

Determination of New Grade and Strength of Steel Bars For Non-Welded Reinforced Concrete Structures With High Carbon Content

Ju Su In^{*1}, Kim Sok Bong¹, Mun Song Hyok¹

¹Faculty of Civil Engineering, Pyongyang University of Architecture, Pyongyang DPR Korea

*Corresponding Author: shypinguo202131@yeah.net

ARTICLE INFO

Article history:

Received 15-11-2024

Revised 30-12-2025

Accepted 28-2-2026

Available online 15-3-2026

E-ISSN: 2622-1640

P-ISSN: 2622-0008

How to cite:

In J S, Bong K S and Hyok M S. Determination of new grade and strength of steel bars for non-welded reinforced concrete structures with high carbon content. International Journal of Architecture and Urbanism. 2026. 10(1):116-127.



This work is licensed under a Creative Commons Attribution-ShareAlike 4.0 International. <http://doi.org/10.32734/ijau.v10i1.18882>

ABSTRACT

The reliability-based calibration of reinforcing steel grades is essential to ensure structural safety consistency under modern limit-state design frameworks. While international standards define strength classes for reinforcing steel, limited attention has been given to the probabilistic validation and reliability calibration of high-carbon reinforcement intended for non-welded applications. This study presents an experimental–statistical–probabilistic evaluation of reinforcing steel with carbon content ranging from 0.25% to 0.37%, aiming to establish a new strength grade consistent with reliability-based design principles. A total of 799 specimens produced between 2017 and 2023 were experimentally tested, of which 571 valid samples were statistically analyzed. The yield strength distribution was verified to follow a normal distribution with a mean value of 400.6 MPa, a standard deviation of 36.03 MPa, and a coefficient of variation of 0.09, indicating stable production quality. Using a 97.73% confidence level, the characteristic yield strength was determined as 328 MPa, leading to the designation of a new reinforcement grade, C320. Ductility requirements were satisfied with a mean elongation of 27.998%, and a conservative minimum elongation limit of 16% was adopted in accordance with international standards. To ensure structural reliability consistency, the target reliability index was calibrated using a Life Quality Index (LQI)-based framework, resulting in reliability indices ranging from 2.7 to 3.9 depending on structural safety class. Based on the measured statistical variability, a material partial factor of $\gamma_s = 1.1$ was established, yielding a design strength of 290 MPa. The integration of long-term experimental data with reliability-based calibration provides a scientifically justified foundation for adopting high-carbon reinforcement in non-welded reinforced concrete structures. The proposed grade ensures safety, statistical consistency, and economic rationality, contributing to the harmonization of material classification with modern reliability-based structural design standards..

Keywords: reinforced concrete structural, reliability index

1. Introduction

Reinforced concrete (RC) structures remain the dominant structural system in modern civil engineering due to their structural efficiency, durability, and economic feasibility. The safety and serviceability of RC structures are fundamentally governed by the mechanical properties and reliability of reinforcing steel. In contemporary structural design practice, limit-state design principles are widely adopted, where structural safety is ensured through calibrated partial safety factors and target reliability indices [1][2][3]. Consequently, the statistical characterization of material properties and the calibration of reliability parameters have become essential components of structural code development.

In recent years, significant research efforts have focused on the determination of target reliability indices for various structural systems and loading conditions. Zhang et al. [4] proposed a methodology to determine target reliability indices for long-span concrete girders based on structural design service life. Similarly, Yuan et al. [5] conducted time-dependent reliability assessments of existing concrete bridges considering non-stationary load and resistance processes, emphasizing the importance of probabilistic modeling in long-term structural performance. Safari et al. [6] extended reliability analysis to extreme limit states under seismic loading, highlighting the need for calibrated reliability targets under different hazard scenarios. These studies collectively demonstrate that reliability-based calibration is now an integral part of modern structural engineering.

