SEISMIC VULNERABILITY ASSESSMENT OF EXISTING BUILDINGS IN INDIA USING GIS TECHNIQUES

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ABSTRACT

Estimation of seismic hazard, structural vulnerability and exposure of building stock are the main components in the seismic risk assessment of an area. India has experienced nine damaging earthquakes in the past two decades, with significant risk to lives, properties and economic activities. The high seismic vulnerability of its housing stock was evident in the Bhuj earthquake in 2001. Methodologies that are capable of predicting accurate and reliable assessment of seismic vulnerability of the existing building stock in future earthquakes are fundamental in the preparation of risk assessment and retrofitting strategies. This paper presents a review of the existing techniques and methodologies that have been developed/ proposed for the assessment of seismic vulnerability of existing reinforced concrete (RC) framed buildings. The key factors of the methodologies, including evaluation of seismic scenarios and ground motion intensity measures; sampling of buildings; characterisation of building parameters; choice of analysis methods and structural models; effect of local soil profile and soil-structure interaction (SSI) on the building performance and estimation of damage levels are discussed. The suitability of the existing methodologies for seismic scenarios in India is studied. The applicability of Geographic Information System (GIS), as a tool to assess the seismic vulnerability for speedy generation and updating of the hazard maps of the areas, with the development of inventory databases of the building stock will also be evaluated.

1. INTRODUCTION

UNISDR (2009) defines the *risk* as: “The probability of harmful consequences, or expected losses resulting from interactions between natural or human-induced hazards and vulnerable conditions”. Crichton (1999) and Kron (2005), formalised the term, ‘risk’ using the following function in Eq. (1):

$$\text{Risk} = f\,(\text{Hazard, Exposure, Vulnerability}) \tag{1}$$

where, *hazard* is described as, ‘A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation’; *exposure* is characterised as, ‘People, property, systems or other elements present in hazard zones that are thereby subject to potential losses’; and *vulnerability* is defined as the set of conditions and processes resulting from physical, social, economic and environmental factors, which increase the susceptibility of a community, ‘(people and assets) to the impact of hazards’ (UNISDR, 2009).

Significant works on seismic hazard by Esteva (1967, 1968) and Cornell (1968), initiated the basic study of seismic risk assessment, which subsequently gained popularity by the experiences from further events. In seismic risk assessment, estimation of seismic hazard, structural vulnerability and exposure of building stock are the three equally important components. The seismic hazard analysis has clear spatial variations, that depends mainly on its identification of potential seismic sources for the region, magnitude recurrence modelling, ground motion predictions, integration of component factors from multiple sources and analysis of site conditions-soil profile, geology and topography, population density, building density and quality and also, the approach strategy of its people. In order to predict the expected consequences of an earthquake on the built environment in any part of the country, it is important to know the seismic vulnerability of the built environment on the seismic areas. The assessment of probable impact also depends on the location and distribution of vulnerable building stock of varied compositions, viz., reinforced concrete (RC) framed, masonry and steel buildings in the seismic-prone areas. Very limited data exists currently, in India to quantify the building stock and their seismic vulnerability in different parts of the country (NDMA, 2013). The high seismic vulnerability of existing building stock in the nation was evident during the nine damaging earthquakes which occurred between 1990 to 2010, especially, high-magnitude intra-plate earthquakes in the peninsular India, after 1990’s, such as the Killari [Moment magnitude (M_w) 6.2, 1993], Jabalpur (M_w 5.8, 1997) and Bhuj (M_w 7.7, 2001) which have claimed a lot of human lives and also, moderate earthquakes in Kerala (M_w 5.0, 2000), Karnataka (M_w 4.3, 2001) and Tamil Nadu (M_w 5.5, 2001) in the southern peninsular India have created enough concern (Kanagarathinam et al., 2008). Apart from these recent major earthquakes, which have occurred in rather unexpected locations, widespread occurrences of mild earthquakes (with $M_w \approx 3.5$) indicate an ongoing seismic activity in the Indian peninsula (Ornthammarath et al., 2008). Chennai city, in South India has experienced three earthquakes of magnitudes greater than or equal to 5.0 in 1807, 1816 and 1823 (Ganapathy, 2005). Therefore, developing a seismic vulnerability map for the regions of low-seismicity, with a generalised appropriate methodology also seems critical and worthwhile. An efficient methodology to assess the seismic vulnerability of existing buildings is also an important factor for planning urban/ regional-scale emergency response and earthquake protection/ retrofitting schemes to protect human lives, as well as, economy.

