Research Article Impact Factor: 4.226 ISSN: 2319-507X
J. G. Ingole, IJPRET, 2016; Volume 5 (2): 716-725 IJPRET

INTERNATIONAL JOURNAL OF PURE AND APPLIED RESEARCH IN ENGINEERING AND TECHNOLOGY

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SPECIAL ISSUE FOR
INTERNATIONAL CONFERENCE ON
"INNOVATIONS IN SCIENCE & TECHNOLOGY: OPPORTUNITIES & CHALLENGES"

ENHANCED ARCHITECTURAL ASPECTS FOR SEISMICALLY RESILIENT STRUCTURES

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Accepted Date: 07/09/2016; Published Date: 24/09/2016

Abstract: *Greater role is enacted on the architects with the kind of Investment and occupational resources put in the modern structures. Even with greater role assigned to the structural engineer's non-computational or architectural aspects plays important role in achieving seismic resilience. This paper focuses on the modern seismic resilience measures in the form of modern and enhanced architectural aspects and their effect on the earthquake performance of building. On one side where modern earthquake resistant technologies such as Tectonic construction, basic, passive & active protection are effective, adoption of enhanced architectural earthquake resistant technologies such as Optimized shapes, Suspended buildings, suspended floors and bridge building could meet the overall requirements from the structure.*

Keywords: *Seismic resilience, Passive Protection, Active Protection, Suspended floors, Suspended Buildings*

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How to Cite This Article:

J. G. Ingole, IJPRET, 2016; Volume 5 (2): 716-725

INTRODUCTION

The work of an architect has the characteristics of a cultural act and artistic achievement. Architectural concepts, which arise through evaluation and ethics, are nowadays determined also by: location and urbanisation of the environment, the morphology of a building and its surroundings, context, the significance of an building with regard to purpose and/or importance, historical determination, building typology, the concept of architectural design, the elements of architectural design, the harmony of composition (ratios, relations) and other starting points, about which an architect's forms an opinion, assesses the existing situation and carries out architectural intervention in the space. In doing so, the Architect takes full responsibility for the space, whereas Earthquake resilience which is more or less looked in to by the Earthquake Engineering. Lebbeus Woods clearly emphasizes seismic resilience by stating that "Earthquakes as natural event are not inherentlycatastrophic. Destruction is not the 'fault' of earthquakes, but rather of thebuildings, which, even in the regions regularly visited by earthquake, are notdesigned to work harmoniously with the violent forces periodically released."Thus destruction is not the 'fault' of earthquakes, but of the buildingswhichnot designed for seismicity. Seismic resilience could be better achieved with harmonization of structuraland architectural, this paper explore various architectural developments along with the traditional & basic requirements for seismically resilient structure.

The seismic resilience is often ensured by providing Tectonic construction (regularity, symmetry, height limitation, etc.),basic protection according to codes (required combination of strength and ductility), Passive protection (base isolation, energy dissipation systems) and Active protection (base isolation + semi-active and active damping systems).These complex requirements of earthquake engineering directly influence the architectural composition and concepts in architecture. With growing intersection and interaction of Architecture with earthquake Engineering, Earthquake Architecture is evolving. Earthquake architecture is an visual or conceptual interconnection between the concepts of earthquake engineering and concepts of architecture. Following section discuss Traditional & modern Earthquake architectural concepts adopted for sesmicresilience

2.0 Modern Concept for Seismic Resilience

Modern design demands compliance with the regulations and recommendations given in building standards and codes. The compliance influence seismic resilience decisively, resilence measures can be categorised into the following four groups: i) tectonic construction, ii) basic protection according to regulations, iii) passive protection andiv) active protection and developing systems.

2.1Tectonic construction (regularity, symmetry, height limitation, etc.)

The Classic, tectonic (also traditional) construction employs principles of regular construction in general followed throughout the history before framing of building codes. The structures mass is concentrated in the lower storeys, walls are made Thick &massive at ground floor being made thinner height wise, structures regularity is maintained by adopting symmetry, imposing height limitations depending upon the type of construction material, using high density construction material for better transmission of horizontal forces into foundations. Examples of markedly non-tectonic construction are buildings with a soft ground floor, with the majority of mass in the upper floors, irregularly shaped, with larger overhangs, etc.

