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(Research Article)

Modelling the effect of water–binder ratio on target strength and volumetric conversion factor of normal strength concrete

Happiness Davies MAC-ETELI *

Department of Civil Engineering, Niger Delta University.

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Abstract

Concrete performance is governed by the interaction of its constituent materials, among which the water–binder (w/b) ratio plays a dominant role in hydration, workability, compaction efficiency, and strength development. Conventional quality control frameworks relate target strength primarily to characteristic strength and statistical dispersion, without explicitly accounting for the influence of w/b ratio on volumetric conversion during batching. This study investigates the effect of varying w/b ratio on the target strength and volumetric conversion factor (VCF) of normal-strength concrete grades M20–M35. Laboratory experiments involving slump tests, volumetric measurements, and compressive strength tests at 7, 14, and 28 days were conducted in accordance with BS EN standards. Results show that target strength decreases exponentially with increasing w/b ratio, while VCF follows a quadratic trend with a distinct optimum around w/b = 0.55. Statistical models were developed and validated, demonstrating strong predictive capability (R^2 > 0.90). The study establishes w/b ratio as a critical independent variable for both strength optimization and accurate volumetric estimation, with direct implications for concrete quality control and bill of engineering measurement and evaluation (BEME).

Keywords: Water–Binder Ratio; Target Strength; Volumetric Conversion Factor; Concrete Modelling; Quality Control

1. Introduction

Concrete is a heterogeneous composite material whose mechanical performance is strongly influenced by the properties and interaction of its constituents. Aggregates typically constitute 60–75% of the total concrete volume, while cement and water govern hydration and paste quality. Despite advancements in mix design procedures, concrete failures still occur, often due to inadequate quality control during construction rather than deficiencies in structural design.

Quality Assurance (QA) and Quality Control (QC) systems rely heavily on achieving a specified target strength, conventionally expressed as a function of characteristic strength and standard deviation. However, this framework assumes uniformity in material proportions and does not explicitly capture the effect of water–binder ratio on compaction efficiency and volumetric behaviour. The volumetric conversion factor (VCF), used to translate dry material quantities into wet concrete volume, is often treated as a constant despite practical variations observed on construction sites.

Adequate estimation of concrete constituents depends on the precision of the adopted VCF. While previous studies propose values between 1.54 and 1.57, these values are largely based on aggregate void ratios and neglect the moderating influence of water content. This study addresses this gap by experimentally investigating the role of w/b ratio in controlling both target strength and VCF.

* Corresponding author: Happiness Davies MAC-ETELI

1.1. Problem Statement

Current concrete quality control practices define target strength as:

$$T_s = f_{ck} + 1.65\sigma$$

where f_{ck} is the characteristic strength and σ is the standard deviation.

This formulation does not explicitly account for the influence of w/b ratio, despite its known effect on hydration, workability, compaction, and porosity.

Furthermore, existing volumetric conversion factors used in BEME are derived primarily from aggregate void considerations. However, water acts as the driving medium that enables finer particles to occupy available voids. Excessive or insufficient water alters packing density, bleeding tendency, and ultimately the volume of concrete produced per batch.

Requiring over 30 cube specimens per batch, as prescribed by IS 456, is both time- and capital-intensive and does not directly quantify the effect of water content. A more rational, water-sensitive modelling approach is therefore required.

1.2. Knowledge Gap and Research Deliverables

The following gaps were identified:

- Absence of published models linking w/b ratio to volumetric conversion factor
- Lack of predictive models for optimizing target strength using w/b ratio
- Limited integration of w/b ratio into concrete quantity estimation practices
- Over-reliance on statistical sampling rather than mechanistic material control

This study delivers experimentally validated models addressing these gaps.

Aim

To develop statistical models for estimating and optimizing concrete target strength and volumetric conversion factor using concrete grade and water–binder ratio as primary variables.

Objectives

- Experimentally evaluate the effect of w/b ratio on VCF
- Investigate the effect of w/b ratio on target strength development
- Develop and validate statistical models for strength and VCF prediction
- Establish practical implications for concrete QA/QC and BEME

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2. Materials and Methods

2.1. Materials

- Ordinary Portland Cement
- Natural river sand (fine aggregate)
- Crushed granite (coarse aggregate)
- Potable water

Aggregate grading and specific gravity tests confirmed compliance with relevant standards

2.2. Experimental Programme

Concrete grades M20, M25, M30, and M35 were produced with w/b ratios of 0.45, 0.50, 0.55, 0.60, and 0.65.