Numerous methods have been developed by many researchers for the estimation of seismic vulnerability of buildings based on analytical methods, with the key factors associated with the derivation of vulnerable functions and are being practised in many countries. Each country has its own specifics for the various aspects of its seismic problems, such as: characteristics of buildings, seismological features of the territories, socio-economical conditions, etc. Generally, the key factors considered in the methodologies include the selection of parameters for representative seismic scenarios and intensity measures (or ground-motion prediction equations), selection of samples of buildings based on building classes and types, selection of analysis methods and structural models, local effects due to ground conditions, soil-structure interaction (SSI) effect on the building performance and estimation of damage levels.

The objective of this paper is to review of existing methodologies for the seismic vulnerability assessments of the RC buildings with regard to these key factors, which are associated with the whole process of obtaining vulnerability functions, not specifically related only to a particular region. It is thus necessary to develop suitable methodologies specific to a particular region with its relevant parametric conditions and compilation of the inventory databases related to these parameters, becomes the most difficult aspect of damage prediction (ATC-13, 1985). The scale of variations and the respective vulnerabilities can be identified based on these parameters and the data available from the recent earthquakes for developing the models to assess the performance of buildings, realistically. The results derived from these assessments can be mapped scientifically, using the powerful statistical analysis GIS (Geographic Information System) tool, for taking necessary decisions/ measurements to control the seismic damage. The structural effects, such as, torsion, pounding, interaction of adjacent buildings and the effects of secondary hazards, like, landslide, liquefaction or fire, which can also have a significant impact on the level of seismic damage, are not examined in this study.

2. APPROACH FOR EVALUATION OF SEISMIC RISK

"Seismic risk is the probability that social and economic consequences of earthquakes will equal or exceed specified values at a site or at various sites or in an area during a specified exposure time", (EERI Committee, 1984). Predicting the likely impacts of an earthquake in a geographic location is generally covered by the scientific study of earthquake risk assessment. The assessment of seismic risk is derived from the estimation of consequences of an earthquake in the nation or a city or a chosen area, in terms of the expected damage and loss from a given hazard to the given elements, at risk. The risk assessment involves evaluation of seismic hazard, vulnerability of buildings, exposure and finally, damage/ loss estimation (NDMA, 2013). Thus, the total seismic risk can be expressed in the following simplified conceptual form, as in Eq. (2):

$$\text{Seismic Risk} = \text{Seismic Hazard} \times \text{Seismic Vulnerability} \times \text{Exposure} \quad (2)$$

3. ANALYSIS OF SEISMIC HAZARD

Ideally, earthquake hazard assessment should include all of the possible hazards from earthquakes, viz., amplified ground shaking, landslides, liquefaction, surface fault rupture, and tsunamis. Nevertheless, strong ground shaking is often the only hazard considered in the hazard assessment methods, which is a commonly acceptable approach, since the size of the model damage/ loss increases, the relative influence of the secondary hazards, like liquefaction and landslides decreases (Bird and Bommer, 2004) and also, the seismic hazard quantifies the ground motions generated due to an earthquake. The severity of ground motion at a particular site is commonly described by seismic hazard, without consideration of the consequences (Kramer, 1996). Effects due to local soil properties, etc. are also included in hazard assessment. The seismic hazard is uncertain in most of the situations and is posed by the sizes or magnitudes of potentially damaging earthquakes, occurring at multiple locations.

4. INFORMATION ON BUILDING EXPOSURE CONDITIONS

The vulnerability characteristic of the exposure information (structural inventory) for a city or region or country is an important aspect for evolving the damage/ loss model. The inventory is divided into buildings, facilities, transportation systems, utility systems, as well as, hazardous material facilities and further partitioned into pre-defined building classes with similar damage/ loss characteristics (Calvi et al., 2006). The development of seismic vulnerability and risk models needs a classification system to characterize the earthquake-exposed building stock and describe its damage (Eleftheriadou et. al., 2014) and it is possible to obtain this information with the data from building typology of the nation.

