EVALUATION OF DESIGN AND CONSTRUCTION PRACTICES OF REINFORCED CONCRETE BUILDINGS IN SAUDI ARABIA

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ABSTRACT. The evaluation of design and construction practices is an essential step in the development of design code for reinforced concrete buildings in the Kingdom. This study was conducted specially for this purpose and comprise two major programs: (1) a survey program which covers the design and consultative practices offered by engineering offices, and quality control procedures adopted by ready-mix concrete plants, and (2) a site inspection program for testing of concrete and reinforcement specimens and measurements of as-built sections and concrete cover to reinforcement at selected sections. The survey of professional practice reveals use of variety of codes of practice and standards by design offices and ready mix plants. The results of the statistical analysis of the strength of concrete and reinforcement are vital for reliability analysis leading to code calibration and determination of strength factors.

1. INTRODUCTION

The evaluation of design and construction practices is an essential step in the development of design code for reinforced concrete buildings in the Kingdom. This study was conducted specially for this purpose. It is a part of a study sponsored by King Abdul-Aziz City for Science and Technology under grant number AR-9-34 [1]. It comprises two major programs: (1) a survey program which covers the design and consultative practices offered by engineering offices, and quality control procedures adopted by ready-mix concrete plants, and (2) a site inspection program for testing of concrete and reinforcement specimens and measurements of as-built sections and concrete cover to reinforcement at selected sections.

2. SCOPE AND OBJECTIVES

The scope of the study is limited to reinforced concrete buildings. The study covered several cities in the Kingdom besides the three major cities: Riyadh, Jeddah and Dammam. The survey of design practice covered 44 design and consulting offices. It was aimed at collecting information on the standards and specifications, methods of design, specified values of material strengths, construction practices as seen by design offices, and site inspection and quality control at sites exercised by these offices.

The survey of ready mix concrete (RMC) plants covered 58 plants. It was aimed at collecting information on the standards and specifications, concrete grades, types and frequencies of various tests for materials and concrete quality, and precautions followed during hot weather concreting.

The site inspection and material testing program covered 102 construction sites. The main objectives of this program were: (1) evaluating the strength of locally produced concrete and reinforcement, (2) investigating the effect of prevalent methods of curing on the concrete strength, (3) evaluating the deviations in sectional dimensions of beams and columns from the specified values under prevalent practice of forming, and (4) measuring the concrete cover on main reinforcements as affected by the prevalent methods of steel placement.

3. DESCRIPTION OF THE STUDY

The scheme of the study is shown in Fig. 1. The survey program was performed by setting two forms of questionnaires for RMC plants and design offices. These forms were filled by the investigation team. The collected information were classified according to their sources as Central Province (CP), Western Province (WP), Eastern Province (EP), and Other Provinces (OP).

For the concrete strength testing, the program covered 995 random samples of concrete specimens which were classified according to the type of mixing and the nominal strength. Five types of concrete were identified as C35, C30, C20, MECH25 and MAN20. The first three types are ready-mixed concrete with nominal cube strengths of 35, 30 and 20 MPa. The last two types are mechanically and manually site mixed concretes with nominal cube strengths of 25 and 20 MPa, respectively. Strength tests were conducted after 28 days of standard curing.

For steel strength testing, the program covered 625 specimens of grade 60 ksi (413 MPa) steel bars of various sizes from 8 to 32 mm locally manufactured in Jubail and Jeddah. Two types of steel were identified (1) the hot rolled steel from bar size 12 mm to 32 mm, and (2) the hot rolled and cold straightened bars for bar sizes 8, 10 and 12 mm.

For the investigation of the efficiency of prevalent concrete curing, the program covered 124 samples of concrete from CP, WP and EP. Each sample consists of three pairs of cubes to represent the standard curing (STD) and the two most prevalent methods of concrete curing: water sprinkling two times a day for seven days (WSP), and water sprinkling two times a day for seven days with a burlap cover (SPC).

