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Probabilistic Analysis of Strength of Structural Concrete for Post-Code Buildings in Developing Countries

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ABSTRACT: *Code compliance and quality construction remain a point of interest for developing countries. For structural vulnerability studies on reinforced concrete buildings, researchers usually adopt random strength parameters to represent the compressive strength of concrete for various structural members. This matter becomes a challenge if researchers are dealing to quantify the structural response of code-compliant buildings. Since the research on the response of code-compliant buildings is limited hence this paper aims at data collection and presenting the probabilistic trends in compressive strength variation of structural concrete being used or has been used in multiple projects of the federal capital city of Pakistan for code-compliant buildings. The data has been collected from well-reputed academic and commercial testing labs in the area for past 10 years (the timeline after implementation of BCP 2007). Compressive strength testing records of concrete cylinders for 28 days strength have been sorted for different structural members i.e., beams, columns, shear walls, slabs and footings separately. From the selected data, histograms have been plotted for each member category and mean values with standard deviations have been highlighted. Obtained results are further compared with anticipated design compressive strengths which were obtained from different tagged reports, design offices and resident engineers of the sites. The produced results would lead to true representation of structural strength of concrete for code-compliant buildings, to be further studied for structural vulnerability and risk assessments of the desired areas in developing countries.*

Keywords: Compressive Strength, Design Strength, Developing Countries, Code Compliant, BCP 2007

1. INTRODUCTION

Developing countries are facing exponential population growth, which has induced expansion in the construction industry. According to predictive analysis, by 2030, about 80% of the world's population will be urbanized (1). However, urbanization is quantified either through infrastructural development or by constructing new residential and commercial buildings, etc. Before the enforcement of seismic codes, most buildings were constructed without seismic safety provisions (2). Moreover, subsequent major earthquake occurrences like Nepal-India Earthquake (1934), Kashmir Earthquake (2005), and Balochistan Earthquake (2008) caused many causalities as well as financial loss (3). Eventually, these hazards resulted in the development and implementation of seismic design codes in most developing countries (4) (5).

Similarly, In Pakistan, the Building Code of Pakistan (BCP) was implemented with effect from 2007 thus leading to improved design practices with more resilient and less seismically vulnerable structures. Since 2007, several RC structures have been constructed in Pakistan, ranging from single to multi-story residential and commercial buildings.

Reinforced concrete (RC) is a vital construction material for different structures. Despite the inclusion of Reinforcement steel, concrete is highly heterogeneous, and its strength is sensitive to various factors. As established, a properly designed building needs quality construction management, hence there is a need to quantify the quality of construction to ensure resilient and safe structures. This paper aims to predict the concrete compressive strength variation caused by on-site human errors, such as poor concrete handling, delays in pouring, poor compaction of fresh concrete, uneven and leaking formworks, etc. Data has been collected from well-reputed academic and commercial quality testing labs for different structural members of various building projects in the federal capital city of Islamabad. The focus was laid only on the data related to construction after the implantation of BCP 2007 (Building Code of Pakistan). The sorted data has been further analyzed using normal distribution curves for each structural member and brackets for the compressive strength of concrete have been identified using a mean and standard deviation of the results.

2. LITERATURE REVIEW

In Nigeria, about 112 buildings collapse were reported between 1978 till 2008 (6). Similarly, between 2005 and 2006 almost 50 roof failures were reported in Germany, Austria, and Poland (7), resulting in major loss of life. Post-earthquake investigations enlightened many structural deficiencies either in the construction phase or designing phase, such as soft-story mechanism (8) (9), irregular plans and elevations, poor quality and low strength construction materials, provision of insufficient reinforcement in joints, weak column–strong beam, exposed rebars in structural members, anchorage and development length, insufficient lap splices, deficient or no seismic hooks, inadequate transverse reinforcement, etc. (10) (6) (11) (12) (13). Notably, the major causes of these building collapses were unsafe design and poor-quality assurance which resulted in materials strength reduction (11) (7).