Reliability calibration has also been extensively applied to resistance factor determination. Oudah et al. [7] presented a unified reliability-based approach for calibrating resistance factors in pile foundations, while Lee and Kim [8] investigated wind load-governed reliability indices for bridge design codes. Furthermore, Kim and Salgado [9] provided reliability-based resistance factor calibration procedures in geotechnical systems. These investigations underline the necessity of statistically consistent resistance and strength factors to ensure uniform safety levels across structural components. Beyond ultimate strength considerations, structural safety assessment increasingly incorporates life-cycle and robustness concepts. Van Coile et al. [10][11] developed decision-support frameworks based on life-safety optimization and life-cycle reliability assessment. Baker et al. [12] emphasized structural robustness as a complementary performance measure beyond reliability indices. Additionally, Köhler et al. [13] proposed probabilistic deterioration models for reinforced concrete structures, demonstrating that reliability assessment must account for both material variability and long-term degradation. Hu et al. [14] further highlighted stability safety considerations during construction stages of long-span bridges, reinforcing the importance of reliability evaluation throughout the structural lifecycle.

International design standards formally incorporate reliability-based principles. ISO 2394 [2] establishes general principles on structural reliability, while ISO 13822 [15] provides guidance for the assessment of existing structures. The latest revision of EN 1990:2023 [3] further consolidates reliability-based design as the foundation of European structural codes. These standards recommend target reliability indices typically ranging between 3.0 and 4.0 for ultimate limit states, depending on safety class and design life [1][3]. Despite the extensive research on structural reliability and calibration of load and resistance factors, limited attention has been given to the statistical determination and reliability calibration of reinforcing steel grades with higher carbon content intended for non-welded applications. In some regions, reinforcing steel with carbon content ranging from 0.25% to 0.37% is widely produced and used; however, its classification within a reliability-based framework has not been systematically validated. Existing international standards primarily regulate mechanical performance without explicitly addressing the probabilistic calibration of such high-carbon reinforcement grades.

Therefore, this study aims to statistically evaluate the mechanical properties of reinforcing steel with carbon content between 0.25% and 0.37%, determine its characteristic strength based on probabilistic analysis, and calibrate the corresponding material reliability factor consistent with modern reliability-based design principles. The target reliability index is established in accordance with internationally recognized frameworks [1][2][3], and the resulting design strength is derived to ensure structural safety while maintaining economic rationality. Through this approach, the study contributes to the harmonization of material classification and structural reliability requirements for high-carbon reinforcing steel used in non-welded reinforced concrete structures.

2. Method

This study adopts an integrated experimental–statistical–probabilistic framework to determine the characteristic strength and design strength of high-carbon reinforcing steel intended for non-welded reinforced concrete structures. The methodological structure is developed to ensure full consistency with limit-state design principles and internationally recognised structural reliability standards, including ISO 2394 and EN

1990:2023. The procedure combines mechanical characterisation, statistical modelling, and reliability-based calibration using the Life Quality Index (LQI) framework.

A total of 799 reinforcing steel specimens with carbon content ranging from 0.25% to 0.37% were collected from industrial production batches manufactured between 2017 and 2023. The specimens were tested in accordance with the applicable national standards for reinforcing steel used in reinforced concrete structures. For each production lot, two specimens were prepared: one for tensile testing and one for bending testing. The tensile test was conducted to determine the upper yield strength (R_{eH}), ultimate tensile strength (R_m), and elongation ratio ($A_{5.65}$), with yield strength adopted as the governing parameter for strength grade classification. The bending test was performed using a 16 mm mandrel with a bending angle of 180° , and the absence of visible cracking in the tension zone was verified to confirm ductility and workability compliance.

Following chemical composition verification, 571 specimens satisfied the specified compositional requirements and were retained for statistical evaluation. The yield strength data of these valid samples were analysed to determine the mean value (μ), standard deviation (σ), and coefficient of variation ($V_s = \sigma/\mu$). The data were grouped into 25 MPa class intervals to construct frequency histograms and probability density curves. The assumption of normal distribution was verified using a chi-square goodness-of-fit test at a 5% significance level. The statistical analysis confirmed that the yield strength follows a normal distribution with a mean value of 400.6 MPa, a standard deviation of 36.03 MPa, and a coefficient of variation of approximately 0.09, indicating stable and consistent production quality.

The characteristic yield strength was determined at a 97.73% confidence level, corresponding to two standard deviations below the mean under the assumption of normal distribution. The characteristic value was calculated using the expression ($f_{yk} = \mu - 2\sigma$), resulting in a characteristic yield strength of approximately 328.5 MPa. Based on this statistically derived value, the new reinforcement grade was designated as Grade C320, where the numerical designation represents the characteristic yield strength in MPa.

