Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

In-situ compressive strength assessment of concrete in under-construction residential buildings at Gaindakot municipality

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ARTICLE INFO

Article history:
Received 12 October 2020
Accepted 22 October 2020
Available online xxxx

Keywords:
In-situ
Compressive strength of concrete
National building code
Ingredients of concrete
Quality control

ABSTRACT

Concrete is the most used construction material in modern era. A general evaluation about concrete's quality can be obtained by determining its compressive strength. In Nepal a few research have been carried out to ensure the in-situ quality of concrete. The objective of this study was to access the compressive strength of concrete produced at site, their ingredient's proportion and compare if they comply with NBC of Nepal. 90 cubical specimens from 30 houses in 10 wards at Gaindakot Municipality were collected purposively and tested for compressive strength value along with the proportion of cement, sand, aggregate and water.

After analyzing cubes from 30 houses, the mean compressive strength was found to be23.928 N/mm^2. Similarly80% of houses constructed at site prepared and placed concrete having compressive strength value more than 20 N/mm^2, complying NBC of Nepal. ANOVA analysis showed that there was no significant difference in compressive strength means among houses of 10 wards but there was higher standard deviation and wider range within houses of same wards. 73.33% of sampled houses produced concrete maintaining water-cement ratio of 0.4 to 0.6 but no consistency in use of sand and aggregates revealing inconsistent and uncontrolled concrete production process. Control chart showed that more than 15% of measured compressive strength of concrete lied outside the control limit point.

Selection and peer-review under responsibility of the scientific committee of the Emerging Trends in Materials Science, Technology and Engineering.

1. Introduction

Concrete is essential building material &most widely used construction material on earth. "An artificially build up stone resulting from hardening of a mixture of cement, aggregates and water with or without a suitable admixture is concrete" [10]. In this modern time without concrete development of infrastructure, industry, housing & the built environment would fail to accommodate rapid development and its quality. Compressive strength is one of the important factor considered to obtain the quality information about the concrete. Standard practice have been developed to batch, mix and cure the concrete to obtain desired compressive strength. However, many factors influence on the properties &qualities of the obtained concrete, since the behavior is directly associated to the used materials, and the production process [20]. As per Alam *et al.* [3], the quality of the concrete is affected by its constituent materials, its proportion, the equipment used, knowledge of person(s) involved and workmanship in concrete production process.

2. Problem statement

Bollinger *et al.* [5] studied main frontal thrust and concluded that on average a great earthquake occurs every 750 ± 140 and 870 ± 350 years in the east Nepal region. Hence Nepal is located in earthquake prone area. After 2015 earthquake, government of Nepal has ruled all municipals to follow the National Building Code (NBC) of Nepal strictly which is available easily to all through various medias like internet, booklets etc. NBC was implemented to control the concrete production process, but no specific study has been carried out to confirm the compliance. The purpose of this study was to find out whether the concrete used in residential buildings of study area was according to the desired mix and strength specified in building code or not.

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https://doi.org/10.1016/j.matpr.2020.10.630
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the Emerging Trends in Materials Science, Technology and Engineering.

3. Objectives

The general objective of this study was to explore the compressive strength of concrete produced at study sites and proportion of ingredients used in preparing the concrete and to compare if they comply with standard.

4. Literature review

4.1. Compressive strength of concrete

In order that the properties of the completed structure be consistent with the requirements, materials for concrete; workmanship in all stages of batching, mixing, transportation, placing, compaction and curing; and the related plant, machinery and equipment; should be used as per the standard. Quality control of concrete can be assured by the use of batching machines while mixing the ingredients. [4,6] gives the standard procedure for quality production of concrete. As per [8], by determining concrete's compressive strength, a general evaluation about concrete's quality can be reached. Hence the compressive strength is one of influential factors on concrete quality which has been tested at 28 days [17]. The standard cube specimen of 150 mm × 150 mm × 150 mm is cured for 28 days and tested in compression testing machine.

Compressive strength test results tend to follow a normal distribution and is lower tailed. For concrete with characteristic compressive strength 20 N/mm^2 and standard deviation 4 N/mm^2 [6], the normal distribution is illustrated in Fig. 1.

A low standard deviation means that most strength results will be close to the mean value; a high standard deviation means that the strength of significant proportions of the results will be well below (and above) the mean value [11].

As per GoN: Ministry of Physical Planning and Works [13], the concrete to be used in footings, columns, beams and slabs, etc. shall have a minimum crushing strength of 20 N/mm^2 at 28 days for a 150 mm cube

As per [21], compressive strength test result showed 40.4% of test results were found to be defective according to compliance criteria's of Ethiopian Building Code Standard [7] where as 31.25% of the test results were found to be defective according to American Concrete Institute-318 [1] compliance criteria's.

Ribero *et al.* [20] observed that the concrete mixes practiced in the sites often do not satisfy the required workability and mechanical properties with absence of effective dosage methods. Hence compressive strength of concrete, in 50% of the constructions presented in study showed values below than specified compressive strength value of 20 N/mm^2.

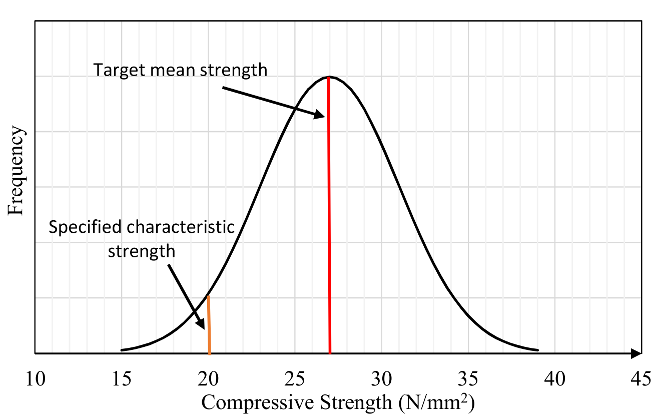

Fig. 1. Illustration of concrete strength distribution.