5. ASSESSMENT OF SEISMIC VULNERABILITY

The seismic vulnerability of a structure can be described as its susceptibility to damage by ground shaking of a given intensity. The expected damage for a building or a class of buildings is defined as a function of the ground motion, establishing the vulnerability function relationship (Figure 1). The capacity of the building and the seismic demand are the two key aspects of a vulnerability analysis. The seismic damage is estimated by comparing, the ability of the building to resist constraints (capacity of the building) with the constraints on the structure, due to the earthquake ground motion (seismic demand) (Lang, 2002). Structural vulnerability refers to the susceptibility of those parts of a building that are required for physical support, when subjected to an intense earthquake or other hazard.

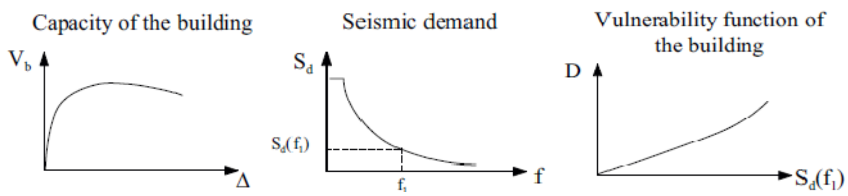

Figure 1: Relationship of a Seismic Vulnerability Function (Lang, 2002).

6. METHODOLOGY OF SEISMIC VULNERABILITY ASSESSMENT

An important component of a damage/ loss estimation model is the development of an accurate and reliable methodology to assess the seismic vulnerability of the existing building stock for predicting the future earthquake scenario, which is the fundamental requirement in the preparation of risk assessment and retrofitting strategies. The main goal of the assessment of seismic vulnerability is to quantify the probability of a given level of damage for a given building type, due to a scenario earthquake, considered. Various assessment techniques for seismic vulnerability, have been proposed and practised over the past decades, which have different principles for loss estimation, in the way earthquake ground motion is represented and building vulnerability is treated (Lang et al., 2012). The vulnerability assessment approaches can be broadly divided into four categories (Figure 2): a). Traditional empirical or statistical approaches (i.e. macro-seismic intensities), which are based on observation of damages, b). Analytical or theoretical methods, which rely on determination of structural performance through analytical procedures, using physical ground-motion parameters, viz., spectral accelerations or spectral displacements, especially in situations where, empirical methods cannot be applied due to lack of data or missing experience from the damages/ loss of previous earthquakes, c). Hybrid approaches combining empirical (damage) data with (nonlinear structural) analytical results to supplement the damage/ loss estimation procedure and d). Experimental methods, which are adopted for full-scale or small-scale field or laboratory tests for identified building or single structural element samples.

