THE EGYPTIAN SOCIETY OF ENGINEERS
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Short Course

ON

SEISMIC DESIGN OF REINFORCED CONCRETE STRUCTURES

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SEISMIC DESIGN OF REINFORCED CONCRETE STRUCTURES

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PREFACE

The main objective of this two-day short course is to provide in-depth information and new developments on the behavior, response, analysis and design of reinforced concrete structures under seismic loads. It is assumed that the participants have basic knowledge in the behavior, mechanics and design of reinforced concrete structures.

The notes which form the basis of this two-day course can not be covered in all their details during the lectures. Because of time constraints, the highlights of the notes and accompanying materials are presented to the participants for future self study. Two appendices contain supplement information are presented at the end of the notes. An excellent reference, which is highly recommended as a supplement material for this notes, is the textbook entitled "Seismic Design of Reinforced Concrete and Masonry Buildings" by Paulay and Priestley published by John Wiley in 1993.

My thanks are due to Professor Fatahallah El-Nahas for welcoming the idea of the short course, the Egyptian Society of Civil Engineers for sponsoring the course and Professor Omar El Nawawy for his effort in preparation and organization of this course.

Ahmad A. Hamid
Philadelphia in November 29,1996

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Introduction to Concepts of Seismic Design

1.1 Seismic Performance : A Review

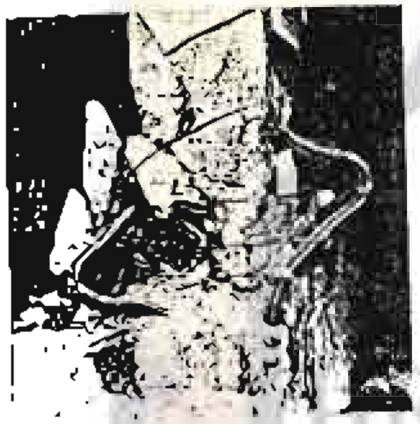
Many parts of the world are seismically active. Recently, Egypt is experiencing some seismic activities. Conceptually, design for earthquake forces is quite different from design for other loads and special provisions should be taken into consideration for seismic design. Four important features of earthquake loads that make seismic design unique and quite different from wind design: 1) forces are inertia-induced (function of mass distribution); 2) forces are related to structural stiffness and ductility (function of deformation state); 3) loads are fully reversed and 4) rate of loading is very high and duration is very small (5-30 seconds).

Despite the increased awareness and understanding of factors influencing the seismic behavior of structures, significant desparity between earthquake engineering theory and its application in design and construction still prevails in many countries. The damage and collapse of many buildings, as shown in Figure 1.1, testify to this disparity. Soft-story sway mechanism (Fig.1.1-a), lack of confinement of reinforced concrete columns (Fig. 1.1-b) and failure of beam-column connection (Fig. 1.1-c) are examples of inadequate seismic design.

With increased research and with gaining significant knowledge from studying performance of buildings after earthquakes the design philosophy has been shifted from emphasis on strength (resistance to large seismic forces) to emphasis on ductility (evasion of seismic forces). Inelastic structural response becomes an essential reality in the assessment of structural design for earthquake forces.

It has been recently accepted that seismic design should encourage structural forms that are more likely to possess adequate ductility. This is related to aspects of structural regularity and careful choice of locations where inelastic flexural deformations may occur (refer to as locations of plastic hinges). Therefore, it is essential in seismic design to assure that the required shear strength must exceed the required flexural strength. This will suppress shear deformation and insure that shear failure which is a brittle mode will not occur. Proper conceptual design and aspects of adequate detailing are critical for satisfactory seismic performance of buildings. It is to be noted that the cost of implementing special provisions for seismic design is minimal compared to the overall cost of the structure.

a- Failure due to soft-story sway mechanism



b-Failure of a column due to inadequate confinement

c- Beam-column connection failure

Figure 1.1 Example of failure as a result of inadequate seismic design

1.2 Seismic Design Limit States

It is common to consider different levels of protection addressing functionality, level of damage and prevention of loss of life. The degree of which levels of protection can be afforded is a matter accepted level of risk and economic constraints. It is the challenging job of the structural engineer to optimize between the degree of protection and cost. The following are the common three limit states considered in seismic design:

1. Serviceability limit state
It is expected for frequent earthquakes inducing comparatively minor intensity of ground motion not to impair the function of the structure (the operation). This means that damage needing repair should occur to the structure or the non-structure components, including contents. The design should concentrate on limiting the deflection and inter-story drifts and ensuring adequate strength of all components to resist the earthquake- induced forces while remaining essentially elastic. No significant yielding of the reinforcement resulting in large cracks nor crushing of concrete should result. The frequency with which the occurrence of an earthquake corresponding to the serviceability limit state will depend on the importance of preserving the functionality of the structure.

In certain situation serviceability of the structure may be controlled by loads and effects other than earthquakes. For example, wind loads with 10 years return period may be used to check compliance with interstory drift limits under service conditions.

2. Damage control limit state
In this state repairable damage is allowed. Yielding of reinforcement and crushing of concrete may occur which will require repair that is feasible and economically affordable. Ground shaking of intensity for this limit state has a low probability of occurrence during the expected life of the structure. It is expected that after the earthquake the structure can be successfully repaired and reinstated to full service.