The site measurements program included two main tasks (1) measurement of the cross sectional dimensions of beams and columns and calculation of the deviations of the as-built dimensions from those specified in drawings. Four parameters were identified: deviations in the width and depth of columns (WC and DC) and deviations in width and depth of wide beams (WB and DB), and (2) measurement of concrete cover at the mid-height in case of columns (CC) and at bottom-face of beams at mid-span (BC) and top-face at both ends (TC).

4. RESULTS

The information obtained from design offices is analyzed from various aspects. The following observations can be made:

1. Variety of design codes and standards were adopted by design offices [2,3,4]. There is no single guideline in this regard which meets the local demand.
2. On the average, seventy three percent of the design offices employ working stress design.
3. The specified nominal cube strength of concrete is in the range of 15 to 28 MPa.

4. Supervision existed on 45 percent of the sites, 33 percent of which received continuos supervision.
5. Ready mixed concrete is about 90 percent in the three major cities while it is only about 58 percent in small cities.
6. Concrete consolidation with mechanical vibrator is about 70 percent in the three major cities while rodding was found to be the prevailing practice in small cities.
7. Concrete curing by water sprinkling (WSP) is very common (about 90 percent) while sprinkling with burlap cover (SPC) is about 10 percent only.
8. Concrete consolidation was seen to be inadequate in about 30 percent of construction sites.
9. Concrete curing was seen to be inadequate in about 25 percent of construction sites.
10. Early removing of forms was observed in about 15 percent of construction sites.
11. Soil test of construction sites existed in large projects only.
12. The most construction deficiencies were found in steel placement and detailing, honeycombed concrete, and plastic shrinkage cracking.

The information obtained on RMC plants reveals the following observations:

1. Variety of foreigner standards [5,6] were adopted for mix design and quality control procedures by RMC plants .
2. In general, concrete grade is defined by the cement content rather than the nominal strength. The most common cement contents are 350 kg/m^3 and 250 kg/m^3.
3. Most of RMC plants employ cube specimens for quality control.
4. Two types of concrete mixing were observed: the central mixing and the truck mixing.
5. About 50% of the RMC plants in the major cities implement good quality assurance plan. However, about 80% of the plants in small cities do not have testing laboratory.
6. The precautions employed by RMC plants in case of hot weather concreting are: use of chilled water or crushed ice, use of additives, covering of the truck drum, cooling of aggregate, and avoid casting in the peak temperature.
7. About 20% of plants in the major cities do not consider any precautions for the hot weather. This percentage increases to about 60% in the small cities.

The results obtained from the testing program are analyzed and the following observations can be made:

1. Table 1 presents the statistical characteristics of concrete strength including the type of the distibution function, the nominal strength X_n, the mean strength X_m, the distribution five percentile $X_{5\%}$ and the coefficient of variation COV%. In general, the values of the mean to nominal strength ratios are low. The values of coefficient of variations are high. The strength of concrete grades can be modeled by normal distribution except MECH25 which is closer to the log-normal distribution with mean to nominal strength ratio of 0.85 and coefficient of variation of 43%. Figs. 2 and 3 show the strength cumulative distribution functions of the five grades plotted on normal prabability forms. More details of modeling procedure are available in Ref. [1].
2. High concrete slumps are observed, for example, about 73% of the slump measures are more than 200 mm in case of MECH25.

