ANALYTICAL REVIEW OF 125 CASE HISTORIES OF BUILDING FAILURES IN THE KINGDOM

A. M. Arafah*, G. H. Siddiqi*, A. A. El-Tayeb* and A. Al Yosef*
*Department of Civil Enginering, King Saud university, Riyadh, Saudi Arabia

ABSTRACT. The term "failure" besides structural collapse, encompasses several cases of nonconformity with design expectations or requirements such as foundation settlements, member deformations, cracking, corrosion and leakage. Many of these building failures can be traced to design errors, sloppy construction practices and/or inadequate construction supervision. This study presents extracts of building failures of various kinds from 125 case histories and identifies their major causes and the resulting consequences. It also points to the shortcomings of the prevalent construction practice in fulfilling the minimum safety and serviceability requirements.

1. INTRODUCTION

The extent of failure in concrete buildings constructed in recent past (within two decades) is so large that retrofitting and restoration operation runs into hundreds of millions of Saudi Riyals. A significant portion of this is spent on restoration of structural adequacy. The term "failure" besides structural collapse, encompasses several cases of nonconformity with design expectations or requirements such as foundation settlements, member deformations, cracking, corrosion and leakage.

Many of these building failures can be traced to design errors, sloppy construction practices and/or inadequate construction supervision. The term "human error" is defined as the departure from specified code of practice or engineering practice acceptable to the profession.

This study presents extracts of building failures of various kinds from 125 case histories and identifies their major causes and the resulting consequences. It also points to the shortcomings of the prevalent construction practice in fulfilling the minimum safety and serviceability requirements. This information , it is hoped, is of educational value to engineering profession.

2. PREVIOUS STUDIES

2.1 International Studies

Among the earlier studies of structural failures is the study of failures of concrete structures carried out by the American Railway Engineering Association [1]. The study covered failures over 25 years and classified the causes under the headings: improper design, poor materials or poor workmanship, premature loading or removal of the forms before complete setting and, subsidence of foundations, fire, etc. The final conclusion of the study was that all good concrete construction should be subjected to rigid inspection. It should be insisted

upon that the inspection shall force the contractor to follow out the specifications to the most minute details.

American Concrete Institute published a monograph [2] in which the following general categories of failure causes were pointed out: design deficiencies, problems during construction, with special attention to form work. The most common design deficiencies leading to failures were attributed to errors in assumptions regarding loading and flexural conditions, along with poor detailing and drafting, careless treatment of connections between members, improper location and spacing of reinforcing bars and splices, and inadequate attention to thermal and shrinkage effects. Among the construction conditions that cause failures are: inadequate overall supervision and inspection, poor mixing and placing practices, and cold and hot weather concreting.

Matousek [3] published the results of a survey on 800 European failures. The analyzed failures totaled 40 million US. Dollars in direct damage, 592 people were injured, and 504 killed. The survey indicated that the cause of failures can always be found in human unreliability. The main causes of failures are attributed to the misjudgment of unfavorable influences such as natural environment, construction procedures, material properties and false dimensions or locations.

A similar survey of concrete structure errors in North America was conducted by ACI Committee 348, Structural Safety [5]. Two hundred and seventy-seven cases of errors in concrete structures were reported. In general, the survey showed remarkable parallels to the results of the European Survey [3].

The Construction Industry Research and Information Association, CIRIA, published the results of a pilot on 120 building failures in the United Kingdom [6]. The objective of the study was to establish reliable information on building failures and analyze it to help in minimizing structural inadequacy in the future. The CIRIA data indicated that in buildings which failed by unserviceability, the condition resulted primarily from cracking and excessive deformation caused by settlement, shrinkage or creep, or thermal movement. The larger portion of failures appeared to have their origin in the design process and mainly attributed to "grossly inadequate appreciation of loading conditions or real behavior of the structure". Bad erection procedures were next in importance in causing failures. The absence of a qualified engineer with effective overall technical responsibility in charge of the project was indicated as a further weakness. The average economic consequence of failure was about 50% of the original cost.

Melchers et. al. [7] made a comparison of the findings of the ACI Survey (Canadian Data) [5], the European study [3], and the British study [6], according to type of failure mode, the structural elements affected, the time of failure, the prime causes of failure, and the reasons for their occurrence. The comparison indicated that: there is a remarkable agreement between the observed types of failures. For serviceability failures, the comparison indicated that cracking in concrete structures, and excessive deformation generally are the most severe problems encountered. Regarding the causes of failure, the comparison shows that human error is a principal cause of failures.

2. 2 Local Studies

Rasheeduzzafar et al. [8] in a survey on the conditions of 42 concrete framed structures located in the Eastern Province found that an alarming degree of concrete deterioration in the form of cracking and spalling due to corrosion of reinforcement; sulfate attack; salt

weathering; and cracking due to shrinkage, thermal gradients, and aggregate-cement reactivity. The main causes of deterioration are attributed to the severe environmental conditions, poor construction practices, and poor material.

