International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Earthquake Resistant Design & Construction Provisions for Reinforced Concrete Structure

Mahipal Burdak

Structural Consultant Engineer, Dara Construction Company Jodhpur, Rajasthan, India

Abstract: ***Seismic design concept of a structure in many ways different because of the uncertainty of the earthquake loading and its behavior. Therefore, a limited damage is permitted without allowing the collapse of the structure when subjected to the most severe earthquake predictable at the site thus ensuring safety of lives and its utility. Accepting the opportunity of damage, on the basis that it is less luxurious to repair when hit by an earthquake rather than making the structure earthquake damage resistant. This thought results in a reasonable design, which will be vulnerable to earthquake damage but will not collapse in an event of severe earthquake. These design criteria are also based on deliberations of allowable stresses, permissible inflexible strain, anticipated factor of safety against collapse, acceptable damage etc. Intelligent framing system, careful design & construction detail can vastly improve the performance of structure to resist earthquake. For very important structures/projects such as nuclear power plants, high dams, high rise buildings, long span bridges, etc. & their high cost requires high degree of safety than the ordinary structures & therefore requires special design criteria. The major developments in basics philosophy & principles of seismic design, development of normalized shape of response spectra and its application, design for strength & ductility, developments in 2D/3D mathematical models and their behavior, soil-structure interaction and dynamic analysis, reinforcement detailing, integrity and continuity of structure, properties of material, energy dissipating devices, Regular mass and stiffness distribution, increasing the plastic deformation capacity and good quality construction and workmanship. This review is presenting the future trends in earthquake resist design features in RCC structure.***

Keywords: Seismic demand, computed load, earthquake proof, response spectra

1. Introduction

The basic design principle, which any earthquake-resistant structure must satisfy, is the following:

Seismic demand ≤ Computed capacity

Seismic demand is the consequence of the earthquake on the structure. 'Computed capacity' is the structure's capability to counterattack that effect without failure. In short, the structure should not fall down. It should be noted that in the dynamic loading environment (formed by earthquakes), the claim and capacity of a structure are very strongly attached. One unseen requirement in the standard shown above is that a structure must meet all functional requirements at least economic cost. Unfortunately, it must be documented that no structure can be completely safe. One, we cannot perfectly forecast the seismic demand due to earthquake loads; two, the calculated versus actual capacity of a intended structure may not match perfectly; three, there could be human errors in design and construction. Earthquake loads are inertia forces resultant from ground activities and they impose certain stresses on the structures related to strength, ductility and energy. The magnitudes of these demands are highly variable and are reliant on the seismicity of the region and the dynamic features of the structure – which is why they cannot be forecast precisely and can be expressed only in probabilistic terms. The design demand is the predicted maximum value of seismic demand for design resolutions and actual distribution designates that there is some probability that it would be exceeded. Similarly, the calculated capacity is obtained by accepted methods of analysis and design. The circulation for capacity suggests that there are some chances that the actual as-built capacity may be less than the computed value. However, due to extra obscurantism in design procedure, there is greater chance that it would be larger. Where capacity is less than demand main efforts in earthquake engineering study are focused towards reducing the level of doubts in predicting the ground motion at a site and the reaction of a structure due to that ground motion. Currently, structural responses can be forecast fairly assuredly, but the prediction of ground motion is far from acceptable. Many new devices, methods and plans have been continuously developed for the structural system to either reduce the seismic demand or to improve the strength, ductility or energy dissipation capacity. Most notable future trends are:

- A complete probabilistic investigation and design method;
- Performance-based design codes,
- Multiple annual probability hazard maps for response spectral accelerations and peak ground accelerations with better classification of site soils, topography, near-field effects;
- New structural arrangements and devices using non-traditional civil engineering materials and techniques; and
- New refined analytical tools for reliable prediction of structural response, including nonlinearity, strength and stiffness degradation due to cyclic loads, geometry effects and more importantly, effects of soil–structure interaction Out of these trends Performance-based design and base-isolation techniques are easy in this paper.