Aguira [2] found in his study that the percentage of non-conformable groups decreases when the characteristic compressive strength increases. For concrete with specified strength 20 MPa there is 50% of non-conformable groups and for the concrete with specified strength 30 MPa, only 7%.

Namyong *et al.* [16] concluded that compressive strength of specimens cured in water at the laboratory construction sites is over 14 ~ 29% as compared with specified compressive strength.

4.2. Ingredient proportion of concrete

Concrete is a composite material produced by the homogenous mixing of selected proportions of water, cement, fine aggregate (sand) and coarse aggregates. The lower the water content, all else being equal, the stronger the concrete. Another durability factor is the amount of cement in relation to the aggregate. Where especially strong concrete is needed, there will be relatively less aggregate [9].

Revealed that water-cement ratio above 0.55 was found to cause a very significant reduction in the compressive strength of the concrete mixes so strict control on the water cement ratio on site is very much required to get good quality concrete [22].

Kumar *et al.* [14] mentioned that for all the ages at curing, the highest strength was obtained from concrete made with lag gravel, followed by river gravel and the last strength was recorded with concrete containing crushed aggregate.

4.3. National building code (NBC)

In the absence of an appropriate building code of its own, most buildings in Nepal were, planned and constructed with little or no regard for seismic safety [19]. The objectives of NBC are to develop the in order to improve the seismic safety aspects and to suggest safer building design and construction practices.

It is not practical in Nepal at present to insist that all small buildings be designed for strength by a professional adviser. So, for classes of buildings not exceeding certain simple criteria as to height, number of stories and floor area, mandatory rulesofthumb is provided which an experienced overseer will be able to understand easily [12].

Revealed that the adopted process and existing institutional mechanism for the implementation of building code is not effective due to lack of building code implementation section, insufficient manpower and non-functionality of environmental section [4].

Presented that mandatory rule of thumb gives the explanatory documents such that an experienced overseer or mason might be able to understand them and present sufficient details at the time of permit application to prove to a non-technical appraiser at the local authority that the requirements are being me [19]t.

5. Research gap

According to Okazaki *et al.* [18], most of the workers do not know that their country has NBC or guideline so, compressive strength of concrete for the structured building with masonry infill wall was about 10–15 MPa, based on study of buildings on Kathmandu valley.

In context to this, in Nepal few research have been done to ensure the in in-situ quality of concrete and others research on concrete was not available representing Nepalese local scenario. Hence, this study will present the in situ assessment of concrete in residential building of Gaindakot Municipality, a municipality of central Nepal, with the variability in material that occur during mixing & placement of concrete.

6. Methodology

6.1. Population and sampling

The non-probability (purposive) sampling technique was adopted in this study. The technique of producing concrete for construction of residential buildings was heterogeneous as it differs from person to person, so the number of samples was taken to be 30 based on time and resources. Total number of 10 wards as blocks was selected from 18 wards as to represent the whole houses. From each wards 3 sample sites was chosen where the houses were in construction phase. From each sample sites, three (3) specimen of concrete cube were taken, as shown in Fig. 2.

6.2. Collection of data

The site for collection of primary data was given in Fig. 3.

6.3. Concrete cube specimen

Three (3) cubical specimens with dimensions 150 mm * 150 mm*150 mm were collectedfrom each project site. In total90cubical specimenswere collected from 30 sites and were analyzed. The collection took place according to the Bureau of Indian Standards (2004). Procedure for sample collection is illustrated as:

- The freshly produced concrete was poured in cubical moulds of size 150 mm*150 mm*150 mm in three layers and was compacted manually to achieve full compaction.
- After immediate casting of concrete cubes at site, the cubes were covered with sacks and was kept in same site at cool place for overnight without any disturbance.
- Then the cubes were transported to lab in suitable vehicle like, 3 wheeler or 4 wheeler without causing disturbance it its natural state. For this transportation media was chosen generating low vibration & speed was limited.
- The cubes were then stored in vibration free area submerged in water at a room temperature about 24–26 °C for 24 h.
- At the end of 24 h; the cubes were removed from the mould and submerged in fresh clean water. The cubes were taken out of the water only at the time of testing.
- After 28 days of curing, the cubes were tested in a test machine and compressive strength of concrete was recorded for each sample according to the requirements set by the Bureau of Indian Standards (2004). The load was applied steadily and uniformly, starting from zero at a rate of 35 N/mm^2/minute until the cube didn't break, and final value was recorded. The test was carried out on lab Bharatpur Metorpolitan city with cali-