To ensure consistency with reliability-based structural design principles, the target reliability index was calibrated using a probabilistic framework grounded in the Life Quality Index theory. The LQI approach integrates structural safety, economic investment, and societal risk acceptance into a unified optimisation concept in which the acceptable probability of failure is determined by balancing construction cost and life-safety expenditure. The socio-economic parameters required in the LQI formulation include the economic productivity ratio (w), the population-weighted parameter, the life expectancy factor (ψ), and the marginal life quality coefficient (q). The representative mean values of these parameters, derived from developed economies and summarised in Table 10 (Mean values of LQI index factors), were adopted as reference inputs for reliability calibration. The use of averaged international LQI parameters ensures that the calibrated safety levels are compatible with internationally accepted reliability targets and provides general applicability beyond national boundaries.

Table 10. Mean values of LQI index factors

Country	w (worker)	w (population)	ψ	q
Canada	0.2027	0.0924	0.5338	0.1912
France	0.1889	0.0745	0.5326	0.1912
Germany	0.1891	0.0854	0.5543	0.1686
UK	0.2034	0.0909	0.5724	0.1749
US	0.2210	0.0959	0.4880	0.2158

Based on the LQI-derived acceptable probability of failure and considering the design service life and structural safety classification, the relationship between failure probability (P_f) and reliability index (β) was established using the inverse standard normal distribution function, expressed as ($\beta = -\Phi^{-1}(P_f)$).

The calibrated target reliability indices corresponding to different structural safety classes were obtained as 3.9 for special-class structures, 3.5 for Class 1 structures, 3.0 for Class 2 structures, and 2.7 for Class 3 structures. These values fall within the internationally recommended reliability ranges for ultimate limit states.

The material strength partial factor (γ_s) was subsequently determined based on the measured statistical variability of reinforcement and the calibrated target reliability indices. Considering the coefficient of variation of approximately 0.095 and adopting a conservative reliability-based approach consistent with first-order reliability principles, the material partial factor was established as $\gamma_s = 1.1$. Finally, the design yield strength of Grade C320 reinforcement was determined by dividing the nominal grade strength by the adopted material partial factor, resulting in a design strength of approximately 290 MPa. This value was adopted as the computational strength for structural design applications. Through the integration of long-term experimental data, rigorous statistical verification, and LQI-based reliability calibration, the proposed methodology provides a scientifically justified basis for the classification and design implementation of high-carbon reinforcing steel in non-welded reinforced concrete structures.

3. Result and Discussion

The mechanical performance and statistical characteristics of reinforcing steel with carbon content ranging from 0.25% to 0.37% were evaluated through tensile and bending tests conducted on 799 specimens produced between 2017 and 2023. The tensile and bending test setups are presented in Figure 1 and Figure 2, respectively. The bending test, performed using a 16 mm mandrel and a 180° bending angle, confirmed adequate ductility, as no visible cracking was observed in the bending zone for specimens that satisfied chemical requirements. Representative chemical compositions and mechanical properties are summarized in Table 1, showing that all reported specimens satisfied the required limits for carbon, manganese, silicon, phosphorus, and sulfur while achieving satisfactory yield strength, tensile strength, elongation, and bending performance.



Figure 1. Bending test

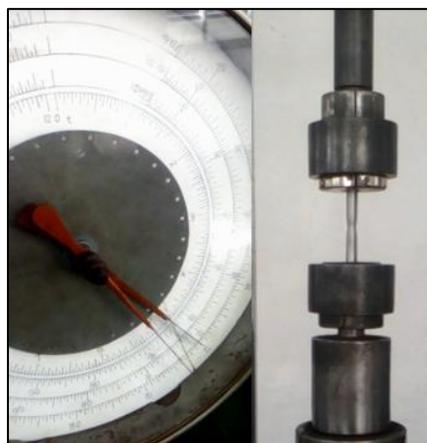
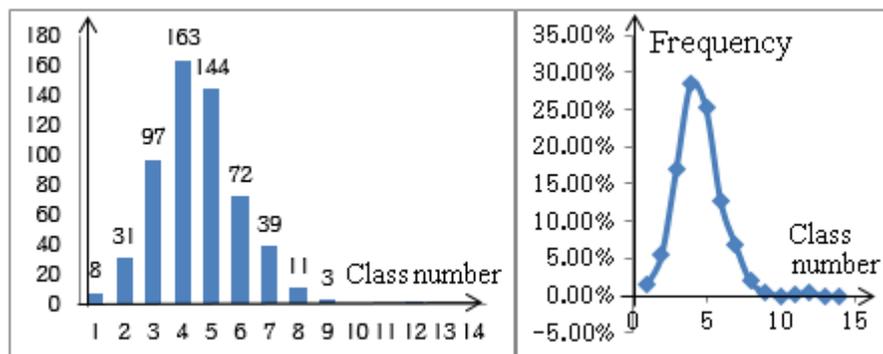