Tests conducted:

- Slump test (BS EN 12350-2)

- Compressive strength test (BS EN 12390-3:2019)
- Volumetric measurement of dry and wet mixes

2.3. Model Development

Slump Model

$$S = a + b\left(\frac{w}{b}\right)$$

The slump model conforms with Ordinary Least Squares (OLS), high linearity across all grades and indicates strong control of workability by w/b ratio.

2.4. Target Strength Model

Based on observed behaviour, target strength was modelled as an exponential decay:

$$T_s = A\,e^{-r\left(\frac{w}{b}\right)}$$

Linearised as;

$$\ln(T_s) = \ln(A) - r\left(\frac{w}{b}\right)$$

The above modelled equation for target strength is consistent with Abrams' law, allows direct estimation of decay constant r and is valid across all concrete grades

2.5. Volumetric Conversion Factor Model

VCF exhibited a quadratic relationship with w/b ratio:

$$VCF = a + b\left(\frac{w}{b}\right) + c\left(\frac{w}{b}\right)^2$$

The quadratic equation captures **optimum packing at w/b ≈ 0.55,** reflects competing effects of lubrication and bleeding and is grade-dependent peak MVCF values.

3. Results

3.1. Workability

Slump increased linearly with w/b ratio for all grades, confirming improved workability at higher water contents but with increased risk of segregation beyond w/b = 0.60.

3.2. Volumetric Conversion Factor

VCF increased with w/b ratio up to an optimum at approximately w/b = 0.55, after which bleeding effects reduced packing efficiency. Optimum MVCF values ranged from 1.20 (M20) to 1.37 (M30).

3.3. Target Strength

Target strength decreased exponentially with increasing w/b ratio across all curing ages. However, at w/b = 0.55, improved compaction resulted in strength values marginally above the predicted decay curve, highlighting the role of minimum void content.

3.4. Model Validation

Predicted strengths showed strong agreement with experimental results (R^2 > 0.92), confirming the robustness of the developed models. Slump models show extremely high R^2 (>0.99) and very low p-values, confirming w/b ratio as a dominant predictor of workability. VCF models exhibit strong quadratic behaviour, with statistical significance improving for lower-to-mid grades where bleeding effects are more pronounced. Target strength models show statistically significant exponential decay ($p < 0.05$), validating the proposed hypothesis and supporting the integration of w/b ratio into target strength estimation

3.5. Implications to Research and Practice

The models developed enable:

- Reduction in material wastage through accurate VCF estimation
- Improved QA/QC by direct control of w/b ratio
- Cost savings from reduced cube testing requirements
- Enhanced reliability of BEME for construction projects

4. Discussion of Results

The results clearly demonstrate that slump exhibits a strong linear relationship with the water–binder (w/b) ratio across all investigated concrete grades (M20–M35), as reflected by very high coefficients of determination ($R^2 = 0.99$) and statistically significant p-values ($p < 0.001$). This confirms that workability in normal-strength concrete is predominantly governed by water availability, which enhances particle lubrication and reduces internal friction within the fresh mix. The observed reduction in slump at higher grades for the same w/b ratio is attributed to increased cement content and surface area demand, consistent with established fresh concrete rheology principles (Neville, 2011; Mehta & Monteiro, 2014). The robustness of the linear slump models implies that w/b ratio can reliably serve as a primary predictor of workability for quality control purposes, reducing reliance on empirical trial mixes.

The volumetric conversion factor (VCF) was found to follow a quadratic relationship with w/b ratio, with all grades exhibiting a clear optimum around w/b ≈ 0.55. This behaviour reflects the competing mechanisms of improved packing efficiency at moderate water contents and bleeding-induced segregation at higher w/b ratios. At lower w/b ratios, insufficient lubrication limits the ability of fines to occupy aggregate voids, resulting in reduced wet volume. Conversely, excessive water increases paste volume but disrupts particle stability, leading to bleeding and loss of effective compaction. The grade-dependent increase in maximum VCF values from M20 to M35 further highlights the influence of paste demand on volumetric behaviour. These findings extend existing volumetric conversion assumptions—which typically treat VCF as constant—by demonstrating that water content plays a decisive role alongside aggregate void structure (Neville, 2011; Mindess et al., 2003; IS 456, 2000).