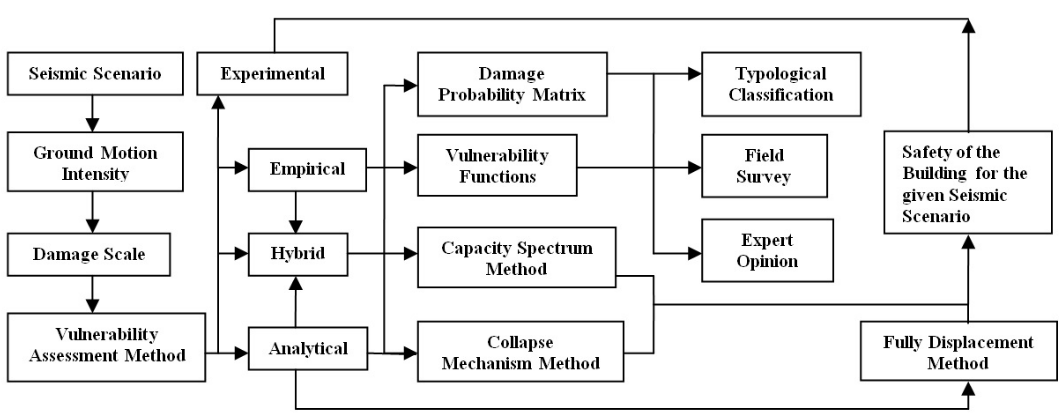

Figure 2: Procedure for the Seismic Vulnerability Assessment Approaches

Currently, several well established seismic vulnerability assessment methods are available in many countries, viz., FEMA-154, FEMA-310, EUROCODE 8, New Zealand Guideline, NRC Guideline, Japanese Seismic Index Method and IS-1893 method, for quantifying the respective strengths under specific purpose of application. All these methodologies have common key parameters to determine the expected seismic damage/ loss of building in a region, such as, collection of the damage evidence from past earthquake which have affected the region, selection of representative earthquakes, measurements of intensity, sampling of buildings, choice of analysis methods, local effects due to soil profile and influence of SSI on the building performance, etc, which are mostly applicable to the respective nations or for the locations with similar parametric conditions. Hence, it is required to identify the common parameters of existing seismic vulnerability assessment methodologies, to arrive at the most suitable 'optimum solution', with regard to the context of a specific area.

These approaches for the seismic vulnerability evaluation can be further classified into three main categories or stages, based on their level of complexity, viz., i). The simplest first level is, walk-down survey to determine the priority levels of the buildings that require immediate intervention, without the need for any analysis, as in FEMA-154, FEMA-310, ii). Preliminary assessment method, when more detailed evaluation of building stocks is required, with simplified analysis of the identified building based on a numerous assessment methods. Data of the dimensions of structural and non-structural elements in the most critical story is required for these analyses procedures, as in FEMA-310. Large building stocks can be surveyed by employing this methodology, within a reasonable time limit and iii). The final evaluation procedures require linear or nonlinear analyses of the building under consideration and require the as-built dimensions and the reinforcement details of all the structural elements. The procedures proposed in FEMA-356, ATC-40 and EUROCODE 8 can be followed for the assessment based on final evaluation. All these stages require considerable time and financial resources, for example, even in the walk-down stage, many engineers are to be employed for a long period of time depending on the size of the building stock, whereas, for the rapid structural evaluation procedures, viz., HAZUS, etc, require short period and are also widely used for the capacity estimation of buildings.

7. KEY FACTORS OF SEISMIC VULNERABILITY ASSESSMENT

7.1 Evaluation of Seismic Scenarios and Ground Motion Intensity Measures

The formulation of an earthquake damage/ loss model that allows the damage to the built environment and important lifelines for a given region is not only of interest for predicting the economic impact of future seismic scenarios (perhaps the repetition of a significant historical earthquake), but can also be of importance for emergency response and disaster planning. The key component of seismic risk is the assessment of vulnerability of structures, which quantifies the susceptibility to damage under a given intensity of ground motion. The aim of the assessment is to obtain the probability of a certain level of damage to a given building class to be exceeded, for a given scenario of earthquake. Evaluation of the median and probability distribution of structural responses (i.e., demand) of buildings is another important parameter in the vulnerability functions. Due to lack of strong motion data in India, ground motion prediction equation based on natural ground motion records is not available. Peninsular India is similar to many other stable continental regions across the world where, data is scarce and not representative of the existing hazard, scenarios.

For the vulnerability assessment of large areas, where the low resolution built environment information may only be available, vulnerability of the buildings based on the macro-seismic intensity scales is most commonly used. Traditionally, empirical observations based on macro-seismic intensity have been adopted for the earthquake loss studies as the intensity parameter at which damages are being measured. Lack of widespread placing of recording stations in many earthquake-prone regions limits the study of earthquake loss estimations based on the realistic physical parameters. Hence, intensity-based studies are the only applicable way to predict damages and loss for a certain earthquake scenario, as of now. Empirical, mostly intensity-based earthquake loss studies use, observed damage data supplemented with expert opinions (Porter and Scawthorn, 2007). In general, post-earthquake investigations are the main source of these datasets, correlating recorded actual damage effects to structures with a locally estimated ground motion level at the respective site. However, due to the lack of sufficient and high-quality observational datasets, some of the most commonly used sets of fragility (vulnerability) curves (ATC-13, 1985) are partly and mostly rely on expert judgment (Douglas, 2007).