2. Performance-Based Design

Initial design measures recognized that seismic forces acting on the structure are inertial forces caused by earthquake acceleration sand therefore, would be relatively to the structure's weight. Over the years, advances in the knowledge of actual behavior of structures have resulted in alteration to this basic technique to reflect the fact that

structural stresses generated by earthquake accelerations are functions of strength and stiffness properties of the structure, in addition to its weight. Conventional codes are narrow in nature and are based on specific observations, which were then comprehensive to cover a wide variety of structures. Seismic risk and the predictable performance of a structure are not openly defined in these codes and they cannot indeed be expressed in such a manner. Furthermore, conventional codes have not followed the growth of new ideas rapidly enough. Performance-based design codes not only characterize a radical shift from the conventional prescriptive codes but also aim to overcome most of their limitations. However, conniving for performance requires a higher level of empathetic of the structural behavior, such as then on linear relations between forces and deformations.

2.1 Characterization of design ground motions

The main issues for stipulating a design earthquake or ground motion are, seismic hazard maps (zoning maps), local site effects, near-source effects on horizontal ground motions, and spatial variations of ground motions. There are also other issues related to the effects of the perpendicular component, energy and period of ground motions. In conventional engineering design despite, a large inconsistency in the ground motion characteristics and a basic deterministic approach is followed. This process is based on a simple parameterization of earthquake magnitude, distance, and site category. Newer research efforts use arithmetical ground motion models based on seismological theory to analyze the origins of these variability's so that the doubt in approximating ground motions can be reduced.

2.2 Seismic Hazard Zoning

The predictable earthquake motion at any given site varies tremendously and a zoning map gives an idea of the size of the earthquake to be used for design. Zoning maps frequently given the magnitude of a design ground motion, such as the peak ground acceleration (PGA) for a certain probability of surpass, typically 10% in 50 years. The response measures of a structure, which are of attention to engineers, are more strictly related to the spectral acceleration (SA), rather than the PGA, of the base motion. The usual of hazard maps of the U.S. Geological Survey (USGS) are based on contours of 5% damped elastic SA for periods of vibration of 0.2, 0.3 and 1.0 seconds. In addition, these maps use chances of exceed of PGA by 10%, 5% and 2% in 50 years (corresponding to approximate return periods of 500, 1000 and 2500 years, respectively)14. These multiple annual probability maps of exceed allow designers to choose the suitable scenario for a specific objective in a performance-based design approach. For example, for a prevention-of-collapse performance standard, a 2% probability of exceed in 50 years can be preferred. Engineers can develop complete design response spectra using the hazard maps, by taking three periods of shaking (0.2, 0.3 and 1.0 s) as control periods. Adding to the response spectra, a set of strong motion time antiquities can be specified for time domain analysis of nonlinear structures. Accuracy of these maps is based on the following three factors: (1) description of seismic sources and reduction relations used for ground motions, (2) the process by which the maps are arranged, and (3) how the maps compare with detailed site-specific studies. The coming years will see major modification in the hazard maps because of better gratitude of the above-mentioned factors. Clearly, the latest USGS maps are a major improvement in the representation of ground motion and should serve as a good model to follow.

2.3 Local Site Effects

Seismic waves spreading from substratum to the earth surface are significantly altered (usually amplified) by the underlying alluvium and ground topographies. In engineering design codes, this effect of local soil sites is measured in a very simplistic fashion by site factor. However, these simple factors do not account for alterations in seismic waves such as duration, energy and frequency gratified. Very simple one-dimensional beam models and wave broadcast theory are currently used to obtain design seismic waves. The obtainability of affordable, large computing power these days is enabling investigators to try more ambitious ideas such as modeling earthquake source mechanisms or making design seismic waves from 2D and 3D models of soil stratum. These lessons would deliver the much needed vision into the effect of ground features (topography, i.e. valleys, slopes, basin edges, and their concentrating effects) on ground motions issues that are presently ignored in engineering design.

3. Ground Motions

3.1 Near-Source Effects on Ground Motions:

It is a well-established fact that characteristics of ground motions near the source are different from those at greater distances from the epicenter. Many recent devastating earthquakes – Chi-Chi (1999, Taiwan); Izmit (1999, Turkey); Northridge (1994, USA); Kobe (1995, Japan) have indicated that the most significant aspect of ground motion is the presence of a huge, middle to long period pulse of ground motion. This pulse is observed to be larger in the direction perpendicular to the strike of the fault, as opposed to those in the direction of the fault (i.e. rupture directivity effects). Analysis have shown that the presence of these big period pulses (also denoted to as flings) at the commencement of the motion can cause peak ground velocities as high as 175 cm/s, imposing exceptionally large displacement demands on large period structures such as bridges, tall buildings and base-isolated structures. Although these effects were noted in many earlier Californian earthquakes, the engineering community has yet to include these observations in the design process! Destruction caused by more recent earthquakes has focused attention again on the effects of the severe pulses in near-fieldregions17. The 1997 UBC (Uniform Building Code) first presented the idea of near-source issues in determining design forces, but this simplistic approach is highly questionable for its reliability in estimating the effects of severe pulses in ground motions18. In rare site-specific studies, these pulses have been comprised in design ground motions, but they are still not a part of our standard design specifications.

