Research Article

International Journal of Advanced Technology and Engineering Exploration, Vol 11(114)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2023.10102334

Evaluation of quality defining attributes of reinforced cement concrete constructions using analytic hierarchy process

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Received: 27-September-2023; Revised: 09-May-2024; Accepted: 11-May-2024

Abstract

This research, which has significant implications for the quality of reinforced cement concrete (RCC) constructions, employed an analytic hierarchy process (AHP) and questionnaire surveys. The survey was validated by 10 industry experts, academics, and consultants which included demographic information as well as Likert scale-based closed-ended questions. The selection of 33 quality attributes was informed by a literature review. Following validation, a comprehensive survey was conducted via email and Google Forms, incorporating suggestions from respondents to enhance its effectiveness. The Likert scale survey gathered responses from academics, consultants, contractors, and industry experts on material and construction quality. Descriptive and inferential statistical analyses verified reliability, while the AHP analysis determined attribute weight. The study analyzed 129 responses from 380 participants, with 85 responses selected for further analysis. The mean scores for grading, particle shape, surface texture, strength, and water absorption were 8.95, 8.36, 7.34, 9.34, and 7.98, respectively. Inferential statistical analysis showed that Cronbach's alpha ranged from 0.80 to 0.95, indicating reliability and consistency in the responses. The AHP model was used to evaluate the impact of attributes like particle shape, strength, and tensile strength on RCC quality. Variations in the quality of constituent materials had a significant impact on the quality of ready-mixed concrete. These variations also affected the workability of the concrete, and experts recommended water ponding as the most effective curing method. The proposed AHP model underwent sensitivity analysis using the Pearson correlation coefficient on five data sets with varying Likert scale values. The model proved satisfactory, as indicated by a Pearson correlation coefficient of 0.8708. This investigation, with its robust methodology and comprehensive findings, provides a foundation for understanding and establishes a framework for assessing the overall quality of RCC constructions.

Keywords

Analytic hierarchy process, Pairwise comparison matrix, Quality indexing, Questionnaire survey, Reinforced cement concrete.

1.Introduction

Reinforced cement concrete (RCC) is the most extensively used construction material in construction industries. The concrete consumption rate every year is about 3 tons per person [1]. By 2050, concrete production is expected to rise by 2.5% annually to 4.4 billion tonnes [2]. The quality of RCC construction is influenced by factors like ingredient quality, production techniques, strength, durability, workability, and homogeneity.

This requires comprehensive and inclusive perception as per Indian standards (IS 456:2000). The quality of finished RCC construction is assessed through various non-destructive testing (NDT).

In contrast, the quality of constituent materials [3] is evaluated through associated destructive testing or laboratory-based investigations. A comprehensive quality assessment of RCC construction is crucial for sustainability and assessing the effect of deviations in concrete ingredients and overall quality and the associated impact on service life and sustainability [4]. Quality consideration of RCC construction can

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be divided into three categories: materials, construction, and finished or hardened state. The quality of RCC is significantly influenced by the mechanical and physiochemical properties of cement, aggregate, water, and reinforcement, which significantly impact the quality of fresh and hardened concrete [5]. The grading of coarse aggregate strongly impacts concrete strength [6] and workability [7]; well-graded aggregate preserves workability better, while poorly-graded aggregate causes bond loss and segregation. The particle shape of the aggregate promotes stronger interlocking, which strengthens and prolongs the life of the concrete. Similarly, the surface texture improves the cement paste and aggregate bond [8]. Coarse aggregate provides structural stability, while fine aggregate fills voids, provides a smooth surface, and reduces plastic shrinkage in concrete structures [9]. High-strength concrete prefers coarse aggregate with better crushing, impact, and abrasion values [10].

Cement is a crucial component in RCC, influencing structure price and grade, and selecting suitable cement is vital for optimum cost performance and sustainability. Reinforcement is embedded as bars or mesh to resist tensile stresses in RCC construction. The quality attributes of the reinforcement, such as bend and re-bend [11], tensile strength [12], and carbon content are crucially responsible for determining the overall quality of any structure. It is essential to determine the quality attributes of the materials used in RCC construction to maximise performance and safety.

Construction aspects involve supervision [13], mixing techniques, transportation, casting, curing, etc. Good workmanship consists of maintaining a proper ratio of materials, quality of constituent material, formwork alignment, proper compaction and homogeneity, and staff safety training [14]. The quality of concrete construction is also evaluated based on its hardened state, considering factors like durability, fire resistance, porosity, density, and other qualitative aspects.

The attributes of its constituent ingredients significantly influence the quality of concrete. Variations in quality attributes such as aggregate size, grading, surface textures, and mechanical properties can lead to varying compressive strengths. These properties, as outlined in IS 383-2016, directly impact the construction quality of concrete. Therefore, it is crucial to adjust these factors to ensure the best possible construction outcome.

Reinforcement bars must meet specific criteria for ultimate and yield strength [15], carbon content, elongation value [16], and tensile strength. The minimum elongation value depends on the diameter and grade of reinforcement bars, with the minimum value between 10%-20%. The tensile strength of reinforced bars should be 8% to 10% higher than yield strength, with specific values such as iron reinforcement bar Fe-500 being over 8% yield strength and 545 MPa. The carbon percentage should be between 0.25% and 0.30%, and the ultimate strength and yield strength ratio should be between 1.189 and 2.287 [17]. Indian and other standards emphasize the quality attributes of constituent materials and provide prescribed standards for each. However, to ensure holistic and effective quality control in RCC construction, there is a need for a numerical weightage system for these constituent materials.

In RCC construction, the selected quality attribute is highly significant due to its involvement, and poor quality of attributes results in low-quality construction. This relation was found relevant in various research. For instance, flaky and elongated particles have a larger specific surface area, so there is a greater need for cement paste in the cement concrete mix. These particles weaken the strength of concrete construction by preventing compaction or breaking under high loads. Nisa and Kumar (2021) [18] determined this through a comparative analysis of various aggregate shapes, such as spherical, elliptical, blade, flaky, elongated, and angular. The aggregate with the angular shape had the highest 28-day compressive strength. On the other hand, the elongated shape of aggregate achieved the least. The findings indicate that the shape of the coarse aggregate influences the strength of concrete, indicating that the shape of the aggregate should be considered when determining the suitability of coarse aggregate for concrete construction. However, other studies indicate the crucial role of aggregate crushing resistance in the mechanical properties of concrete. For instance, Góra and Piasta (2020) [19] investigated the crushing resistance of various aggregates. Notably, basalt aggregate demonstrated the highest crushing resistance (96%), followed by gravel (91%) and granite aggregate (85%). The concrete with granite aggregate exhibited poor deformation properties. However, concretes with basalt aggregate exhibit better characteristics than granite aggregate, with the highest modulus of elasticity, ultimate stress, and lowest strain at peak stress, distinguishing it from other aggregates. This emphasizes the importance of considering appropriate aggregate good quality attributes in concrete construction. Most research studies primarily focused on specified quality assessment methodology, which is somehow unable to quantify the relative importance of quality assessment criteria of RCC construction. An independent and holistic quality assessment process becomes ineffective due to quality assessment criteria being subjective and comparative approaches. Achieving and enhancing holistic quality criteria in RCC construction necessitates identifying and categorizing the essential variables affecting construction quality as it proposes a method for delivering outstanding quality control on these attributes and ensuring their best possible performance. Evaluation of quality indexing of each RCC attribute offers a numerical approach to the quality parameters, which is the most effective method of evaluating the RCC construction quality. Relative weightages of RCC construction attributes play a key role in developing a framework for numerical indexing of RCC construction and its related facilities.

This study aims to identify the most critical quality attributes in RCC construction associated with material as well as construction quality consideration. A framework for improving comprehension and establishing a correlation among the quality attributes was provided through this proposed model. Determination of quality attributes and assign them a relative weight that reflects their contribution to the overall quality of RCC construction. A questionnaire survey with the expert to identify the importance of various attributes involved in RCC construction; the closed-end survey was conducted to collect the responses, which were analysed to check the reliability of responses by descriptive as well as inferential statistical analysis after the analytic hierarchy process (AHP) model was incorporated to find the relative weightage of each identified attributes. Furthermore, consistency checks are performed to check the effectiveness of AHP model.

Literature review is explored in Section 2. Methods are discussed in Section 3. Section 4 covers the results and experimentation. Discussion of the results is presented in Section 5. Finally, conclusions are provided in Section 6.

2.Literature review

This section describes research studies on evaluating RCC construction quality employing various techniques, including experimental, analytical, and post-construction performance techniques, along with associated studies on the relative weightage of various RCC quality attributes.