Seismic hazard maps in most of the nations are defined presently in terms of PGA (or spectral ordinates) and thus PGA needs to be related to ground motion intensity. When the vulnerability is to be defined directly, in terms of PGA, where recordings of the level of ground motion are not available at the earthquake damage site, a ground motion prediction equation may be necessary to predict the ground shaking at the site; however, the uncertainty, particularly, in the component related to spatial variability needs to be suitably accounted for, Calvi et al. (2006). Depending on the type of data available from the damage/ seismic-prone site, the basic approaches to be applied must utilize appropriate damage probability matrices that estimate the level of damage or fragility (vulnerability) functions, corresponding to ground motion intensity, as a conditional probability factor. Empirical and analytical vulnerability functions based on spectral acceleration or spectral displacement, have also been developed since, the PGA cannot represent the frequency content of the ground motions.

7.2 Sampling of Existing Buildings

The consideration of representative building samples for a class of buildings have traditionally been followed in accordance with their construction materials, as they are considered to be directly related to the seismic vulnerability of the buildings. When classes of buildings are considered for risk assessment which is an important step in analytical seismic vulnerability assessment, the vulnerability can be established in terms of the structural characteristics and suitable modifiers to the vulnerability function can be established in terms of the geometrical characteristics. Earthquake risk models, as in HAZUS, etc. classify buildings according to types of construction materials, lateral load resisting elements and heights of buildings (FEMA, 2012). The degree of seismic vulnerability varies for each building, as the seismic resistance of a building depends on several parameters, such as, its geometrical characteristics (say, dimensions of height, plan and elevation configurations, etc.) and structural characteristics (like, material of construction, structural system, mass, stiffness, quality of construction, age, strength, intrinsic ductility, state of stress, seismic displacements, nonlinear behaviour parameters and other structural information). Hence, it is not feasible to evaluate the vulnerability in detail, for each and every building in an area. Moreover, the construction practices vary in different parts of the country even when using the same construction material and hence, it is required to develop the typology catalogue for the sampling of building class with the appropriate vulnerability functions of different buildings for each region separately (NDMA, 2013).

7.3 Characterisation of Building Parameters

The key parameters characterising seismic capacity and response of the building include material properties, building dimensions, structural detailing and geometric configuration (D'Ayala et al., 2014). Capacity of a building may change significantly with changes in material quality, lateral and longitudinal reinforcement ratios, structural system type, structural irregularities and some other factors. Most of the research studies, consider only the variation in material properties in their selection of building samples, due to the complexity of analytical seismic vulnerability assessment. For RC frames, Singhal and Kiremidjian (1996) used analytical vulnerability functions, by considering variation in steel yield strength and concrete compressive strength.

7.4 Choice of Analysis Methods and Structural Models

With the introduction of the nonlinear static ('pushover') analysis having minimal computational efforts, the Capacity Spectrum Method (CSM), which is a performance-based seismic analysis technique with the comparison between an inelastic response spectrum and a capacity curve (Figure 3) as adopted by seismic damage/ loss models, such as, HAZUS (FEMA, 2012) and the Displacement Coefficient Method (FEMA 273, 1997; FEMA 356, 2000; FEMA 440, 2005), analytical methods came in the seismic damage/ loss assessment field (Lang *et al.*, 2012). CSM is popularly being used as a rapid evaluation procedure for assessing the seismic vulnerability of buildings (ATC-40, 1996). Nonlinear dynamic analyses are generally complex at situations, especially, if multiple analyses are required to represent a building population and ground motion uncertainties, which results in compromises on the structural modelling. Single-degree of freedom idealisation with first mode of response (Mosalam et al., 1997), which minimises computation time or multi-degree of freedom model of the building can be adopted for the analysis. If a multi-degree of freedom model is adopted, buildings models are assumed to be regular in plan and height (Singhal and Kiremidjian, 1996; Rosetto and Elnashai, 2005).

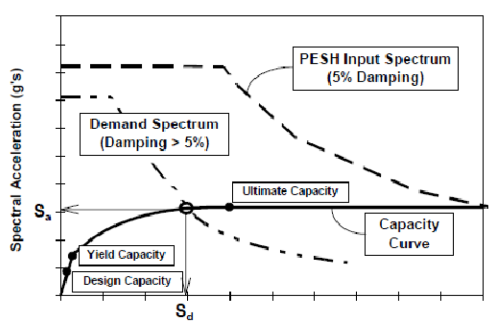

Figure 3: Capacity spectrum method (FEMA, 2012)

When nonlinear dynamic procedures are adopted, selection of input motions which, contributes to the uncertainties in vulnerability analyses, is crucial and there are no consistent guidelines currently available, on the selection of ground motions for the vulnerability assessments. Most guidelines require matching the target spectrum by scaling the amplitude of the earthquake ground motion over a certain period range. The selected records should have magnitudes, fault distances and source mechanisms that are representative of the earthquake scenarios which control the target spectrum, as in EUROCODE 8, FEMA-356 and ATC, 2012.

