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Performance Based Analysis and Design of Building Frames with Earthquake Loading

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Abstract—Analysis and design of building structures subjected to earthquake forces is complex task as earthquake forces are random in nature & unpredictable. In performance based analysis and design estimation of proper response parameters of structure is priorly considered to evaluate its performance. In the present work performance based analysis and design of building frames with earthquake loading is carried out. The performance of the structure considering potential hazards and uncertainties in assessment of the actual building responses are studied. Performance objectives are selected in performance based analysis and design followed by the development of a preliminary design. Further redesign and reassessment are carried out until the desired performance levels are achieved. Buildings frames are analyzed and redesigned by improving the reinforcement of various components of building frames. Multi storied building frames are analyzed enhancing the reinforcement of structural members in different combination as well as at different storey levels. The results of the analysis and design performed to meet required performance are presented in terms of displacement and forces.

Keywords—Performance based design, Seismic analysis, pushover analysis.

I. Introduction

Earthquakes being the natural disaster have the potential for causing the greatest damages to the structures and its members.
Engineering techniques should have to be modified accordingly to analyze and design the structures under the action earthquake loading as earthquake forces are more disastrous and unpredictable in nature. The performance-based seismic design process explicitly evaluates how a building is likely to perform having the potential hazard it is likely to experience. Also how the building behaves considering uncertainties inherent in the quantification of potential hazard and uncertainties in assessment of the actual building response. The long-term risk and benefit implications usually cannot be assessed using a traditional design approach.

Performance-based design begins with the selection of design criteria considering one or more performance objectives. Each performance objective considers the acceptable risk of incurring specific levels of damage and the consequential losses that occur as a result of this damage, at a specified level of seismic hazard.
The concept of performance based design is not limited to buildings alone, but is generally applicable to all structures and their supported non-structural components and contents. Michael Symans et. al (2002) studied base isolation and supplemental damping systems for seismic protection of wood structures. Chopra (2001) performed comparing response of SDF Systems to Near-Fault and Far-Fault Earthquake Motions in the Context of Spectral Regions. Priestley (2000) carried out performance based seismic design. Whittaker (1998) studied displacement estimates for performance based seismic design. Xue (2001) carried out a direct displacement based seismic design procedure of Inelastic Structures. Zou and Chan (2005) provide an optimal resizing technique for seismic drift design of concrete buildings subjected to response spectrum and time history loading. Sayani et. al. (2011) emphasized on comparative response assessment of minimally compliant low-rise base isolated and conventional steel moment resisting frame buildings. Wankhade and Landage (2014) studied static analysis for fixed base and base isolated building frame with storey levels. Wankhade (2014) studied performance based design and estimation of forces for building frames with earthquake loading.

Performance-based seismic design can be effectively used to design individual buildings structure with a higher level of confidence that the performance intended by present building codes will be achieved. It is possible to design individual buildings capable of meeting the performance intended by present building codes with lower construction costs. Individual buildings to achieve higher performance and lower potential losses can be designed

II. Concept of Performance Based Design

The main objective of performance-based seismic design process is to evaluate how a building is likely to perform under potential hazards. And uncertainties It not only considers uncertainties inherent in the quantification of potential hazard but also uncertainties in assessment of the actual building response. In performance-based design, identifying and assessing the performance capability of a building is an integral part of the entire design process. Performance-based design begins with the selection of design criteria stated in the form of one or more performance objectives. Each performance objective is a statement of the acceptable risk of incurring specific levels of damage. The consequential losses that occur as a result of the damage at a specified level of seismic hazards are calculated. Losses can be associated with structural damage, non-structural damage, or both. They can be expressed in the form of casualties, direct economic costs, and downtime (time out of service), resulting from damage. In performance-based design, identifying and assessing the performance capability of a

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building is an integral part of the design process which guides the many design decisions that must be incorporated. Figure 1 shows a flowchart which presents the key steps in the performance-based design process. It is an iterative process that begins with the selection of performance objectives, followed by the development of a preliminary design, an assessment as to whether or not the design meets the performance objectives and finally redesign and reassessment, if required, until the desired performance level is achieved.

