Study on Non Linear Behaviour of R.C Framed Structure with and without Considering Stiffness of Slab

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Abstract— Skeleton framing system composed of only reinforced concrete columns and beams have been adopted in analysis for many framed buildings. Generally, flexural stiffness of slabs is ignored and the floor load is transferred as uniformly distributed load on to the supporting beams in the conventional analysis of bare frame structures. However, in reality, the floor slabs may have some influence on the lateral response of the structures. Consequently, if the flexural stiffness of slabs in a frame system structure is totally ignored, the lateral stiffness of the framing may be underestimated. So, to study on the behavior of R.C structure with considering stiffness of slab is very essential. The research was already done on linear analysis of R.C structure with considering stiffness of slab. To predict the exact capacity of the R.C structure with considering stiffness of slab, need to depend on non-linear static analysis .To Model the Complex behavior of reinforced concrete analytically in its non-linear zone is difficult. This has led Engineers in the past to rely heavily on empirical formulas which were derived from numerous experiments for the design of reinforced concrete structures for structural design and assessment of reinforced concrete structures including force redistribution This analysis of the nonlinear response of R.C Structures to be carried out in routine fashion, it helps in the investigation behavior and the cracks pattern. Therefore the objective of the present investigation is to study the nonlinear behavior of the R.C structure with considering the effect of increased stiffness due to slab elements in R.C space frames, subjected to seismic loading, on the parameter like displacement etc. By comparing the two models of frame such has Skeleton framed structure (SFS), Skeleton framed Structure with considering stiffness of slab (SFWS), the effect of increased stiffness on the above parameters studied and also the increased capacity of framed system studied. This study is carried out on five storied R.C framed structure with two types of framing system (i.e with and without considering stiffness of slab). Performed nonlinear static analysis by using ETABS software. Frames are modelled with floor area of 225m2 (15m x15m) with three equal bays along X&Y direction. This prototype model is calibrated for R.C space framed buildings for four seismic zones of India. The framing systems compared based on the capacity curves obtained from the pushover analysis.

Key words: SFWS, SFS, Non Linear Behaviour of R.C Framed Structure

I. INTRODUCTION

The Buildings, which appeared to be strong enough, may crumble like hours of cards during earthquake and deficiencies may be exposed. Experience gain from the recent earthquake of Bhuj, 2001 demonstrates that the most of buildings collapsed were found deficient to meet out the requirements of the present day codes. In last decade, four devastating earthquakes of world have been occurred in India, and low to mold intensities earthquake of world frequently. Due to wrong construction practices and ignorance for earthquake resistant design of buildings in our country, most of the existing buildings are vulnerable to future earthquakes. In the simplest case, seismic design can be viewed as a row-step process. The first, and usually most important one, is the conception of an effective structural system that needs to be configured with due regards to all important seismic performance objectives, ranging from serviceability consideration to life safety and collapse prevention. This step comprises the art of seismic engineering, since no rigid rules can, or should, be imposed on the engineer's creativity to devise a system that not only fulfils seismic performance objectives, but also pays tribute to functional and economic constraints imposed by the owner, the architect, and other professionals involved in the design and construction of a building. By default, this process of creation is based on judgment, experience, and understanding of seismic behavior, rather than rigorous mathematical formulations. Rules of thumb for strength and stiffness targets, based on the fundamental knowledge of ground motion and elastic and inelastic dynamic response characteristics, should involve a demand/capacity evaluation at all important performance level, which requires identification of important capacity evaluation at all important performance level, which requires identification of important capacity parameters and prescription of acceptable values of these parameters, as well as the prediction of the demands imposed by ground motions. Suitable capacity parameters and their acceptable values, as well as suitable methods for demands prediction will depend on the performance level to be evaluated. In light of these facts, it is imperative to seismically evaluate the existing building with the Present day knowledge to avoid the major destruction in the future earthquakes. The Buildings found to be seismically deficient should be retrofitted or strengthened. Only reinforced concrete columns and beams, have been adopted in analysis for many framed buildings. Generally, flexural stiffness of slabs is ignored and the floor load is transferred as uniformly distributed load on to the supporting beams in the conventional analysis of bare frame structures. However, in reality, the floor slabs may have some influence on the lateral response of the structures. Consequently, if the flexural stiffness of slabs in a frame system structure is totally ignored, the lateral stiffness of the framing may be underestimated. So, to study on the behavior of R.C structure with considering stiffness of slab is very essential. The research was already done on linear analysis of R.C structure with considering stiffness of slab.