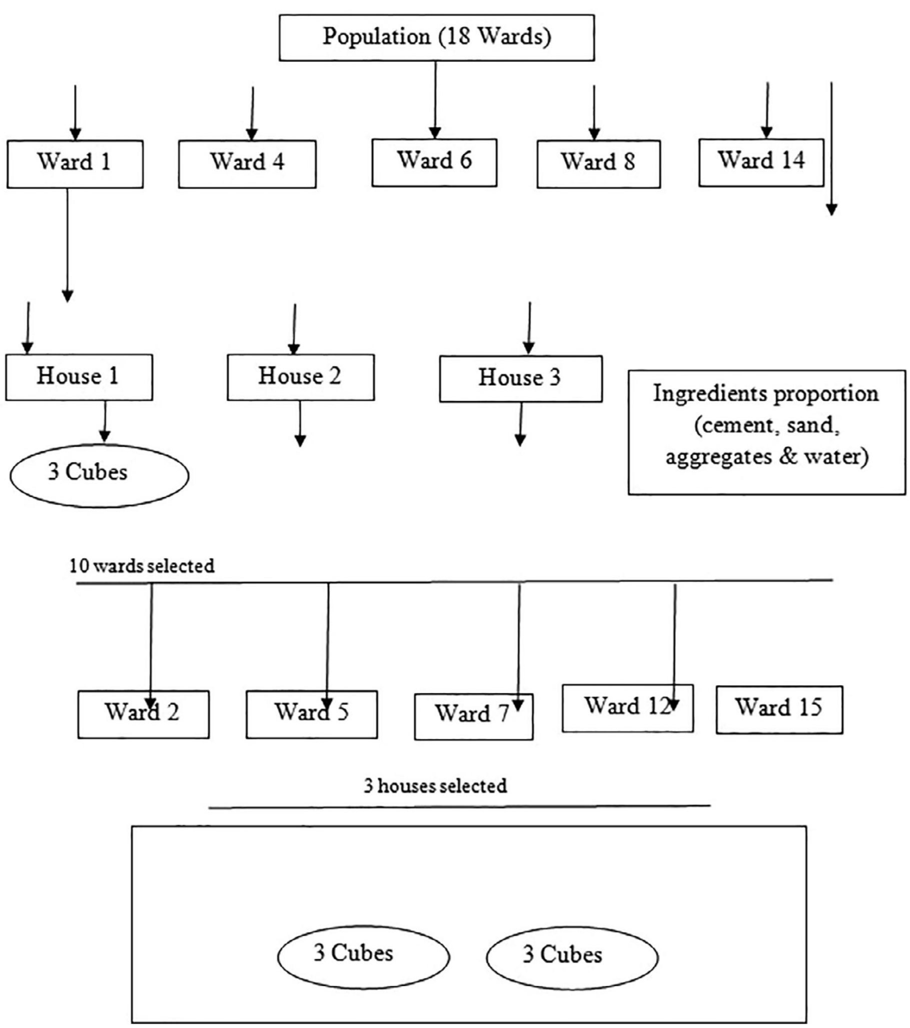

Fig. 2. Sampling (Research design).

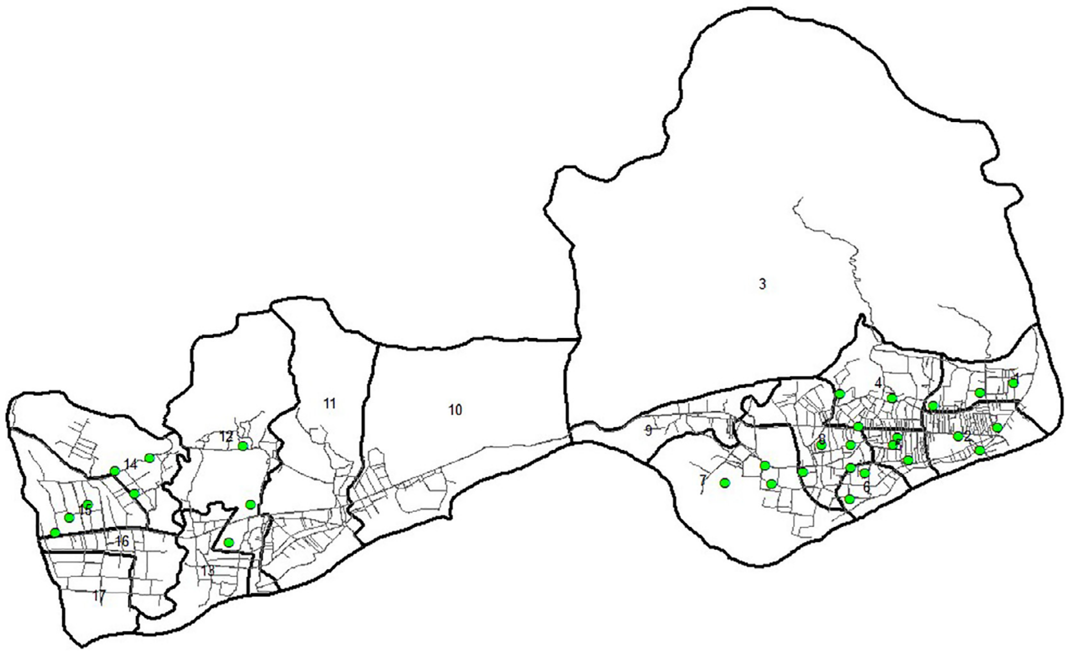

Fig. 3. Primary data collection sites. (Green circle). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

brated compressive strength machine of 2000 KN load capacity. The calibration constant of compressive machine is 0.94, as given in Annex III.

6.4. Ingredient's proportion for producingconcrete.

- First the weight of measurement boxes was taken and recorded. For taking weight, weighing machine of 100 kg with proper calibration electronic balance was used.
- Before placing the ingredients (sand, aggregate) on concrete mixer, the measurement box full with ingredients was weighted on weighing balance and recorded. Then empty weight was deducted to obtain the amount used.
- In manual mixing, the weight of ingredients was directly measured using weight balance and used for mixing. Here the ingredients was weighted putting in sacks before mixing.
- Water was poured from the filled bucket with known volume. After pouring, the remaining amount of water was measured to determine the amount of water used for mixing of concrete. For measuring volume 40 L bucketwas used.

7. Analysis of data

7.1. Compressive strength of concrete

- Statistical analysis wascarried out. The variation in data from house to house was analysed. Mean and standard deviation was calculated for each ward. The mean of each house was compared with the minimum required as given in NBC of Nepal.
- The ANOVA test wascarried out to test the significance of result based on set hypothesis. ANOVA table was set up as given in Table 1 [15].