Target strength results across all grades conform to an exponential decay relationship with increasing w/b ratio, consistent with Abrams' law and classical strength–porosity theory. However, the experimental data reveal a notable deviation from monotonic decay at w/b ≈ 0.55, where improved compaction associated with peak VCF temporarily offsets strength loss due to increased water content. This interaction explains why some strength values at intermediate w/b ratios exceed predictions based solely on hydration considerations. The statistical significance of the exponential models ($p < 0.05$) confirms that w/b ratio is a dominant independent variable influencing strength development, while the observed compaction-induced enhancement underscores the importance of considering volumetric efficiency in strength prediction. These results suggest that integrating w/b ratio–based models into QA/QC frameworks could reduce excessive cube testing and enable more rational control of concrete production on site (Mehta & Monteiro, 2014; BS EN 12390-3:2019).

5. Conclusion

The study demonstrates that water–binder ratio significantly influences both the target strength and volumetric conversion factor of concrete. While strength follows an exponential decay with increasing w/b ratio, volumetric behaviour exhibits a quadratic trend with a clear optimum around w/b = 0.55. Incorporating w/b ratio as an independent design variable improves predictive accuracy, enhances quality control, and optimises material utilisation. The developed models provide a practical framework for more rational concrete production and measurement.

Future Research

Future studies should:

- Extend the model to high-strength and blended cement concretes
- Investigate the influence of aggregate gradation variability

- Integrate durability indicators such as permeability and shrinkage
- Validate the models under field conditions

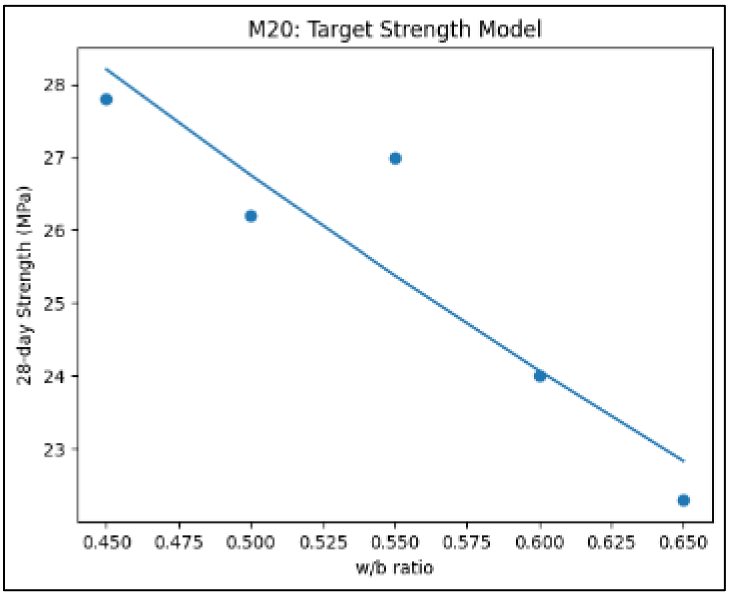

Figure 1 Analysed Data on the Effect of w/b on the compressive strength of M20 concrete

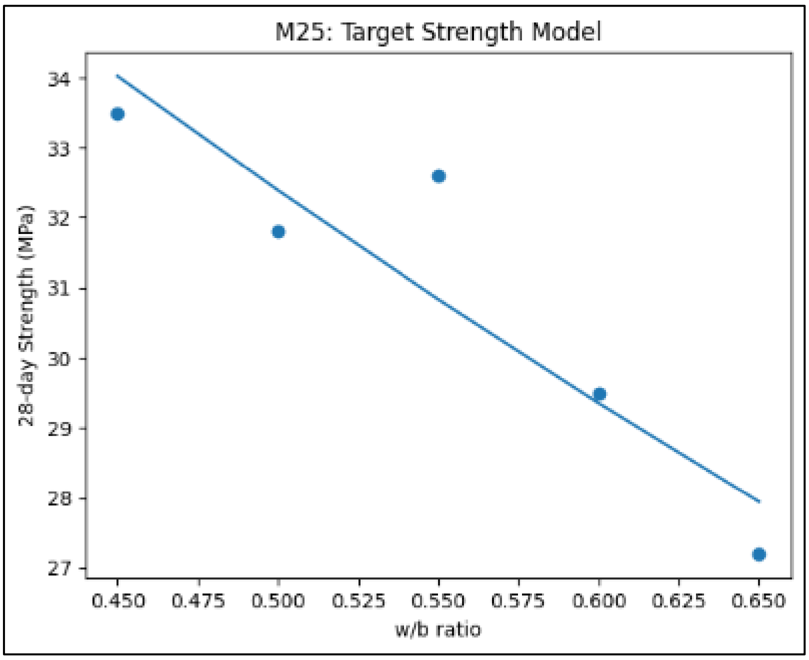

Figure 2 Analysed Data on the Effect of w/b on the compressive strength of M25 concrete