On the other hand, Concrete is non-homogenous material, highly sensitive to field conditions, and requires proper handling and curing. Furthermore, preparing a uniform mix with desired strength requires an optimum water-cement ratio, compatible aggregate properties (14), and a suitable cement-aggregate ratio. Similarly, Concrete strength also depends upon factors like mixing technique, optimum vibrations and compaction, curing technique and temperature, external weather conditions, and concrete slump, etc. (15) (16) (17) If not properly handled, results will be segregation, slump loss, cold joints, air entrainment, workability issues, and insufficient water for the hydration process, and subsequently strength loss. As discussed, safe design needs quality construction. For Instance, countries like Turkey, Nepal, Nigeria, India, and Pakistan face successive building failures due to poor construction quality. Moreover, In Pakistan, delays in Consultant appointments, construction without detailed drawings (18) (12), and irresponsible labor attitude (19) (20) are common issues. Similarly, in countries like Nepal, Turkey, Nigeria, Iran, and India same substandard is practiced on the field (21) (9) (22) (23).

3. OBJECTIVE

From previous lines, importance of true identification of compressive strength of concrete is well established. This research aims to fill the research gap of the non-availability of realistic compressive strength of concrete for code-compliant buildings. The results of this research would give a more realistic insight into the structural vulnerability and risk studies of the areas in developing countries with updated building inventories.

4. METHODOLOGY

To predict the trend for variation in concrete strength for various developing countries, a Case study region is considered. Pakistan is seismically vulnerable due to the interaction of the three tectonic plates. In Pakistan, Islamabad city is considered as it lies in Zone 2B (5) and has a PGA Value ranging between 1.6g – 2.4g (5).

The researchers were able to collect the data for 10 years i.e from 2011 to 2021. Concrete Compressive strength test results from different construction sites and testing labs located in Islamabad city were collected and sorted accordingly for different structural members like beams, slabs, columns, shear walls and footings. Since the different sites were using different testing standards, so in order to homogenize the data, testing results of concrete cylinders with diameter of 150mm and a height of 300 mm were considered. The strength data of the beams, columns, slabs, footings, and shear walls was segregated as per available information. Outliers of the results for each structural member were identified and a data range was selected to plot the normal distribution curves such as for the beams and slabs, strengths were selected within the range from 1500 psi to 4500 psi, while for the column, footing, and shear wall strengths were selected within the range from 2000 psi to 5000 psi.

After data processing, histograms were plotted, and the average strengths were determined using simple arithmetic techniques. Similarly, standard deviation and variance were also calculated. The results have been presented in range form, rather than a single number so that structural responses for future studies could be predicted over poor to average and above average concrete properties accordingly.

5. DATA SAMPLING AND ANALYSIS

As stated above, data from different academic and site-specific testing labs was sorted, there were around 1205 samples which were segregated into the following 5 categories. The distribution for number of samples against each category is shown in Table 1.

a) Beams
b) Column
c) Slabs
d) Shear Walls
e) Footings

Table-1: Number of samples as per Category

Categories	**Samples**
Slabs	300
Beams	107
Columns	362
Footing	281
Shear Walls	155

This data was separated based on the tagged information available on the test reports. The segregated data was further plotted to achieve standard deviations using normal distribution curves. Plots for different categories as highlighted above are shown in Figs. 1 to 7.

Along the vertical axis, the number of concrete samples have been represented as frequency distribution of the class intervals. The concrete samples are divided into serval classes with a class interval of 400 psi. The comparison at the end has been made while considering the anticipated design compressive strength of concrete for different structural members as some of the reports were containing information design strengths. Also, a site survey was conducted from different structural designers to get the information above typical design compressive strength of concrete for various types of structural members. Under construction sites for concrete structures in oil and gas sector were also visited to interview the resident engineers about the target design compressive strengths of the different official use and residential buildings.