7.2. Control on concrete production

Control charts were developed, to analyse the control in production of concrete. To create a control chart, central line (CL) as well as lower and upper control limits, LCL and UCL respectively are necessary. For the calculation of these two limits the knowledge of the "natural" standard deviation of the process is required.

Control limits for the R–chart:

$$\text{The central limit (CL)} = \bar{R}$$

$$\text{The upper control limit (UCL)} = \bar{R} * D4$$

$$\text{The lower control limit (LCL)} = \bar{R} * D3$$

Control limits for the $\bar{X}$ chart:

$$\text{The central limit (CL)} = \bar{X}$$

$$\text{The upper control limit (UCL)} = \bar{X} + \bar{R} * A2$$

$$\text{The lower control limit (LCL)} = \bar{X} - \bar{R} * A2$$

The values of D3, D4 & A2 are obtained from 'Table for Control Chart Constant'.

7.3. Ingredient proportion of concrete

- The frequency table was constructed to observe the pattern of use of ingredients. The variation in proportion of ingredient was analysed and compared based on nominal mix given by NBC of Nepal.
- A relation graph of cement content vs compressive strength, aggregates content vs compressive strength and water cement ratio vs compressive strength was constructed. Correlation between the compressive strength of concrete and individual proportion of ingredients was analysed to understand the effect in compressive strength of concrete due to variation in ingredient proportion.
- Regression analysis was carried out using SPSS software. The dependent variable being compressive strength of concrete with respect to independent variable (amount of cement, sand,

Table 1
Setting up of ANOVA table.

Source of variation	Sums of squares (SS)	Degrees of freedom (df)	Mean squares (MS)	F
Between treatments	$SSB = \sum n_j \left(\bar{X}_j - \bar{X}\right)^2$	k-1	$MSB=\frac{SSB}{K-1}$	$F=\frac{MSB}{MSE}$
Error or Residual	$SSE = \sum\sum \left(X - \bar{X}_j\right)^2$	N-k	$MSE=\frac{MSE}{N-K}$	
Total	$SST = \sum\sum \left(X - \bar{X}\right)^2$	N-1		

Where,
X = individual observation,
$\bar{X}_j$ = sample mean of the j^{th} treatment (or group),
$\bar{X}$ = overall sample mean,
k = the number of treatments or independent comparison groups,
N = total number of observations or total sample size.

aggregate and water). In regression analysis, the higher the R-squared value, the better the model fits data & less the standard error of estimate, there is more accuracy in the estimate of data. Procedure for regression analysis is described [15].

Here: Dependent variable: 28 days mean compressive strength N/mm^2 (C)

Independent variable	: Water Cement Ratio (x)
	: Amount of Sand in Kg (y)
	: Amount of Aggregates in Kg (z)

Let the regression equation be:

$$C = Ax + By + Cz + D \tag{3.7}$$

Where, A, B, C & D are constants obtained from the analysis of data on software (SPSS).

8. Result and discussion

8.1. Compressive strength of concrete

The cubes of concrete were casted in site from the under construction residential buildings at Gaindakot Municipality. The cubes were cured and tested in lab at an interval of 28 days. Test was done in lab of Bharatpur Metropolitan city, with calibrated compressive strength test machine of 2000 KN capacity. The result of mean compressive strength of concrete cubes obtained from 30 different houses were presented in Fig. 4.

From Fig. 4., mean compressive strength of cubes of concrete obtained from houses 1, 10, 13, 21, 23, 24were less than minimum specified as 20 N/mm^2. The standard nominal mix for M20 concrete was 1:1.5:3 (cement: sand: aggregate) but it could be observed that the mix of ingredients were high in proportion in given specified houses ranging from (1:2.44:3.59) to 1:3.65:3.41), showing inconstancy in concrete production with less in desired strength.

A study conducted by Sisay [21] showed that quality of concrete produced on those public projects have higher uncertainties and varies from good to bad, similar result were obtained in this study too. The result showed higher uncertainties as breaking stress varied from maximum of 33.047 N/mm^2 to minimum of 15.388 N/mm^2.

The target mean strength of M20 concrete was 27 N/mm^2 (with standard deviation-4). Hence frequency table was developed in 3 categories and was presented in Fig. 5.

Fig. 5 showed that the mean compressive strength of 20% of sampled houses was less than minimum specified value of 20 N/mm^2. Similarly test result showed 30% of sampled houses produced concrete with more than the targeted mean strength of 27 N/mm^2. Overall result showed that 80%of houses produced concrete satisfying the minimum standard compressive strength value of 20 N/mm^2 as specified in NBC of Nepal.

Okazaki (2012) revealed that compressive strength of concrete for the structured building with masonry infill wall is about 10–15 MPa, based on study of buildings on Kathmandu valley. From our study it could be observed that the minimum of 15.388 MPa with average of 23.928 M Pawas found on test sites.

Similarly Ribero *et al.* [20] observed that the compressive strength of concrete, in 50% of the constructions presented in study showed values below than specified compressive strength of 20 N/mm^2. And this study showed, 20% of compressive strength of concrete was less than specified 20 N/mm^2 for construction. It showed that the practice of concerting was improving to obtain the con-

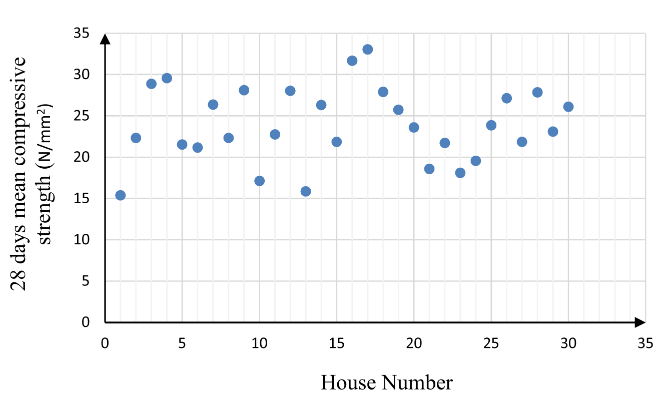

Fig. 4. Compressive strength test result.

