International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

Pushover Analysis of R.C Frames Considering Soil Structure Interaction

Halkude S.A†, Kalyanshetti M.G† and Kadlag V. A†*

†Civil Engg. Dept., Walchand Institute of Technology, Solapur, India

Accepted 12 Jan 2015, Available online 01 Feb 2015, **Vol.5, No.1 (Feb 2015)**

Abstract

Generally structures are analyzed for its structural behaviour assuming base condition as a fixed base. However it is observed that due to assumption of fixity at base condition, the results obtained are very much different from actual condition. In view of the above, while evaluating seismic structural behavior, the effect of soil structure interaction is of paramount importance. Therefore, in this study various structures are analyzed for fixed base as well as for various flexible base conditions, which are categorized as medium soil and soft soil. For analysis purpose in this study structures are considered from G+5 stories to G+25 stories at an interval of 5 stories. While assessing the seismic behaviour of structure, the pushover analysis is employed and accordingly its effect in the form of failure hinge formulation is studied.

Keywords: *Pushover analysis, Soil structure interaction, Flexible soil, Hinge failure, Non-linear static method.*

1. Introduction

Recently occurred earthquakes viz. Izmit 1999, Bhuj 2001, El hoceima 2004 [M.Mouzzoun *et al*, 2013] shows that many concrete structures have been severely damaged or have collapsed, which highlights the seismic vulnerability of structures for failure. During earthquake the possibility of structural vulnerability to damage need to be identified with respect to safety requirements. Simplified linear elastic methods are not adequate for assessment of structural damage during earthquake. Therefore, a new generation of design philosophy that incorporate performance based design is required and it is changing from simplified linear elastic method towards a more nonlinear technique i.e. pushover analysis.

The response of a structure subjected to seismicity is complex and it depends upon various parameters namely characteristics of ground motion, allowable deformation limits of the structure, strength of structural material, soil structure interaction and many others. Till date most of studies have been carried out considering base of the structure as a fixed, but this is not the ground reality. Therefore soil structure interaction effect is incorporate to study the seismic behaviour of various structures [K. Bhattacharya *et al*, 2004].

1.1 Push-over approach

The pushover analysis is a nonlinear static method described in (Eurocode 8, 2003). In this method lateral force (thrust) distribution is applied to the structure and monotonically increased. Plot of the total base shear versus roof displacement is then obtained which indicates any premature failure or weakness this is called capacity curve [M. Belgasmia *et al*, 2014], as shown in Fig.1.

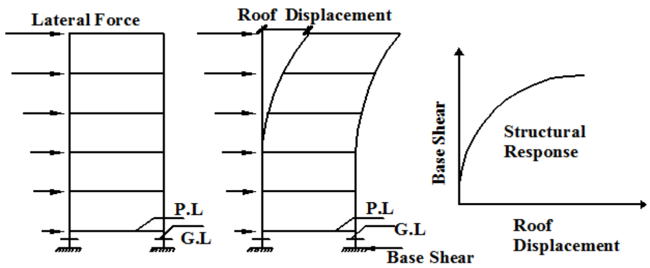


Fig.1 Capacity curve

The lateral forces applied on the structure is gradually increasing and this increment is maintained until a number of structural members yield; in the next step structure is reformed to account for the reduced stiffness of yielded members and lateral force are again increased until additional members yield. The process is continued until a displacement at top of building reaches a level at which structure becomes unstable.

The seismic performance of structure is measured by the state of damage occurred under a certain level of seismic hazard. The state of damage is quantified by the drift of the roof and the displacement of the structure and it is given in various building

*Corresponding author: **Kadlag V. A**

performance levels as per guidelines [FEMA-356, 2000] as shown in Fig.2.

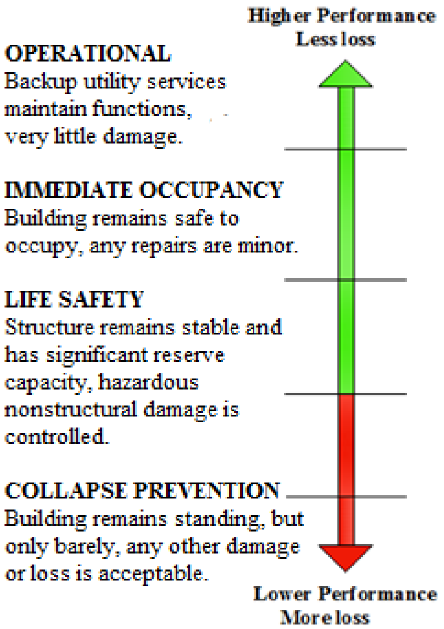
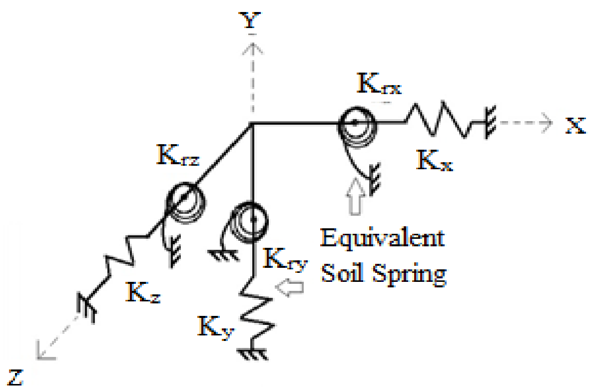


Fig.2 Building performance levels

1.2 Winkler approach

Winkler approach represents the soil medium as a system of identical but mutually independent, closely spaced, discrete, linearly behaving elastic springs. The effect of soil flexibility is suggested to be accounted through consideration of springs of specified stiffness's [S. C. Dutta 2002].