Figure 2. Tensile test

Table 1. Chemical composition and mechanical properties of the samples

№	Occupancy number	C	Si	Mn	P	S	upper yield limit (R _{el})	strength limit (R _m)	Elongation ratio (A)	Bending test
1	170	0.35	0.25	0.59	0.027	0.032	371	596	28.5	Pass
2	169	0.35	0.36	0.53	0.029	0.03	400.5	607.5	23	Pass
3	150	0.35	0.26	0.53	0.025	0.043	375	570	26	Pass
4	31	0.35	0.31	0.51	0.031	0.025	382	603	25	Pass
5	82	0.35	0.21	0.5	0.026	0.038	427	566.5	28	Pass
6	33	0.35	0.17	0.5	0.023	0.036	353	530.5	29.5	Pass
7	36	0.35	0.34	0.52	0.026	0.036	440	600	24.5	Pass
8	68	0.35	0.25	0.51	0.02	0.03	421	628	28	Pass
9	110	0.35	0.36	0.55	0.027	0.047	421	639	24.5	Pass
10	236	0.35	0.24	0.53	0.033	0.039	397	588	27	Pass

After excluding samples that did not meet the specified chemical composition limits, 571 valid specimens were retained for statistical analysis. The frequency distribution of yield strength is illustrated in Figure 3 and detailed numerically in Table 2. The results show that the majority of yield strength values fall within the 375–425 MPa range, accounting for more than 50% of the total observations. The computed statistical parameters indicate a mean yield strength of 400.6 MPa, a standard deviation of 36.033 MPa, and a coefficient of variation of 0.09. The relatively low coefficient of variation demonstrates stable production quality and limited variability in mechanical performance. The distribution was verified to follow a normal distribution using a goodness-of-fit test, and the corresponding density function is expressed in Equation (1).

**Figure 3.** Frequency and probability distribution curve of the test data of 571 samples**Table 2.** Frequency and frequency ratio of the test data of 571 samples

Class number	Class width		Frequency	Frequency ratio
	25	Class		
1	300	325	8	1.40%
2	325	350	31	5.43%
3	350	375	97	16.99%
4	375	400	163	28.55%
5	400	425	144	25.22%
6	425	450	72	12.61%
7	450	475	39	6.83%
8	475	500	11	1.93%
9	500	525	3	0.53%
10	525	550	0	0.00%
Total			571	100%

Class number	Class width	25	Frequency	Frequency ratio
Class				
Mathematical expectation			400.6	
Standard deviation			36.033	
Coefficient of variation			0.09	

The annual variation of mechanical properties is presented in Table 3, while the overall yield and tensile strength distribution curves are shown in Figure 4 and Figure 5. Although slight annual fluctuations are observed, the long-term average values remain consistent, confirming production stability over the seven-year period. The overall mean ultimate tensile strength was 594.67 MPa with a coefficient of variation of 0.063, and the mean elongation was 27.998% with a coefficient of variation of 0.093. These results indicate that the material satisfies both strength and ductility requirements for structural applications.

Table 3. Results of mechanical characteristics analysis

№	Upper yeild limit (R _{eH})			Strength limit (R _m)			Coefficient of elongation(A _{5.65})		
	Mathematical expectation	Standard deviation	Coefficient of variation	Mathematical expectation	Standard deviation	Coefficient of variation	Mathematical expectation	Standard deviation	Coefficient of variation
2017-2019	429.051	34.311	0.08	620.54	39.503	0.064	27.839	2.665	0.096
2020	393.64	30.872	0.078	589.8	34.683	0.059	28.27	2.588	0.92
2021	394.61	36.338	0.092	588.78	36.516	0.062	27.352	2.66	0.097
2022	398.01	27.709	0.07	593.44	30.833	0.052	28.15	2.112	0.075
2023	395.11	28.127	0.071	584.8	31.241	0.053	28.302	2.385	0.084
2017~2023	400.6	36.033	0.09	594.67	38.006	0.063	27.998	2.613	0.093