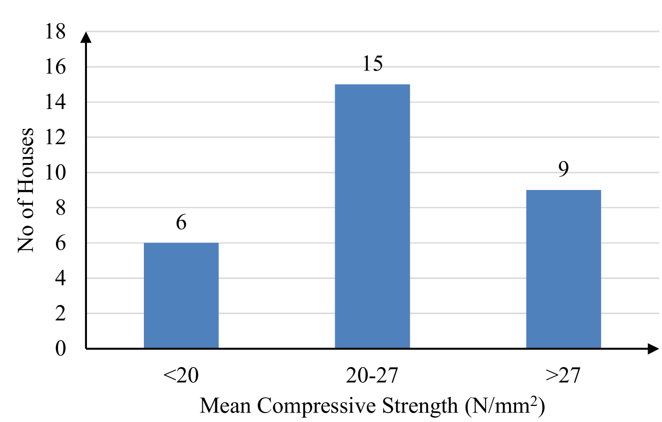

Fig. 5. Frequency distribution of mean compressive strength of concrete.

crete with better strength. This was due to recent earthquake, government rule to enforce NBC & awareness of people towards safety.

According to the data obtained in field and the result of lab test showed that there was high variation in breaking load for different sampled houses ranging from 282 to 817.8 KN. The result revealed that the strength of concrete produced at site was in consistent. This revealed that, the inconsistent concrete practice should be taken into account seriously. To ensure the effective implementation of building code, which is the minimum standard, so the workmanship and continuous supervision could be focused?

8.2. ANOVA analysis on mean compressive strength of concrete

From data obtained from lab, the ANOVA test was carried out between the mean compressive strength obtained in 10 wards. The test statistic is presented in Table 2.

Here $F_{calc} < F_{table}$, Hence the null hypothesis (H_0) was accepted. (I.e. there is no significant difference in the means of compressive strength of concrete producedin study area.)

From Table 2 the ANOVA test carried out on the result of mean compressive strength of 10 wards showed that there wasno significant difference in the compressive strength means of concrete obtained from sampled houses. But, from statistical analysis of data it was found that minimum strength observed was 15.388 N/mm^2 whereas maximum was 33.047 N/mm^{2}with a lot of variation within the sampled houses. The maximum range of strength within houses was 14.207 N/mm^2. Similarly the maximum standard deviation was found to be 5.819 N/mm^2, which shows that there is no consistent in concreting process. Proper quality assurance as presented in this study could be applied with proper supervision to achieve the consistency in concreting process.

Similarly from the statistical analysis of data of 10 wards, it was found that the standard deviation of compressive strength within single ward was ranging from minimum of 5.013 N/mm^2 to maximum of 16.239 N/mm^2. As per ANOVA analysis carried on between 10 wards, there was no difference in compressive strength means, but within the wards, there was high variation, showing no uniformity in concrete production process.

8.3. Ingredients proportion for concrete production

The proportion of ingredients for used producing concrete in the sites was presented in Annex III. The proportion of use of water, sand and aggregate along with their frequency is given in Figs. 6-11.The frequency distribution table is constructed for the amount of water, sand and aggregate, used in concrete production at the class interval of 5 L for water & 20 kg for sand and aggregates. The class interval was determined based on observation to accommodate most occouring datas.

Figs. 6 and 7 showed that in production of concrete 43.33% of the test sites were using water between 20 and 25 Ltr. 73.33% test sites were found using water 20 ltr to 30 ltr. It shows that the water cement ratio was maintained between 0.4 and 0.6. As per Bureau of Indian Standard (2000), the maximum amount of water for M20 concrete was 30 ltr. (i.e water-cement ratio 0.6), only 6.66% of sites were using water cement ratio greater than 0.6. Similarly, water cement ratio less than 0.3 makes concrete difficult to use due to low workablility. It shows that in majority of sites use of water was according to standard Fig. 8.

Fig. 9 showed that use of sand was in between 120 kg and 140 kg for 50.00% of test sites. The use of sand between 100 and 140 kg stands for 73.33% of test sites. As per standard nominal mix, amount of sand to be used for making M20 concrete as 75 kg for a batch with 50 kg cement but, from minimum of 99.91 kg to maximum of 191.40 kg was found in test sites. It shows that, the use of sand is inconsistent with standard with maximum dispersion.

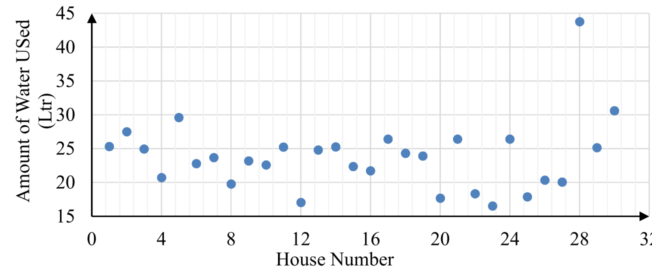

Fig. 6. Amount of water used in concrete production.

