_f}\right)^2} \qquad \ldots(12)$$

Where, $\partial y / \partial A_p = 1$; $\partial y / \partial Ap_f = -1$

The failure surface equation is,

$$g(z) = f_{pu}\, A_{pw}\,(d - 0.42\, x_4) + 0.675\, f_{ck}\,(b - bw)\, D_f\,(d - 0.5\, D_f) - W_L L^2 / 8 - W_D L^2 / 8 = 0 \qquad \ldots(13)$$

Normalizing the basic variables the equation becomes;

$$g(y) = (\mu f_{pu} + Y_1\, \sigma\, f_{pu})\,(\mu A_{pw} + Y_2\, \sigma\, A_{pw})\,[(\mu_d + Y_3\, \sigma_d) - 0.42\,(\mu x_u + Y_4\, \sigma x_u)] + 0.675\,(\mu f_{ck} + Y_5\, \sigma\, f_{ck})\,[(\mu b + Y_6\, \sigma b) - (\mu bw + Y_7\, \sigma\, bw)]\,(\mu Df + Y_8\, \sigma D_f)\,[(\mu d + Y_3\, \sigma d) - 0.5\,(\mu Df + Y_8\, \sigma\, Df)] - [((\mu w_d + Y_9\, \sigma w_d)\,(\mu L + Y_{10}\, \sigma L)^2)/8] - [((\mu w_L + Y_{11} \sigma w_L)\,(\mu L + Y_{10}\, \sigma L)^2)/8] = 0 \qquad \ldots(14)$$

Evaluate, $\partial g(y) / \partial y_1 = h'_1$; $\partial g(y) / \partial y_2 = h'_2$; $\partial g(y) / \partial y_3 = h'_3$; $\partial g(y) / \partial y_4 = h'_4$; $\partial g(y) / \partial y_5 = h'_5$; $\partial g(y) / \partial y_6 = h'_6$; $\partial g(y) / \partial y_7 = h'_7$; $\partial g(y) / \partial y_8 = h'_8$; $\partial g(y) / \partial y_9 = h'_9$; $\partial g(y) / \partial y_{10} = h'_{10}$ and $\partial g(y) / \partial y_{11} = h'_{11}$.

Step 1: Determine an expression for g (x).

Step 2: Evaluate an expression for h (y).

Step 3: Determine an expression for all first derivates of h(y), h'_i.

Step 4: Set $y_i = 0$, and β = 0.

Step 5: Evaluate all h'_i values.

Step 6: Evaluate h(y).

Step 7: Evaluate standard deviation of Z, from:

$$\sigma z = \sqrt{\sum (h'_i)^2}$$

Step 8: Evaluate new values for y, from:

$$y_i = -\frac{h'_i}{\sigma z}\left[\beta + \frac{h(y)}{\sigma z}\right]$$

Step 9: Evaluate, $\beta = \sqrt{\Sigma y_i^2}$

Step 10: Repeat steps 5 to 9 until values converge.

A MATLAB program was developed to perform the above calculation. Reliability Index is determined for various beams with span 10 m to 17 m and combined load 15 N / mm² to 25 N / mm².

Table 3: Results of β from AFOSM method

No	Case	Reliability Index β
1	PS1	4.82
2	PS2	4.69
3	PS3	4.70
4	PS4	4.68
5	PS5	4.74
6	PS6	4.39
7	PS7	4.36
8	PS8	4.37
9	PS9	4.41
10	PS10	4.29
11	PS11	4.17
12	PS12	4.21
13	PS13	4.23
14	PS14	4.29
15	PS15	4.24

V. Code Calibration

The development of structural reliability methods during the last 3 to 4 decades have provided a more rational basis for the design of structures in the sense that these methods facilitate a consistent basis for comparison between the reliability of well tested structural design and the reliability of new types of structures. For this reason the methods of structural reliability have been applied increasingly in connection with the development of new design codes over the last decades. By means of structural

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reliability methods the safety formats of the design codes i.e., the design equations, characteristic values and partial safety factors may be chosen such that the level of reliability of all structures designed according to the design codes is homogeneous and independent of the choice of material and the prevailing loading, operational and environmental conditions. This process including the choice of the desired level of reliability or "target reliability" is commonly understood as "Code Calibration" [14, 15].

5.1. Partial Safety Factors:

The reliability based design criteria is developed using the First-order second moment approach. The reliability in terms of β was calculated for given safety factor for a given limit state. Now the process is reversed: partial safety factors are to be evaluated for a given target β_0. The same First-Order Second Moment approach is used. In the normalized coordinate system, for a given failure surface the shortest distance from the origin 'O' to the failure surface defines the safety of the design [7, 15]. Different levels of safety (i.e., β) will yield different failure surfaces amounting to different designs.