7.5 Effect of Local Soil Profile of Site and Soil-Structure Interaction

Local site conditions considerably influence the important characteristics, such as, the acceleration amplitude and frequency of ground motion during an earthquake. The extent of this influence depends on the configuration, thickness and properties of the soil profile and characteristics of the input motion. The local site effects on the ground motion are commonly evaluated by one-dimensional ground response analysis. One-dimensional ground response analysis can be done with equivalent linear or non-linear methods. It is preferable to carry out nonlinear ground response analysis with the site specific modulus reduction and damping curves or constitutive models.

SSI analysis determines the combined response of three linked systems, viz., the structure, the foundation and the soil underlying and surrounding the foundation. Inertial displacements and rotations, which result from inertia-driven forces from seismic base shear and moment, at the foundation level of a structure, can be a significant source of flexibility and energy dissipation in the soil-structure system. The shear wave velocity, V_S, (i.e., wave passage effects), is closely related to soil shear modulus, *G*, and soil mass density, ρ_S , computed as in Eq. 3:

$$V_S = (G/\rho_S)^{1/2} \tag{3}$$

The studies by, Stewart et al., 1999a; 1999b, confirm that, the most important parameter controlling the influence of inertial interaction is only $h/(V_S T)$. The inertial SSI effects are generally negligible for $h/(V_S T) < 0.1$, which occurs in flexible structures (e.g., moment frame buildings) located on hard soil or rock and approximately between 0.1 and 0.5 for shear wall and braced frame structures. The inertial SSI effects are significant for stiff structures, such as shear wall or braced frame buildings, located on softer soils and can increase the base shear in relatively short-period structures. However, high-rise buildings typically have low $h/(V_S T)$ ratios, which is more important for controlling inertial SSI effects and hence, the period lengthening in high-rise buildings is near unity (i.e., little or no period lengthening).

7.6 Estimation of Damage Levels for Buildings

The estimation of damage levels for the vulnerability assessment of buildings is also a vital criterion in the construction of vulnerability curves. Descriptive damage states are used to characterise the damage levels of buildings for empirical vulnerability functions, as in EMS-98 which defines five levels of damage states with qualitative descriptions for each level. Different damage levels are commonly defined for analytical vulnerability functions, based on drifts which have been calibrated to observations of building damages or experimental results (Singhal and Kiremidjian, 1996; Rossetto and Elnashai, 2005). Various seismic assessment guidelines, viz., EUROCODE 8 (CEN, 2004) and FEMA-356 (ASCE, 2000), provide the definition of each damage state and the corresponding inter-storey drift value. HAZUS (1997) and EDMPI (2000), classify the building damages into 4 categories, namely, light, moderate, heavy, very heavy. The buildings, not included in any one of these, are considered as non-damaged. Each damage state is characterized by median and standard deviation of seismic damage.

8. SUITABILITY OF THE EXISTING METHODOLOGIES FOR SEISMIC SCENARIOS IN INDIA

Existing building stock in India is with varied compositions, consisting of unreinforced masonry and RC buildings. The most vulnerable, RC buildings in India are commonly constructed with moment resisting frames for shallow buildings or seldom, combined shear walls and frames for the high-rise buildings. The parametric studies by Fardipour et al., 2011 showed that the deformation behaviour of moment resisting frames under earthquake excitations is different to that of shear walls. The deformation behaviour of walls within buildings is generally found to dominate the deformation behaviour of the buildings (Figure 4). Many of the buildings are generally found to be laterally supported by shear walls that are eccentrically located in the building plan and are proved to be highly sensitive to the seismic effects, causing amplification of the displacement of the peripheral building frames. Based on the existing guidelines for seismic vulnerability assessments, RC frames, which are considered as primary lateral load resisting elements, are often assessed in isolation from the overall structures. In view of the varied types of construction forms in India, it is important to consider the behaviour of structural systems as a whole, in the seismic vulnerability assessments of RC buildings, with the consideration how the deformation behaviour is controlled by the types of lateral load resisting elements.