Parameters	Values (Psi)
Mean Value	3479
Class Interval	400
Standard Deviation	707

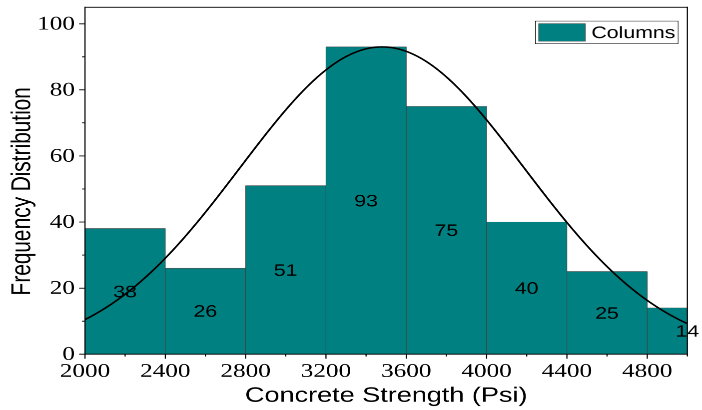

Fig -1: Frequency distribution of concrete strength for columns in the case study region

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Parameters	Values (Psi)
Mean Value	3769
Class Interval	400
Standard Deviation	745

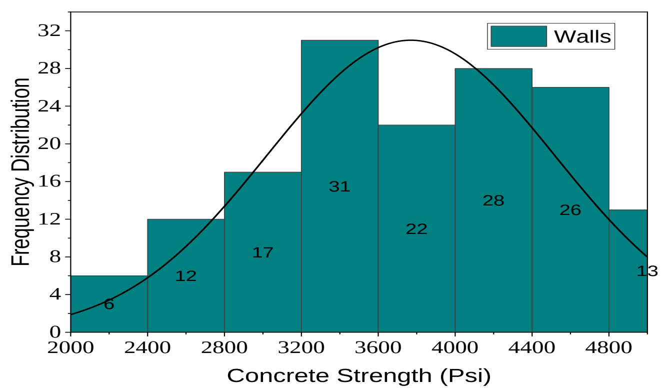

Fig -2: Frequency distribution of concrete strength for shear walls in the case study region.

Parameters	Values (Psi)
Mean Value	3454
Class Interval	400
Standard Deviation	743

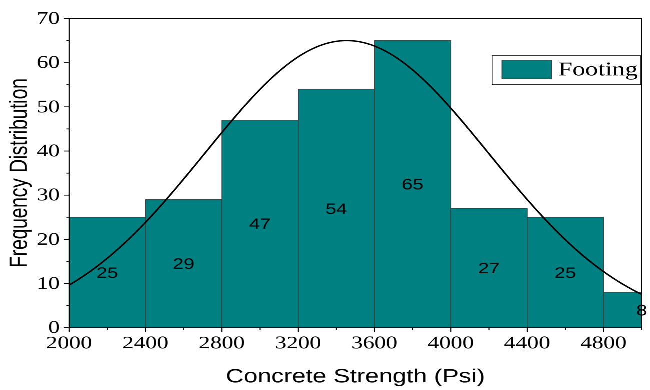

Fig -3: Frequency distribution of concrete strength for footings in the case study region.

Parameters	Values (Psi)
Mean Value	3074
Class Interval	400
Standard Deviation	634

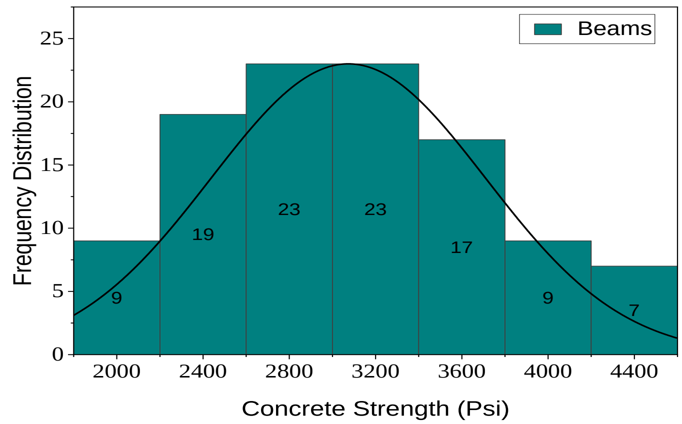

Fig -4: Frequency distribution of concrete strength for the beams in the case study region.