Gupta et al. (2024) [20] investigated to identify and find the importance of the factors such as causing construction and demolition waste, especially in the Indian construction industry. The study used a closed-ended questionnaire to gather data from 204 respondents with experience from 1 to 43 years, focusing on building projects based on their end-use. The questionnaire was divided into two sections: general information (information about respondent details, organization, years of professional experience, work nature, building type, size, and establishment area) and causative factors (attributes rated on a five-point Likert scale). The study used principal component analysis to extract eight components with 44 attributes, and reliability tests were conducted to assess consistency and repeatability. Cronbach's alpha value was 0.970, and a Kaiser–Meyer–Olkin test value was 0.917. The significance of the factors causing construction and demolition waste was tested using a one-sample t-test. A residential building project case study in Haryana confirmed the study's findings. It was seen that there needed to be more supervision at the site, which caused a lot of construction waste. Construction and demolition waste is a significant problem in India that must be thoroughly investigated to identify its root causes and create a thorough framework for performance evaluation.

Arogundade et al. (2024) [21] surveyed 41 United Kingdom construction professionals to understand their participation in carbon minimization. The questionnaire included 16 barrier variables and a five-point Likert scale to assess respondents' views on the criticality of barriers hindering carbon reduction strategies. The survey received 48 responses, with seven removed. The statistical package for social sciences (SPSS) program examined the data using Cronbach's alpha and Shapiro-Wilk tests. Reliability was indicated by the 16 barrier variables' Cronbach's alpha value of 0.781. The respondents ranked the following five barriers as the most critical: unclear government regulations, lack of support from top management, higher construction project costs due to carbon reduction efforts, lack of cooperation between clients, consultants, and contractors, and non-involvement during the design and specification stage.

Ashtiani and Vosoughifar (2023) [22] conducted a case study to evaluate the quality of various precast concrete construction (PCC) using a proposed comprehensive framework in considering the safety and quality of PCC based on a modified building information modeling technique used to achieve the desired quality by combining the various processes to enhance building information modeling procedures. Fuzzy-based analysis was included to obtain the weight of the variables. The suggested algorithm can accurately predict the modified building information modeling index since there was a strong correlation between the computed values and the adjusted building information modeling index. According to the sensitivity study, the index of system quality has the most significant impact on the modified building information modeling index compared to other indices.

Gounder et al. (2023) [23] used a five-point Likert scale questionnaire form, including regression analysis, qualitative factor analysis, and weighted index. They examined the primary obstacles to using sustainable materials in construction projects in developed nations like Australia. In their respective fields of expertise, 109 experts have an average experience of 12.83 years. It was found that rising costs make it more challenging to use sustainable materials, that project cost overruns could occur, that government policies and incentives could be improved, and that industry resistance stems from issues with the supply chain and a lack of necessary knowledge. Stakeholders must overcome these challenges, which include reluctance to use more environmentally friendly materials in future projects, concerns about money and time, and technological issues. The report highlights the necessity of actively guiding the industry towards sustainable building materials through legislative changes, incentives, government action, and training and education. The study was limited, though, in that it only included data from Australian construction professionals; it needed to consider the opinions of other important stakeholders, and different types of construction projects may have distinct obstacles in terms of priority.

Bhyan et al. (2023) [24] used a pairwise comparison scale to collect questionnaire responses and employed additional AHP to rate the responses. At each phase of the building life cycle, stakeholder agreement was evaluated for reliability using Kendall's coefficient of concordance. At 95% confidence, each of the ten values was statistically significant. The research prioritised environmental factors like water, energy, and site planning while analysing the weighting of the housing-specific green building rating system criteria. The five preconstruction stage factors are site selection, housing costs, material selection, design consideration, and innovation. Site preparation, energy efficiency, water conservation, waste management, and construction quality management were all included in the building stage. The standards for residual material management, service quality and maintenance, and performance quality assessment were all included in the operating stage. The project aims to create a web-based system for evaluating the sustainability of high-rise group housing developments in India so that academics, researchers, and local governments can make well-informed choices.

Daoud et al. (2023) [25] conducted a survey using a 5-point Likert scale to evaluate Egypt's current situation of construction and demolition waste. The questionnaire includes demographic information, green building techniques, models for the procurement of building materials, the efficacy of Egyptian legislation, awareness-raising and cultural initiatives, and the projected enhancement of multiple project aspects via waste minimization, which were all covered in the survey. The survey also evaluated the effectiveness of awareness and behaviour initiatives in Egypt. A pilot study assessed the survey questionnaire's comprehensiveness, clarity, and feasibility with 30 participants, including 15 industry professionals and 15 academics with over ten years of experience. Additionally, statistical methods for inference and description were applied to the survey data to generate graphical and numerical representations of the collected data. The research indicates that purchasing correct materials was the most applied factor while reducing material use through prefabricated elements and durable materials was the most effective.

Al-atesh et al. (2023) [26] introduced general building material criteria for materials selection in Malaysia to improve the quality and execution of large-scale building projects. Twenty-nine criteria were identified from literature and interviews with experts. Responses were analysed using the AHP pairwise comparison method to determine criterion weight, with consistency checks for each level. A hybrid multi-criteria decision-making process can resolve competing general building material criteria on an environmental, economic, and social sustainability basis. The pairwise comparison matrix of the expert's opinions was used to determine the weight of the environmental criterion. The environmental criterion with the highest weight, 0.5579, was waste management. Water consumption was ranked third with a weight of 0.1104, and potential for recycling and reuse was ranked second with a weight of 0.3317. Among the economic criteria, operation and maintenance costs were given the highest weight (0.4860). Material life expectancy was ranked third with a weight of 0.2524 and second with a weight of 0.2617, respectively, indicating that stakeholder needs were met. Among the social criteria, health and safety were given the highest weight (0.6137). Next were the labour availability (0.2275) and the utilisation of locally produced materials (0.1588). Eight experts created a model of decision-making to assess the primary categories, criteria, and substitute materials.

Mahadik and Topkar (2023) [27] developed a master list of the criteria and sub-criteria that will be used to evaluate the performance of contractors. A structured, closed-ended, multiple-choice questionnaire survey approach was employed in an exploratory study. Two stages of the survey were carried out: validation and reliability. A questionnaire was sent to 100 experts, with 30 responding. 80% had 10-30 years of experience, while 7% had over 30 years. 50% had road construction experience, while the remaining had experience in industrial projects, bridges, and buildings. The responses were analysed using SPSS software. The Cronbach's alpha value of 0.925 indicates high internal consistency in the questionnaire's data set. The requirements were arranged in ranking order, the relative importance of each criterion was determined using the relative importance index, and the weights of the criteria and sub-criteria were determined using the information gathered. The most crucial factor was client satisfaction, with health and safety coming in second. It also describes the relative weights given to the various criteria and sub-criteria used to assess contractor performance throughout the project execution stage.

Abdelkhalek and Zayed (2023) [28] The performance assessment model was created to assess the efficacy of NDT techniques during concrete bridge deck inspection. Forty parameters comprise the model, organised as criteria, sub-criteria, and parameters. Data were gathered via a survey questionnaire, and importance weights were calculated using the analytic network process technique. A questionnaire survey was conducted among 24 respondents from government organizations, consultants, and academicians, with most having 10-20 years of experience. It was discovered that capability, data collection speed, and confidence in delamination detection results were the most critical factors for implementing NDT technologies in inspection processes. Next were inspection cost and speed. The inspection process's use of NDT technologies was evaluated based on performance scores. The camera came in top regarding cost, speed, and ease of use. On the other hand, impact echo and ground-penetrating radar were the most effective and capable in various environments. infrared thermography was the top performer in the total performance index. A sensitivity analysis was conducted to ascertain how the ranking of NDT technologies would change if the relevance weights of the proposed factors were changed. The objective of the model's development was to make choosing the best technologies for inspection easier. The small sample size (24 replies) and the use of a survey questionnaire for data collection, however, were found to be the study's two primary drawbacks. Other techniques, including field and laboratory testing, should be employed in future studies to address greater trust in the assessment findings.

Mishra et al. (2023) [29] examined to evaluate Nepal's acceptance of ready-mix concrete (RMC) for residential construction. The relationship between average compressive strength, slump value, and water-cement ratio was established based on nominal mixes from laboratory tests and a questionnaire survey. The outcome indicates that RMC has a higher compressive strength than site mix concrete. Five individuals were asked to respond to the 23 questions on the questionnaire form, which came from each of the chosen sites. The RMC was favoured over the site mix concrete by over 60% of users who answered the questionnaire. Price, however, was probably the biggest obstacle to RMC adoption in the market, according to the experts consulted. However, a detailed statistical analysis still needs to be done in response to the survey conducted through questionnaires.