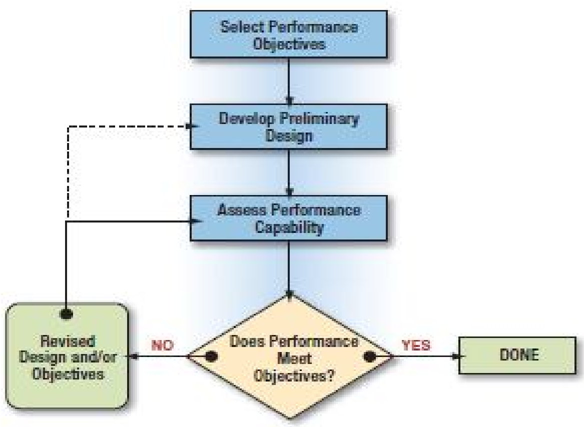

Figure 1: Performance based design flow diagram

Selection of Performance Objectives

The first element in PBSD is selection of performance objectives and is composed of two parts: a performance level and a hazard level which describes the expected seismic load at the site. The process begins with the selection of design criteria stated in the form of one or more performance objectives. Figure 2 describes the relationship between earthquake design level and performance levels

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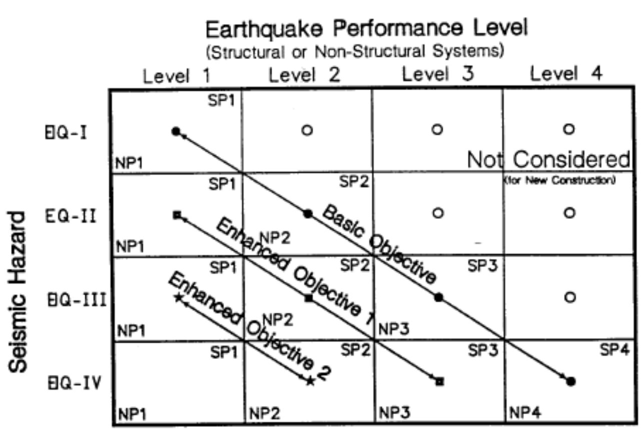

Figure 2: Relationship between earthquake design level and performance levels

Building Performance assessment includes the following steps:

1. Characterization of the ground shaking hazard.
2. Analysis of the structure to determine its probable response and the intensity of shaking transmitted to supported nonstructural components as function of shaking intensity. In the case of extreme loading, as would be imparted by a severe earthquake, simulations may be performed using nonlinear analysis techniques.
3. Determination of the probable damage to the structure at various levels of response.
4. Determination of the probable damage to nonstructural components as a function of structural and nonstructural response.
5. Determination of the potential for casualty, capital and occupancy losses as a function of structural and nonstructural damage.
6. Computation of the expected future losses as a function of intensity, structural and nonstructural response, and related damage.

In figure 3, the displacement capacity 'dc' can be identified corresponding to various performance levels in increasing order of 'dc' and hence damage from immediate occupancy to collapse prevention. In Figure displacement demands for various hazard levels are plotted on the upper horizontal axis, whereas limits on displacement capacities for various performance levels are plotted on the lower horizontal axis. This combined plot provides a complete picture of the risk associated with a particular design of the structure. A structure meets a specific performance objective if the corresponding ratio, (d_c /d_d), of displacement demand and capacity is 1.0 or greater.

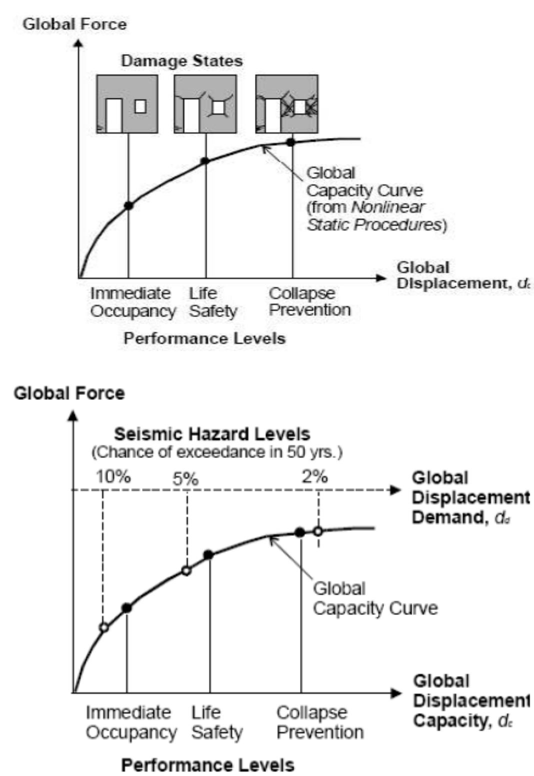

Figure 3: Global displacement demands and capacities for various performance levels

