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Analysis of Sustainable Concrete by Using Reliability Methods

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Abstract: ***The building industry plays a crucial role in realising sustainable community development goals. Considering that the selection of construction materials is a major stumbling block in the way of better project performance with respect to sustainable development indicators, the use of sustainable materials is a significant achievement in this direction. Sustainable concrete, manufactured by partially substituting fine aggregates with waste foundry sand, will be compared to traditional concrete to gauge its compressive strength. The current work treats the strength as a random variable to develop a reliability-based partial safety factor for the compressive strength of concrete with partial substitution of fine aggregate by waste foundry sand. In this investigation, concrete is broken down into components: cement, fine aggregates, coarse aggregates, and Waste Foundry Sand. A methodical approach has been developed to calculate partial safety factors for Waste Foundry Sand concrete. Significant amounts of information have been gathered on the mean, standard deviation, and coefficient of variation of compressive strength of concrete in relation to the variation in parameters. The experimentally obtained compressive strength data has been analysed using normal-probability distribution functions. In addition, the collected data will be analysed to determine partial safety factors in connection to the relevant per cent confidence level values.***

Keywords: Reliability, correlation, multicollinearity, coefficient of variation

1. Introduction

The sustainability approach is a key conceptual principle to consider in cement and concrete production worldwide. This work aims to simply enhance the methodology of a versatile, effective sustainability assessment. The feasibility of the proposed methodology is demonstrated on selected field applications related to reinforced concrete bridge deck slabs where strength and durability are of prime interest. This work intends to the present world scenario. The waste generated by industries has increased considerably with the development of industries. Industry wastes, normally land filled and dumped on wasteland, pollute the movement. Using these wastes in concrete would provide a good alternative to land factor or dumping. Performing reliability analysis is the rational way of catering for uncertainties. This work intends to evaluate the compressive strength of sustainable concrete, which will be prepared by partially replacing fine aggregates with waste foundry sand. In the present work, a reliability-based Partial safety factor for compressive strength of concrete with partial replacement of fine aggregate by Waste Foundry Sand is to be developed considering the strength as a random variable. The compressive strength of concrete depends upon the properties of its constituent materials, viz. cement, fine aggregates, coarse aggregates, and Waste Foundry Sand in the present normal–probability-by-step procedure has been suggested to find out the partial safety factors for Waste Foundry Sand concrete. An extensive data bank on the basic variables, viz. compressive strength of concrete in terms of mean, standard deviation and coefficient of variation corresponding to the variation in parameters, has been generated. The compressive strength data generated experimentally has been analysed using normal–probability distribution functions. Furthermore, based on the analysis of the generated data, partial safety factors are computed relative to corresponding per cent confidence level values. Reliability often improves during the initial development and testing of a system. This improvement can be attributed to a variety of factors. For example, as failures occur, analysing these failures provides information, that is., used to improve the system. Also, experience gained in constructing test components is applied to producing better components as time progresses. If the system reliability is periodically re-assessed during this initial period, it will be found to be increasing in value; this phenomenon is termed as “Reliability Growth”. The tracking, prediction and reporting of this growing phenomenon is a function of Reliability Growth. Finally, the comparison will be tabulated.

1.1 Waste Foundry Sand

To cast ferrous (iron and steel) and nonferrous (copper, aluminium, and brass) metals, foundries require clean sand, uniform in size, and high quality. These sands are pristine before they're used, but they could have contaminants after they're cast. A staggering 95% of all foundry sand comes from the ferrous (iron and steel) industries. Industry and its component suppliers are the primary producers of foundry sand. The sand cast system is the most widely employed casting method in the foundry sector. Green sand moulds predominate in the sand-casting industry, and they're used almost exclusively for producing ferrous castings. Green sand comprises 90% high-quality silica sand, 10% bentonite clay (used as a binder), 2-5% water, and 5% sea coal (a carbonaceous mould additive to improve casting finish). Which additives and sand grits are used in a casting process depend on the metal being used. More than 90% of the moulding materials in this process are green sand. Green sand moulds and chemically bonded sand cast systems are both employed. To create these systems, one or more organic binders (typically proprietary) are combined with catalysts and various hardening/setting processes.

