BASIC STUDIES TOWARDS THE DEVELOPMENT OF A R.C. BUILDING CODE IN SAUDI ARABIA

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Abstract

The need for a local design and quality control code has been widely recognized in the Kingdom. The development of such a code will be of great benefit to both the society and the national civil engineering profession. Recently King Abdul-Aziz City for Science and Technology has sponsored a research for establishing a basic foundation for the development of a reinforced concrete building code for the Kingdom. This paper presents the theoretical background, the experimental and the analytical parts of the study. The initial findings of the study are reported in other papers.

1. Introduction

In the last two decades, the Kingdom of Saudi Arabia has witnessed a huge construction boom in both private and public sectors. During that period, the high demand for construction has diverted the attention from developing a unified local code for structural design and quality control. The construction process has been based on several international codes and part of it does not follow any standard. Consequently, problems related to reinforced concrete buildings are inevitable. Although the number of reported building collapses is very small, durability problems are very common [1,2] . The consequences of these problems varied from high maintenance cost to complete collapse or loss of utility of the building.

The need for the development of a local building code for design and quality control seems to be of atmost importamce. The purpose of such a code will be to provide a set of defined design and quality control requirements that assure structural safety and serviceability.

2. Studies Towards Code Development

Some steps have already been taken towards the development of a local design code. The Saudi Arabian Standards Organization has initiated a program for the setting such a code. In the program several international codes have been reviewed [3,4,5] and some experimental studies have been started [6]. Other studies towards code development can be summarized as follows:

1. Setting a general concept for the organization of code development [7].
2. Investigation of the properties of local materials [8,9].
3. Investigation of material behaviour under local environmental conditions [6,10].
4. Investigation of local problems related to reinforced concrete buildings [1,11].

Although the number of these studies is limited, their contributions towards the development of the local building code have been of great importance.

This paper describes the outlines of a research on development of a solid foundation for a local reinforced concrete building code for the Kingdom of Saudi Arabia. The outline includes the theoretical background, the experimental and analytical parts of the study.

3. Bases of Code Development

3.1 Types and Sources of Uncertainties

The process of structural design and construction is surrounded by many types of uncertainties which increase the possibility of structural collapse or failure in service. Identification of these uncertainties and their related factors is an essential step towards any code developement. In general, sources of uncetainties surrounding the design and construction process can be classified into several types including:

1. The natural variations of basic design parameters (loads and strength parameters). The loads parameters include dead and live loads, wind and thermal loads, and differential settlement of foundations. The strength parameters include material properties, structural dimensions and geometry. Natural variations of strength are highly influenced by the surrounding environmental conditions, level of wokmanship and methods of design, construction and quality control. Therefore, there is a high possibility of unfavorable deviations of load and/or strength parameters from their characteristic values. The characteristic values of the strength and load parameters are respectively defined as the 5 and 95 percetiles of thier distribution functions. Table 1 presents typical examples of statistics of basic strength parameters.

2. Uncertainties of the statistical modeling of design parameters and analytical modeling of structural behviour under different loading conditions.

3. Uncertainties of the consequences of structural collapse or failure in service including the economical consequences and danger to community.

4. The major source of uncertainties is the human errors committed during design, construction and utilization of the buildings. A human error is defined as the departure from the acceptable practice [12]. In conditions of unclear design and quality control requirements, poor workmanship, ignorance of the owner and/or the absence of supervision, all types of errors are expected. The result is a poor product which may collapse or fail in sevice in the early stages of its expected service life time. Examples of human errors are incomplete design, unclear design drawings, incorrect methods of construction and improper utilization of the building.

The main objective of the local building code is to deal with such problems in order to minimize their effects so that the desired level of structural safety is achieved. This can be accomplished by providing defined requirements for structural safety including material properties, rules of analysis and design, and quality control procedures which are all mutually dependent aspects of the safety requirement. Most of the related uncertainties are usually considered in the setting of the safety factors. However, the occurrence of human errors is usually controlled by applying the proper quality control and assurance methods during design and construction.

4.2 Theory of Structural Safety

International codes have applied probabilistic methods to guide the selection of load and strength factors which account for the variabilities in design parameters and give the desired overall level of safety. Considering a limit state, such as bending or shearing strength, safety is theoretically assured by assigning a small probability P_f to the event that the limit state will be reached i.e.,

$P_f =$ **خطأ!....خطأ!** $f_x (x_1,x_2, \ldots x_n)\ dx_1\ dx_2 \ldots dx_n$ (1)

in which f_x $(x_1, x_2, \ldots\ x_n)$ is the joint probability density function for the basic variables and the integration is performed over the region in which the limit state is exceeded [13,14,15].