Li et al. (2022) [30] performed questionnaire surveys to study the quality of canal lining construction. Fifteen experts with five to twenty-five years of experience in construction, supervision, evaluation agencies, research, and academia scored the evaluation indicators, and subjective weights were assigned based on expert opinions. Human (40.56%), mechanical (19.47%), material (24.61%), method (9.79%), and environmental difficulties (5.57%) were the factors that affected the quality. The construction and quality inspection units were the next to report the most issues during construction supervision, after the supervision unit. To identify the main factors that affect the quality of the concrete lining of the canal, such as soil loss, the timing of the slab cut joints, the depth of the cutting slab, and insufficient joint filling, and the fuzzy attribute hierarchical model approach was applied to 172 water-conserving projects in China. These factors can be improved technically, and the construction and management processes should center around them. The fuzzy attribute hierarchical model technique was a new decision-making method that relies on experts' in-depth knowledge rather than eigenvector calculations or consistency checks.

Bonney et al. (2022) [31] studied consumer preferences for cement brands in four major cities. Respondents, including homeowners and construction companies, had significant preferences for the cement brands available. Preferences were influenced by brand name, dependability, style, appealing packaging, accessibility in nearby stores, and recommendations from outside sources. The choice of cement brand was also highly influenced by demographic factors like age, gender, length of cement consumption, and educational attainment. The study showed good internal consistency and dependability, with a Cronbach's alpha of 0.948. This implies that consumers prefer certain brands because of their demographics and other influencing factors. It also means marketers and manufacturers can use these elements to differentiate their products from the competition.

Badraddin et al. (2022) [32] studied to identify and categorize critical attributes for successful concrete recycling. After reviewing the literature and interviewing 15 industry experts, 89 experts with 6-30 years of experience participated in a questionnaire survey. The results showed that out of 12 factors, 10 critical success factors were identified, including internal factors like construction waste management plans, effective marketing strategies, and stakeholder awareness, as well as external factors like favourable legislation and government policy support. The survey's reliability was confirmed by a Cronbach's alpha value of 0.846. This study offers a better understanding of the factors affecting concrete recycling.

Tushar et al. (2022) [33] The study used expert feedback and a literature review to identify supplier selection criteria. Ten industry experts were selected based on a bachelor's degree, field experience, building and construction materials, operations, project management, and sustainability expertise. Global weight was determined using the fuzzy-analytic hierarchy process and Buckley's methods. It ranked circular suppliers and classified them by focusing on delivery on time, meeting specifications, rejection rate, corporate reputation, and delivery reliability. On-time delivery was ranked as the most crucial factor, with a global weight of 0.148. The best supplier was identified as supplier 4, and the worst supplier was identified as supplier 2. However, the study has limitations as the final ranking and selection criteria were based on the subjective opinions of industry experts.

Zoghi et al. (2022) [34] developed a multi-criteria decision-making model using Kano and a fuzzy-analytic hierarchy process to assist designers in selecting materials for separation and reuse as the construction industry increasingly focuses on deconstruction as an alternative to demolition. The Kano model was used to classify and rank identified essential criteria based on one-dimensional and attractive groups. Five types of walls were ranked using a fuzzy AHP: precast gypsum board, poured concrete, brick, precast wood sections, and vinyl plastic. Precast gypsum board was the best option for wall construction based on its easy disassembly and recyclability. Precast wood's accuracy and recyclability make it a popular choice for interior walls. Because vinyl plastic panels can't be recycled or reused, they have a moderate rating. Despite their popularity, brick walls require demolition because they are challenging to separate during maintenance or disassembly. Because they are not flexible, concrete blocks are inappropriate for post-demolition recovery or maintenance. This framework could be used with information and communication technologies to automatically choose the best building materials.

Yildiz and Ahi (2022) [35] explored supply chain decision-making problems in the construction industry, particularly emphasizing performance monitoring, assessment, and decision-making procedures. A novel and inventive decision support model was a compelling case study for a real-world example in the construction sector. The study compared critical supply chain operations to those in other industries using an analytical network process and decision-making laboratory model. The findings indicated that the three main variables affecting supply chain performance were cash-to-cash cycle time, return on working capital, and flawless order fulfillment. The study advised future research using this methodology on various corporate data sets to provide a thorough comparison and enhancement.

Chai and Wang (2022) [36] proposed a computer vision-based model methodology to achieve intelligent evaluation, eliminate subjectivity and discrepancies, and increase inspectors' inspection efficiency. It has helped shorten inspection times, lower human resources demand, and encourage using artificial intelligence in construction. They interviewed experts to evaluate the proposed model and decision-making framework in building and structural engineering. Although this model uses a construction database, it should be expanded to ensure the efficiency of the suggested model.

Hussain et al. (2019) [37] examined the connection between client satisfaction and construction quality using a questionnaire survey of industry professionals and various statistical tools, such as Cronbach's alpha, combined reliability rating, variance, and a partial least squares structural equation modeling technique. Four factors govern the quality of construction: material, construction, stakeholder, and design.

ElMousalami (2019) [38] proposed that the fuzzy summation model was the most effective quality indexing of preconstruction project planning. Delphi technique was incorporated in a questionnaire survey with the AHP to produce a list of factors influencing preconstruction project planning and obtain the weightage of factors in the model. It was concluded that the fuzzy model reduces ambiguity and offers a comprehensive approach to provide accurate results.

Jacobs (2018) [39] investigated separately and in-situ prepared specimens for density, compressive strength, chloride migration coefficient, freeze-thaw resistance, and carbonation coefficient. Twenty-eight days of compressive strength and density of the concrete core were typically 20% and 1-2% lower than separately manufactured concrete specimens, even though chloride migration generally was 50% higher than specimens made independently.

Jain and Bhattacharjee (2012) [40] adopted a questionnaire survey and fuzzy model to propose a numerical formula for the structural condition index (SCI), as shown in Equation 1. To save time, money, and effort, condition indices may also be helpful as a foundation for accelerating the evaluation, which can offer more precise information about the health of the structural elements.

$$\mathrm{SCI} = \frac{\sum_{j=1}^{n} w_j CI_j}{\sum_{j=1}^{n} w_j} \quad (1)$$

Where
CI_j = condition index,
w_j = weight factor,
j = number of deteriorating elements.

Minchin and Smith (2005) [41] developed a performance rating system based on the quality model to rate the performance of contractors using questionnaire surveys. It was based on aspects of project performance and contractor characteristics. Project employees, schedule commitment, equipment and facilities, contractor company, and project management/control were among the many factors combined to evaluate the project's performance and enhance the quality monitoring system.

Song et al. (2004) [42] examined the quality of ongoing construction through the causes of quality problems into work error, design error, defective material, and damage on site, mainly focused on two aspects, i.e., quality cost indicators and quality status indicators. Construction quality improves, and the construction industry becomes more competitive when quality-related indicators are used to track performance.

Bubshait (2001) [43] proposed a pavement performance index through a questionnaire survey to evaluate the various attributes and their relative importance. The performance of the pavement index can be categorized based on three aspects, i.e., managerial-related aspects, design and specifications-related parameters, and construction-related factors. Index characterizations help improve pavement performance as well as help optimize cost.

Rad and Khosrowshahi (1998) [44] conducted a research investigation using a questionnaire survey to rank the attributes of building structure on a scale of 1 to 5 using weighted average normalization through a forward feeding model. Suggested an approach to measure the quality of a building structure from three different perspectives, viz, client, constructor, and third party, and found quality ratings of 39%, 35%, and 26%, respectively.

The literature on the various models to determine quality in RCC concrete construction, such as fuzzy model, various inferential statistical methods, descriptive statistical methods, quality rating models, and analytic hierarchal process with questionnaire survey to determine and rate of parameters involved in multiple types of construction such as building construction, pavement construction, bridge construction, canal construction, etc. From the literature review, it is inferred that most research studies have attempted to identify the most effective approaches to ensure overall high-quality construction and various types of factors that both directly and indirectly affect construction quality. More research is needed to identify and rank the factors that significantly affect RCC construction and create models related to quality.

2.1Introduction of questionnaire survey

A questionnaire survey is a research method used to collect information from a respondent, and it contains a set of queries related to a particular aspect of the investigation. It includes many questions, including open-ended and closed-ended, dichotomous, multiple-choice, scaling, pictorial, etc.

Closed-ended questions are responses such as yes/no, multiple choice, or scaled questions restricted to a predetermined set of options. Examples include the Likert scale and semantic differential scale. Scales use an ongoing process to grade responses, such as the performance of a product. These types of questions are commonly used in research.