Parameters	Values (Psi)
Mean Value	3186
Class Interval	400
Standard Deviation	701

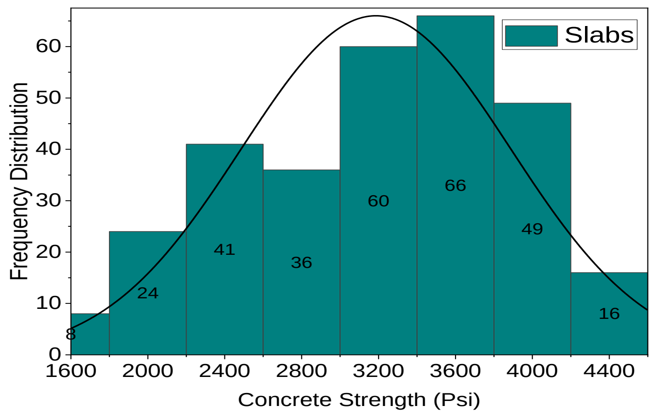

Fig -5: Frequency distribution of concrete strength for the slabs in the case study region.

Parameters	Values (Psi)
Mean Value	3463
Class Interval	400
Standard Deviation	729

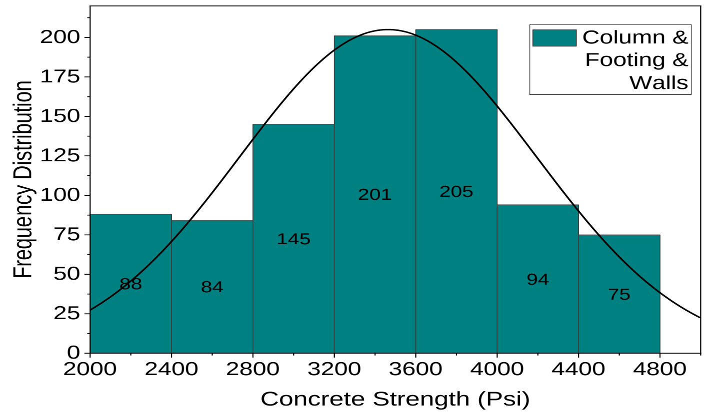

Fig -6: Frequency distribution of concrete strength for Columns, footings, and shear walls (combined) in the case study region.

Parameters	Values (Psi)
Mean Value	3156
Class Interval	400
Standard Deviation	686

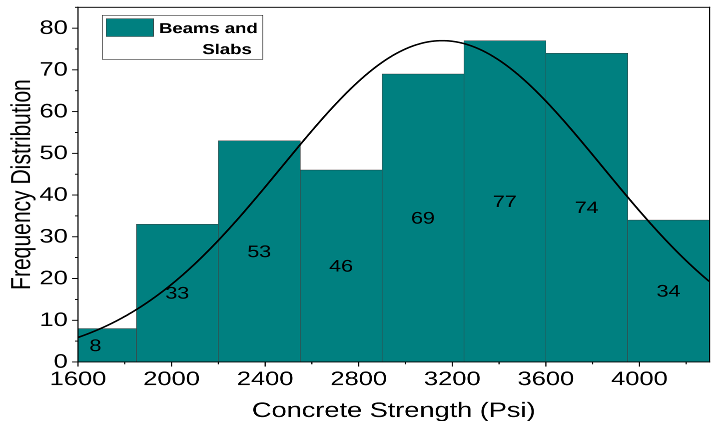

Figure -7: Frequency distribution of concrete strength for slabs and beams (combined) in the case study region.

As shown above, mean, and standard deviation for each category of the data set was identified and listed in following Table 2. The values in Table 2 also contain for upper and lower bound which have been calculated using mean plus 1 standard deviation and mean minus 1 standard deviation respectively.

Table-2: Summary of the data analysis for each category (units in psi)

Arithmetic Mean	Standard Deviation	Upper Bound	Lower Bound
Beams			
3074	634	3707	2440
Columns			
3479	707	4186	2773
Footings			
3454	743	4198	2711
Shear Wall			
3769	745	4515	3024
Slab			
3186	701	3887	2486

From data in Table 2, the results could very well be compared with the designed strength of code compliant buildings of the specific seismic hazard area. Like, as general practice in the case study region for reinforced concrete buildings, the design strengths for beams and slab are usually kept at 3000 psi while for footings, columns, and shear walls it is 4000 psi. From data in Table 2, it is identified that the mean compressive strength of all members is larger than 3000 psi but is significantly less than 4000 psi.