3.2 Spatial Variations of Ground Motions:

Spatial differences of ground motion for multiple-supported structures include incoherent base motion, wave passage effects, weakening effects and differential site response. Wave passage effect refers to non-vertical spread of seismic waves, whereas variable distances of the numerous supports of the structure give rise to attenuation effects. Prolonged source effects are due to mixing of wave types from different points on the fault, i.e. waves initiating from source segment A will inhibit with source segment B. The ray path unintelligibility is caused by sprinkling of waves and complex 3D wave propagation. Though there was some minimal research done presentation that the effect of spatial differences is not significant if the differential site response is small, it is still not sufficiently clear when these effects can be neglected. In the case of extended structures such as bridges, the current practice is to ignore spatial variations of ground motions, an example of neglecting what we do not understand.

4. New Structural Systems and Materials

In recent times, many new schemes and devices using non-conventional civil engineering materials have been developed, either to reduce the earthquake forces acting on a structure or to absorb a part of the seismic energy. Figure 1 shows four main types of techniques employed to control structural response during earthquakes. There are many differences under each broad category and many new techniques are being developed, evaluated and applied,

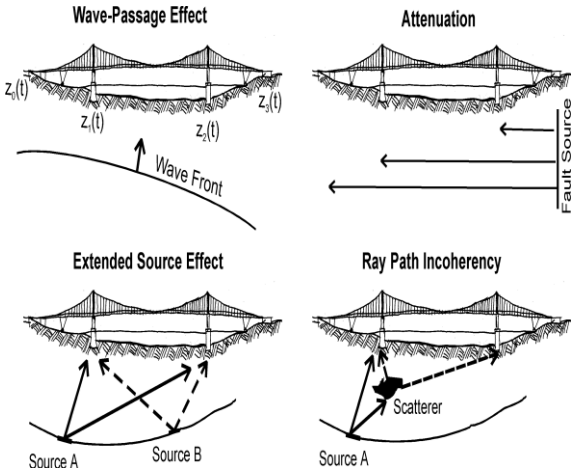

Figure 1: Wave Impact

4.1 Base-Isolation Systems

Conventional earthquake-resistant structural schemes are fixed-base schemes that are 'fixed' to the ground. They originate their earthquake resistance from their aptitude to engross seismic energy in specially designed regions of the structures, such as in beams near beam-column joints of RC frames. These areas should be capable of distorting into an inelastic range and sustaining large reversible cycles of plastic distortion, all without losing strength and stiffness to a level where it would jeopardize the constancy and honesty of the structure. These inflexible activities also mean large distortions in main structural members resulting in significant amount of structural and non-structural damage. However, in base-isolated systems, the superstructure is isolated from the foundation by convinced devices, which reduce the ground motion communicated to the structure. These devices help decouple the superstructure from destructive earthquake components and absorb seismic energy by adding important damping. In comparison to fixed-base systems, this technique significantly reduces the structural response and damages to structural as well as non-structural components. A important number of base-isolation devices have been advanced, some of which have already found applications in real life structures. Scheming a base-isolated system is still a compound process, and its dynamic response tends to be more complicated than the fixed-base system. Presently, only certain types of structures are best suited for base-isolation for earthquake resistance, although technology is gradually overcoming these limitations.

4.2 Passive energy dissipation systems

Conventional fixed base systems rely on strength and ductility to control seismic response. A current strategy, widely favored for enhancing the seismic performance of fixed-base systems, involves dissipating the seismic energy through various Energy Dissipating Devices (EDD). These devices are like 'add-ons' to conventional fixed-base system, to share the seismic demand along with primary structural members. A good design reduces the inelastic demand on primary structural members, leading to significant reduction in structural and non-structural damage. A quick survey of the engineering literature reveals that a number of EDDs using metal hysteresis, viscous damping, friction and visco-elasticity have been proposed. Quite a few of them have already been applied in the field. The supplemental damping provided by EDDs helps to control excessive deformation and damage to fixed-base systems at a minimal additional cost. However, there are many issues related to the integration of these devices into structural systems, their analysis, design, construction methodologies and architectural aspects, which will be the focus of research and development in the coming years.