2.2 Basic protection according to codes (combination of strength and ductility)

This ensures minimum level of earthquake resistant construction, emphasisedon structure design, which means that all systems used must comply with code requirements for safety and quality.

2.3 Passive protection (base isolation, energy dissipation systems)

This group includes various passive base isolation systems, which are usually combined with various types of passive energy dissipation systems or devices. These structural protective devices can be divided into two major groups: 1) Seismic isolation (elastometric or lead rubber bearings, sliding friction pendulum bearings and sliding bearings with restoring force) and 2) Damping systems (histeretical dampers, viscous dampers, tuned mass/liquid dampers, phase transformation dampers) These systems can be placed above the foundations or in critical areas along the entire structure.

2.4 Active protection (base isolation + semi-active and active damping systems)

Employs latest technologies, such as semi-active and active energy dissipation systems (mass/fluid dampers, bracing systems etc.), computer controlled response of buildings to earthquake simulation using electrorheological (ER) and magnetorheological (MR) dampers and other smart variable stiffness and damping systems. The material properties of ER and MR materials can be changed in milliseconds by an applied low-power electric, or magnetic, field. At zero electric field, these materials are viscous liquids. At high fields they behave like viscoelastic-plastic solids. Members making use of ER or MR fluids can regulate very large forces with almost no external energy. One of the most promising developing technologies today in areas with frequent (regular) seismic activity is Neuro-fuzzy logic systems or Fuzzy systems (also Neural fuzzy models) [Kim et al, 2005]. It is an active, computer controlled system, which monitors earthquake activity in the location itself, and treats the building and its surroundings as a complex dynamic system. After processing information, it can in this way calculate the highest probability of earthquake direction and automatically “prepares” for an earthquake. After several earthquakes, the computer as a neuron network uses the “fuzzy logic” principle to predict the next earthquake. Neuro-fuzzy logic system enables a certain form of local seismic predictions, which are thought to be the most accurate for the building in question, and is related to (semi-)active protection systems.

3.0Modern ArchitecturalConcepts for seismic resilience

The inclusion of the requirements of seismic resilience in the process of creating and conceptualizing the architecture of a real building can be based on conceptual or visual level. Earthquake architecture believes in including the principles of earthquake engineering in the architectural concept.New design concepts are based on deformation, motion, discontinuity, visibility, shape and comfort for imparting resilience.

The principle of deformation proposes higher capacity for large local displacements for better performance of seismic dissipative devices. Vertical dissipative bracing dissipating seismic energy with relative displacement through adjacent floors and Horizontal bracing can be equipped with dampers dissipating seismic energy through the horizontal shifts of braced floors are employed. In both cases, large displacements via adjacent connections guarantee remarkable energy dissipation and seismic resilience.

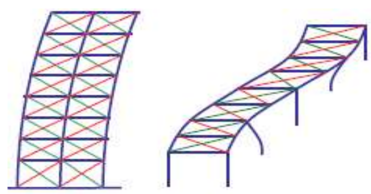

Figure 1: Vertical and horizontal deformation capability

Significant seismic energy dissipation could be well achieved by allowing movements that is change in position with time. The movement may affect the entire structure or only a section. The devices mounted it deforms devices that, mounted between the building and the firm soil or between building sections which have relative movement, dissipate energy and reduce lateral response.

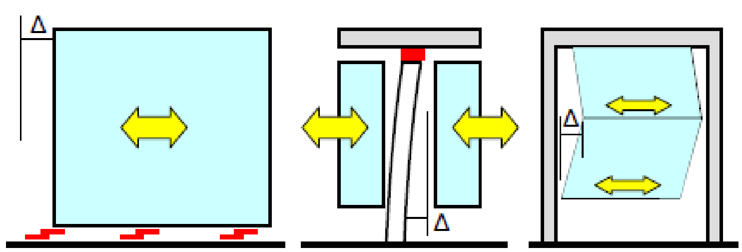

Figure 2: Vertical and horizontal movement capability

The deformability and motion characteristic of building could create trouble under ordinary service condition. The large lateral movement likely to develop under seismic loading conditions is admissible; however there is possibility of movements in ordinary service loading conditions and hence must be checked against the comfort of the occupants. Comfort and panic controls criteria, generally well established both in national andinternational codes and based on the examination of the cinematic parameter, can be applied. However this should not deter from

application of theinnovative systems, actually, the presence of isolating or dissipating devices and, even more so, of active orhybrid systems for the control of vibrations, usually has a positive effect on the construction dynamic, reducingthe impact that vibrations may have on occupants.Some of the modern architectural Concepts for Seismic resilience are discussed below