A survey of deteriorating buildings in Jazan town was conducted by the Ministry of Municipal and Rural Affairs [9] as a part of a study to identify deficiencies in engineering practice leading to structural problems in buildings. Nearly 10% of damaged buildings surveyed suffered from subsidence. Of the remainder, common deficiencies are spalling of concrete due to steel corrosion, concrete cracking due to thermal and shrinkage movements. The study indicated that corrosion is mainly attributed to grossly inadequate cover to reinforcing bars, poor concrete quality, use of sea water or chloride contaminated aggregates in concrete, and the aggressive nature of the environment [9].

Bayazeed [10] in his survey on 30 existing buildings and 40 were under construction found that 22 of the existing buildings and almost all those under construction had structural defects. The common failures were serviceability related problems such as cracking and excessive deflection. Placement of reinforcing steel and concreting practices are the most dominant types of errors.

3. CURRENT STUDY

3.1 Sources of Information

The technical reports on building failures in the archives of Governmental agencies and constructing firms were the main sources of information. Beside this, information was sought from design offices in the major cities of the Kingdom. A questionnaire was developed for the purpose to assess causes and consequences of failure in the format employed by ACI Committee 348 on Structural Safety and reported by Fraczek [5]. A total of 125 case of histories of failure were records in this survey. Sixty cases were reported from the Ministry of Public work and Housing, 53 cases from consulting offices and universities, and 12 cases from the Ministry of Interior.

3.2 Findings of the study

The survey indicated that the main causes of failures are attributed to human unreliability at the stages of design, construction and utilization of the buildings. A total of 322 errors were detected from the 125 case histories. About 34 percent of cited errors are classified as design errors where 41 percent are considered as construction errors. The remaining errors are those related to misuse errors.

Design errors leading to failures are listed in Fig. 1. One third of these errors involve faulty analysis and/or design procedures. Construction phase was responsible for 41 percent of all errors reported. Types and frequencies of these errors are shown in Fig. 2. The majority of construction errors involved defective concrete quality and concreting procedure each accounted for 24 percent of construction errors. The main causes of failures during the utilization phase are shown in Fig. 3. The rise in ground water level was the most dominant cause of failure accounting 47 percent of utilization errors reported. The relative frequency of all types of errors are listed in Table 1 .

Table 2 provides a summary of the affected ultimate limit states. Tension in concrete and reinforcement are seen to be the most affected characteristics. The most affected serviceability limit states are listed in Table 3. These failures are cracking, leakage, deterioration, and spalling involves nearly 57 percent of the cases.

The age of buildings at which the failures were detected are shown in Table 4. Fifty six percent of all failures occurred within the first 10 years of occupancy while only 3 percent of the cases were detected at age more than 30 years.

The remedial measures suggested in the case histories are listed in Table 5. Seventy six percent of cases were recommended to be rectified. Cases recommended for complete or partial demolition accounted for 22 percent. The total percentage of demolition and rectification exceeds 100 percent because in some cases partial demolition as well as rectification were both recommended.

4. CONCLUSIONS

The study identifies types and frequencies of human errors from 125 case histories of failure during the design, construction and operational stage of reinforced concrete buildings. These occurrences are due to below par professional practice, acts of omission and commission negligence and deficient specifications. Results indicate that there is an urgent need for formulation of a code of practice to provide effective guidance and exercise control over the profession conducts.

Table 1. Distribution of Design, Construction and Utilization Errors from 125 Case Histories (CH).

Errors	Percent of 125 CH
Change in ground water level	12
Erroneous analysis and/or design procedure	10
Defective concrete mix	10
Defective concreting procedure	10
Defective placement of reinforcement	7
Misuse or improper maintenance	7
Omission or improper application of water-proofing	5
Defective curing or protection	5
Overloading/change of occupancy	5
Inadequacy of design load	4
Not conducting of soil investigation	4
Erroneous working drawings	4
Deficient specifications	2
Erroneous shop drawing	2
Erroneous interpretation of working drawings	2
Calculation mistakes	1
Early removal of form or reshoring	1
Improper erection of forming/ shoring	1
Improper refurbishing	1

Table 2. Consequential effects (CE) on Ultimate Limit States (ULS)

Affected ULS	Percent of CE	Percent of 125 CH
Tension in concrete	27	53
Tension in reinforcement	16	32
Bond or anchorage	11	22
Bearing	11	22
Beam shear	10	21
Compression in steel	8	17
Stability	5	9
Punching shear	2	4

Table 3. Consequential effects (CE) on Serviceability Limit States (SLS)

Affected SLS	Percent of CE	Percent of 125 CH
Cracking	27	78
Deterioration	16	46
Leakage	14	40
Spalling	13	38
Settlement	10	28
Reduction in load capacity	8	25

Live load deflection	4	13
Loss of utility	3	9
Creep deflection	2	7
Displacement	2	6
Vibration	1	4

Table 4. Failure detection age from 98 of the total case histories

Building Age (Years)	Percent of 98 CH
1 to 5	34
6 to 10	22
11 to 15	10
16 to 20	11
21 to 25	16
26 to 30	4
31 to 35	3

Table 5. Remedial measures (RM) recommended in the case histories (CH)

Solution	Percentage of 125 Cases
Rectification	76
Demolition	22
Partly Demolition	7
Limited Utilization	2

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Figure 1: Design errors (DE) from the case histories (CH)

Figure 2: Construction deficiencies (CD) from the case histories (CH)

Figure 3: Operational abuses (OA) from the case histories (CH)

WD: Working drawings WP: Water proof