Advantages of Base Isolation-

- Reduced floor Acceleration and Inter-Storey Drift
- Less (or no) Damage to Structural Members
- Better Protection of Secondary Systems
- Prediction of Response is more Reliable and Economical.

4.3 Active, Semi-Active and Hybrid Control Systems

In contrast to the earthquake-resistant systems stated earlier, there is another growing class of systems referred to as 'smart' or active control systems. The active systems vary from the passive systems in the sense that they control the seismic response through suitable adjustments within the structure, as the seismic excitation changes. In other words, active control systems present elements of dynamism and adaptability into the structure, thereby supplementing the capability to resist exceptional earthquake loads. A mainstream of the proposed methods involves regulating lateral strength, stiffness and dynamic possessions of the structure during the earthquake to reduce the structural

response. Many studies and a few arena applications have highlighted their potential in reducing the structural response. However, many serious problems exist with respect to the time delay in control actions, modeling errors, insufficiency of sensors and controllers, structural nonlinearities and reliability, not to mention the high operational costs. Researchers are investigating with many novel concepts to overcome these limitations and to develop a cost-effective mixture and semi-active class of systems which can combine the robustness of passive systems with the adaptability of active systems.

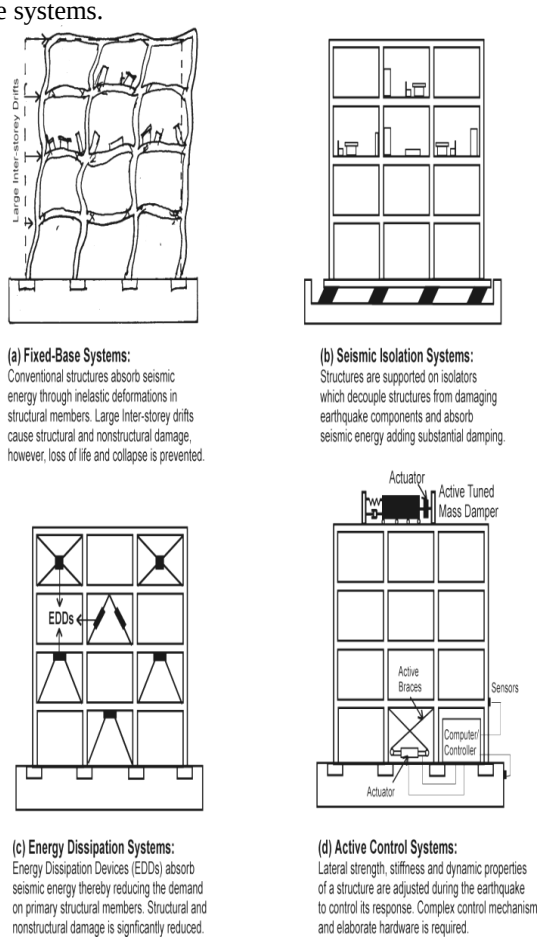

Figure 2: Base Isolation Techniques

5. New Materials and Devices

5.1 Active, Semi-Active and Hybrid Control Systems

Many non-conventional civil engineering materials are production inroads into earthquake-resistant construction methods. Recently developed techniques use materials such as rubber, lead, copper, brass, aluminum, stainless steel, fiber-reinforced plastics and even expensive shape-memory alloys. These materials are intentionally used to modify the force deformation response of structural components and improve their energy dissipation potential. For example, fiber-reinforced plastic fabrics and sheets are an attractive alternative over steel or concrete jacketing to restore the load-carrying capacity of earthquake-damaged reinforced concrete beams or beam–column joints. They are lightweight.