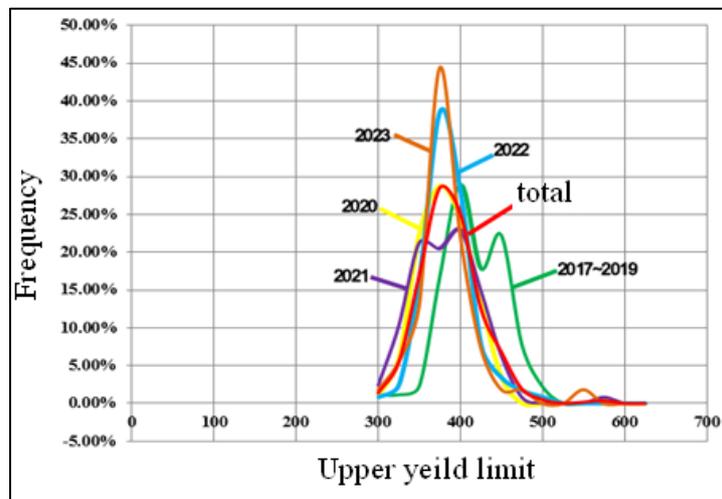


Figure 4. Yield limit distribution curve

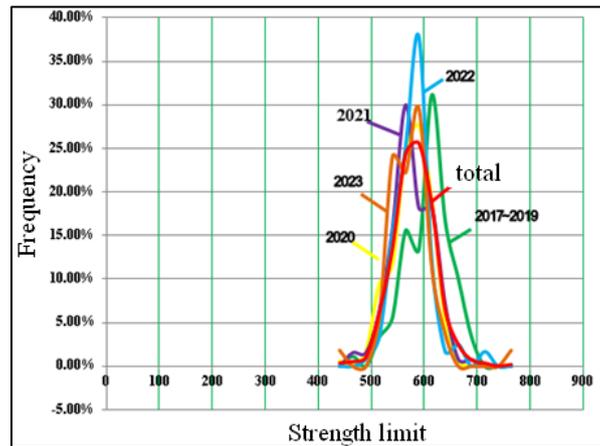


Figure 5. Strength limit distribution curve

The characteristic yield strength was determined using a 97.73% confidence level, corresponding to two standard deviations below the mean. The acceptance and rejection limits for reinforcement grading are illustrated in Figure 6. Based on this statistical criterion, the calculated characteristic strength was approximately 328 MPa, which supports classification under the 320 MPa grade level. Accordingly, the new non-welded reinforcement grade was designated as Grade C320 (translated from the original national designation), where the numerical value represents the characteristic yield strength in MPa.

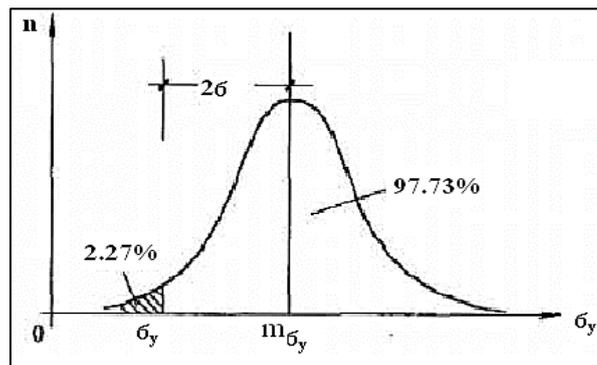


Figure 6. Limit of passing and rejecting of steel reinforcement

The statistical analysis of elongation resulted in a mean value of 27.998% and a standard deviation of 2.613%. Although the statistical lower bound corresponding to the 97.7% confidence level exceeds 20%, the minimum elongation requirement for the new grade was conservatively established as 16% in accordance with ISO 6935-1 and the current seismic structural design standard. This ensures compatibility with international ductility requirements while maintaining sufficient safety margins.

The finalized chemical composition limits and grade classifications are presented in Table 4 for plain bars and in Table 6 for ribbed bars. In these tables, the suffix “W” (translated from the original national notation meaning “for welding”) indicates weldable reinforcement, while grades without this suffix are intended primarily for non-welded applications. The tensile property requirements corresponding to each grade are summarized in Table 5 for plain reinforcement and Table 7 for ribbed reinforcement. For Grade C320, the specified minimum yield strength is 320 MPa, the minimum tensile strength is 470 MPa, and the minimum elongation is 16%, reflecting the statistically validated mechanical performance.