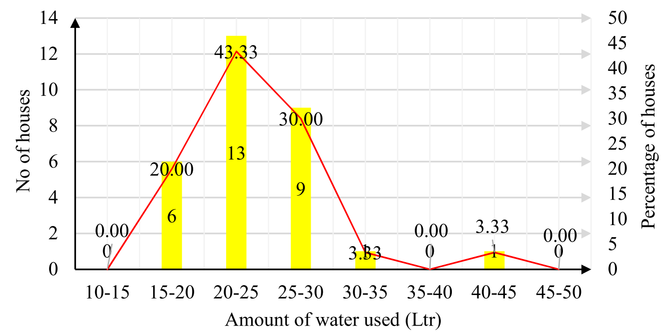

Fig. 7. Frequency distribution of amount of water used in concrete production.

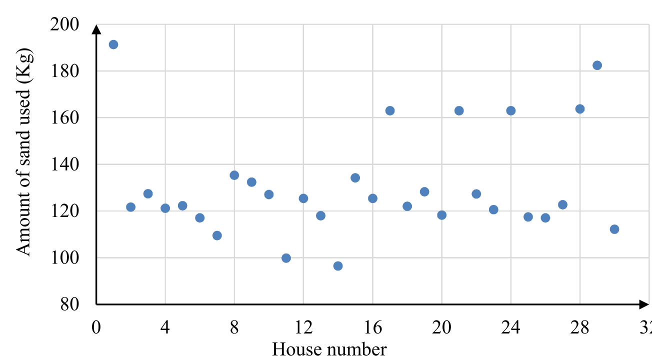

Fig. 8. Amount of sand used in concrete production.

Table 2
F test statistics.

Source of variation	Sums of squares (SS)	Degree of freedom (df)	Mean squares (MS)	F (calculated)	F(from table)
Between Treatments	178.2329	9	19.8037	0.9479	2.39
Error (or Residual)	417.8529	20	20.8926		
Total	596.0858	29			
df1 = k-1	9				
df2 = N-k	29				

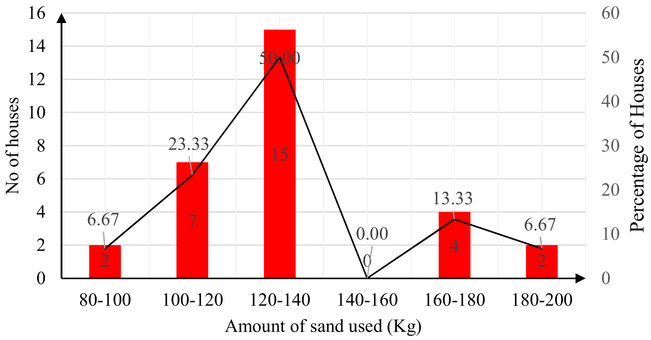

Fig. 9. Frequency distribution of amount of sand used in concrete production.

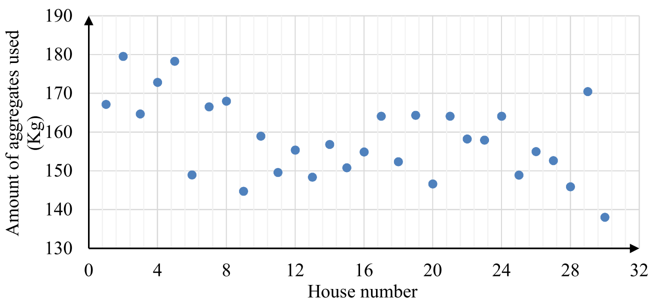

Fig. 10. Amount of aggregates used in concrete production.

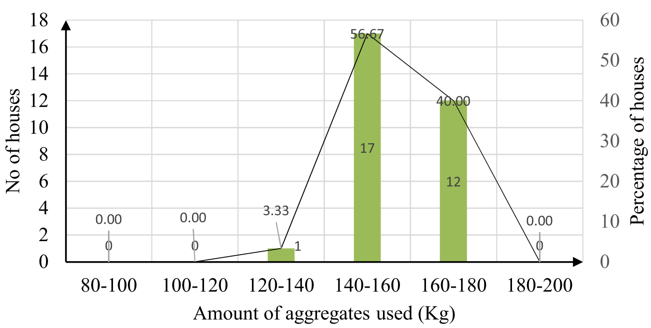

Fig. 11. Frequency distribution of amount of aggregates used in concrete production.

Fig. 8 and Fig. 9 showed that amount of sand was kept high, it was done so to make concrete more workable. It was also found that for a site with high amount of concreteing work, the worker keep more sand to make more volume or concrete. It shows that the workmanship for producing concrete was not as per standard. Quality could be assured with proper guidance and timely supervision.

Figs. 10 and 11 showed that use of aggregate is in between 140 and 160 kg for 56.67% of test sites. The use of aggregates between 140 kg and 180 kg stands for 96.67% of test sites. As per standard, amount of sand to be used for making M20 concrete is 150 kg for for a batch with 50 kg cement. The test result shows that the use of aggregates compliedstandard with minimum dispersion then sand.

Here the amount of aggregates and water used for making concrete was found with minimum dispersion, with range whose mean complies with standard. The scenerio found for sand was disastarous. Since the production of concrete was carried out by low level workers, there is need of proper guidance and training to them.

Fig. 12 showed that the total amount of sand and aggregate used was high in amount than specified in code for making concrete mix of M20. As per Bureau of Indian Standards (2000), the total amount of aggregate is 250 kg, but study showed that the use of aggregate range from minimum 249.52 kg to maximum of 358.60 Kg. Only one house comply with standard requried with total aggregates 249.52 Kg. Similarly ratio of fine to coarse aggregate as given in code is 1:2 (lower 1:1.5 & upper 1:2.5) but study showed the ratio in study area was ranging from lower limit of 1:0.874 to upper limit of 1:1.625, showing the high amount in fine aggregate (sand) and low amount of coarse aggregate, but Fig. 4.8 showed that 56.67% of study area were using coarse aggregates within acceptable proportion. It concluded that the amount of fine aggregates (sand) using in sites were more than the required proportion.