In open-ended questions, the respondents can answer in their own words without adhering to predetermined categories. Respondents can fill in blank conversations, finish sentence fragments, and voice their opinions on these questions. Most information or data is collected quickly via questionnaire surveys. Personal interviews, telephonic interviews, mail questions, and internet questions are surveying methods. Face-to-face interviews have high response rates and can be in-person, while telephonic interviews are conducted from a central office. Telephonic surveys have a reasonable response rate, fast response, and control over respondent selection. Mail questions have a reasonable response rate, are easy to obtain, and can cover a wider geographical area. Internet questions are fast, customizable, and can be accessed through email. However, they may need to be more confidential, have better control over the respondent selection, and have difficulty obtaining probability samples.

A pilot survey is a preliminary phase of research conducted before a comprehensive study to evaluate the effectiveness of the research methodology.

2.2Introduction of analytic hierarchy process (AHP)

The subjective nature of the multi-decision view makes it extremely challenging to select the ideal opinion. Saaty developed the AHP from 1971 to 1975 at the Wharton School, one of the most valuable techniques for prioritizing many choice factors to control the subjective approach [45]. The AHP measurement theory derives ratio scales from discrete and continuous paired comparisons. The AHP is a problem-solving technique that requires a hierarchical or network structure and pairwise comparisons to establish relations within it. These comparisons produce kernels of Fredholm operators in the continuous case and dominance matrices in the discrete case, from which ratio scales are obtained as principal eigenvectors or eigenfunctions, depending on the circumstances. These sets are composed of positive and reciprocal matrices, e.g., amn = l/amn. The AHP is a numerical method that uses pairwise comparisons to identify the best and worst course of action, focusing on departure from consistency, measurement, and dependence within and between its structure. The AHP technique ranks multiple decision opinions based on their potency and significance, assigning relative weightage. It aids in selecting a course of action among complex views and provides an analytical method to evaluate the potency and coherence of multi-criteria opinions. The AHP is frequently used in planning, resource allocation, multi-criteria decision-making, and conflict resolution. It is a nonlinear framework that allows for dependence and feedback, considers several variables simultaneously, and supports deductive and inductive reasoning without using syllogisms.

In this study, AHP can be used to model concrete quality parameters such as material and construction process and attribute to a hardened state. AHP facilitates generating the relative weighting and ranking of the expert responses collected through a pairwise comparison matrix in the form below:

$$
\begin{matrix}
a_{11}a_{12}a_{13} \ldots a_{1n} \\
a_{21}a_{22}a_{23} \ldots a_{2n} \\
a_{31}a_{32}a_{33} \ldots a_{3n} \\
a_{41}a_{42}a_{43} \ldots a_{4n} \\
\vdots
\end{matrix}
$$

$\vdots$

$a_{m1} a_{m2} a_{m3} \cdots a_{mn}$

Where 'm' represents alternative and 'n' represent criteria. In the pairwise matrix given above, the element a_(n×m) is the reciprocal value of the component a_(m×n).

This study aims to determine the quality attributes of RCC constructions with their relative weightage through a questionnaire survey along with AHP. These relative weights were beneficial in understanding the importance of different RCC construction quality attributes. A questionnaire survey was used to gather responses from experts. Subsequently, the coherence of the gathered Likert scale responses was examined to ascertain the accuracy of the survey results. Additionally, consistency assessments were incorporated to ensure the reliability of pairwise comparison matrices, which were generated by transforming Likert scale responses. The AHP model was incorporated into pairwise comparison matrices to assess the relative weightages of attributes. These relative weightages indicate the degree of involvement of corresponding attributes in RCC construction. Additionally, it shows how much its associated attributes impact RCC construction. Furthermore, it provides a fundamental structure for developing a model that accesses and enhances the overall quality of RCC structures and construction facilities by employing associate attributes.

3.Methodology

3.1Identification of quality attributes

Quality assessment of a constructed facility involves linguistic attributes. Quality expressed through linguistic terms leads to generalization rather than uniqueness. It was envisaged that the quality of RCC constructions, when expressed numerically through a numerical quality index, would lead to improved quality assessment and comparison of projects on a uniform quality scale. The questionnaire survey aims to collect and provide expert opinions regarding the quality of RCC and the associated construction process while considering the specified quality features. The quality aspects, including material composition, construction process, product characterization, and quality assurance on site, have been included in the questionnaire survey based on a thorough literature review. The responses to a questionnaire survey with experts in the relevant area of specialization were compiled using a Likert scale, which was transformed into a pairwise scale [46]. Following this conversion, the AHP was used to determine the relative weighting of the quality attribute of RCC constructions. Additionally, consistency tests were carried out to validate impartial judgments. The flow chart of the research investigation is shown in *Figure 1*.

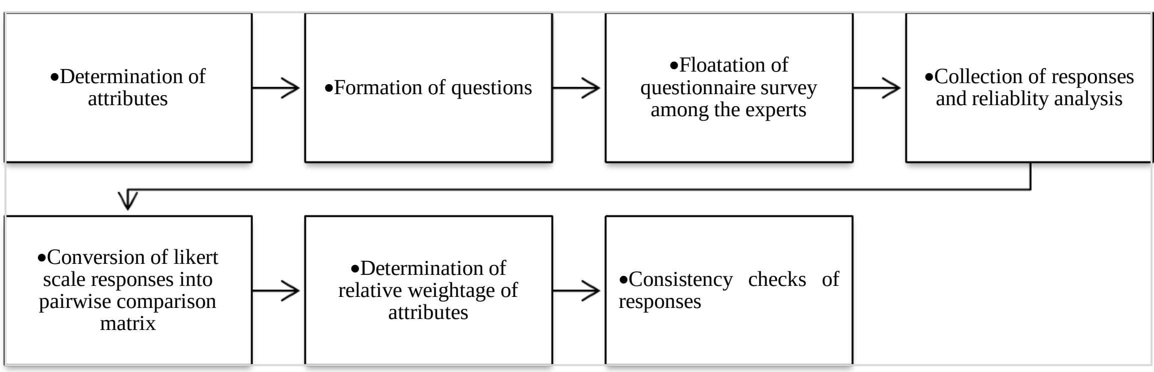

Figure 1 Flow chart of research investigation

3.2Responses through questionnaire survey

This questionnaire was essential because it aimed to determine how much weight was given to each attribute. The comprehensive yet straightforward questionnaire design aims to validate the contextualized aspects by experts. Closed-ended multiple-choice questions make up the structure of the questionnaire, and there was space for respondents to add more information if needed. The 33 attributes of the various aspects involved in RCC construction were included in the final questionnaire. The questionnaire consists of two parts:

Part 1: Compile data regarding respondent details, professional background, experience, qualification, organisation details, project type, membership in professional associations, etc.

Part 2: Consists of the characteristics of different aspects. The qualities need to be ranked on a Likert scale from 1 to 10, with 1 being the least significant and 10 being the most important, according to their importance in RCC construction.
There are two stages to the questionnaire survey: a pilot run and a full-scale survey.

Pilot run

Testing the questionnaire format before a full-scale study is essential to ensure sufficient instructions, precise wording, and appropriate order. This aids in implementing the necessary adjustments before the comprehensive research. Usually, a small group of people participate in a pilot study, and the questionnaire is modified in response to their input. This procedure guarantees a transparent and efficient study by ensuring participants can easily understand and complete the questionnaire. A pilot study of 10 respondents from industrial experts, academics, and consultants was conducted. Based on the feedback from the validation survey, which revealed no errors, confusion, or ambiguity in the questions, the questionnaire was considered validated. The respondents suggested reducing the question length and adding a question about a widely used curing technique.

Full-scale survey

After validating the questionnaire form, 380 experts, comprising academicians, consultants, contractors, and industry specialists with experience in their relevant area of specialization, were chosen for the questionnaire survey, as shown in *Table 1*. The qualifications of the experts involved in the questionnaire survey were nineteen post-graduates, seven Ph.D. holders, and fifty-nine graduates. The questionnaire survey was conducted via Google Forms and emails.

Table 1 Demographic details of experts

Year of experience	Work experience	Area of expertise			
		Industrial expert	Contractors	Academicians	Consultants
1-5 years	16	15	0	0	1
5-10 years	29	27	1	0	1
10-15 years	14	11	2	0	1
15-20 years	17	11	4	1	1
20-30 years	7	0	4	3	0
More than 30 years	2	1	0	1	0
Total	85	65	11	5	4

Out of the 129 responses collected, 85 were chosen, and the remaining responses were rejected according to the literature review, incomplete and unacceptable responses, and codes of practice provisions. The details of collected responses from various experts are shown in *Figure 2*. These responses were utilized to generate a weighted average of each considered attribute, which was then used to determine relative weightage using AHP.