To predict the exact capacity of the R.C structure with considering stiffness of slab, need to depend on non-linear static analysis. To Model the Complex behavior of reinforced concrete analytically in its non-linear zone is difficult. This has led Engineers in the past to rely heavily on empirical formulas which were derived from numerous experiments for the design of reinforced concrete structures for structural design and assessment of reinforced concrete structures including force redistribution This analysis of the non linear response of R.C Structures to be carried out in routine fashion, it helps in the investigation behavior and the cracks pattern.

Therefore the objective of the present investigation is to study the nonlinear behavior of the R.C structure with considering the effect of increased stiffness due to slab elements in R.C space frames ,subjected to seismic loading ,on the parameter like displacement etc. By comparing the two models of frame such has Skeleton framed structure (SFS), Skeleton framed Structure with considering stiffness of slab (SFWS), the effect of increased stiffness on the above parameters studied and also the increased capacity of framed system studied.

This study is carried out on five storied R.C framed structure with two types of framing system (i.e with and without considering stiffness of slab). Performed nonlinear static analysis by using ETABS software. Frames are modelled with floor area of 225m2 (15m x15m) with three equal bays along X&Y direction. This prototype model is calibrated for R.C space framed buildings for four seismic zones of India. The framing systems compared based on the capacity curves obtained from the pushover analysis.

II. LITERATURE REVIEW

A. General

Structures are expected to deform in elastically when subjected to severe earthquakes, so Seismic performance evaluation of structures should be conducted considering post-elastic behavior. Therefore, a nonlinear analysis procedure must be used for evaluation purpose a post-elastic behavior cannot be deter mind directly by an elastic analysis. Moreover, maximum inelastic displacement demand of structures should be deter mind to adequately Estimate the seismically induced demands on structures that exhibit inelastic behavior.

Various simplified nonlinear analysis procedures and approximate methods to estimate maximum inelastic displacement demand of structures are proposed in literature. The widely used simplified nonlinear analysis procedure, pushover analysis, has been an attractive subject of study.

In the following section, studies on the nonlinear static pushover method will be presented. In addition, recent studies on the multi-storied buildings will be summarized.

B. Past studies on Pushover Analysis

Chopra (2001) extracted an improved Direct Displacement-Based Design Procedure for Performance-Based seismic design of structures. Direct displacement-based design requires a simplified procedure to estimate the seismic deformation of an inelastic SDF system, representing the first (elastic) mode of vibration of the structure. This step is usually accomplished by analysis of an “equivalent” linear system using elastic design spectra. In their work, an equally simple procedure is developed that is based on the well-known concepts of inelastic design spectra. This procedure provides: (1) accurate values of displacement and ductility demands, and (2) a structural design that satisfies the design criteria for allowable plastic rotation. In contrast, the existing procedure using elastic design spectra for equivalent linear systems is shown to underestimate significantly the displacement and ductility demands.

In this work, it is demonstrated that the deformation and ductility factor that are estimated in designing the structure by this procedure are much smaller than the deformation and ductility demands determined by nonlinear analysis of the system using inelastic design spectra. Furthermore, it has been shown that the plastic rotation demand on structures designed by this procedure may exceed the acceptable value of the plastic rotation

Ceroni et al., (2007) formulated that ductility of R.C. elements has been widely studied either experimentally and theoretical since its evaluation is basic to carry out a reliable non-linear analysis of structures; post-elastic deformability is a resource for redistributing stresses in a structure to increase the ultimate load but, above all, to absorb and dissipate energy during major earthquakes. However, the problem remains open and models still need an improvement in two directions. On one side, mechanical models can be implemented to take into account constructive details, shear-flexure interaction, size effects as well as non-linear constitutive relationship of materials and steel-concrete bond. On the other side, simplified approaches have to be assessed in order to allow an easy but reliable ductility evaluation without using any sophisticated analytical model, generally not very designers friendly. In this paper a wide parametric analysis with a refined model is carried out in order to build on a reliable formulation for the plastic hinge length of R.C. columns subjected to axial and flexural load. The model used to analyze the non-linear behavior of the element and to estimate the plastic rotation is a point by point model, including an explicit formulation of the bond slip relationship and capable to take into account the effect of the distributed and concentrated non-linearity, as the spread of plasticity along the member and the fixed end rotation. Its efficiency has been already successfully applied to experimental comparison.