Consider an application where the limit state function contains only two variables R, and Q, where R is the resistance and Q is the load effect. The failure event in this case and its probability are given by:

$R - Q < 0$, and

$P_f = P\,(R < Q)$ = خطأ! (2)

in which

F_R is the cumulative distribution function for R, and

f_Q is the probability density function for Q.

If both R and Q have normal distribution, then

$P_f = \Phi$ [خطأ!] (3)

where

R, σ_R are the mean and standard deviation for R,

Q, σ_Q are the mean and standard deviation for Q, and

$\Phi\,[\ ]$ is the standard normal distribution function.

3.3 Safety Format and Partial Safety Factors

Current international codes have applied level I reliability approach to provide the desired safety level. The approach includes two major steps: selection of safety format and calculation of safety factors considering the related types of uncertainties. There are several forms of the safety format which can achieve the desired level of safety. For example, the ACI Code [16] assigns several safety factors for load parameters, whereas a single factor is used to account for all uncertainties which may reduce strength of the structural element in a certain limit state. Other codes have adopted different safety factors for different strength parameters [3,13,17,18,19] . The first method is simple, however, it could be far from the economical use of materials. Table 2 presents a summary of safety factors applied by various design codes.

The process of calculation of safety factors includes several steps which can be summarized as follows:

1. Sampling, testing and site measurements of all related load and strength parameters. The sampling process should be random and representative of the current acceptable practice. The testing is usually performed according to the standard testing procedures.
2. Determination of the mean, standard deviation and the characteristic (nominal) values of these parameters.
3. Finally, using level I relaibility methods the partial safety factors can be expressed as follows [13] :

$$\gamma_i = \lambda_i / (1- \alpha_i \beta V_i) \quad (4)$$

where

λ_i is the mean to nominal (characteristic) ratio of the parameter i,
α_i is a parameter related to the formulation of the limit state function,
β is the relaibility index which indicates the desired safety level, and
V_i is the coefficient of variation of the parameter i.

Structural safety is assured by dividing the characteristic values of parameters by the corresponding safety factors. The obtained values are called the design values of these parameters which, in case of srength parameters, are expected to be about the 0.005 percentile of their distribution functions.

3.4 Construction Requirements

Design Codes include the basic requirements for the construction process. There are several methods of construction. For example, concreting procedure coprise of concrete mixing, transporting, casting, consolidation and curing. Placement of reinforcing steel includes cutting, bending, spacing, and fixing of the steel rebars. These tasks can be performed by different levels of workmanship and in accordance with different methods of execution. Variations of strength parameters are different for different methods of construction. Code writting committees should set defined requirements for the acceptable methods of construction.

International codes specify the tolerance limits of variations in most of the basic strength parameters including concrete strength [16,20], sectional dimensions and parameters related to reinforcing steel placement [21]. Mothods of construction that fulfil these requirements could be considered as acceptable practices. Within these practices different variations in strength parameters are also expected. These variations should be considered in the process of setting the design safety factors.

3.5 Quality Control Requirements

The design code should also include the basic requirements for quality control. International design codes have adopted different acceptance criteria for concrete and reinforcing steel. The size, shape, and number of needed samples are also different. For example, ACI Code [16] requires a single test (average of two cylinders) to be conducted for each 150 cubic yard (110 m^3) of concrete but not less than once a day. The CP110 Code [17] requires a single cube specimen where the rate of sampling depends on the volume of production.

In the Kingdom, cube specimens are commonly used, but no rate of testing is specified. For example, every ready-mixed concrete plant claims that it follows the requirements of an international code.

The Saudi Arabian Standards Orgnization has adopted acceptance criteria for reinforcing steel [22] . These requirements are widely used at ports and local steel factories.

3.6 Code Implementation

The process of development of a local design code includes several aspects which involve several parties including Government Agencies, Universities, Research Centers, and representatives from local designers, consultants, contractors and concrete and steel producers. The process of sampling, testing and modeling is a step in this process. Other actions should be taken to adopt and organize the process of code development. Public awarness is increasing and people have started to be concerned about the quality as well as the cost. It is therefore high time to initiate such a program.

4. Description of the Present Study

The present study includes the following three tasks:

1. A survey on causes and consequences of building failures in the Kingdom.
2. An experimental and analytical program.
3. A survey on the current engineering practice.

4.1 Survey on Building Failures

A survey on causes and consequences of building failures in the Kingdom is being conducted. The survey includes a detailed description of problems related to reinforced concrete buildings. It also includes investigation of the main causes of such problems. The survey will point out where the current practice has failed in providing the desired level of safety and serviceability. The initial findings of this survey will be reported in paper [23].