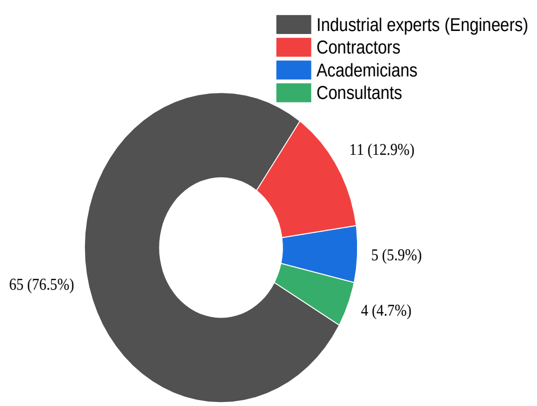

Figure 2 Distribution of responses

3.3 Formation of the questionnaire

The questionnaire was based on Likert scale, dichotomous, and multiple-choice questions. Among these, the responses based on the Likert scale were selected for detailed analysis. The Likert scale (1 to 10 scale) questions are listed in *Table 2* and *Table 3*. These queries were widely related to experts' perceptions of the strength, workability, and reinforcement properties of RCC constructions.

As discussed in *Table 2*, The various conditions of material quality considerations that were taken into account when determining the quality of RCC constructions for further study were (1) The relative importance of aggregate properties that influence the overall quality of coarse aggregate, (2) The relative importance of coarse aggregate properties influencing the workability of concrete and (3) The relative importance of reinforcement properties and a parameter that influences the overall quality of the RCC.

As listed in *Table 3*, the different conditions for defining the construction quality parameters were (1) the ease of attainment of specific RCC construction requirements that have an impact on the overall quality of RCC constructions, (2) the quality of concrete considered through variation from batch to batch in RMC, (3) the various methods to enhance the workability of concrete in RCC constructions and (4) the five curing methods that were most frequently used in RCC constructions.

Table 2 List of questions on the Likert scale related to material attributes of RCC constructions

S. No.	Material quality considerations (Likert scale)		
	Conditions	**Attributes**	**References**
1.	The overall quality of coarse aggregate	• Grading	Zheng et al. (2023) [6]
		• Particle shape (elongated & flakiness)	Deng et al. (2023) [8]
		• Surface texture	Deng et al. (2023) [8]
		• Strength (crushing, impact, abrasion)	Oikonomopoulou et al. (2022) [10]
		• Water absorption	Oikonomopoulou et al., (2022) [10]
2.	Workability of concrete	• Grading	Mkpaidem et al. (2022) [7]
		• Particle shape (Elongated & Flakiness)	Haach et al. (2011) [47]
		• Surface texture	Haach et al. (2011) [47]
		• Maximum size	Hou et al. (2024) [48]
		• Water absorption	Sun et al. (2022) [49]
3.	Reinforcement properties	• Performance in bend re-bend test	Bame et al. (2023) [11]
		• Tensile strength	Butt et al. (2023) [12]
		• Ratio f_u/f_y (f_u: ultimate strength, f_y: yield strength)	Achamyeleh et al. (2022) [15]
		• Elongation after fracture	Zhang et al. (2023) [16]
		• Carbon equivalent	Tavio et al. (2018) [17]

Table 3 List of questions on the Likert scale related to construction quality considerations of RCC constructions

S. No.	Construction quality considerations (Likert scale)		
	Conditions	**Attributes**	**References**
		• Attaining avoidance of plastic shrinkage.	Liu et al. (2023) [9]
1.	Ease of attainment	• Attaining stability and homogeneity.	Tutu et al. (2022) [14]
		• Attaining avoidance of honeycombing.	Tutu et al. (2022) [14]
		• Attaining workability at the site.	Tutu et al. (2022) [14]
		• Attainment of target strength at the laboratory.	Mishra et al. (2023) [29]
		• Attainment of compliance strength at site.	Mishra et al. (2023) [29]
2.	Quality of RMC	• Variation in the quality of constituent materials.	Trinugroho and Ningrum (2021) [3]
		• Variation in the mix proportion due to batching.	Trinugroho and Ningrum (2021) [3]
		• The quality of supervision & workmanship	Alaa et al. (2019) [13]
		• Variation in mixing equipment.	Minchin and Smith (2005) [41]
		• Variations due to sampling & testing of concrete specimens.	Li et al. (2018) [50]
3.	Methods of workability attainment	• Improving grading of coarse aggregates.	Zheng et al. (2023)[6]
		• Improving combined flakiness-elongation index	Nisa and Kumar (2021) [18]
		• Increasing water content,	Haach et al. (2011) [47]
		• Improving grading of fine aggregates.	Haach et al. (2011) [47]
		• Reducing the fine aggregate content.	Haach et al. (2011) [47]
		• Using workability-aiding admixtures.	Hou et al. (2024) [48]
4.	Curing methods	• Water ponding,	Bashandy (2016) [51]
		• Chemical curing	Bashandy (2016) [51]
		• Water-proof cover,	Bashandy (2016)[51]
		• Water-saturated cover,	Smyl et al. (2016) [52]
		• Fog spray,	Yang et al. (2018) [53]

3.4 Analysis of questionnaire responses

The gathered questionnaire responses were needed to calculate statistical parameters, including mean, median, standard deviation, variance, range, minimum value, and maximum value in SPSS software and perform reliability analyses like Cronbach's alpha. A reliability measure known as Cronbach's alpha value contrasts the total variance and the shared variance among the variables in a survey. It is used to characterize the dependability of raters and multiitem scales, especially when noncategorical data is involved. The inter-rater reliability alpha is determined by the number of items and the strength of inter-item correlations, which separate information into common phenomena and distinctive characteristics of each data source. The final score of an item measuring emotionality is a combination of the respondent's actual emotionality level and any unintentional features. Typically, the Cronbach's alpha reliability coefficient falls between 0 and 1. A group of scale elements with a high alpha value is more reliable and internally consistent than other scale factors. All variables can be considered consistent if Cronbach's alpha exceeds 0.6. As can be seen in *Table 4*, the analysis shows that Cronbach's alpha ranges from 0.80 to 0.95, showing that the responses were reliable and consistent. Descriptive statistical analysis, such as standard deviation, mean, median, variance, range, minimum, and maximum, was performed on the responses related to the overall aggregate quality, as shown in *Table 5*. The mean of the gathered responses for grading, particle shape [elongated & flakiness], surface texture, strength [crushing, impact, abrasion], and water absorption were 8.95, 8.36, 7.34, 9.34, and 7.98, respectively.

Table 4 Cronbach's alpha value of "quality considerations" responses on a Likert scale

S. No.	Quality considerations (Likert scale)	Cronbach's alpha	Number of attributes
1.	The overall quality of coarse aggregate	0.896	5
2.	Workability of concrete	0.888	5
3.	Reinforcement properties	0.868	5
4.	Ease of attainment	0.826	6
5.	Quality of RMC	0.863	5
6.	Methods of workability attainment	0.906	6
7.	Curing methods	0.885	5

Table 5 Descriptive statistical analysis of the "overall quality of coarse aggregate " responses on a Likert scale

Descriptive statistical analysis	Grading	Particle shape [elongated & flakiness]	Surface texture	Strength [crushing, impact, abrasion]	Water absorption
Mean	8.94	8.36	7.34	9.34	7.98
Median	9.00	8.00	7.00	9.00	8.00
Standard deviation	0.885	0.784	0.907	0.749	0.873
Variance	0.783	0.615	0.823	0.561	0.761
Range	5	5	7	4	6
Minimum	5	5	2	6	4
Maximum	10	10	9	10	10

3.5 Conversion of Likert scale to pairwise comparison matrix

The weighted average of expert responses on a 1 to 10 Likert scale and the relative importance of the attribute of coarse aggregates influencing the overall properties of coarse aggregate were listed in *Table 6*. The tabulated responses were used to construct a square matrix, and the elements of the square matrix were generated by using Equation 2.

$$a_{ij} = Sc_{ik} - Sc_{jk} \quad (2)$$

Where a_{ij}: is the matrix element with i^{th} column and j^{th} row, Sc_{ik}= descriptor i for individual k, and Sc_{jk}= descriptor j for individual k, obtained by successive subtraction of the weighted average of responses.

Table 6 Weighted average of responses in Likert scale (1-10)

S. No.	Attribute	The arithmetic mean of response
1	Grading	8.941
2	Particle shape [elongated & flakiness]	8.365
3	Surface texture	7.341
4	Strength [crushing, impact, abrasion]	9.345
5	Water absorption	7.976

The matrix elements, i.e., a_{ij} had positive and negative values.
To fix the range between the 1 and 9 scales, as used in the pairwise comparison scale, the positive values of the matrix elements (a_{ij}) were regenerated by adding 1, as shown in Equation 3.

$$A_{ij} = a_{ij} + 1 \quad (3)$$

Also, the negative values of elements of the matrix (a_{ij}), were replaced by the reciprocal of the transposed value of individual elements having positive values, as in Equation 4.

$$A_{ij} = \frac{1}{A_{ij}^{T}} \quad (4)$$

The generated square matrix element (A_{ij}) with i^{th} column and j^{th} row of responses in pairwise comparison scale converted from Likert scale responses using Equations 2, 3 and 4 as shown in *Table 7*, which was further used to perform the AHP analysis to calculate the relative weightage of attributes and perform the consistency check of the model.