Chung-Yue Wang et al., (2007) in this paper he presented a method for the determination of the parameters of plastic hinge properties (PHP) for structure containing RC wall in the pushover analysis is proposed. Nonlinear relationship between the lateral shear force and lateral deformation of RC wall is calculated first by the Response-2000 and Membrane-2000 code. The PHP (plastic hinge properties) value of each parameter for the pushover analysis function of SAP2000 or ETABS is defined as the product of two parameters α and β. Values of α at states of cracking, ultimate strength and failure of the concrete wall under shear loading can be determined respectively from the calculations by Response-2000. While the corresponding β value of each PHP parameter is obtained from the regression equations calibrated from the experimental results of pushover tests of RC frame-wall specimens. The accuracy of this newly proposed method is verified by other experimental results. It shows that the presented method can effectively assist engineers to conduct the performance design of structure containing RC shear wall using the ETABS.

ETABS is a well-known and widely accepted, general-purpose, three-dimensional structural analysis program. The pushover analysis module has been installed into the ETABS. In the procedure of the pushover analysis, the assignment of the values of plastic hinge properties (PHP) strongly affects the prediction of the capacity curve of RC structure.

ETABS program includes several built-in default hinge properties that are based on average values from ATC-40 for concrete members. These built-in properties can be useful for preliminary analyses, but user-defined properties are recommended for final analyses (Habibullah and Pyle, 1998). Yielding and post-yielding behavior can be modeled using discrete user-defined hinges. Currently ETABS allows hinges can only be introduced into frame elements; the PHP properties can be assigned to a frame element at any location along it. The authors have been developed a dual parameters method to define the PHP properties of RC frame structure for the pushover analysis (Ho and Wang, 2006). The purpose of this paper is to extend the application of this method to the RC structures containing RC shear wall. In order to use the functions provided by the ETABS code, the RC shear wall is treated as a wide, flat column. Modeling a RC wall as a wide and flat column (frame elements) not only can consider the steel reinforcements in RC elements exactly, but also can assign the PHP of RC walls according to its plastic behavior. In ETABS, the default properties are available for hinges in the following degrees of freedom:

- Axial(P)
- Major shear (V2)
- Major moment (M3)
- Coupled P-M2-M3 (PMM)

He concluded that a dual parameters method is introduced to define the plastic hinge properties (PHP) of RC wall in the pushover analysis of RC structure. The effectiveness of this simple method is verified by the agreement of the prediction curves with some additional test data. This newly proposed method is quite simple and is easy for engineers to link with commercial structural analysis code to conduct the performance design of structure under seismic loading.

Dileep et al., (2011) explained the practical difficulties associated with the non linear direct numerical integration of the equations of motion leads to the use of nonlinear static pushover analysis of structures. Pushover analysis is getting popular due to its simplicity. High frequency modes and nonlinear effects may play an important role in stiff and irregular structures. The contribution of higher modes in pushover analysis is not fully developed. The behavior of high frequency model responses in nonlinear seismic analysis of structures is not known. In this paper an attempt is made to study the behavior of high frequency model responses in nonlinear seismic analysis of structures.

Nonlinear static pushover analysis used as an approximation to nonlinear time history analysis is becoming a standard tool among the engineers, researches and professionals worldwide. High frequency modes may contribute significantly in the seismic analysis of irregular and stiff structures. In order to take the contribution of higher modes structural engineers may include high frequency modes in the nonlinear static pushover analysis. The behavior of high frequency modes in nonlinear static pushover analysis of irregular structures is studied. At high frequencies, the responses of nonlinear dynamic analysis converge to the nonlinear static pushover analysis. Therefore nonlinear response of high frequency modes can be evaluated using a nonlinear static push over analysis with an implemental force pattern given by their modal mass contribution times zero period acceleration. The higher modes with rigid content as a major contributing factor exhibit a better accuracy in nonlinear pushover analysis of structures when compared to the damped periodic modes.