6. RESULTS AND CONCLUSION

Upon analysis of data, the following values are summarized for quick reference to readers.

a. Column concrete has a compressive strength variation ranging from 4707 psi to 3293 psi, having a mean value of 3479 psi and a standard deviation of 707 psi.
b. Shear wall concrete has a compressive strength variation ranging from 4745 to 3255 psi, having a mean value of 3769 psi and a standard deviation of 745 psi.
c. Beam concrete has a compressive strength variation ranging from 2366 psi to 3634 psi, having a mean value of 3074 psi and a standard deviation of 634 psi.
d. Footing concrete has a compressive strength variation ranging from 4743 psi to 3257 psi, having a mean value of 3454 psi and a standard deviation of 743 psi.

e. Slab concrete has a compressive strength variation ranging from 2299 psi to 3701 psi, having a mean value of 3186 psi and a standard deviation of 701 psi.

From data analysis, conclusion is appended in following lines. The trends are also shown in graphical form in Figs. 8 and 9. The conclusion has been drawn based on information obtained from some of the reports which were containing information about target design strength and upon feedback from some of the design offices.

a. For combined column, footing, and shear wall about 78% of the data is below design strength of 4000 psi.
b. For the shear wall, 57% of the data lies below design strength of 4000 psi.
c. For footing, 79% of the data lies below the design strength of 4000 psi.
d. For column 78.5% of the data lies below design strength of 4000 psi.
e. For slabs, 36% of the data lies below design strength of 3000 psi.
f. For beams, 48% of the data lies below design strength of 3000 psi.
g. For combined slabs and beams 39.8% of the data lies below the design strength of 3000 psi.

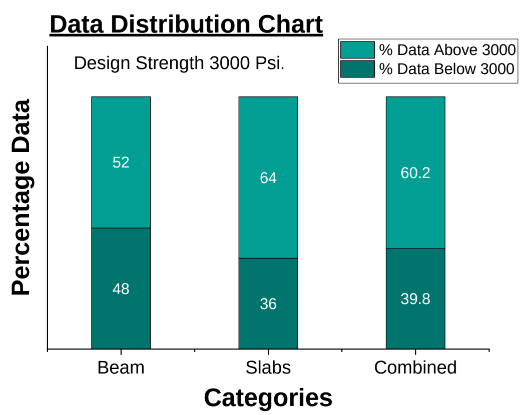

Fig -8: Concrete Strength sample's distribution for slabs, beams above and below 3000 psi.

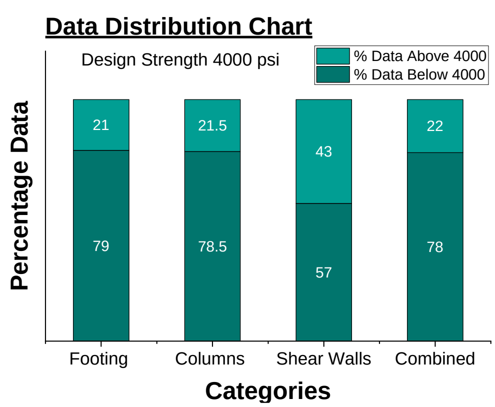

Fig -9: Concrete Strength sample's distribution for footing, columns, walls and combined above and below 4000 psi.

A considerable percentage of concrete compressive strength results have been found less than anticipated design strength of the members. The vast versatility of the concrete compressive strengths of different structural members of code-compliant reinforced concrete structures implies the significance of further studies. The presented data is a true representation of the samples hence the data set and ranges are recommended to be used in seismic analysis and risk assessment of buildings for the areas containing a significant number of code-compliant buildings inventory. The data could also be used for the performance-based analysis of a case study building with known parameters for concrete design strengths.

7. LIMITATIONS AND FUTURE RECOMMENDATIONS

The data set provided in this study only represents the concrete compressive strength for structures in the Islamabad area. Being a federal capital, it is believed that protocols for quality construction are better as compared to the areas where code compliance construction is not being supervised by any qualified engineer. It is assumed that the reason for reduced compressive strength could be among multiple possibilities as such data is very difficult to acquire from labs. For more specific reason identification, parametric studies by researchers could be done if desired. A more versatile area-based data could also be acquired to represent the concrete strength variations in different areas of the Pakistan.

8. ACKNOWLEDGMENT

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