Table 7 Pairwise comparison responses matrix

Attributes	**Grading**	**Particle shape [elongated & flakiness]**	**Surface texture**	**Strength [crushing, impact, abrasion]**	**Water absorption**
Grading	1	1.576	2.600	0.712	1.965
Particle shape [elongated & flakiness]	0.634	1	2.024	0.505	1.388
Surface texture	0.385	0.494	1	0.333	0.612
Strength [crushing, impact, abrasion]	1.404	1.981	3.004	1	2.369
Water absorption	0.509	0.720	1.635	0.422	1
Summation ∑ (aij)	3.932	5.772	10.263	2.972	7.333

The summation of each matrix column with the element 'A_{ij}' was calculated [$\sum (A_{ij})$], and used to generate the matrix of individual weightage of each attribute (W_{mj}) shown in *Table 8*. Equation 5 was used to determine the W_{mj}.

$$W_{mj} = \frac{A_{mj}}{\sum_{j=1}^{n} A_{mj}} \quad (5)$$

Where
W = Individual weightage of attributes
m = Number of columns of matrix
j & n = Number of rows of matrix
The calculated relative weightage (c_i) of responses as displayed in *Table 8*. After determining the relative weightage of an attribute, the consistency checks were performed using the AHP model.

Table 8 Matrix of individual weightage of attributes along with relative weightage

Attributes	**Grading**	**Particle shape (Elongated & Flakiness)**	**Surface texture**	**Strength (crushing, impact, abrasion)**	**Water absorption**	**Relative Weightage**
Grading	0.254	0.273	0.253	0.240	0.268	0.258
Particle shape (Elongated & Flakiness)	0.161	0.173	0.197	0.170	0.189	0.178
Surface texture	0.098	0.086	0.097	0.112	0.083	0.095
Strength (crushing, impact, abrasion)	0.357	0.343	0.293	0.336	0.323	0.330
Water absorption	0.129	0.125	0.159	0.142	0.136	0.138

As shown by Equation 6, the consistency checks were carried out by calculating the consistency index (CI).

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (6)$$

Where n: the order of the matrix λ_{max} is the principal eigenvalue, calculated as given in Equation 7.

$$\lambda_{max} = \sum_{i=1}^{m} \frac{w_p / c_i}{m} \quad (7)$$

In *Table 5*, the weighted sum values of the individual attributes of the matrix elements in each row (p = 1, 2, 3, … n) are represented by wp, which was determined by Equation 8.

$$w_p = \sum_{j=1}^{n}(c_i \times A_{ij}) \quad (8)$$

Where the arithmetic average of the individual weightage of each matrix (*W*), as determined in Equation 9, equals the relative weightage of the same row in the matrix (c_i).

$$c_i = \frac{\sum_{i=1}^{m} W_{in}}{\mathrm{m}} \quad (9)$$

The random index (RI) was determined by T.L. Saaty (1980) [54]. Constant based on the matrix size (i.e., the number of criteria or alternatives being compared) and also called the Saaty RI [55], shown in *Table 9*. These values are used as a reference to assess the consistency of the decision-makers for pairwise comparison judgments.

Table 9 RI proposed by Saaty

Order of matrix	**RI**
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

The consistency ratio (CR), as given in Equation 10, is used to check the responses' reliability and should be less than or equal to 0.10; it is a measurement that shows how far responses may vary from consistency. *Table 10* indicates the ratio of weighted sum (w_p) and relative weightage (c_i), which was used in determining the CI and CR as shown in Equations 10 and 11, respectively.

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \quad (10)$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (11)$$

Table 11 lists the CR of responses to quality attributes for material and construction quality consideration for several attributes, as described in *Tables 1* and *2*. Since the CR values for each attribute were less than 10%, each attribute's relative weightage was reliable and consistent.

Table 10 Matrix of weighted sum value and relative weightage

Attributes	**Product of relative weightage & A_{ij}**					**Weighted sum value (w_p)**	**Relative weightage (c_i)**	$\frac{w_p}{c_i}$
Grading	0.258	0.281	0.248	0.235	0.272	1.294	0.258	5.020
Particle shape [Elongated & Flakiness]	0.163	0.178	0.193	0.167	0.192	0.893	0.178	5.014
Surface texture	0.099	0.088	0.095	0.110	0.085	0.477	0.095	5.008
Strength [crushing, impact, abrasion]	0.362	0.353	0.286	0.330	0.328	1.659	0.330	5.020
Water absorption	0.131	0.128	0.156	0.140	0.138	0.693	0.138	5.009
λ_{max}(Mean of $\frac{w_p}{c_i}$)								5.014

Table 11 Consistency ratio of various quality considerations

	Material quality consideration			**Construction quality consideration**			
Parameters	**The overall quality of coarse aggregate**	**Workability of concrete**	**Reinforcement properties**	**Ease of attainment**	**Quality of concrete in RMC**	**Methods of workability of concrete**	**Curing methods**
Consistency Ratio (CR, %)	0.317	0.139	0.247	0.118	0.162	1.098	0.512

3.6 Sensitivity analysis was carried out on the proposed AHP model

The sensitivity analysis was performed on the proposed AHP model using the Pearson correlation coefficient formula, as shown in Equation 12, to analyse the linear relationship between different Likert scale values and their corresponding relative weightages of selected attributes.

The degree of linear correlation between two variables is measured statistically by the Pearson correlation coefficient. It is named after Karl Pearson, an English mathematician and biostatistician. The coefficient values lie in the closed interval (−1, +1). A perfect positive correlation is represented by a value of +1, a perfect negative correlation is represented by a value of -1, and no correlation is represented by 0. The Pearson correlation coefficient is considered satisfactory when $r_{XY} > 0.70$ and very satisfactory when $r_{XY} > 0.85$.

$$Pearson\ \text{correlation coefficient}\ (r) = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n}\sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left[\sum_{i=1}^{n} x_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2\right]}\sqrt{\left[\sum_{i=1}^{n} y_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} y_i\right)^2\right]}} \quad (12)$$

Here, n = number of observations; x_i and y_i are observed and estimated values. The analysis used the Likert scale value and the estimated relative weightages through the AHP model with a consistency check. As shown in *Table 12*, Five sets of proposed data with varying Likert scale values were compared pairwise and then utilized in the AHP model to determine their relative weightage along consistency checks. The Pearson correlation coefficient was 0.8708, indicating a satisfactory relationship between the Likert scale and the relative weightages of attributes.

Table 12 Sensitivity analysis of the proposed AHP model

Attributes	**Set 1**		**Set 2**		**Set 3**		**Set 4**		**Set 5**	
	Likert scale value	**Estimated value (relative weightage)**	**Likert scale value**	**Estimated value (relative weightage)**	**Likert scale value**	**Estimated value (relative weightage)**	**Likert scale value**	**Estimated value (relative weightage)**	**Likert scale value**	**Estimated value (relative weightage)**
Grading	8	0.264	9	0.262	8	0.236	7	0.254	6	0.242
Particle shape	7	0.165	10	0.416	7	0.156	5	0.119	5	0.166
Surface texture	9	0.418	6	0.062	4	0.047	3	0.049	1	0.041
Strength	4	0.0490	8	0.161	5	0.0710	9	0.502	8	0.491
Water absorption	6	0.104	7	0.099	10	0.489	4	0.076	2	0.060
Consistency ratio (CR, %)	0.022		0.015		0.031		0.030		0.038	

4.Results

4.1Material quality considerations

Figures 3, *4*, and *5* illustrate the relative weightage of the attributes of materials used in RCC constructions. The abscissa shows the characteristics of the aspects under consideration, and the ordinate indicates the relative weighting on a scale from 0.0 to 1. The relative weightage of grading, particle shape, surface texture, strength (including crushing value, impact value, and abrasion), and water absorption were 0.258, 0.178, 0.095, 0.331, and 0.138, respectively, based on expert opinion using AHP model, as shown in *Figure 3*. The overall quality of coarse aggregate such as crushing, impact, and abrasion value had the highest significance, whereas surface texture had the least.

According to expert opinion and the AHP model, as illustrated in *Figure 4*, the relative weightage of the attributes of coarse aggregate, namely surface texture, grading, maximum size, particle shape, and water absorption, that affect concrete workability was 0.146, 0.244, 0.134, 0.351, and 0.125, respectively. The aggregate's particle shape was the most significant factor, while water absorption was the least significant attribute.