Hence, in the reliability based design, the problem is to determine the design values of the variables that will result in designs having failure surfaces that comply with the required safety index β. If x_i is the design value of the original variable X_i, the failure surface equation is,

$$g\,(x^*_1, x^*_2 \ldots\ldots\ldots\ldots x^*_n) = 0 \qquad \ldots(15)$$

If the partial safety factors are to the nominal values of variables:

The above equation becomes

$$g\,(\gamma_1 x_{n1}, \gamma_2 x_{n2} \ldots\ldots r_n x_{nm}) = 0 \qquad \ldots(16)$$

The design point should be the most probable failure point. In the normalized coordinate system, the most probable failure point is given by

$$z^*_i = \alpha^*_i \beta \quad i = 1, 2 \ldots\ldots n \qquad \ldots(17)$$

Where

$$\alpha_i^* = \frac{-(\partial g_1/\partial zi)_*}{\sqrt{\left[\sum_{i=1}^{n}(\partial g_1/\partial zi)_*^2\right]}}$$, are the directional cosines along the axes Z_i $\qquad \ldots(18)$

The original variates are given by

$$\begin{aligned} x^*_i &= \mu_i + \sigma_i z_i^* \\ &= \mu_i + \sigma_i \alpha_i^* \beta \\ &= \mu_i (1+\partial_i \alpha_i^* \beta) \qquad \ldots(19) \end{aligned}$$

where ∂_i is the coefficient of variation of X_i. Hence the partial safety factor required for the given β is

$$\gamma_i = x_i^* / x_{ni} = \mu_i (1+\partial_i \alpha^*_i \beta) / x_{ni} \qquad \ldots(20)$$

if the partial safety factors are specified with respect to the mean value then,

$$\gamma_{ci} = x^*_i / \mu_i$$
$$\gamma_{ci} = 1 + \partial_i \alpha^*_i \beta \qquad \ldots(21)$$

5.2. Sample calculation:

It is to determine the partial safety factors for the design variables if the Target Reliability Index is 4.0

Table 3 (a) Statistics of the study variables

Variable	Mean Nominal	Nominal Value	δ	Distribution
X_1: Yield Strength of Prestressing steel	1.04	1020.51 N / mm^2	0.1	Normal
X_2: Compressive Strength of Concrete	1.1	40 N/mm^2	0.81	Normal
X_3: Combined Load	1.25	15 N/mm	0.18	Lognormal

The limit state equation in the original space,

$$g\,(x) = 0, \text{ is } g\,(z) = [f_p A_{pw} (d-0.42\, x_u) + 0.675\, f_{ck} (b-bw)\, D_f (d-0.5\, D_f) - WL^2 / 8] = 0$$

If x^*_1, x^*_2 and x^*_3 are the design points, Then

$$g(z) = x_1 A_{pw} (d-0.42\, x_u) + 0.675\, x_2 (b–bw) D_f (d-0.5\, D_f) – x_3L^3 / 8 = 0 \qquad \ldots(22)$$

The procedure for computing of the partial safety factor is as follows:

Step 1: Start with any x^*_1, x^*_2 and x^*_3.

Step 2: Compute σ_3 and μ_3 of the non-normal variable X_3 at the design point x^*_3; using the equation;

$$\mu'_{Xi} = -\sigma'_{Xi}\Phi^{-1}[F_{Xi}(x_i^*)] + x_i^* \qquad \ldots(23)$$

$$\sigma'_{Xi} = \frac{\phi\{\Phi^{-1}[F_{Xi}(x_i^*)]\}}{f_{Xi}(x_i^*)} \qquad \ldots(24)$$

Step 3: Compute design constant 'd' by using the equation

$$d = [x_1 A_{pw}\, 0.42\, x_u + 0.675\, x_2 (b–bw)\, 0.5\, D_f^2 + x_3 L^2 / 8] / [x_1 A_{pw} + 0.675\, x_2 (b–bw) D_f] \qquad \ldots(25)$$

Step 4: Compute directional cosines; using the equations

$\alpha_1 = \partial g(x) / \partial x_1$; $\alpha_2 = \partial g(x) / \partial x_2$ and $\alpha_3 = \partial g(x) / \partial x_3$.

Step 5: Determine the new design points

$$x_i^* = \mu_i^* + \sigma_i^* \alpha\beta \qquad \ldots(26)$$

Step 6: Go to step 2, and repeat the procedure till the required convergence is achieved.

A MATLAB program has been developed for computing the partial safety factors and the calculated sample values are tabulated in Table 4.

Table 4: Calculation of partial safety factors

Variable	Iteration						
	Start	1	2	3	4	5	6
x^*_1	1061.330	1010.050	945.100	932.690	912.680	908.250	942.680
x^*_2	48.000	39.090	35.700	31.590	30.179	29.600	29.600

x^*_3	15.200	22.470	21.040	20.990	20.983	20.700	20.700
d	217.860	324.470	329.830	329.830	329.830	329.830	329.830
α_1	-0.070	-0.150	-0.160	-0.157	-0.159	-0.160	-0.160
α_2	-0.520	-0.710	-0.712	-0.717	-0.719	-0.720	-0.720
α_3	0.850	0.690	0.689	0.685	0.680	0.680	0.680