This practice showed that, to make workablility of concrete high and to increase the rate of production of concrete, the ingredients proportion was used based on the site condition. There was no any standard followed at site, reaveling inconsistency in concrete production. This unsystematic process could be managed by proper supervision and application of suitable quality assurance measures.

8.4. Compressive strength of concrete and proportion of its ingredients

Based on the lab test result of compressive strength of cube a relationship diagram was developed between mean compressive strength of concrete & amount of ingredients used for producing concrete as presented in Figs. 13 and 14

The result showed that there was weak correlation between the proportions of individual ingredients based on linear correlation. However if it is considered all three variables, then multiple collinear effect would be seen in resultant strength.

Figs. 13 and 14 showed that the individual effect cannot be predicted to make a relation between compressive strength of concrete and their proportion of ingredients. It should be studied in detail with considering all qualitative and workmanship factors. The unfit relation was due to various factors. There was different brands of cements with different ages for different study areas. Source and gradation of aggregates (fine & coarse) was also different.

8.5. Relation between compressive strength of concrete & its ingredients

Using SPSS, the multiple regression analysis was done to predict the correlation between 28 days mean compressive strength of concrete and their proportion of ingredients used. The modal summary result was shown in Table 3.

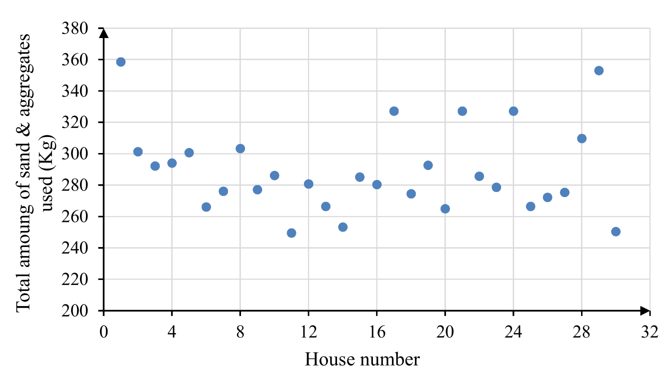

Fig. 12. Total amount of sand & aggregates used in concrete production.

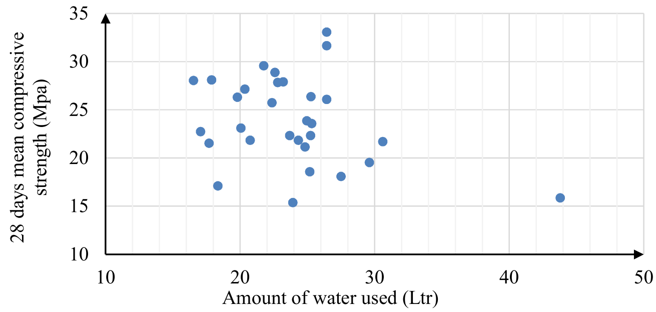

Fig. 13. Graph of compressive strength vs amount of water used.

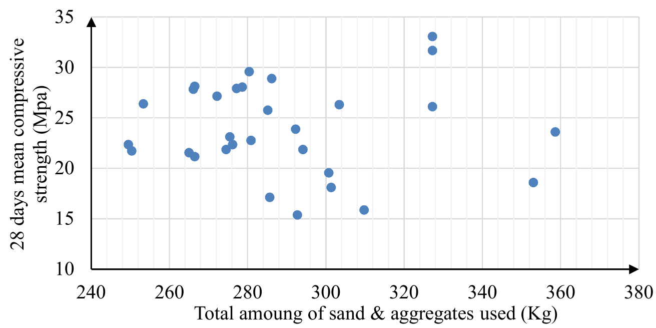

Fig. 14. Graph of compressive strength vs total amount of sand & aggregates used.

Table 3
Regression analysis model summary.

R square	Adjusted R square	Std. error of the estimate
0.162	0.066	4.3824451

Predictors: Constant, aggregates, w-c ratio, sand.
Dependent variable: 28 days mean compressive strength (S28)

Based on the results of correlation analysis influential factors were water-cement ratio, sand contents, and aggregate content in order. The w/c is most influential. The model on Table 4 showed the value of R-square is less and the standard error of estimate is high revealing that it could not be related the value of compressive strength of concrete solely based on proportion of ingredients used for making concrete. Others various factors should be considered while making a model such as cement brand, age of cement, workmanship, quality of ingredients etc. It will be efficient to consider the effects of various influential factors for reliability of prediction of compressive strength.

8.6. Control charts for production process

Control charts (Shewhart charts) were developed based on the compressive strength of concrete obtained from site. Mean and range charts were developed to check the control in production process of concrete.

For developing chart, the sample number used was 25, as 'Table for control chart constant'is available for 25 numbers of samples. In this study, first houses number 1 to 25 and secondly houses number 6–30 was used to create mean and range control chart. As per western electric rule, more than single data are out of control limit and the production is not in control. So the process should be corrected to produce concrete with desired strength. The variation in the ingredients may be the possible cause for uncontrolled production and could be corrected with proper guidance to achieve consistency in production Table 5.

Similarly, the value for control chart constant for houses 6 to 30 is given in Table 6.

Figs. 15-18 showed that, more than 15% of study sites, the observed mean and range were found to be out of control limits in both mean and range chart. Hence the process was said to be not in control revealing that the process for production of concrete with required strength was not in control and the proportionate of material was inconsistent. So quality assurance measures should be strictly employed, to make our construction consistent.