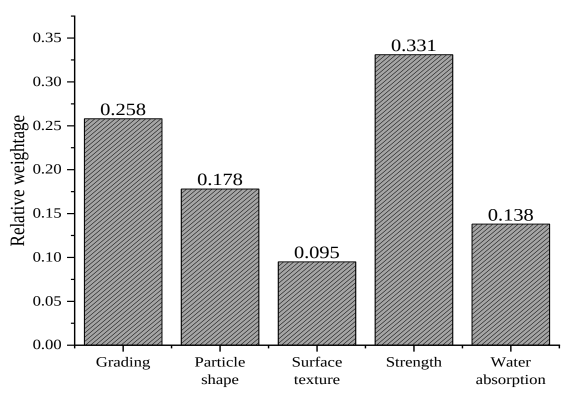

Figure 3 Relative weightages of attributes of coarse aggregates

Tensile strength, elongation after fracture, ratio of fu and fy, performance in bend and re-bend test, and carbon equivalent were the properties of reinforcement that affected quality of RCC construction. As demonstrated in *Figure 5*, the two most crucial reinforcement properties for RCC constructions were elongation after fracture and tensile strength. The relative weightage of tensile strength was 0.372, while the weightage of elongation after fracture was 0.210.

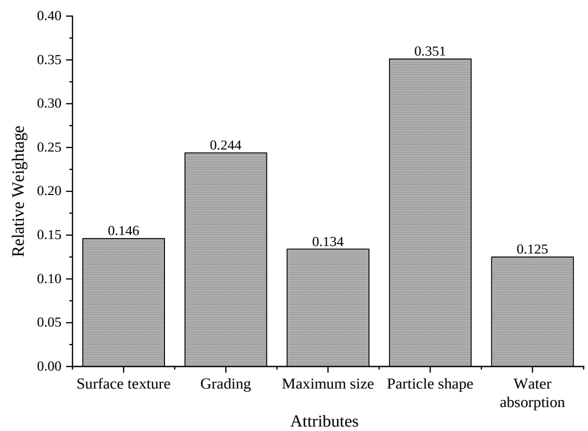

Figure 4 Relative weightages of coarse aggregate properties

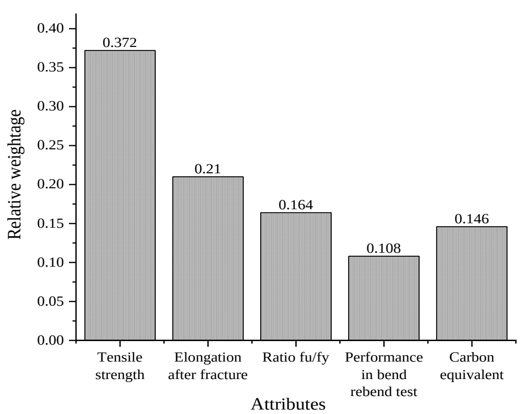

Figure 5 Relative weightages of reinforcement properties

4.2Construction quality considerations

This section highlights the significance of construction quality in *Figures 6*, *7*, and *8*. Expert opinions and the AHP model indicate that *Figure 6* shows how easily specific RCC construction requirements that affect the overall quality of RCC constructions can be achieved. The following criteria must be met: target strength in the laboratory, compliance strength at the site, workability at the site, stability and homogeneity, avoidance of honeycombing, and avoidance of plastic shrinkage. These factors were 0.225, 0.265, 0.120, 0.185, 0.136, and 0.068, respectively.

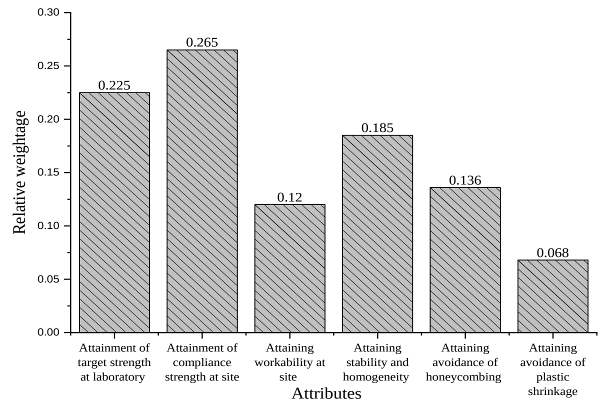

Figure 6 Relative weightages of ease of attainment of various aspects of concrete production

The factors that affected the quality of RMC were shown in *Figure 7*. These included variations in the related process and factors such as variations in the quality of constituent materials, variations in the mix proportion due to batching, variations in mixing equipment, the quality of supervision & workmanship, and variations due to sampling & testing of concrete specimens.

The relative weightages of these factors were 0.303, 0.187, 0.137, 0.265, and 0.108, respectively. *Figure 8* depicted the different approaches to improve the workability of concrete in RCC constructions. The relative weightage of each technique was in order: 0.080, 0.068, 0.298, 0.138, 0.231, and 0.184. Some of these techniques included reducing the fine aggregate content, increasing water content, using workability-aiding admixtures, improving the grading of fine aggregates, improving the grading of coarse aggregates, and improving the combined flakiness-elongation index.

As per experts, the five curing techniques most applied in RCC constructions are depicted in *Figure 9*. These methods were water ponding, water-saturated cover, fog spray, water-proof cover, and chemical curing with relative weightages of 0.356, 0.261, 0.104, 0.194, and 0.085, respectively.

5.Discussion

A rigorous literature review was conducted in the research investigation to determine the various aspects of concrete quality consideration. The literature review was carried out in relevance to material consideration and construction process consideration; these helped achieve the different quality benchmarks related to concrete construction projects. In material quality consideration, the quality parameters of coarse aggregate and fine aggregates such as mechanical properties, physiochemical properties, and reinforcement quality defining attributes, i.e., tensile strength and elongation value, bend re-bend value, carbon content, etc. After validation of questionnaire survey through pilot run, the full-scale questionnaire survey was conducted to identify the relative importance of various attributes with 380 experts comprising academicians, consultants, contractors, and industry specialists.

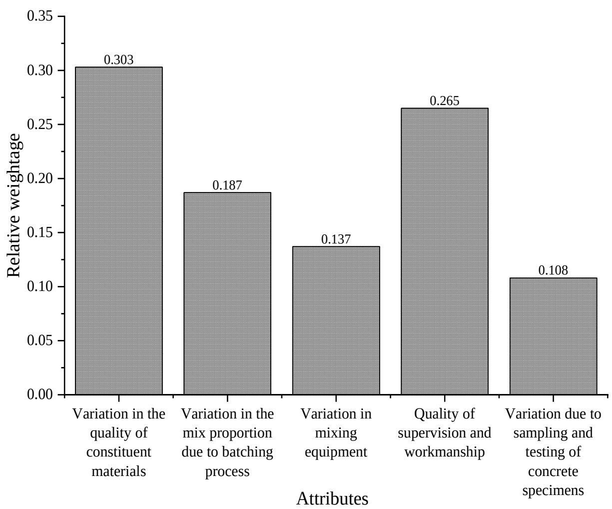

Figure 7 Relative weightages of factors affecting the quality of concrete in RMC

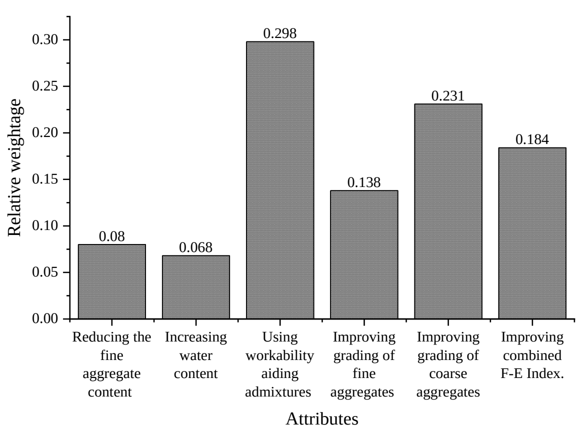

Figure 8 Relative weightages of factors affecting the workability of concrete

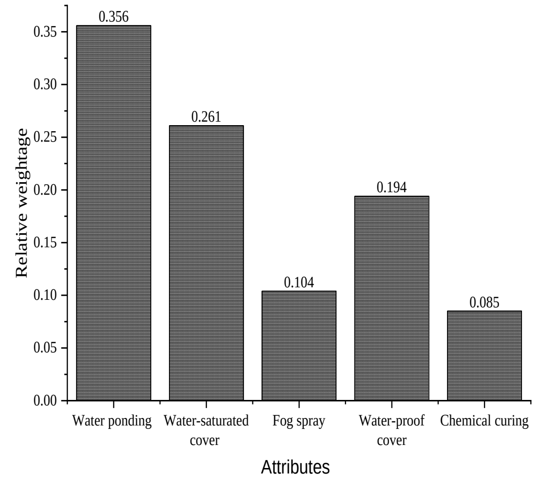

Figure 9 Relative weightages of various types of curing

There were only 129 experts took part in the survey of which 85 were chosen for further analysis. To check the reliability of gathered Likert scale responses, a Cronbach's alpha analysis was performed, and all alpha values greater than 0.8 showed that the gathered responses were reliable. The responses were analysed by performing descriptive statistical analysis such as mean, variance, minimum value, maximum value, standard deviation, etc using SPCC software. The mean value of Likert responses lies between 7.34 and 9.34 for quality attributes of overall quality of coarse aggregate shows; experts believe that all attributes are quite crucial and closely associated to ascertain the quality of RCC construction.