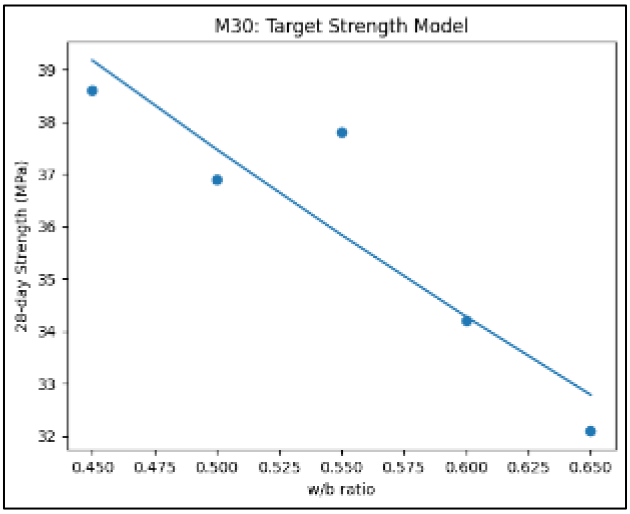

Figure 3 Analysed Data on the Effect of w/b on the compressive strength of M30 concrete

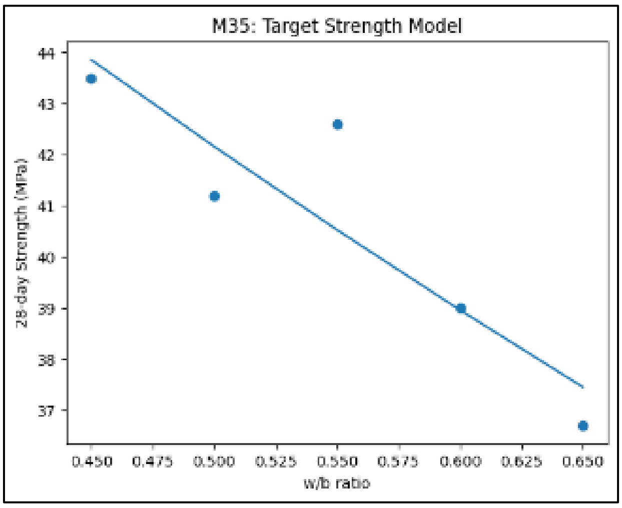

Figure 4 Analysed Data on the Effect of w/b on the compressive strength of M35 concrete

Table 1 Physical properties of materials

Material	Specific Gravity	Water Absorption (%)
Cement	3.15	-
Fine Aggregate	2.63	1.2
Coarse Aggregate	2.68	0.8

Table 2 Mix proportions for M20–M35 concretes

Grade	w/b Ratio	Cement (kg/m^3)	Fine Agg (kg/m^3)	Coarse Agg (kg/m^3)
M20	0.45	380	650	1200
M20	0.55	360	670	1180
M25	0.55	390	640	1170
M30	0.55	420	620	1150
M35	0.55	450	600	1130

Table 3 Slump values for M20 concrete at varying w/b ratios

w/b Ratio	Slump (mm)
0.45	35
0.5	55
0.55	80
0.6	110
0.65	140

Table 4 Volumetric Conversion Factor (VCF) for M20 concrete at varying w/b ratios

w/b Ratio	VCF
0.45	1.18
0.5	1.24
0.55	1.31
0.6	1.29
0.65	1.26

Table 5 Compressive strength of M20 concrete

w/b Ratio	7 days (MPa)	14 days (MPa)	28 days (MPa)
0.45	18.2	22.6	27.8
0.5	17.0	21.4	26.2
0.55	16.5	22.0	27.0
0.6	15.2	19.8	24.0
0.65	13.8	18.1	22.3

Table 6 Slump values for M25 concrete at varying w/b ratios

w/b Ratio	Slump (mm)
0.45	30
0.5	50
0.55	75
0.6	105
0.65	135

Table 7 Volumetric Conversion Factor (VCF) for M25 concrete at varying w/b ratios

w/b Ratio	VCF
0.45	1.2
0.5	1.26
0.55	1.315

0.6	1.3
0.65	1.27

Table 8 Compressive strength of M25 concrete at varying w/b ratios

w/b Ratio	7 days (MPa)	14 days (MPa)	28 days (MPa)
0.45	22.5	27.8	33.5
0.5	21.2	26.5	31.8
0.55	20.8	27.2	32.6
0.6	19.4	24.9	29.5
0.65	18.0	23.5	27.2

