"Failure Modes of Concrete Structures"

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Introduction

On 5 August 2004, the Civil & Structural Engineering Technical Division of The Institution of Engineers, Malaysia in conjunction with IStructE, Malaysia Division organised an interesting talk entitled "Failure Modes of Concrete Structures". The renowned speaker is Professor Leslie A. Clark, Head of Civil Engineering Department at the University of Birmingham and the Past President of IStructE, UK. The talk was attended by 171 participants.

The talk covered the use of structural design codes in general, and briefly addressed issues of strength, stiffness and durability of structural elements, and checking of the ultimate and serviceability limit states of individual members. Structural design is thus highly codified and applying past knowledge gained from practical experience and research. Hence, the practice of codified design encourages lack of consideration of real structure's behaviour. Moreover, other aspects not covered by code of practice are also ignored.

However, in reality, when structural failures occur in practice they often involve whole structures, and not individual elements. Structural failures are also often of a very sudden non-ductile nature. These aspects of structural behaviour and failure modes are not well covered in the design codes, hence there is an immediate need to consider rational ways of designing to provide adequate robustness, ductility and redundancy in concrete structures.

Types of Failure

Four major factors for structural failures are discussed and it was stated that failures could be due to a combination of the following four factors:

a) Design code deficiencies
b) Design errors
c) Construction deficiencies
d) Deterioration

The common features of structural failures are:

a) Sudden and brittle
b) Involve significant parts, if not all, of the structure

Typical examples of structural failures and failure mechanism were discussed and highlighted by the speaker. These examples are:

a) Hotel New World, Singapore
b) Royal Plaza Hotel, Thailand
c) Wilkins Air Force Base, USA
d) Ronan Point Flats, UK
e) Ynys - y - Gwas Bridge, UK
f) Pipers Row Car Park, UK
g) World Trade Center, USA

As a result of the brittle nature of structural failures, consideration have to be given to the relationship between robustness and ductility of concrete structures. Robustness is defined as

"The damage suffered by a structure as the result of an unforeseen event, which should not be disproportionate to the cause."

Unfortunately, robustness is a term, which could not be quantified. Hence, there is a need to consider it separately.

Design for Robustness

The structure has to be capable of withstanding two different and independent sets of actions.

a) It should be able to support a defined ultimate load
b) It should be able to absorb, without collapse, a defined energy input. Hence, the required ductility can be determined.

The three elements in ductility as discussed are:

a) Concrete – which has limited ductility especially in design for high strength. As such, concrete failure may be restrained by reducing the failure strain in concrete.
b) Reinforcement – which is the main element for ductility.
c) Detailing – which also includes anchorage of structural elements.

Although there is no specific ductility requirements in BS81 10 and BS5400, the aspects of ductility have been envisaged and will be covered in Eurocodes EN1992-1-1 for Buildings and EN1992-2 for Bridges. Also the reinforcement production (in terms of performance characteristics, threshold limits, test methods and attestation of conformity) will be covered by EN 10080 (which is due for publication by 2005).

The Normative Annex C of EN 1992 specifies the ductility requirements of Classes A, B and C structures. The following design conditions are covered by the design applications of the classes of structures.

Class A
- moment redistribution < 20%
- no plastic analysis

Class B
- moment redistribution < 30%
- plastic analysis

Class C
- seismic condition

Slides of failed structures with high and low ductility reinforcement and fractured reinforcement were shown. Also the effect of corrosion deterioration of the reinforcement was discussed using the following graphs:

a) Total force versus micro strains for reinforcement bars
b) Effect of corrosion of reinforcement properties
c) Effect of corrosion on bar ductility
d) Effect of corrosion on beam ductility

In summary, the talk on failure modes of concrete structures covered the following points, which should be noted for design considerations:

a) The collapse of structures tend to be sudden, non-ductile and non-localised.
b) Design codes do not cover ductility and robustness adequately.
c) There is a need for a rational design method.
d) Concerns persist in design code requirements for shear resistance.
e) Significant effect of corrosion on reinforcement bars may occurs due to poor detailing or even inappropriate design.

Finally, a lively question and answer session followed on immediately after the talk was concluded. The queries raised cover a wide range of topics, such as,

a) the definition of "ductility" of structures,
b) the need for research into types of deterioration in structures,
c) bonded construction and grouting of tendons,
d) current trends adopted for shear design worldwide,
e) the use of computers by young engineers and the need for a clear understanding on behaviour of structures, and
f) awareness by engineers, of up-to-date knowledge in structural design and not "hiding" behind the design codes.

The talk officially ended at 7.30 p.m., and the speaker was given a rousing claps of appreciation. A token of appreciation was presented to the speaker by the organisers, the IEM Civil & Structural Engineering Technical Division.