Then, the Likert responses were converted into pairwise square matrices, which were further used in the AHP model to generate the relative weightage. In the AHP model, pairwise square matrices were utilized to create the individual weightage of attributes. Finally, these individual weightages of each attribute were used to generate relative weightage. The reliability analysis was carried out on generated relative weightages through a CR, which should be less than 0.10 (10%) for relative weightage reliability. The lower CR value showed that determined values hold good consistency and have good reliability aspects; however, higher CR values greater than 10% are undesirable, and show results are unreliable as well as doubtful accuracy.

The sensitivity analysis was performed with the proposed AHP model using the Pearson correlation coefficient; a perfect positive correlation is represented by a value of +1, a perfect negative correlation by a value of -1, and no correlation is represented by a value of 0. In this analysis, the correlation coefficient was 0.8708, indicating a satisfactory relationship between the Likert scale and the relative weightages of attributes. Additionally, a consistency checks on estimated relative weightage and a lower CR value (0.15% to 0.38%) depicted that model has good stability.

The AHP analysis was performed on all obtained responses through a questionnaire survey. It was concluded that the strength parameter, which includes the crushing, impact, and abrasion values, had the highest relative weightage of 0.330 among the five coarse aggregate quality attributes. In contrast, the grading parameter had the second-highest relative weightage of 0.258. Higher relative weightage of attributes of coarse aggregate showed that degree of importance on RCC quality and crucial to sustaining the good quality of RCC construction. Attributes such as strength of coarse aggregate directly influence the strength of RCC and grading of aggregate reduces void ratio as well as increase density and overall increasing strength of RCC.

Likewise, the highest relative weightages of particle shape and grading (0.351 and 0.244) impacted the workability of concrete. Particle shape directly influences the workability, in which angularity of coarse aggregate decreases the workability but increases the strength whereas rounded shape of coarse aggregate increases the workability but reduces the strength. Similarly, well-graded coarse aggregate also increases the workability whereas gap-graded coarse aggregate reduces the workability.

Tensile strength and elongation after fracture are the two most essential reinforcement characteristics. The relative weightage of tensile strength was 0.372, while the weightage of elongation after fracture was 0.210. Tensile strength and elongation after fracture of the reinforced bar provide tensile strength as well as flexure strength and increase the bond strength RCC structure.

In construction quality consideration, it was determined that the attributes with the highest relative weightage were those that significantly affected the quality of construction. These attributes included water ponding, using workability-aiding admixtures, attaining compliance strength at the site, and variations in the quality of constituent materials and their respective values were 0.356,0.298, 0.265, and 0.303. Water ponding is the most commonly used curing technique and it is crucial in any construction, ensuring optimal moisture and temperature levels for hydration, promoting hardened properties, and enhancing its strength and durability over time. Admixture is widely employed to increase the workability of concrete without changing the water content. To ensure the durability and strength of the RCC structure, it is crucial to attain compliance strength at the site. Cement, water, aggregate, and reinforcement are the main ingredients of RCC, and variations in the quality of constituent materials degrade the construction quality.

This model aids in developing a priority list for the quality parameters of RCC construction and is useful for determining the relative weightages of attributes. It also provides a framework for understanding the relative importance of various aspects of RCC construction.

The primary limitation of this framework was that it was limited to RCC construction projects. To apply this model in various sectors, it is necessary to redefine the numerous related parameters constantly. This requires expertise in the field to obtain knowledge-based responses with a comprehensive evaluation. This model is unable to determine and validate the relative weightages of the subjective questionnaire responses due to inconsistent standard limits. Some restrictions on the questionnaire survey include experts having hectic schedules, needing to follow up frequently to receive their responses, and sporadically returning incomplete responses, which led to a rejection responses sheet.

Appendix I provides a summary of all abbreviations.

6.Conclusion and future work

A questionnaire survey was undertaken with experts in the domain to determine the relative weightage of various attributes considered for RCC constructions. Responses were gathered using a Likert scale, transformed to a pairwise comparison scale, and subsequently employed in an AHP model to determine the relative weightage of attributes.

Using inferential statistical analysis such as Cronbach's alpha analysis and various descriptive statistical analysis, the Likert scale responses were analysed and determined to be reliable. After the AHP analysis, the consistency checks were applied to the relative weightages of attributes to ensure data consistency. A sensitivity analysis was carried out using the Pearson correlation coefficient to assess the effectiveness of the suggested AHP model.

The following two attributes of coarse aggregate, with relative weightages of 0.331 and 0.258, respectively, can highly influence the overall quality of coarse aggregate in RCC constructions. Grading and particle shape of coarse aggregate, with relative weightage of 0.244 and 0.351, respectively, have a considerable effect on the workability of concrete in RCC constructions.

Furthermore, the most influential reinforcement properties in RCC constructions were tensile strength and elongation after fracture, with relative weightages of 0.372 and 0.210 on a scale of 1.0. According to the results of the investigation, the most crucial factor in the RCC constructions was the strength (hardness and toughness) of the coarse aggregate, and the particle shape (elongated & flakiness) of the coarse aggregate has a substantial effect on the workability of the concrete mixture. However, the surface texture and maximum size of coarse aggregate were less important factors that enhanced the quality of RCC constructions. According to professionals, the tensile strength of the reinforcement was also a critical factor in determining the overall quality of RCC constructions. Regarding construction quality consideration, achieving compliance strength on-site, which has a relative weightage of 0.265, and achieving target strength in the laboratory, which has a relative weightage of 0.225, were the two best ways to achieve quality control. Variations in the quality of the component materials and the quality of supervision and workmanship, which have relative weightages of 0.303 and 0.265, respectively, were the two factors in RMC that have the most influence on how the quality of concrete changes with time and from batch to batch. It was easy to enhance the workability of freshly mixed concrete by adding admixtures and improving coarse aggregate grading with relative weightages of 0.298 and 0.231, respectively.

Moreover, water ponding and water-saturated cover were the most frequently used curing methods in RCC constructions, with relative weightages of 0.356 and 0.261, respectively. These relative weightages of attributes help to understand the relative importance of various aspects in RCC construction and help to establish a priority list for the quality parameters in RCC construction. This study will be extended to develop a quality indexing model using a soft computing model and attempt to develop a model for universal quality rating that can be applied to different industries.

Acknowledgment
I am grateful for the facilities and resources provided by the Structural Engineering Laboratory, Department of Civil Engineering, Motilal Nehru National Institute of Technology, to carry out this research study.

Conflicts of interest
The authors have no conflicts of interest to declare.

Data availability
The data that support the findings of this research investigation are available on request.

Author's contribution statement
Gaurav Singh: Investigation, methodology, data curation, visualization, preparing original manuscript. **Laxmi Kant Mishra:** Conceptualization, visualization, supervision, writing-review and editing. **Virendra Kumar Paul:** Conceptualization, visualization, supervision, review.

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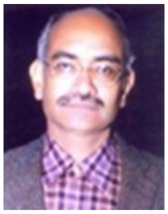

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Appendix I

S. No.	Abbreviation	Description
1	AHP	Analytic Hierarchy Process
2	(A_{ij})	Square Matrix Element with i^{th} Column and j^{th} row
3	(A_{ij}^{T})	Transpose square matrix (A_{ij})
4	a_{ij}	Matrix element with i^{th} column and j^{th} row
5	CI_j	Condition Index
6	CI	Consistency Index
7	CR	Consistency Ratio
8	Fe	Iron reinforcement Bar
9	f_u	Ultimate Strength
10	f_y	Yield Strength
11	IS	Indian Standards
12	j	Number of Deteriorating Elements
13	NDT	Non-Destructive Testing
14	PCC	Precast Concrete Construction
15	RI	Random Index
16	RCC	Reinforced Cement Concrete
17	RMC	Ready Mix Concrete
18	SCI	Structural Condition Index
19	Sc_{ik}	Descriptor i for individual k
20	Sc_{jk}	Descriptor j for individual k
21	SPSS	Statistical Package for Social Sciences
22	w_j	Weight factor
23	W_{mj}	Individual weightage of each attribute