9. Conclusion & recommendation

9.1. Conclusion

- 80% of the houses sampled in Gaindakot Municipality comply with the minimum compressive strength of concrete as required by NBC of Nepal. It revealed greater improvement in strength factor for construction.
- There was a wide dispersion in dosage of ingredients. The worker was dosing ingredients of concrete their selves without knowledge of any systematic procedure resulting unsystematic concreting practice. Similarly the production process of concrete was not in control to produce concrete with consistent strength.
- There were multiple collinear effects, due to which it couldn't be related or predicted compressive strength of concrete based on dosage of ingredients.

9.2. Recommendations

- Formal trainings, regular supervision and monitoring from concern authority should be carried out for consistent in production process. The workers should be educated in formal way so as to improve the systematic mechanism of concreting to ensure controlled production process to give consistent strength as required.
- With lots of problems in workmanship discussed, 80% of the houses were constructed with minimum strength required by standard. So small effort might be adequate for consistent production.
- All the factors like age of cement, grade of cement, workmanship, quality of aggregates should be considered beyond proportion of ingredients for systematic prediction of compressive strength of concrete produced.

Table 4
Regression analysis coefficients.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	Beta		
1	Constant	40.469	13.2		3.066	0.005
	Water-cement ratio	−17.207	8.346	−0.395	−2.062	0.049
	Sand	0.047	0.04	0.234	1.165	0.255
	Aggregates	−0.091	0.084	−0.206	−1.086	0.287

Table 5
Control limits for mean and range chart (house 1–25).

Value of A2	:	1.023	(From statistical table for 3 data in one group)
Mean	:	23.67	(Mean compressive strength for houses 1-25)
Control limits			
Upper control limit	:		28.411
Lower control limit	:		18.930
Value of constants for range control chart.			
Value of D3	:	0.459	(for n=10 groups)
Value of D4	:	1.541	(for n=10 groups)
Mean Range	:	4.634	(Range of compressive strength value for houses 1-25)
Control Limits			
Upper control limit	:		7.141
Lower control limit	:		2.127

Table 6
Control limits for mean and range chart (House 6–30).

Value of A2	:	1.023	(From statistical table for 3 data in one group)
Mean	:	24.003	(Mean compressive strength for houses 6-30)
Control Limits			
Upper control limit	:		28.388
Lower control limit	:		19.618
Value of constants for range control chart.			
Value of D3	:	0.459	(for n=10 groups)
Value of D4	:	1.541	(for n=10 groups)
Mean range	:	4.634	(Range of compressive strength value for houses 6-30)
Control limits			
Upper control limit	:		6.605
Lower control limit	:		1.967

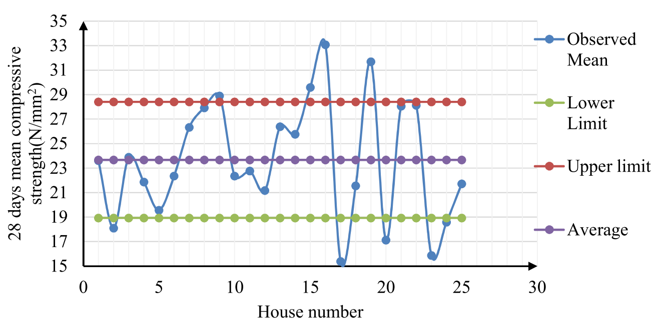

Fig. 15. Mean chart (House 1–25).

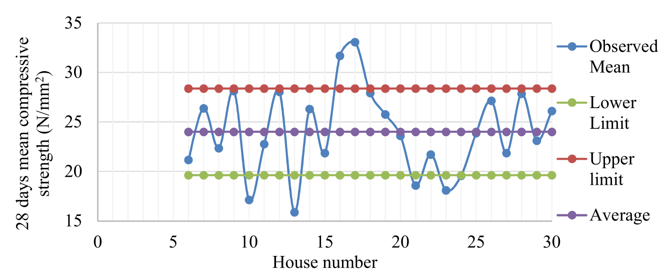

Fig. 17. Mean chart (House 6–30).

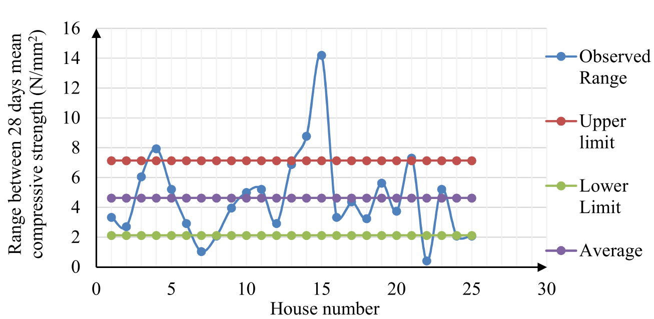

Fig. 16. Range chart (House 1–25).

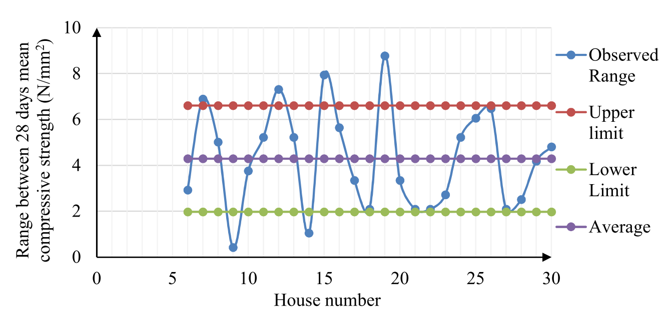

Fig. 18. Range chart (House 6–30).

Declaration of Competing Interest

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

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Further Reading

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