Table 1 Statistical Characteristics of Concrete Compressive Strength

Type	Distribution	X_n	X_m	$X_{5\%}$	COV%

	Function	(MPa)	(MPa)	(MPa)	
C35	Normal	35	36.74	26.92	16.14
C30	Normal	30	30.60	20.38	12.74
C20	Normal	20	18.96	12.16	21.62
MECH25	log-Normal	25	21.23	8.97	42.96
MAN20	Normal	20	17.04	8.08	30.64

3. The five percentiles of concrete strength are lower than the nominal strength in all grades. The five percentiles should be at least equal to the grade nominal strength according to the British Standards and Euro-Code [3,7].
4. The variability in the strength of locally produced steel follows the log-normal distribution with high mean value of 503 MPa and coefficient of variation of 10.2 percent.
5. The values of the concrete strength ratios WSP/STD and SPC/STD are calculated. The mean values of these ratios, in CP are 0.84 and 0.93, respectively. This ratio should not be less than 0.85 according to ACI-318 [2]. This indicates that curing by water sprinkling two times a day for seven days without burlap cover in dry climate does not meet the ACI-318 [2] and ACI-308 [8] requirements.
6. The values of the concrete strength ratios WSP/STD and SPC/STD from WP and EP show that the mean values of these ratios are about 0.93 and 0.99. This indicates the influence of higher relative humidity on the curing process.

The deviations of the as-built dimensions from those specified in the drawings are calculated. The following observations can be made:

1. Small deviations are observed in case of the parameters WC, DC, and DB. Higher variation was observed in case of WB.
2. On the average, the probability of exceeding the tolerance limits specified by ACI-318 [2] is about 15 percent.

The results from concrete cover measurements are analyzed. The probabilities of exceeding tolerance limits that specified by ACI-318 [2] are calculated. The upper tolerance limit (UTL) is 40 mm whereas the lower tolerance limit (LTL) is 28 mm. The following observations can be made:

1. In case of the parameter CC the mean value is 26 mm and the probabilities of exceeding the UTL and LTL are 5.4% and 38% respectively.
2. In case of the parameter BC the mean value is 21.25 mm. A minimum value of 0.0 was observed. The probabilities of exceeding the UTL and LTL are about 0.0% and 93% respectively. This indicates that the protection cover for the reinforcement is in general far less than the specified values. This mainly attributed to the improper steel placement methods which are commonly employed by unskilled labors.
3. In case of the parameter TC the mean value is 45.39 mm. The probabilities of exceeding the UTL and LTL are about 76% and 8% respectively. This means that there is a high probability of the effective depth of compression reinforcement being less than the specified value. This adversely affects the flexural capacity of the beam at these sections.

5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be made:

1. The results of the survey program indicate that in the absence of unified design code and incomplete local standards in the field of construction, design offices and RMC plants employ various foreigner (mostly out-dated editions) standards, various rules of thumb, and/or personal judgment. This situation reduces the quality and increases serviceability problems. This indicates that there is an urgent need for unified design code and complete set of Saudi Standards in the fields of construction. The quality control requirements should be built in as an integral part of the national design code.
2. The possibility of non-standard construction practices (concrete mixing, consolidation and curing) should be considered in the national code. In such cases design code should permit the use of lower values of the resistance factor.
3. Concrete grades C35, C30 and C20 were well represented by normal distributions while the reinforcing steel was well modeled by log-normal distribution. The statistics of these two basic parameters are essential for the process of calibration and determination of resistance factors of the future design code.
4. The values of the 5 percentiles of concrete compressive strength are lower than the nominal values. This discrepancy can be attributed to errors in the mix design, poor quality control of concrete production and/or changing mix proportions at the site by adding water.
5. The mean value of WSP/STD ratio in Riyadh is 0.84 which means that most of the results are less than 0.85 the minimum requirement of ACI-318, while the mean value of the SPC/STD ratio was 0.93. The future design code should highly recommend the use of wet cover for concrete curing in hot and dry areas of the Kingdom.
6. The results indicate that locally produced reinforcing steel satisfies the strength requirements. The mean yield strength is 503 MPa with coefficient of variation of 10.2 percent.
7. In general, deviations of as-built dimensions from those specified in drawing are relatively small which means that sectional dimensions can be assumed to be deterministic parameters in the reliability analysis and code calibration.
8. The prevalent methods for steel placement are deficient which reduce the flexural capacity of the beam and/or reduce the protection cover for the reinforcement which usually causes corrosion and other durability problems.

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