1.2 Sustainability in Construction

The construction sector can significantly contribute to general sustainability objectives, mainly due to the amount of material and energy resources required to produce and maintain the built environment [3]. The Global Consensus on Sustainability in the Built Environment [3] indicates that the construction sector is currently responsible for more than 20% of global annual CO2 equivalent emissions. Between one-quarter and one-half of these emissions are due to the production of cement, and thus are directly related to concrete structures. EN 1990 [15] and the 2020 draft of its revision [16] include the following general guidance concerning sustainability in construction: the favourable effects to the society, environment and economy can be achieved by appropriate verification methods, construction process, building materials, their manufacture, durability, and recyclability. Three main aspects of sustainability that can be controlled or affected by design procedures or approaches to reliability assessment are identified:

- Consumption of resources.
- Reuse of resources.
- Use of renewables.

2. Correlation

2.1 Linear Correlation: Meaning and Coefficient:

Correlation is a statistical technique for examining the closeness of a link between two variables. Their correlation coefficient quantifies the degree to which two variables are related. Pearson's product-moment correlation coefficient and Spearman's rank correlation coefficient are the most common correlation coefficients utilised in practice. Pearson's Simple Linear Correlation is the primary method of analysis in this work because of its versatility and ease of use in examining correlations between data sets. Pearson introduced the concept of a correlation coefficient in 1896 (Hauke and Kossowski, 2011), building on earlier work by Francis Galton and Auguste Bravais in the areas of statistical analysis of correlation and relative contribution, respectively (Denis, 2001). Hauke and Kossowski (2011) indeed agree that Pearson's Product Moment Correlation Coefficient (R or r) is a scale to quantify the degree of the linear relationship between variables. Variables having a normal distribution should be considered when calculating the correlation coefficient, which assesses the degree to which two or more variables are linearly related to one another. A mathematical expression of Pearson's method for measuring the strength of a correlation (R) between two variables (X and Y) is as follows.:

$$R = \frac{n(\sum XY)-(\sum X).(\sum Y)}{\sqrt{n(\sum X^2)-(\sum X)^2}\sqrt{n(\sum Y^2)-(\sum Y)^2}} \text{------ (1)}$$

Where
N= Number of observations
X= Measure of variable 1
Y= Measure of variable 2

$\sum XY$
$= Sum\ of\ product\ of\ respective\ variable\ measures$

$\sum X = Sum\ of\ measures\ of\ variable\ 1$

$\sum Y = Sum\ of\ measures\ of\ variable\ 2$

$\sum X^2$
$= Sum\ of\ squared\ values\ of\ measures\ of\ variable\ 1$

$\sum Y^2$
$= Sum\ of\ squared\ values\ of\ measures\ of\ variable\ 2$

A correlation's strength can be either positive (strong), neutral (weak), or negative (weak), depending on the direction it points towards. In analyses, positive and negative correlations may be treated the same way because obtaining a correlation coefficient of zero between two variables in practice is uncommon. When one variable's trend is positive and relatively like that of another, there's a good chance that the two are correlated positively; when one variable's trend is positive and relatively opposite that of another, there's a good chance that the two are correlated negatively, yielding a negative correlation coefficient. The linear correlation coefficient is commonly used in research and analysis to investigate the strength of a relationship between two variables, as well as to assess multicollinearity and reveal mediating or moderating relationships.

2.2 Multicollinearity:

Since partial regression coefficients cannot be computed reliably, and standard errors grow high, multicollinearity makes it laborious to investigate the appropriate predicting variable in work. This further substantiates the hypothesis that the independent variables have been oversimplified. Researchers use the Variance Inflation Factor (VIF) to evaluate the degree of multicollinearity between independent variables and avoid it in analytic regression models. Multicollinearity between predictors can be detected with the help of the Variance Inflation Factor (VIF). VIF for predictors is calculated using a correlation coefficient.

$$VIF = \frac{1}{(1-R^2)} \qquad (2)$$

Where, R = Correlation Coefficient between the predictors

The criteria for interpreting VIF are

Criteria		Interpretation on Multicollinearity
VIF= 1	(Implies no correlation)	Null
1< VIF < 5	(Correlated)	Low Level
5> VIF < ∞	(Highly Correlated)	High Level
VIF →∞	(Perfectly Correlated)	Perfect Multicollinearity

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3. Methodology

M20 grade of concrete and their mix ratio:
In this post, we will learn about the many grades of concrete, such as m5, m7.5, m10, m15, m20, and m25, as well as the mix ratios required for each. Plain cement concrete (PCC) and Reinforced Cement Concrete (RCC) are the two main varieties of concrete (RCC). Cement concrete can be either plain, in which no reinforcement is used, or reinforced, in which reinforcement is present. As a result, plain cement concrete (grades M5, M7.5, M10, and M15) is used for things like footings and foundations, while RCC work (grades M20, M25, and higher) is used for things like forming columns and beams and compressive life slabs.