Table 4. Grade and chemical composition (%)

Grade	C	Mn	Si	P	S
				Less than	
C240W	0.14*~0.25	0.40~0.80	0.15~0.35	0.045	0.055
C240	0.14*~0.25	Less than 0.4	Less than 0.4	0.045	0.055

C300W	0.18*~0.25	0.40 ~ 0.80	0.15~0.35	0.045	0.055
C300	0.18*~0.25	Less than 0.4	Less than 0.4	0.045	0.055
C320	0.25~0.37	0.50 ~ 0.80	Less than 0.4	0.045	0.055

Table 5. Tensile properties of circular reinforcement

Grade	Upper yield limit (R_{eH})	Strength limit (R_m)	elongation ratio ($A_{5.65}$)
	MPa, more than		%, more than
C240W,C240	240	370	21
C300W,C300	300	420	19
C320	320	470	16

Table 6. Grade and chemical composition of steel (%)

Grade	C	Mn	Si	P	S	C large
				Less than		
HRB300W	0.18~0.25	0.50 ~ 0.80	Less than 0.4	0.05	0.05	0.5
HRB320	0.25~0.37	Less than 1.5	Less than 0.4	0.05	0.06	
HRB350	0.25~0.31	Less than 1.5	Less than 0.4	0.05	0.06	-
HRB400	0.3~0.37	Less than 1.5	Less than 0.4	0.05	0.06	-
HRB400W	0.14~0.22	0.8~1.5	Less than 0.6	0.05	0.05	0.5

Table 7. Tensile properties of ribbed reinforcement

Grade	Upper yield limit (R_{eH})	Strength limit (R_m)	elongation ratio ($A_{5.65}$)
	MPa, more than		%, more than
HRB300W	300	420	18
HRB320	320	470	16
HRB350	350	490	16
HRB400	400	540	14
HRB400W	400	540	14

To determine the design strength of the newly established grade, the material strength reliability factor was calibrated based on probabilistic structural reliability theory. The target reliability index was determined using the Life Quality Index (LQI) framework, which balances structural safety and socio-economic considerations. The conceptual relationship between construction cost, life safety expenditure, and failure probability is illustrated in Figure 7. The threshold failure probabilities corresponding to different safety classes are summarized in Table 11, while the correlation between reliability index and failure probability is presented in Table 12.

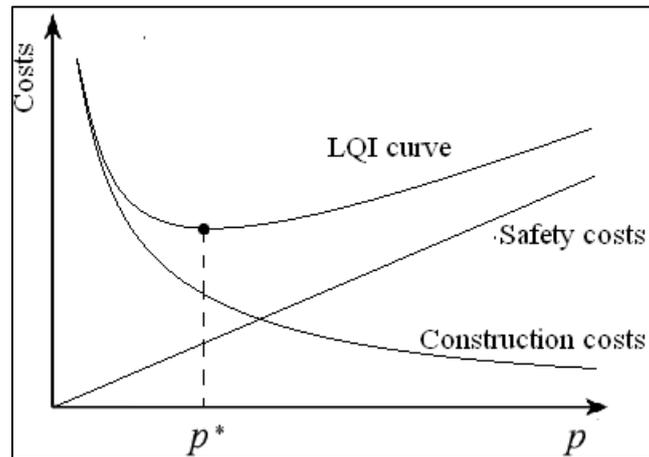


Figure 7. LQI curve for economic viability

Table 11. Threshold values of probability of failure according to the safety class

classify	Design Period, Year	safety grade	threshold of failure probability- P^*
1	100	special class	4.69×10^{-5}
2	50	Class 1	2.345×10^{-4}
3	25	Class 2	1.173×10^{-3}
4	5	Class 3	5.863×10^{-3}

Table 12. Correlation of the structural reliability index β with the failure probability P_f

β	1.0	1.5	2.0	2.5	2.7	3.0	3.2
P_f	1.59×10^{-1}	6.68×10^{-2}	2.28×10^{-2}	6.21×10^{-3}	3.5×10^{-3}	1.35×10^{-3}	6.9×10^{-4}
β	3.5	3.7	4.0	4.2	4.5		
P_f	2.23×10^{-4}	1.1×10^{-4}	3.17×10^{-5}	1.3×10^{-5}	3.4×10^{-6}		