5.2 General ERD Provisions For RCC Structures Served By Common Structural Systems:-

- A Truss is a Structural System consisting of members that are designed to resist only axial forces
- Axially loaded members are assumed to be pin connected at their ends.
- Joints in a structure are those points where two or more members are connected.
- A Structural System in which joints are capable of transferring end moments is called a frame.
- Members in these systems are assumed to be capable of resisting bending moment, axial forces and shear Force.
- Beams are those members that are subjected to bending or flexure.
- Ties are members that are subjected to axial tension only while strut (Column or Post) are members subjected to axial compression only
- Structural analysis is determination of the forces and deformation of the structure due to applied load.
- Structural design involves the arrangement and proportioning of structures and their component in such a way that the assembled structure is capable of supporting the designed load within the allowable defined limit state.
- Diaphragm- it is a horizontal, or nearly horizontal system, which transmit lateral forces to the vertical resisting elements, for example, reinforced concrete floors and horizontal bracing system
- Horizontal bracing system is a horizontal truss system that serves the same function as a diaphragm.
- Lateral force resisting element is part of the structural system assigned to resist lateral forces.
- P-Δ Effect- it is the secondary effect on shears and moments of frame member due to action of the vertical loads, interacting with the lateral displacement of building resulting from seismic forces
- Shear wall: It is a wall designed to resist lateral forces acting in its own plane. The shear wall should extend from the foundation either to the top of the building or to a lesser height as required from design consideration. In design, the interaction between frame and the shear walls should be considered properly to satisfy compatibility and equilibrium conditions.

5.3 Shear Frame System

- Resist lateral deformation by joint rotation.
- Requires high bending stiffness of columns and beams.
- Rigid joints are essential for stability.
- Not effective for height more than 30 stories.
- Wall Structures and Frame-Shear Wall System:
- A vertical cantilever, resisting the lateral load primarily in bending.
- Very stiff system and building heights up to 50 storey can be achieved.
- Acts as rigid partition hindering the flexibility of usage. More suitable to residential buildings
- Suitable for service core in office buildings.
- Frame deforms in shear mode while shear-wall deforms in flexure mode.

- Interaction: In the lower portion the two components press each other, while in the upper portion they pull each other.
- Sharing of the lateral force between the two components is complex.
- Modeling as frames with wide columns.
- Coupled Shear Walls
- Shear wall having opening for windows or passage.
- Efficiency depends highly on the stiffness of coupling beams. Coupling beams are subjected to very high shear forces and should be appropriately designed.
- Frame with Core and Outrigger
- Increases efficiency by inducing axial forces in the columns and reducing bending moments in columns and beams.
- In concrete, shear wall core and store deep girders.
- Modeling as space frames.
- Vertical load behavior is also modified due to outrigger.
- Framed-Tube System
- Closely spaced columns and deep spandrel beam along the periphery
- High lateral rigidity due to hollow tube like section
- Vertical shear transfer takes place at the corner.

6. Conclusions

- In the coming years, the field of EQRD of structures is most likely to witness the following significant developments:
- A complete probabilistic analysis and design approach that rationally accounts for uncertainties present in the structural system will gradually replace deterministic approaches, especially in the characterization of the loading environment.
- Performance-based designs processes will take center Stage, making conventional descriptive codes obsolete.
- The acceptable risk criterion for design purposes will be prescribed in terms of performance objectives and hazard levels.
- Multiple annual probability maps for response spectral accelerations and peak ground accelerations along with more realistic predictions of the effects of site soils, topography, near-source rupture mechanisms and spatial difference should deliver better characterization of design earthquakes and expected ground motions.
- The development of new structural systems and devices will continue for base-isolation, passive energy dissipation and active control systems, along with the proliferation of non-traditional civil engineering materials and techniques.
- Analytical tools for reliable prediction of structural response (essential tools in performance-based design Processes) will continue to improve and be updated frequently to include new devices and materials.
- The area of soil structure interaction perhaps the least understood aspect in the field of earthquake Engineering – is poised to witness the emergence of new numerical techniques to model nonlinear soils and structures in a way that was not conceivable until Now, due to the enormous computational efforts Required.
- It is fairly well accepted that earthquakes will continue to occur and cause disasters if we are not prepared.
- Assessing earthquake risk and improving engineering strategies to mitigate damages are the only options before us.
- Geologists, Seismologists and Engineers are continuing their efforts to meet the requirements of improved zoning maps, reliable databases of earthquake processes and their effects; better understanding of site characteristics and development of EQRDS.
- Goal will remain the same: to design the perfect, but cost effective structure, that behaves in a predictable and acceptable manner. The continuing research and growth activities in the area of EQRD of structures offer important promise in realizing that goal in the coming years.

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