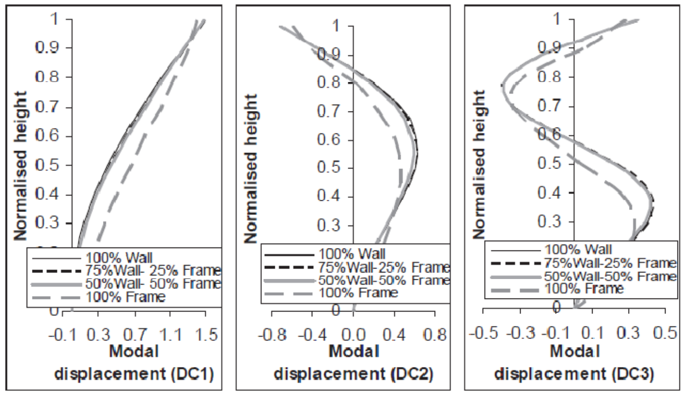

Figure 4 Displacement behaviour of frames and walls (Fardipour et al., 2011)

The RC frames of most of the existing buildings in the nation are with masonry in-fill walls. The buildings also often have soft-storey ground floor without in-fill walls, causing an abrupt change in the lateral stiffness along the height of the buildings. The effects of soft-storey features on the displacement behaviour of buildings are demonstrated in Figure 5 based on elastic modal dynamic analyses conducted by Sofi et al. (2013). It is demonstrated that, the building featuring a soft-storey is subject to a larger displacement and inter-storey drift on the ground floor under the earthquake excitation than the building without a soft-storey. The larger displacement and inter-storey drift could cause concentration of damages on columns located at the ground floor. In view of the displacement behaviours and types of damages that could occur on the buildings, RC frames featuring soft-storeys should be incorporated in the classification of buildings for seismic vulnerability assessments.

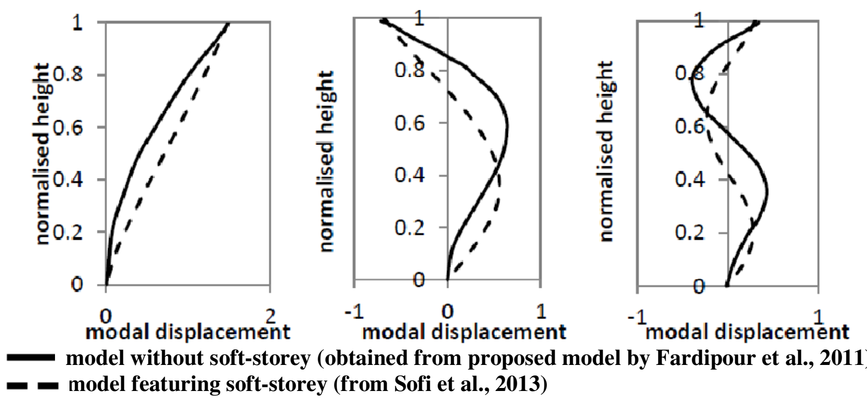

Figure 5 Comparison of modal displacements of buildings with and without soft-storey

Considering the volume and density of varied types of building construction in most of the cities or regions in India, the idealisation of identified buildings into single-degree of freedom models with the consideration of first mode, incorporating the effects of displacement behaviour of buildings in the higher modes can be adopted in the analysis to minimise the computation time with reasonable accuracy.