Based on the design service life and safety classification defined in Table 8 and Table 9, the resulting target reliability indices are provided in Table 13. The calibrated reliability indices were determined as 3.9 for special-class structures, 3.5 for Class 1, 3.0 for Class 2, and 2.7 for Class 3 structures. These values fall within internationally accepted reliability ranges for ultimate limit states. Using the measured coefficient of variation of reinforcement (approximately 0.095), the material strength reliability factors were computed for each safety class, as shown in Table 14. For the highest safety class, the calculated factor is approximately 1.09, while for lower safety classes it approaches unity. For practical and conservative design purposes, the material partial factor was adopted as $\gamma_s = 1.1$.

Table 8. Design period and safety grade of the structure

classify	Design Period, Year	safety grade	Type of structure
1	100	special class	Building and structure that is specified by the nation
2	50	Class 1	Buildings, structures, public buildings, houses, service facilities and structures etc of national significance
3	25	Class 2	Industrial buildings and structures without major equipment, various warehouses, single-story agricultural production buildings, structures, walls, fences etc
4	5	Class 3	temporary building, structure and barrack

Table 9. k_s According to the design period and safety grade

classify	Design Period, Year	safety grade	k_s
1	100	special class	0.001
2	50	Class 1	0.01
3	25	Class 2	0.1
4	5	Class 3	1

Table 13. Target reliability index (β^*) according to safety grade

classify	Design Period, Year	safety grade	β^*
1	100	special class	3.9
2	50	Class 1	3.5
3	25	Class 2	3
4	5	Class 3	2.7

Table 14. Strength reliability coefficient of the 《大 320》 bar according to the safety grade

Sample amount	Upper yield limit (ReH)			target reliability index according to safety grade β^*			
	mathematical expectation	standard deviation	coefficient of variation	special class	Class 1	Class 2	Class 3
				3.9	3.5	3	2.7
571	400.95	38.12	0.095	1.08797	1.0611	1.0189	1.00238

Finally, the design strength of Grade C320 reinforcement was determined by dividing the nominal grade strength by the adopted reliability factor. This resulted in a design strength of approximately 290 MPa. The calibrated design value ensures consistency with the target reliability indices established for different safety classes and aligns with reliability-based design principles adopted in modern structural standards.

Overall, the results demonstrate that reinforcing steel with carbon content up to 0.37% exhibits stable statistical behavior, adequate ductility, and sufficient strength capacity to justify classification as Grade C320 for non-welded reinforced concrete structures. The integration of experimental data with reliability-based calibration provides a rational and scientifically supported basis for the adoption of this new reinforcement grade within updated national standards.

4. Conclusion

This study presented the experimental validation and reliability-based calibration of a new reinforcing steel grade with carbon content ranging from 0.25% to 0.37% for application in non-welded reinforced concrete structures. A total of 799 specimens produced between 2017 and 2023 were tested, of which 571 samples met the specified chemical composition requirements and were subjected to statistical evaluation. The yield strength data were verified to follow a normal distribution, with a mean value of 400.6 MPa, a standard deviation of 36.033 MPa, and a coefficient of variation of approximately 0.09, indicating stable and consistent production quality. Using a 97.73% confidence level, the characteristic yield strength was determined to be approximately 328 MPa, leading to the classification of the new reinforcement as Grade C320. The elongation characteristics satisfied ductility requirements, and a conservative minimum elongation value of 16% was adopted in accordance with relevant international standards. The finalized chemical composition limits and tensile properties were incorporated into updated national reinforcement specifications.

To ensure structural safety consistency with modern limit-state design principles, the material strength reliability factor was calibrated using a probabilistic framework based on the Life Quality Index (LQI) theory. The target reliability indices corresponding to different structural safety classes ranged from 2.7 to 3.9. Based on the measured statistical variability of the reinforcement, a conservative material partial factor of $\gamma_s = 1.1$ was adopted. Consequently, the design strength of Grade C320 reinforcement was established as 290 MPa. The integration of experimental testing, statistical verification, and reliability-based calibration provides a scientifically justified foundation for the adoption of high-carbon reinforcing steel in non-welded reinforced concrete structures. The proposed grade ensures structural safety, production stability, and economic feasibility within the framework of reliability-based structural design.