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To complete a performance assessment, statistical relationships between earthquake hazard, building response, damage, and then loss are required. In a general sense, the process involves the formation of four types of probability functions, respectively termed: hazard functions, response functions, damage functions, and loss functions, and mathematically manipulating these functions to assess probable losses.

In this section, a G+9 storied reinforced concrete frame building situated in Zone V is taken for the purpose of study. The plan of building is shown in figure and the bay span is 5m, and along z-axis the bay span is 4m. Height of the building is 32 m with each storey height of 3.5 m. The building is considered as a Special Moment resisting frame. The preliminary design of the building is performed using STAAD.Pro (according to I.S. 456:2000) for Dead Load and Live load case only for getting the reinforcement detail.

III. Methodology

G+9 BUILDING subjected to earthquake forces is considered for the performance based design.

D.L on floor = 12 kN/m2
D.L on roof = 10 kN/m2
L.L on floor = 4 kN/m2
L.L on roof = 1.5 kN/m2
Soil type=Medium- soil
Residential Building – OMRF
Total Height = 32 m
Seismic Zone = 5
Total D.L on floor = 1728 kN
Total D.L on roof = 1440 kN
Live load = 50% of 4×12×12
= 288 kN
No. of L.L on roof
W = D.L + L.L
W1 to W9 = 1728 + 288 = 2016 kN
W10 = 1440 kN
W = 20394 kN

VB = Ah × W
Ah = (z × I × Sa) / (2 × R × g)
Ta = 0.09 × h / d½
= 0.09 × 32 / 12½
= 0.83
Sa / g = 1.36 / 0.83 = 1.64
z = 0.24
I = 1
R = 3
Ah = (0.24× 1 × 1.36) / (2 × 3 × 0.83)
= 0.06554
5% Damping..
Therefore, Damping = 1
VB = Ah × W × 1
= 0.06554× 20394
= 1336.6 kN

Qi = VB ×(Wi× hi2 / ∑ Wi × hi2)

Table 1. Calculation of Q_i

Storey Level	Wi	hi	Wihi2	Wi× hi2 / ∑ Wi × hi2	Qi = VB ×(Wi× hi2 / ∑ Wi × hi2)
10	1440	32	1474560	0.076	101.58
9	2016	28.8	1972151.0	0.10	133.667
8	2016	25.6	1321205.7	0.67	895.57
7	2016	22.4	1011548.1	0.052	69.5
6	2016	19.2	743178.2	0.038	50.79
5	2016	16	516096	0.026	34.75
4	2016	12.8	330301.4	0.017	22.72
3	2016	9.6	185794.5	0.0095	12.69
2	2016	6.4	82575.3	0.0042	5.61
1	2016	3.2	20643.8	0.00106	1.4168

∑ = 19458054.4

The building is designed by STAAD.Pro (according to I.S. 456:2000) for Dead Load and Live load case only for getting the reinforcement details.

Table 2: Design and Reinforcement details

Element	Dimension	Reinforcement Area in mm2
Corner columns	0.35*0.35	650
Mid face columns	0.35*0.35	810
Interior column	0.35*0.35	810
Beams first storey	0.35*0.5	720 (top),500 (bottom)
Beams second storey	0.35*0.5	690 (top),550 (bottom)
Beams third storey	0.35*0.5	610 (top),550 (bottom)
Beams fourth storey	0.35*0.5	610 (top),555 (bottom)
Beams Fifth storey	0.35*0.5	610 (top),550 (bottom)
Beams sixth storey	0.35*0.5	610 (top),555 (bottom)
Beams seventh storey	0.35*0.5	610 (top),550 (bottom)
Beams eight storey	0.35*0.5	610 (top),,555 (bottom)
Beams ninth storey	0.35*0.5	610 (top),550 (bottom)