Mehmet et al., (2006) explained that due to its simplicity, the structural engineering profession has been using the nonlinear static procedure (NSP) or pushover analysis. Modeling for such analysis requires the determination of the nonlinear properties of each component in the structure, quantified by strength and deformation capacities, which depend on the modeling assumptions. Pushover analysis is carried out for either user-defined nonlinear hinge properties or default-hinge properties, available in some programs based on the FEMA-356 and ATC-40 guidelines. While such documents provide the hinge properties for several ranges of detailing, programs may implement averaged values. The user needs to be careful; the misuse of default-hinge properties may lead to unreasonable displacement capacities for existing structures. This paper studies the possible differences in the results of pushover analysis due to default and user-defined nonlinear component properties. Four- and seven-story buildings are considered to represent low- and medium- rise buildings for this study. Plastic hinge length and transverse reinforcement spacing are assumed to be effective parameters in the user-defined hinge properties. Observations show that plastic hinge length and transverse reinforcement spacing have no influence on the base shear capacity, while these parameters have considerable effects on the displacement capacity of the frames. Comparisons point out that an increase in the amount of transverse reinforcement improves the displacement capacity. Although the capacity curve for the default-hinge model is reasonable for modern code compliant buildings, it may not be suitable for others. Considering that most existing buildings in Turkey and in some other countries do not conform to requirements of modern code detailing, the use of default hinges needs special care. The observations clearly show that the user-defined hinge model is better than the default-hinge model in reflecting nonlinear behavior compatible with the element properties. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the program and should avoid the misuse of default-hinge properties.

He concluded that the interior frames of 4- and 7-story buildings were considered in pushover analyses to represent low- and medium rise reinforced concrete (RC) buildings for study. Beam and column elements are modeled as nonlinear frame elements with lumped plasticity by defining plastic hinges at both ends of the beams and columns. The frames were modeled with default and user-defined hinge properties to study possible differences in the results of pushover analyses.

The Following findings were observed:

1) The base shear capacity of models with the default hinges and with the user-defined hinges
2) For different plastic hinge length and transverse reinforcement spacing are similar; the variation in the base shear ca plasticity is less than 5%. Thus, the base shear capacity does not depend on whether the default or user-defined hinge properties are used.
3) Plastic hinge length (Lp) has considerable effects on the displacement capacity of the frames. Comparisons show that there is a variation of about 30% in displacement capacities due to Lp.
4) Displacement capacity depends on the amount of transverse reinforcement at the potential hinge regions. Comparisons clearly point out that an increase in the amount of transverse reinforcement improves the displacement capacity. The improvement is more effective for smaller spacing. For example, reducing the spacing from 200 mm to 100 mm provides an increase of up to 40% in the displacement capacity, while reducing the spacing from 200 mm to 150 mm provides an increase of only 12% for the 4-story frame.
5) Comparison of hinging patterns indicates that both models with default hinges (Case A) and the user-defined hinges (Case B3) estimate plastic hinge formation at the yielding state quite well. However,

there are significant differences in the hinging patterns at the ultimate state. Although the hinge locations seem to be consistent, the model with default hinges emphasizes a ductile beam mechanism in which the columns are stronger than the beams; damage or failure occurs at the beams. However, this mechanism is not explicitly guaranteed for the structures designed according to the 1975 Turkish Earthquake Code or pre-modern codes in other countries.

6) Time-history results point out that pushover analysis is reasonably successful in capturing hinging patterns for low and medium-rise buildings, except that the plastic hinge formation in the upper levels is not estimated adequately by pushover analysis, as observed by other researchers.
7) The orientation and the axial load level of the columns cannot be taken into account properly by the default-hinge properties. Based on the observations in the hinging patterns, it is apparent that the user-defined hinge model is more successful in capturing the hinging mechanism compared to the model with default hinges.
8) Although the capacity curve for the default-hinge model is reasonable for modern code compliant buildings, it may not be suitable for others. Considering that most existing buildings in Turkey and some other countries do not conform to requirements of modern code detailing, the use of default hinges needs special care.

Some programs (i.e. ETABS) provide default-hinge properties based on the ATC - 40 or FEMA-273 documents to make modeling practical for nonlinear analysis. If they are used cautiously, they relive modeling work considerably. The misuse of default-hinge properties may result in relatively high displacement capacities. Based on the observations in this study, it is clear that, although default-hinge properties provided in SAP2000 are suitable for modern code compliant buildings, the displacement capacities are quite high for other buildings. Pushover analysis of the default-hinge modal emphasizes a ductile beam mechanism for buildings constructed according to pre-modern codes, while Pushover analysis of the user-defined hinge model and time-history analysis of both models indicate strong beams and weak columns. This study is carried out to investigate the possible differences between Pushover analysis of the default-hinge and user-defined hinge models. The observations clearly show that the user-defined hinge model is better than the default-hinge model in reflecting nonlinear behavior compatible with element properties. However, if the default-hinge model is preferred due to simplicity, the user should be aware of what is provided in the programmed and should definitely avoid the misuse of default-hinge properties.