4.2 Testing Program

The experimental and analytical programs include a statistical description of the natural variations in the mechanical properties of local concrete and reinforcing steel. This will be accomplished by material testing and application of statistical approaches to model these variations. The compressive strength of concerte, being the most important property, has been emphasized in this study.

Sampling and testing program for concrete has been desiged to represent the concrete industry in the Kingdom. Major cities in the Kingdom have been divided into several groups according to their geographic locations. These groups are as follows:

Group One:	Riyadh area.
Group Two:	Dammam, Dhahran, Khobar.
Group Three:	Jaddah, Makkah, Taif.
Group Four:	Quassim, Hail, Madinah.
Group Five:	Abha, Baha, Bisha, Najran, Jazan, and Sharora.
Group Six:	Tabuk, Yanbu, Quryat, and Hafr-Albaten.

The total number of concete tests is about 1050 tests (each test consists of two cubes). These tests were divided among the different groups so that two hundred samples will be collecteded from each of the first three groups and a hundred and fifty samples will be gathered from each of the last three groups.

The sampling program has been designed in such a way as to assure the randomization of the process. Samples will be collected from job sites regardless of the type of project, cast structural elements, source or type of concrete. This will ensure randomization of the sampling process and provide a true representation of concrete used in construction all over the Kingdom.

Concrete sampling and testing have been started in many cities of the Kingdom. The testing programs in Riyadh, Western and Eastern Provincies are under the direct control of the project investigators, where testing is being conducted in the laboratories of KSU, KAU, and KFUPM. In other areas, the program is being implemented with the cooperation of the local municipalities and laboratories of Ministry of Public Works and Housing branches. Some of the initial findings of the testing program are presented in other papers [24,25].

So far, samples of three types of reinforcing steel have been collected from the local market in Riyadh. These types are: Saudi high tensile steel, Qatari high tensile steel, and Korian low tensile steel. Sixty samples have been collected randomly from each type. The obtained samples have been tested according to the Saudi Specifications SSA 107/1979. The total number of steel tests is planned to be about 1000 tests.

The experimental and analytical programs also include a statistical modeling of the natural variations in the dimensions of structural elemets and placement of reinforcing steel. This will be achieved by site measurements and feild inspection.

4.3 Survey of Current Engineering Practice

The study also includes a survey of the current practice of design, construction and quality control. The survey program constitutes an important part of the evaluation process. The collected information, in addition to the experimental program results, will be of great importance for reaching solid conclusions about the level of the current practice in the Kingdom. For this purpose several sets of questionnaires have been prepared. These questionnaires include special forms for:

1) Local municipalities in selected cities all over the Kingdom,
2) Design and consulting engineering firms,
3) Ready-mixed concrete plants,
4) Construction sites including special forms for concrete testing and site measurements.

The form for the local municipalities includes the following items:

a) General information about construction volume in the area for the last five years.
b) Types of construction materials in use.
c) The use of ready-mixed concrete as compared to site mixed concrete.
d) Common problems in conrete structures in the area.
e) General information about the local design offices.
f) General information about the workmanship in the area.

The form for the design and consulting engineering firms includes the following items:

a) General information about applied specifications and methods of design.
b) Design loads.
c) Values of material nominal strengths.
d) Typical dimensions of some structural elements.
e) The most important technical notes attached to the drawings.
f) Quality control demand.
g) Types and methods of control.
h) General description of construction process.
i) Errors in the construction process.
j) Errors in the design process.
k) Common problems in concrete structures in the area.
h) General inforamtion about the workmanship in the area.

The form for the ready-mixed concrete plants includes the following items:

a) General information.
b) Proportion of raw materials for different types of concrete mixes.
c) Applied methods of concrete quality control.
d) Precautions in cases of hot weather and transportation to long distances.

The form for the site visits includes the following items:

a) General discription of workmanship and used construction equipment.
b) Availability of an engineer.
c) Methods of quality control.
d) Main structural notes on the drawings.
e) General description of construction process.
f) Construction errors.
g) Design errors.
h) Major problems in buildings and their causes.

Figure 1 presents a block diagram showing the different tasks of the reseach.

5. Conclusions and Recommendations

The paper presented the objectives and design of a current research entitled "Development of a Solid Foundation for a Local Reinforced Concrete Building Code". Bases for the code development are also briefly discussed. Some initial findings are presented in other papers [23,24,25]

This study is a step towards the development of the local building code. The authors recommend that the research should continue to cover other studies inculding the following topics:

1. Development of tolerance limits for variations of strength parameters.

2. Development of probability-based criteria for the acceptance of concrete strength.
3. Investigation of the strength variation of R.C. concrete elements in different limit states.
4. Investigation of the variations of load parameters.
5. Development of design safety format and safety factors on the basis of level I reliability methods.

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