Grade of concrete:
The grade of concrete is classified into 3 categories, according to the mix proportion of cement sand and aggregate and the ratio of the grade of concrete.

Characteristic compressive strength of grade of concrete:
The strength of concrete is commonly known as characteristics compressive strength, represented by fck (Fck = Characteristic strength of concrete. K = 1.65). The different concrete grade is represented as m5, m 7.5, m10, m15, m 20. In which m stands for concrete mix design, and numerical figure 5, 7.5, 10, 15 and 20 is characteristics of the compressive strength of concrete after 28 days of casting and curing time in general. It is represented as 5 N/mm2, 7.5N/mm2, 10N/mm2, 15N/mm^2, 20N/mm2 respectively. it means fck value for m20 grade of concrete is 20 N/mm2.

Different grades of concrete have different concrete mix ratios. The nominal mix of the grade of concrete has the general proportion of sand cement and aggregate, and it is not decided by design mix. it is generally used in the construction of residential buildings. The simple grade of concrete is m5, m 7.5, m10, m15, m 20, having decided the grade of the concrete mix ratio according to their nominal mix.

Concrete mix design is the process of finding the right proportion of cement sand and aggregate for concrete to achieve target strength in a structure. The concrete mix design involves various steps, calculations, and laboratory tests to find the Right Mix proportion. The benefit of concrete mix design is that it provides the right proportional material making the concrete construction economical as required characteristics of compressive strength of structural members. But merely giving the concrete mix ratio for different grades of concrete is incorporated.

1) The ratio of cement to sand to aggregate in m5 grade concrete is 1: 5, with sand making up the other 5 parts of the mixture.
2) The proportions of cement, sand, and aggregate in m7.5-grade concrete are 1: 4: 8. The aggregate makes up 60%, while the sand accounts for 40%.
3) The recommended proportions for m10 grade concrete are 1 part cement, 3 parts sand, and 6 parts aggregate.
4) The proper proportions of cement, sand, and aggregate for an m15 grade of concrete are 1 part cement, 2 parts sand, and 4 parts aggregate.
5) The mix ratio for m20 grade concrete is 1: 1.5: 3, which means that for every three pieces aggregate, there is one part cement and one and a half parts sand.
6) The cement-to-sand-to-aggregate ratio for m25 grade concrete is 1: 1: 2, with one component cement, one part sand, and two parts aggregate.

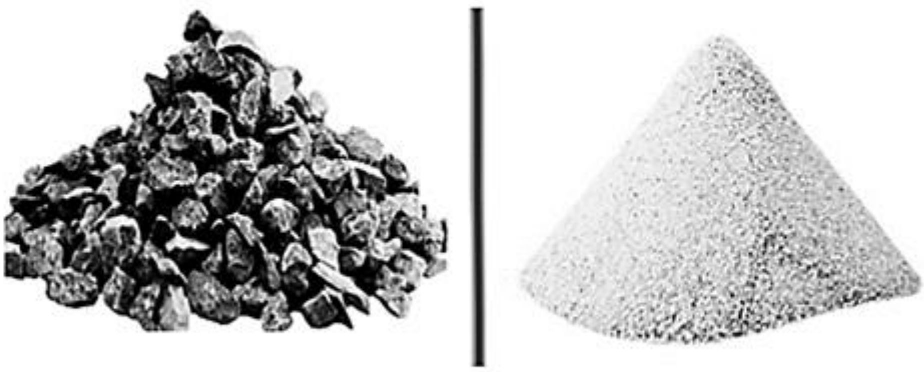


Figure 1: Grade concrete and grade mix ratio

The minimal nominal mix of concrete used in RCC work of constructing a building's structural members, including compressive members like footings, foundations, and columns, and flexural members like beams and slabs, is M20 grade of concrete. Concrete with a degree of "M20" indicates that its compressive strength increases by 20 per cent after 28 days of curing, where "M" stands for "concrete mix design. " The value of their compressive strength, or fck, is 20 N/mm2. M20 grade concrete is a mixture of cement, sand (fine aggregates), and coarse aggregate with a cement-to-water ratio of 0.4 to 0.6, with a nominal cement-to-sand-to-coarse-aggregate ratio of 1: 1.5: 3. One part cement, 1.5 parts sand, and 3 parts aggregate (or stone) make up a batch of M20 concrete, which follows a mix ratio of 1: 1.5: 3. For an M20 concrete mix, this would be 1 bag of cement, 1.5 bags of sand, and 3 bags of aggregate.