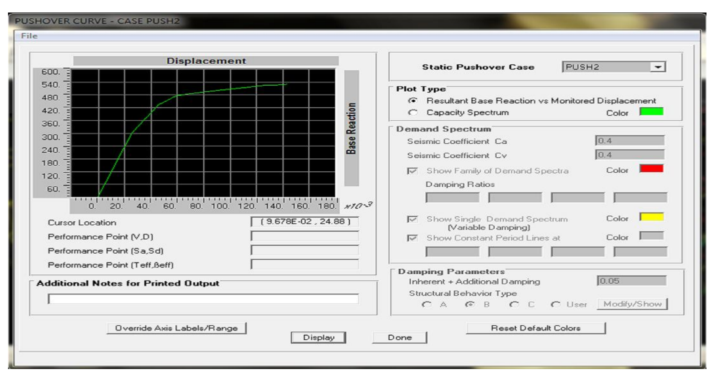

Figure 7. Pushover Curve

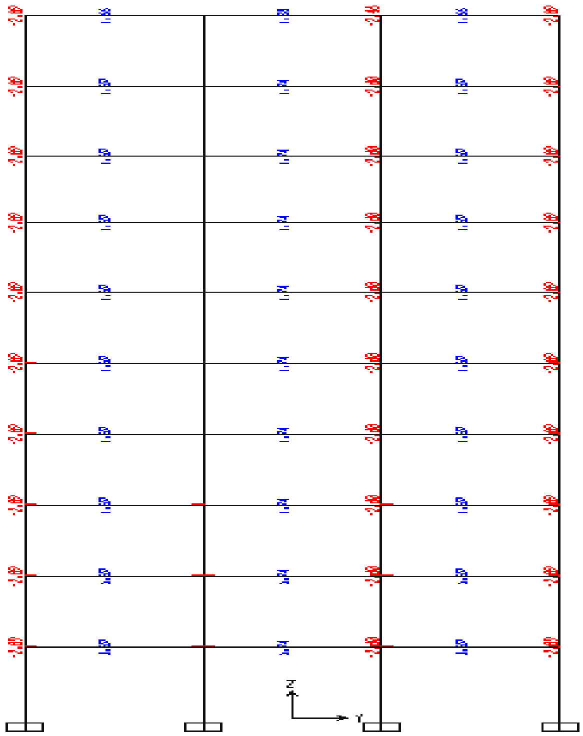

Fig. 4 Geometry of G+9 Building Frame

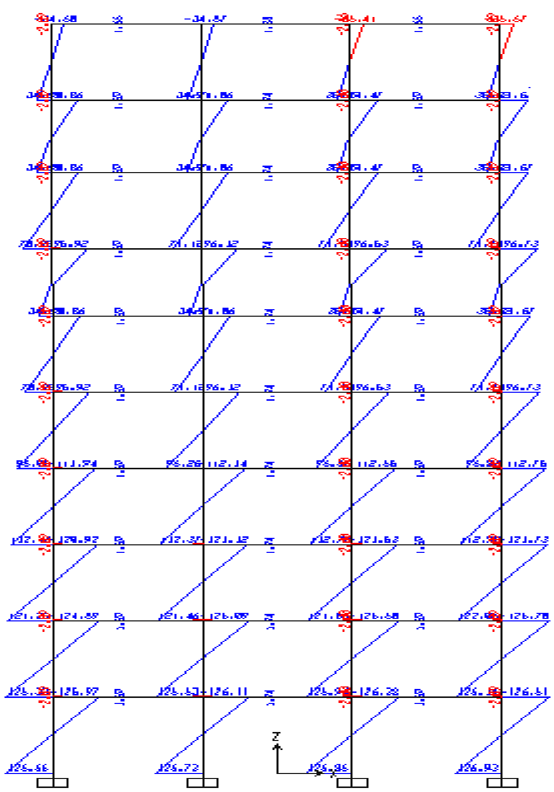

Fig. 5 G+9 Frame with Fixed Base (Moment 3-3)