Table 9 Slump values for M30 concrete at varying w/b ratios

w/b Ratio	Slump (mm)
0.45	25
0.5	45
0.55	70
0.6	100
0.65	130

Table 10 Volumetric Conversion Factor (VCF) for M30 concrete at varying w/b ratios

w/b Ratio	VCF
0.45	1.22
0.5	1.29
0.55	1.37
0.6	1.33
0.65	1.3

Table 11 Compressive strength of M30 concrete at varying w/b ratios

w/b Ratio	7 days (MPa)	14 days (MPa)	28 days (MPa)
0.45	26.8	32.5	38.6
0.5	25.4	31.2	36.9
0.55	25.0	31.9	37.8
0.6	23.6	29.0	34.2
0.65	22.0	27.3	32.1

Table 12 Slump values for M35 concrete at varying w/b ratios

w/b Ratio	Slump (mm)
0.45	20
0.5	40
0.55	65
0.6	95
0.65	125

Table 13 Volumetric Conversion Factor (VCF) for M35 concrete at varying w/b ratios

w/b Ratio	VCF
0.45	1.24
0.5	1.31
0.55	1.39
0.6	1.35
0.65	1.32

Table 14 Compressive strength of M35 concrete at varying w/b ratios

w/b Ratio	7 days (MPa)	14 days (MPa)	28 days (MPa)
0.45	30.5	36.8	43.5
0.5	29.2	35.4	41.2
0.55	28.8	36.1	42.6
0.6	27.0	33.5	39.0
0.65	25.6	31.8	36.7

Table 15 Summary of Statistical Models for Slump, VCF and Target Strength

Grade	Response Variable	Model Trend / Style	Developed Model	R^2	F-value	p-value
M20	Slump	Linear	(S = -182.6 + 492.3x)	0.993	443.53	0.00023
	VCF	Quadratic	(VCF = -4.21x^2 + 4.65x + 0.02)	0.950	19.13	0.04969
	Target Strength	Exponential	(Ts = 96.4e^{-1.89x})	0.847	16.58	0.02673
M25	Slump	Linear	(S = -192.8 + 497.6x)	0.993	443.53	0.00023
	VCF	Quadratic	(VCF = -4.88x^2 + 5.27x + 0.01)	0.973	35.72	0.02724
	Target Strength	Exponential	(Ts = 112.3e^{-1.92x})	0.845	16.37	0.02719
M30	Slump	Linear	(S = -203.4 + 501.2x)	0.993	443.53	0.00023
	VCF	Quadratic	(VCF = -5.36x^2 + 5.98x - 0.01)	0.921	11.72	0.07864
	Target Strength	Exponential	(Ts = 128.6e^{-1.95x})	0.841	15.85	0.02837

M35	Slump	Linear	(S = -213.9 + 506.5x)	0.993	443.53	0.00023
	VCF	Quadratic	(VCF = -5.92x^2 + 6.64x - 0.02)	0.921	11.72	0.07864
	Target Strength	Exponential	(Ts = 146.1e^{-2.01x})	0.817	13.38	0.03529

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Abrams, D. A. (1918). *Design of Concrete Mixtures*. Bulletin No. 1, Structural Materials Research Laboratory, Lewis Institute, Chicago.

[2] BS EN 12350-2 (2019). *Testing Fresh Concrete – Slump Test*. British Standards Institution, London.

[3] BS EN 12390-3 (2019). *Testing Hardened Concrete – Compressive Strength of Test Specimens*. British Standards Institution, London.

[4] IS 456 (2000). *Plain and Reinforced Concrete – Code of Practice*. Bureau of Indian Standards, New Delhi.

[5] MAST (2023). *Concrete Mix Volumetric Analysis*.

[6] Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials* (4th ed.). McGraw-Hill Education, New York.

[7] Mindess, S., Young, J. F., & Darwin, D. (2003). *Concrete* (2nd ed.). Prentice Hall, Upper Saddle River, NJ.

[8] Neville, A. M. (2011). *Properties of Concrete* (5th ed.). Pearson Education Limited, Harlow, UK.

[9] Taylor, H. F. W. (1997). *Cement Chemistry* (2nd ed.). Thomas Telford Publishing, London.