3. Survival limit state
The most important design limit state which should control the design is survival. Modern seismic design codes are based on the criterion that loss of life should be prevented even during the strongest ground shaking feasible for the site. Damage will be irreparable, but collapse must not occur. Large inelastic deformations are expected and relatively large displacements should be accommodated without significant loss in lateral force resistance and that integrity of the structure to support gravity loads is maintained.

It is to be noted that the boundaries between these three limit states can not be defined precisely. There is uncertainty involved in the design forces recommended by building codes and the design should be aimed at accommodating such an uncertainty. The capacity design process (see section 1.6) allows the designer to achieve this goal.

Usually, one limit state controls the design. this depends on the intensity of the earthquake forces and the accepted levels of risk.

The specific structural properties that need to be considered in conjunction with the above three limit states are: stiffness, strength and ductility.

1.3 Structural Response

The most important structural properties that are considered in the seismic design and are associated with the three limit states are *stiffness, strength* and *ductility*. These are indicators of the structural response of a reinforced concrete element expressed in terms of the relationship of load and displacement, see Fig. 1.2

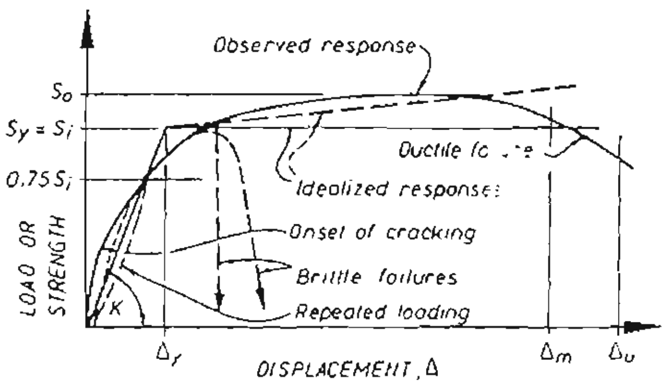


Figure 1.2 Typical load-displacement relationship for a reinforced concrete flexural member

Stiffness
Estimate of member stiffness is required to calculate deformation under load. For reinforced concrete member the effect of cracking should be considered for a realistic estimate of stiffness. This is critical if a serviceability criteria to be satisfied with a reasonable degree of confidence. The load-displacement relationship shown in Fig. 1.2 shows nonlinear response after cracking. For the purpose of design a bi-linear relationship may be used. The slope of the line, K, corresponding to 75% of the yield load can be used to quantify stiffness. This value may be used to calculate elastic deflection corresponding drift for code compliance and for calculation of structural stability (P-delta effect).

Strength
The structure must have adequate strength (S_i in Fig. 1.2 to resist internal forces generated during the elastic response of the structure and to prevent major damage. This seismic action combined with those due to other loads on the structure, such as gravity, will lead to the proportioning of the structural members.

Ductility
To minimize major damage and to prevent collapse (ensure survival) the structure must be capable of sustaining a high proportion of their initial strength while allowing large deformation beyond the elastic limit. The the ability of the structure or its components to offer resistance in the elastic

of the center of rigidity is dependent upon the location and geometry of the lateral load resisting elements.

Displacements due to story twist, when combined with those resulting from floor translations can result in excessive interstory displacements which may be difficult to accommodate. Therefore, the design engineer should make an effort in the early stage of planning to minimize the distance between the center of rigidity and the center of mass. Symmetric structures will experience very little torsion and will behave in a predictable manner.

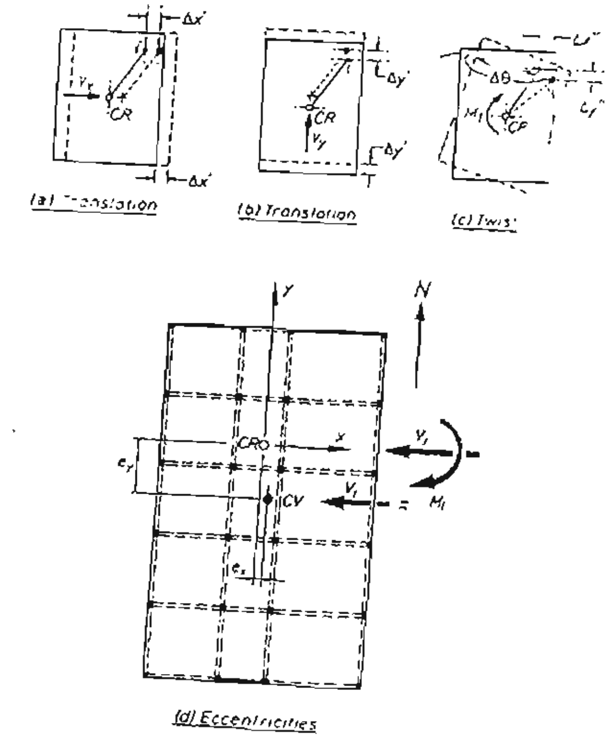


Figure 1.4 Translation and twist modes of deformation under lateral loads

1.5 Influence of Building Configuration on Seismic Response

In seismic design the choice of building configuration can play a major role in determining the seismic response. It is crucial in the early phase of planning the building to consider the effect of configuration, both in elevation and in plan, on seismic load determination and structural response.

A more effective seismic design can be achieved by closely observing the following fundamental principles pertaining to building configuration:

1- Simple, symmetric and rectangular plans are preferable. Buildings with articulated plans such as T and L shapes should be avoided or subdivided into simpler forms, see Fig. 1.5