3.1Performance optimizing Shape

Though shape is not an absolute factor directly influencing the effectiveness ofthe seismic response anymore, but it affects the efficiency and positioning of the seismic energy dissipating devices. Two principlesguide the morphology of a building equipped with enhanced protection system are

1) The shape must optimize the performance of the seismic protection system. Specific criteria must be foundfor each system. In base isolation, for instance, the stiffness centrifugation of the isolator system and theperimeter concentration of vertical load have been proven to optimize the device behavior and the buildingresponse [Mezzi, 2003]. The application of new criteria can even lead to innovative global shapes as shownin Figure 8 [Parducci, 2001].

2) This forms of shapes allow to overcome the traditional shape constraints related to symmetry, compactnessand regularity, considering the whole effect of global building shape, discontinuities and devices position.These factors interact and determine the real behaviour of buildings: for example, buildings with complexirregular in-plan shapes can have a "regular" response, strongly mitigating torsion effects, if an isolationsystem, characterized by the absence of eccentricity between mass and stiffness centers and by good stiffnesscentrifugation, is provided.

Figure 3 : Shape optimized for SeismicEnergy dissipating devices and mitigating torsion effects

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3.2 Enhanced Configurations of New Buildings

Structural innovative solution proposed by Architects (Mezzi et al. 1994) compatible with discontinuity and motion. Different structural schemes are proposed such as Suspended Building, Suspended floors and Bridge Building are innovative structural system proposed for imparting seismic resilence in the enhanced configuration, same are discussed in following section. The first consists of seismically isolated suspended buildings in which energy dissipating devices are inserted between the oscillating floor block and the rigid core; the second is based on the suspension of the floor slabs connected to the main structure by means of dissipative devices; and the third conceptualized on bridge where floors are suspended and laterally connected with seismic energy dissipating devices.

3.2.1Suspended buildings

Mezzi et al. 1994 carried out study on configuration of suspended buildings aimed at analyzing seismic behavior, pointing out designcriteria, designing special dissipating devices and a prefabricated structural system and planning itsindustrialized production. Different global configurations, shown in Figure 4, were compared.

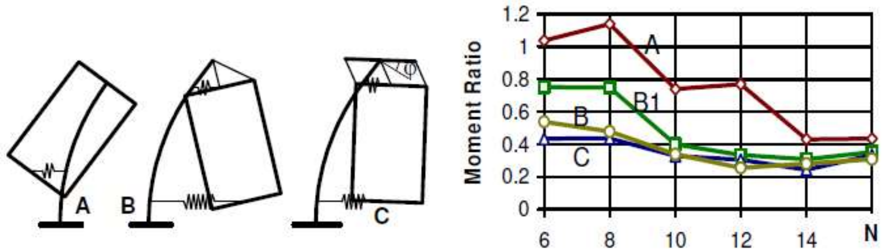

Figure 4 :Schemes and performances of suspended buildings [Mezzi et al., 1994]

They suspended model differed in the internal connecting system between the structural parts: in scheme A the topconnection is rigid, in scheme B the connection is pinned, in scheme C a balancing beam isprovided as suspension deck. Six schemes were compared considering - apart from the basicschemes A, B and C in Figure 4 - in variant B1 the upper lateral connection was omitted. The permormance analysis of the suspenced systems are evaluated in terms of bending moment ratio at the bottom section of the core wall versus the building height. The least observed and reported moment is for scheme C as it permits reduction in rotation of suspended story-block .

3.2.1 Suspended floors

Suspended floors are another class of suspended configurations wherein floors are in suspension whereas the main vertical structures remain rigidly connected. This class of configurations are preferred as structural solution of those architectural themes which implies a regular framed structure as support and container of a free distribution of floors occupying only part of the building plan and having irregular shapes differing at different levels so that a complex distribution of spaces with different heights can be obtained within the container-structure. The Future University of Hakodate in Japan, designed by Riken Yamamoto, represents a good example of this distribution, Figure 5 shows an internal view of the building where the space articulation can be appreciated.