5. Acknowledgments

The authors would like to express their sincere appreciation to the Faculty of Civil Engineering, Pyongyang University of Architecture, for providing laboratory facilities and technical support throughout the experimental program. The authors also acknowledge the cooperation of the steel production plants involved in supplying specimens and production data from 2017 to 2023. Their support made the comprehensive statistical evaluation possible.

6. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. The research was conducted independently, and no financial or commercial relationships influenced the study design, data analysis, interpretation of results, or manuscript preparation.

References

- [1] S. Vrouwenvelder, “Target reliability and partial safety factors in structural codes,” *Heron*, vol. 62, no. 1, pp. 5–25, 2017. doi: 10.47981/heron.2017.62.1.5
- [2] ISO 2394:2015, *General Principles on Reliability for Structures*, International Organization for Standardization, Geneva, Switzerland, 2015.
- [3] EN 1990:2023, *Eurocode – Basis of Structural and Geotechnical Design*, European Committee for Standardization (CEN), 2023.
- [4] Z. Zhang, H. Li, J. Xiong, F. Wang, L. Wei, and L. Ke, “Determination of the target reliability index of the concrete main girder of long-span structures based on structural design service life,” *Buildings*, vol. 12, no. 3, 2022, Art. no. 327. doi: 10.3390/buildings12030327
- [5] Y. Yuan, W. Han, G. Li, Q. Xie, and Q. Guo, “Time-dependent reliability assessment of existing concrete bridges including non-stationary vehicle load and resistance processes,” *Engineering Structures*, vol. 184, pp. 645–655, 2019. doi: 10.1016/j.engstruct.2019.01.094
- [6] M. Safari, S. H. Ghasemi, and S. A. H. S. Taghia, “Target reliability analysis of bridge piers concerning the earthquake extreme event limit state,” *Engineering Structures*, vol. 246, 2021, Art. no. 113047. doi: 10.1016/j.engstruct.2021.113047
- [7] F. Oudah, M. H. El Naggar, and G. Norlander, “Unified system reliability approach for single and group pile foundations – Theory and resistance factor calibration,” *Computers and Geotechnics*, vol. 109, pp. 40–52, 2019. doi: 10.1016/j.compgeo.2019.01.006
- [8] H. S. Lee and J. H. Kim, “Wind pressure statistics and target reliability index for wind load-governed limit state of reliability-based bridge design codes,” *KSCE Journal of Civil Engineering*, vol. 23, no. 8, pp. 3464–3475, 2019. doi: 10.1007/s12205-019-1213-1
- [9] D. Kim and R. Salgado, “Resistance factors for MSE wall sliding and overturning checks,” *GeoCongress 2012*, ASCE, updated reliability calibration studies cited in 2017 revisions. doi: 10.1061/9780784412121.127

- [10] R. Van Coile, R. Caspeele, and L. Taerwe, “Decision support tool on investments in life safety based on sampling theory,” *Structure and Infrastructure Engineering*, vol. 11, no. 7, pp. 905–917, 2015. doi: 10.1080/15732479.2014.917171
- [11] R. Van Coile and R. Caspeele, “Life-cycle reliability analysis of reinforced concrete structures,” *Engineering Structures*, vol. 196, 2019, Art. no. 109336. doi: 10.1016/j.engstruct.2019.109336
- [12] J. W. Baker, M. Schubert, and M. H. Faber, “On the assessment of robustness,” *Structural Safety*, vol. 86, 2020, Art. no. 101959. doi: 10.1016/j.strusafe.2020.101959
- [13] J. Köhler, R. Sørensen, and M. H. Faber, “Probabilistic modeling of deterioration and reliability assessment of reinforced concrete structures,” *Structural Safety*, vol. 64, pp. 1–12, 2017. doi: 10.1016/j.strusafe.2016.10.001
- [14] F. Hu, P. Huang, F. Dong, and A. Blanchet, “Stability safety assessment of long-span continuous girder bridges in cantilever construction,” *Journal of Intelligent & Fuzzy Systems*, vol. 34, no. 4, pp. 2623–2634, 2018. doi: 10.3233/JIFS-169485
- [15] ISO 13822:2010 (reviewed 2017), *Bases for Design of Structures – Assessment of Existing Structures*, International Organization for Standardization, Geneva, Switzerland.