The partial safety factors with respect to nominal values, for Target Reliability Index $\beta_0 = 4.0$ are;
$\gamma_1 = \gamma_{fp} = 908.25 / 1020.51 = 0.89$; $\gamma_2 = \gamma_{fck} = 296 / 4.0 = 0.74$; $\gamma_3 = \gamma_W = 20.7 / 15 = 1.38$

The partial safety factors for different values of Target Reliability are computed and tabulated below:

Table 5: Partial safety factors for different Target β_0

β_0	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
$\gamma_1(\gamma_{fp})$	0.96	0.94	0.93	0.91	0.89	0.87	0.84	0.82	0.79	0.76	0.73
$\gamma_2(\gamma_{fck})$	0.89	0.85	0.82	0.78	0.74	0.7	0.66	0.61	0.57	0.52	0.47
$\gamma_3(\gamma_w)$	1.22	1.26	1.31	1.34	1.38	1.41	1.44	1.46	1.47	1.48	1.49

VI. Sensitivity Analysis

The most sensitive parameters in the reliability analysis are identify and these parameters are considered as prime target in the effort to control probability of failure. Using the developed system reliability procedure, the sensitivity functions were developed for designed girders. Each sensitivity functions represents the relationship between a parameter and reliability index.

Various values of the bias factor (mean / nominal value) are considered for the parameter under study, from the actual value required by the code, up to value that is over 30% different, either larger (loads) or smaller (strength). The results indicate that the most important parameters are related to resistance. On the other hand, the least sensitive parameters are compressive strength of concrete and dead load.

The sensitivity analysis is performed by

1) Keeping the uncertainty only in variable under study and considering other variables as deterministic, the reliability index β is calculated.
2) By considering the uncertainty in all other variables except the variable under study, the reliability index β is calculated.

This procedure for all the variables

The value of β obtained from (1) for most sensitive variable will be the minimum and correspondingly β obtained from (2) for the same variable will be the maximum.

Sensitivity analysis of the PSC girders is carried out and the results of PS1 and PS2 are tabulated in Table 6. The basic design variables are listed in the order of their sensitivity.

Table 6: Sensitivity study for PS1 and PS2

Study variable	**PS1**		**PS2**	
	Uncertainty in all variable Except study variable	**Uncertainty only in study variable**	**Uncertainty in all variable Except study variable**	**Uncertainty only in study variable**
f_{ck}	16.37	5.63	16.12	5.46
b	5.5	22.07	5.35	21.51
W_L	5.47	27.62	5.31	28.08
W_D	5.47	30.23	5.3	31.23
D_f	5.45	35.39	5.29	34.42
F_p	5.45	44.93	5.29	43.44
B_w	5.42	70.62	5.26	69.51
A_p	5.43	91.71	5.27	92.65
b_w	5.43	70.62	5.27	69.51
f_{pu}	5.42	2215.71	5.26	2228.16
d	5.42	2215.71	5.26	2228.16
L	5.42	2315.71	5.26	2428.16

VII. Code Calibration using LRFD Method

The design equation is

$$\phi\, Rn \geq \gamma_L M_L + \gamma_D M_D \quad \ldots(27)$$

Where, ϕ = Strength factor
ϕRn = Nominal (or design) strength
γ_L = Load factor for live load component
γ_D = Load factor for dead load component
M_L = Live load moment
M_D = Dead lead moment

The following are the steps involved for calibration of the LRFD specifications by reliability theory.

Step 1. Estimate the level of reliability implied in the current LSD methods for analysing the girder.

Step 2. Observe the variation of reliability levels with different span lengths, load ratios, section geometry and methods of predicting resistance.

Step 3. Select target reliability index based on the margin of safety implied in current designs.

Step 4. Calculate resistance factors consistent with the selected target β_0.

The sample results for $\beta_0 = 4$; are tabulated below:

Table 7: Results of ϕ, γ_L and γ_D for $\beta_0 = 4$

LL/DL	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
ϕ	0.69	0.69	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
γ_D	1.12	1.10	1.09	1.09	1.08	1.08	1.08	1.07	1.07	1.07	1.07	1.07
γ_L	1.44	1.49	1.53	1.55	1.57	1.58	1.59	1.59	1.60	1.61	1.61	1.61

VIII. Conclusion

Limit state of flexure is selected in the present study. Prasadrao method is found to be best suited for generating optimum sections for various design situations. The resistance statistics generated by Monte Carlo simulations shows that a normal distribution is adequate to fit the data. The bias factor is about 1.12 and value of COV of randomness of moment of Resistance is about 10% and β varies from 2 to 6. AFOSM method is used to find β, which varies from 4.2 to 4.8. Reliability based design is proposed, partial safety factors were calculated for different β. The recommended values provide a uniform safety level for the considered design cases. PSF for f_p varies from 0.73 to 0.96 when β varies from 7 to 2 and corresponding values of f_{ck} and combined load vary from 0.47 to 0.89 and 1.49 to 1.22 respectively. By sensitivity analysis, the order of sensitivity of variables is established. An attempt is made for code calibration using LRFD method for the PSC bridge girders.

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