Moehle (2008) presented a performance based seismic design of tall buildings in the U.S. He presented that the building codes in the United States contain prescriptive requirements for seismic design as well as an option for use of alternative provisions. Increasingly these alternative provisions are being applied for the performance-based seismic design of tall buildings. Application of performance-based procedures requires: An understanding of the relation between performance and nonlinear response; selection and manipulation of ground motions appropriate to the seismic hazard; selection of appropriate nonlinear models and analysis procedures; interpretation of results to determine design quantities based on nonlinear dynamic analysis procedures; appropriate structural details; and peer review by independent qualified experts to help assure the building official that the proposed materials and system are acceptable. Both practice- and research-oriented aspects of performance-based seismic design of tall buildings are presented.

He said that the west coast of the United States, a highly seismic region, is seeing a resurgence in the design and construction of tall buildings (defined here as buildings 240 feet (73 meters) or taller). Many of these buildings use high-performance materials and framing systems that are not commonly used for building construction or that fall outside the height limits of current buildings codes. In many cases, prescriptive provisions of governing building codes are found to be overly restrictive, leading to designs that are outside the limits of the code prescriptive provisions. This is allowable through the alternative provisions clause of building codes. When the alternative provisions clause is invoked, this normally leads to a performance-based design involving development of a design-specific criteria, site-specific seismic hazard analysis, selection and modification of ground motions, development of a nonlinear computer analysis model of the building, performance verification analyses, development of building-specific details, and peer review by tall buildings design experts.

His views about the new generation of tall buildings in the western U.S. are that urban regions along the west coast of the United States are seeing a boom in tall building construction. To meet functional and economic requirements, many of the new buildings are using specialized materials and lateral-force-resisting systems that do not meet the prescriptive definitions and requirements of current building codes.

According to Moehle's a design criteria document generally is developed by the designer to clearly and concisely communicate to the design team, the building official, and the peer reviewers the intent and the process of the building structural design. A well prepared document will likely include data and discussion regarding the building and its location; the seismic and wind force-resisting systems; sample conceptual drawings; codes and references that the design incorporates in part or full; exceptions to aforementioned code prescriptive provisions; performance objectives; gravity, seismic, and wind loading criteria; load combinations; materials; methods of analysis including software and modeling procedures; acceptance criteria; and test data to support use of new components. The document is prepared early for approval by the building official and peer reviewers, and may be modified as the design advances and the building is better understood. The design criteria document must define how the design is intended to meet or exceed the performance expectations inherent in the building code. Performance-based seismic analysis of tall buildings in the U.S. increasingly uses nonlinear analysis of a three-dimensional model of the building. Lateral-force-resisting components of the building are modeled as discrete elements with lumped plasticity or fiber models that represent material nonlinearity and integrate it across the component section and length. Gravity framing elements increasingly are being included in the nonlinear models so that effects of building deformations on the gravity framing as well as effects of the gravity framing on the seismic system Because the behavior is nonlinear, behavior at one hazard level cannot be scaled from nonlinear results at another hazard level. Furthermore, conventional capacity design approaches can underestimate internal forces in some structural systems (and overestimate them in others) because lateral force profiles and deformation patterns change as the intensity of ground shaking increases

Shuraim et al., (2007) summarized the nonlinear static analytical procedure (Pushover) as introduced by ATC-40 has been utilized for the evaluation of existing design of a new reinforced concrete frame, in order to examine its applicability. Potential structural deficiencies in RC frame, when subjected to a moderate seismic loading, were estimated by the code seismic-resistant design and pushover approaches. In the first method the design was evaluated by redesigning under one selected seismic combination in order to show which members would require additional reinforcement. It was shown that most columns required significant additional reinforcement, indicating their vulnerability if subjected to seismic forces. On the other hand, the nonlinear pushover procedure shows that the frame is capable of withstanding the presumed seismic force with some significant yielding at all beams and one column. Vulnerability locations from the two procedures are significantly different. The paper has discussed the reasons behind the apparent discrepancy which is mainly due to the default assumptions of the method as implemented by the software versus the code assumptions regarding reduction factors and maximum permissible limits. In new building Design, the code always maintains certain factor of safety that comes from load factors, materials reduction factors, and ignoring some post yielding characteristics (hardening). In the modeling assumptions of ATC-40, reduction factor is assumed to be one, and hardening is to be taken into consideration. Hence, the paper suggests that engineering judgment should be exercised prudently when using the pushover analysis and that engineer should follow the code limits when designing new buildings and impose certain reductions and limits in case of existing buildings depending on their conditions. In short software should not substitute for code provisions and engineering judgment.

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