9. BUILDING INVENTORY SURVEY AND ASSESSMENT OF DAMAGE LEVELS WITH GIS

The computation of damage levels that result from the ground shaking effects of an earthquake basically requires the use of software that is able to process available information on ground motion characteristics, building inventory and building fragility (vulnerability). Nowadays, a great deal of seismic damage estimation (SDE) software is available that makes use of the different approaches, as described earlier. Building inventory survey with portable computing devices for field data collection with amenability to database management into the SDE software is the faster scientific approach for the collection of input data. Rapid visual screening (RVS) without performing any structural calculation can also be chosen as a method for input information of each and every building in an area. This survey is carried out based on the checklist provided in forms. Weight estimation for different building parameters, vulnerability index estimation and vulnerable class identification etc. are the main steps to find out seismic vulnerability of buildings. Weight for each building parameter is estimated by analytic hierarchy process (AHP). Then vulnerability index for different combinations of building parameters can be quantified by certain query operations. Finally, a spatial representation of the study areas combined with selected attribute data as input in GIS and use of seismic damage computation software, which shows the vulnerability of each building element and overall vulnerability of selected areas against earthquake through the vulnerability maps. Since the seismic vulnerability of a city or region is determined from several factors and all of them have to be studied simultaneously, multi-criteria decision-making (MCDM) techniques can be used. Multi-criteria evaluation is a quantitative approach of geographic problem-solving and decision support that combines multiple spatial data sets with score areas based on a set of predetermined criteria. The GIS development process is typically shown in Figure 6, below:

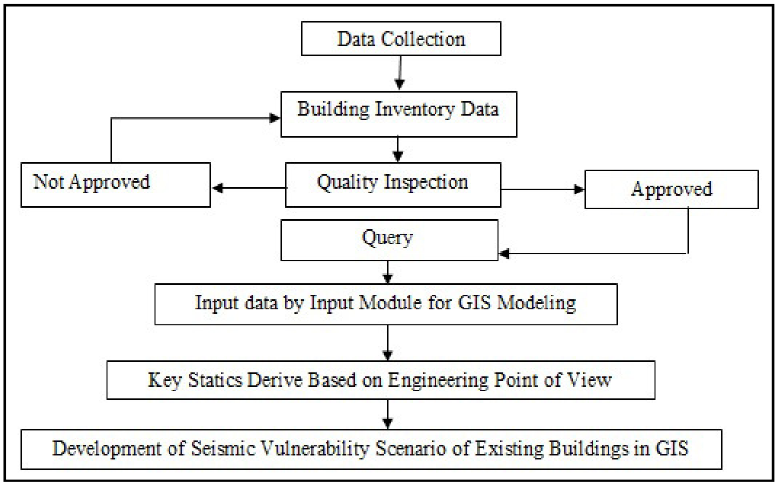

Figure 6: Development of Seismic Vulnerability Factors of Existing Building in GIS (Mohinuddin, A. M., 2014)

10. Discussions and Conclusions

The vulnerability assessment is useful for disaster preparedness, damage assessment, planning for buildings rehabilitation and represents a significant aspect of the seismic risk mitigation of a particular region. Existing methodologies for seismic vulnerability assessments have been reviewed in the context of the selection of key factors, for the evaluation of seismic scenarios and ground motion intensity measures, sampling of existing buildings, characterisation of building parameters, choice of analysis methods and structural models and the effect of local soil profile of site and SSI and estimation of damage/ loss levels for buildings. Spectral displacement and spectral acceleration values were generally viewed as better parameters in representing the intensity of earthquakes than PGA and intensity parameters due the ability of the spectral values to better represent the frequency characteristics of the earthquakes. Although nonlinear time history analyses have been generally viewed to better represent the effects of ground motion characteristics on the response of structures, they are considered to be computationally intensive. As a result, compromises were often made in the assessments such as idealisation of structural models into single-degree of freedom systems and two-dimensional models ignoring the effects of asymmetry.

The classification of buildings in the existing methodologies for seismic vulnerability assessments has been reviewed and its suitability to the construction forms in India has been discussed. Many of the buildings are generally found to be laterally supported by shear walls that are eccentrically located in the building plan and are proved to be highly sensitive to the seismic effects, causing amplification of the displacement of the peripheral building frames. In view of the varied types of construction forms in India, it is important to consider the behaviour of structural systems as a whole, in the seismic vulnerability assessments of RC buildings, as against the behaviour of RC frames in isolation from the overall structures. The buildings in the nation also often have soft-storey ground floor without in-fill walls, causing an abrupt change in the lateral stiffness along the height of the buildings and hence, larger inter-storey drifts which could cause concentration of damages on columns located on the ground floor. The idealisation into single-degree of freedom model with consideration of first mode, incorporating the effects of displacement behaviour of buildings in the higher modes can be adopted in the analysis to minimise the computation time with reasonable accuracy.

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