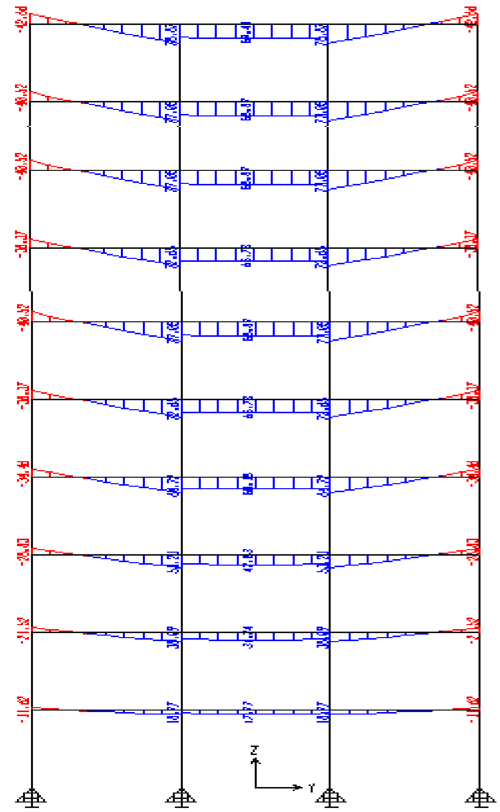

Fig. 6 G+9 Frame with isolated base (MOMENT3-3)YZ

Table No.3 Description of various cases

	Displacement		
Joint	U1	U2	U3
1	0	0	0
2	0.03805	0.03805	-0.70856
3	0.076237	0.076239	-1.30521
4	0.113565	0.113566	-1.78983
5	0.148439	0.148442	-2.16238
6	0.178674	0.178676	-2.42284
7	0.201496	0.201498	-2.57115
8	0.213551	0.213553	-2.60715
9	0.224271	0.224271	-2.61783
10	0.238863	0.238863	-2.62764
11	0.243582	0.243582	-2.63887

Various case studies performed in the work

To study the effect of change of main reinforcement on the performance of the building structure different cases are considered. All beams and columns at a particular story are given same reinforcement. Reinforcement in columns is varied per storey. Table No.4 shows cases incorporated in the study:

Table No.4 Description of various cases

Sr. no.	Description of cases
1	Increasing reinforcement in beams of 1st storey only
2	Increasing reinforcement in beams of 2nd storey only
3	Increasing reinforcement in beams of 3rd storey only
4	Increasing reinforcement in beams of 4th storey only
5	Increasing reinforcement in columns of 1st storey only
6	Increasing reinforcement in columns of 2ndstorey only
7	Increasing reinforcement in columns of 3rd storey only
8	Increasing reinforcement in columns of 4th storey only
9	Increasing reinforcement of beams and columns of 1st storey only
10	Increasing reinforcement of beams and columns of 2nd storey only
11	Increasing reinforcement of beams and columns of 3rd storey only
12	Increasing reinforcement of beams and columns of 4thstorey only
13	Increasing reinforcement of beams and columns of each storey up to top.

To study the effect of change of main reinforcement of various columns on the performance of the structure, various cases are made. For each improvement in reinforcement, results are studied considering desired performance level.

IV. Results and Discussion

Performance based analysis and design is performed for G+9 storey building frame. Building frames with both fixed and isolated bases are considered. With increase in the percentage of reinforcement in the beams and columns at different levels various cases are considered in the performance based design. As reinforcement is increased reduction in roof displacement is observed for interior column and for corner and mid-face columns which is appreciable. On the other hand performance of the building decreases as the sectional sizes of beams and columns are reduced while keeping same reinforcement.

It is observed that with increase in reinforcement of beams only, there is a nominal percentage change in the base force varying from 0.09 % to -9.78%, which the structure can carry. However, with the increase in reinforcement of storey columns, there is quite an appreciable change in the base force carrying capacity of the structure. The combination of change of reinforcement in beams and columns both show a consistent increase in base force capacity. The performance based seismic analysis and design obtained by above procedure satisfies the acceptance criteria for immediate occupancy and life safety limit states for various intensities of earthquakes. As performance-based design requirements allow designers to come up with a variety of solutions, the performance-based approach enhances creativity and innovation in the design process.

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