This M20 grade concrete is made in accordance with IS: 10262-2019 and can be used in place of regular concrete or waste foundry sand. Testing for fineness of cement, setting time, water absorption, specific gravity, and water content are performed as preliminary tests. This mix design requires a water-cement ratio of 0.547. Fine aggregates have had 10, 20, or 30% of it swapped out for waste foundry sand. The concrete was tested for strength once it had set. Waste foundry sand concrete is compared to regular concrete in terms of its strength. The collected information will be put through a probabilistic analysis to determine the ideal amount of waste foundry sand.

4. Results

Materials:

Cement Coarse Aggregate

Fine Aggregate Manufactured Sand

Figure 2: Materials

Figure 3: Practical implementation

Results obtained for Cement:

S. no	Characteristics of cement	Values
1	Specific gravity	3.14
2	Normal consistency	33%
3	Initial setting time	39 mins
4	Final setting time	276 mins
5	Fineness of cement	8.70%

Results obtained for Coarse aggregates:

S. no	Characteristics	values
1	Specific gravity	2.7
2	Water absorption	1%
3	Impact value	13.7

Results obtained for Waste foundry sand:

S. no	Characteristics	Values
1	Specific gravity	2.64
2	Water absorption	0.87%
3	Fineness modulus	1.78

Workability test on concrete:

Tests	Conventional concrete	WFS concrete (10%)	WFS concrete 20%)	WFS concrete (30%)
Slump cone test	75mm	70mm	45mm	35mm

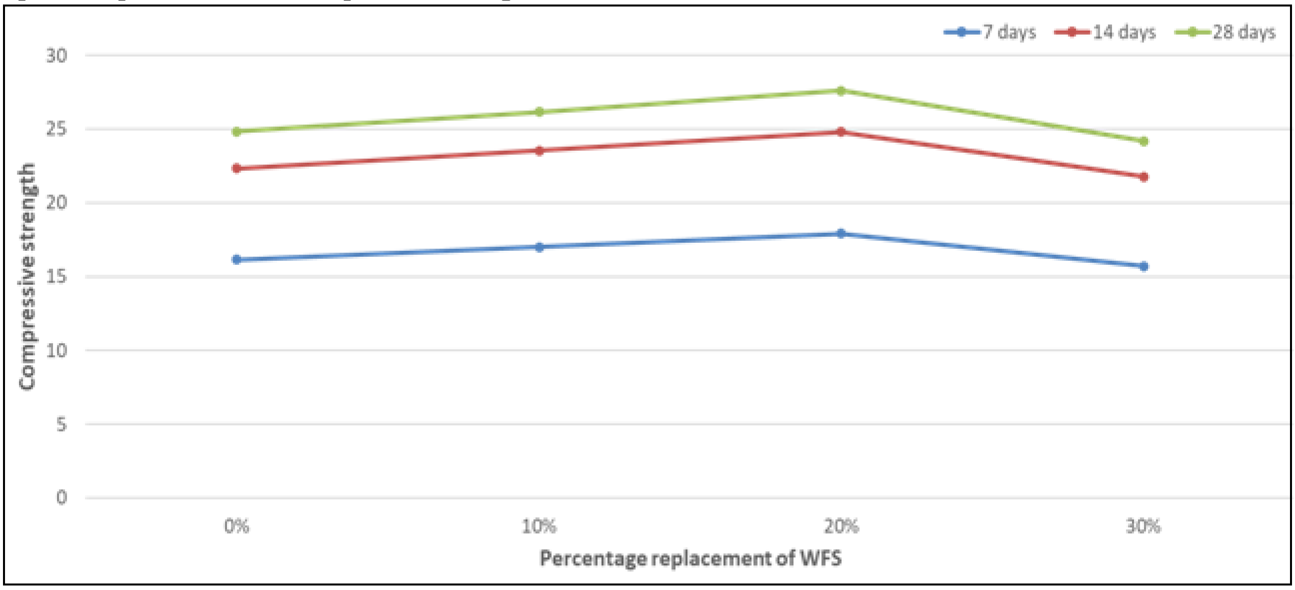
Results Obtained for Compressive strength test:

Percentage replacement of WFS	7 Days in N/mm2	14 Days in N/mm2	28 Days in N/mm2
0%	16.135	22.34	24.83
10%	17.005	23.545	26.165
20%	17.91	24.8	27.6
30%	15.71	21.755	24.18

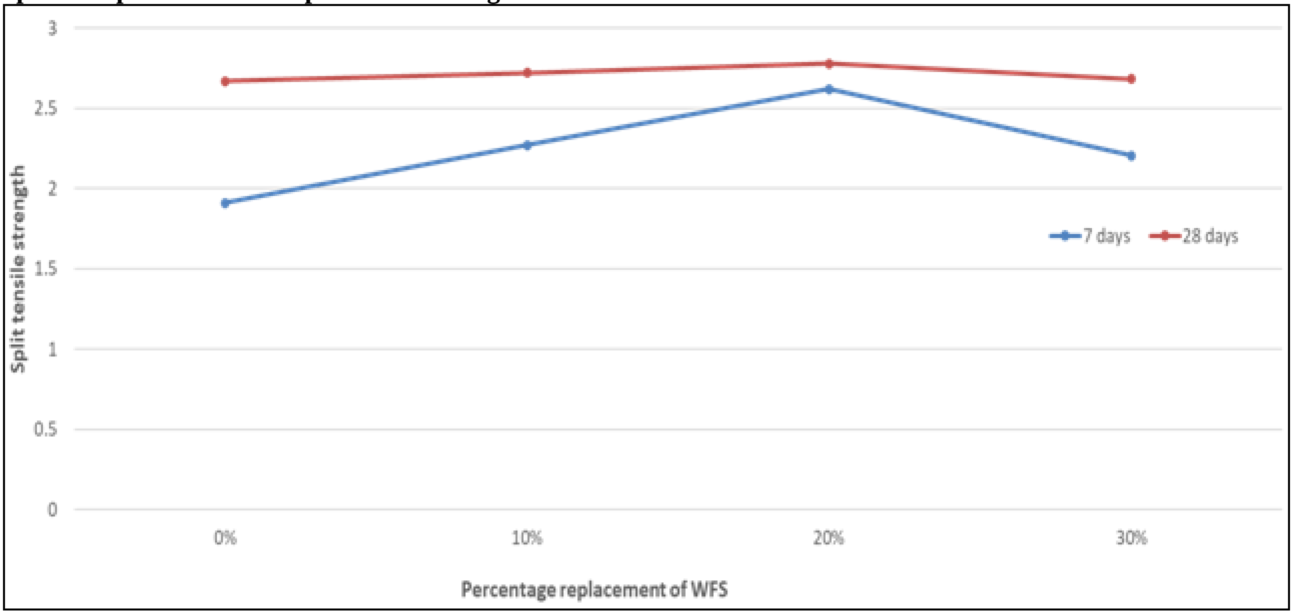
Results obtained for Split tensile strength test:

Percentage replacement of WFS	7 Days in N/mm2	28 Days in N/mm2
0%	1.91	2.67
10%	2.27	2.72
20%	2.62	2.779
30%	2.206	2.682

Graphical representation of compressive strengths:



Graphical representation of split tensile strengths:



Comparison tables:

Results (Compressive strength test):

Percentage replacement of (WFS)	Coefficient of correlation (R)	Various inflation factor (VIF)
10%	0.89	4.81
20%	0.96	12.75
30%	0.72	2.07

Results (Split tensile test):

Percentage replacement of (WFS)	Coefficient of correlation (R)	Various inflation factor (VIF)
10%	0.85	3.6
20%	0.98	25.25
30%	0.78	2.55

5. Conclusion

- As a result, we see high-level multicollinearity with a replacement factor of 20%. (WFS).
- According to our calculations, a 20% replacement rate is optimal for this building.
- This is a comprehensive study of the effectiveness of dependability techniques in evaluating sustainable concrete.

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