This class of solutions was investigated in depth in a thesis (Ottaviano 2002) addressing various solutions that differed in the dissipating system adopted to limit the horizontal forces transmitted to the main structure. Figure 5 shows the three solutions that were studied: suspended floors laterally connected with plastic devices (SP); suspended floors braced with viscous devices (SV); isolated floors (IF). The schemes have a span length of 12 m and a story height of 5 m, the story mass is 1.066 t/m2. Two solutions were adopted for the main structure, the first including ground-roof free columns, the second framing beams at floor level. Dynamic analyses carried out on simple schemes, using four artificial accelerograms having PGA equal to

0.35 g and fitting the spectrum B of (Eurocode 2001), show the effectiveness of the isolated or dissipated solutions.

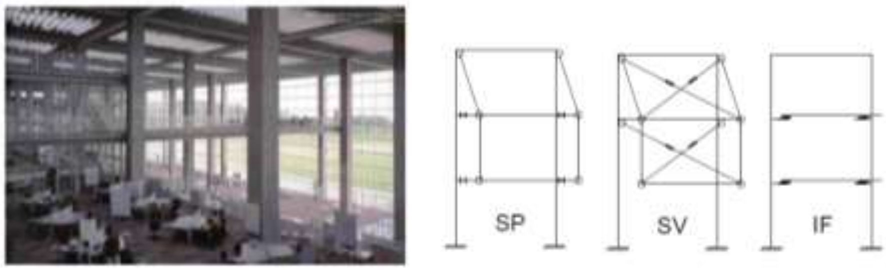

Figure 5. Left: internal view of the Future University of Hakodate in Japan (designer Riken Yamamoto). Right: elementary schemes of floor suspension.

Table 1 Ratio of shear force, V, and bending moment, M, (average of the four responses) at the column base

Scheme	Free Columns		Framed Colums	
	V/Vref	M/Mref	V/Vref	M/Mref
IF	0.33	0.35	0.31	0.32
SP	0.37	0.36	0.37	0.38
SV	0.32	0.35	0.30	0.33

Table 1 shows the ratio of shear force, V, and bending moment, M, (average of the four responses) at the column base for the different enhanced solutions to the reference solution (REF) of the conventional continuous frame. The base shear and bending moment can be reduced to about one third of their nominal value, with reduction effectiveness practically independent of the type of enhancing solution used.

3.3 Bridge buildings

Bridge buildings is the enhanced architectural solution for seismic resilience where the entire shape of the structure reproduces the opening typical of bridges. The voidof the bridge building may be "filled" with a suspended block of stories thus obtaining thestructural scheme of suspended "bridge buildings", consisting of a main bridge structure were thefloors are suspended, like in Figure 6 (c). The lateral connections between floors and the mainstructure consist of dissipative devices that limit the force transmitted and dissipating energy.

Figure 6. (a) Grand Arche de la Défense, Paris (design Johan Otto von Spreckelsen), (b) Umeda Sky Building, Osaka (design Hiroschi Hara), (c) Hong Kong and Shanghai Bank Building, Hong Kong (design Norman Foster).

Analytical evaluations recorded by the author on simplified plane models of bridge Buildings. The model reproduces the lateral behavior of a thin building with different plastic threshold values assigned to the laterally connecting devices. Evidently, optimized device distribution reduces the column base shear of about 40%.

4.0 Conclusion

From the study carried out over the development in earthquake architecture for achieving better resilience in the structure we can make the following observations andconclusions:

- Earthquake architecture is the “missing link” between earthquake engineeringand architecture. It combines the best of both fields and establishes a newapproach and quality in construction in earthquake prone areas, mainly incompliance with measures of architectural excellence.
- A correct design using innovative seismic protection systems requires new basic criteria controlling the relation between architectural and structural configuration.
- Code provisions entitling compliance with the recommendation provide basic resilience to the structure.
- Modern seismic resilience measures such as Isolation, damping,energy dissipation, active control, greatly enhance buildings performances.
- Enhanced architecture for earthquake resilient structure could well explore concepts of flexibility, discontinuity, motion, device insertion, shape and comfort.

- Out of the box lateral thinking leading to enhanced architectural conceptualisations such as optimized shape, suspended building, suspended floors and bridge building are effective in reduction of the imposed moments and shear forces.

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