Effect of soil flexibility is mathematically represented by considering equivalent springs with six degrees of freedom as shown in Fig.3. The stiffness along these six degrees of freedom is determined with help of G. Gazetas formula [K. Bhattacharya *et al*, 2004] and is shown in Table1.



K_x, K_y, K_z = Stiffness of equivalent soil springs along the translational DOF along X,Y and Z axis.
K_{rx}, K_{ry}, K_{rz}= Stiffness of equivalent rotational soil springs along the rotational DOF along X,Y and Z axis.

Fig.3 Equivalent soil spring stiffness along 6 degrees of freedom

2. Problem formulation

Structural members of building frames are designed in accordance with specifications and guideline given by IS 456-2000 for reinforced concrete and IS 1893-2002 for earthquake forces. The structure is located in ZONE III, material properties are considered to be M20 grade of concrete and Fe415 for reinforcement steel. Plan and sectional elevation are given in Fig.4

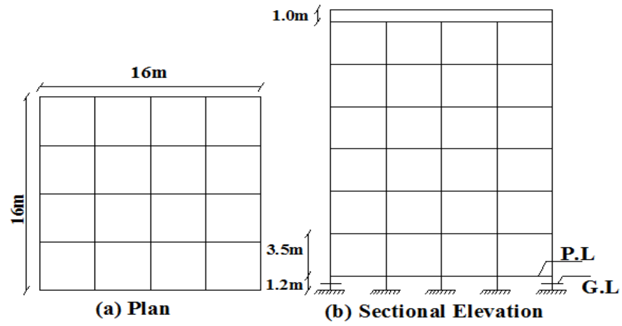


Fig.4 Plan and sectional elevation of structure

Spring stiffness required for various structures are calculated by using Table 1 [K. Bhattacharya *et al*, 2004].

Table 1 Spring Stiffness Formulae (Gazetas – 1992)

Degrees of freedom	Stiffness of equivalent soil spring
Vertical	$[2GL/(1-\nu)](0.73+1.54\chi^{0.75})$ with $\chi = A_b/4L^2$
Horizontal (lateral)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})$ with $\chi = A_b/4L^2$
Horizontal (longitudinal)	$[2GL/(2-\nu)](2+2.50\chi^{0.85})-[0.2/(0.75-\nu)]GL[1-(B/L)]$ with $\chi = A_b/4L^2$
Rocking (longitudinal)	$[G/(1-\nu)]I_{bx}^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$
Rocking (lateral)	$[G/(1-\nu)]I_{by}^{0.75}(L/B)^{0.15}$
Torsion	$3.5G\, I_{bz}^{0.75}(B/L)^{0.4}(I_{bz}/B^4)^{0.2}$

Where, A_b is area of the foundation, B and L half-width and half-length of a foundation respectively. I_{bx}, I_{by}, and I_{bz} moment of inertia of the foundation area with respect to longitudinal, lateral and vertical axes respectively.

Sizes of structural members are calculated as per specifications given by IS 456-2000 code and are as shown in Table.2

Table 2 Structural members of building frames

Structural members	B1	C1	C2	C3
C/S area (mm^2)	230x345	230x345	380x385	525x525
Structural members	C4	C5	C6	
C/S area (mm^2)	525x650	650x650	700x700	

Where, B1=Sizes of beams and C1 to C6= Sizes of columns.

Table 3 Floor wise assignment of structural members to various structures

Structure	Floors assigned					
	C1	C2	C3	C4	C5	C6
G + 5	3rd,4th,5th	G.F,1st,2nd	----	----	----	----
G + 10	9th,10th	6th,7th,8th	3rd,4th,5th	G.F,1st,2nd	----	----
G + 15	12th,13th,14th,15th	8th,9th,10th, 11th	4th,5th,6th, 7th	G.F,1st,2nd,3rd	----	----
G + 20	16th,17th,18th,19th,20th	12th,13th,14th,15th	8th,9th,10th, 11th	4th,5th,6th, 7th	G.F,1st,2nd,3rd	----
G + 25	21st,22nd,23rd,24th,25th	16th,17th,18th,19th,20th	12th,13th, 14th ,15th	8th,9th,10th,11th	4th,5th, 6th ,7th	G.F,1st,2nd,3rd

In accordance with Winkler approach, it is possible to vary the base condition of structure from fixed base condition to flexible base by incorporating springs with six degree freedom system beneath each column.

Table.4 shows spring constants for medium soil as well as soft soil to various structures considered in this study.

Table 4 Spring stiffness's of various structures

Structures		Stiffness of equivalent soil spring (kN/m)					
		Vertical	Horizontal (lateral)	Horizontal (longitudinal)	Rocking (longitudinal)	Rocking (lateral)	Torsion
G+5	M.S	82617.19	82617.19	111135.42	121611.43	125804.93	21443.24
	S.S	35407.37	35407.35	47629.46	52119.19	53916.4	9189.96
G+10	M.S	105468.75	105468.75	141875.0	253008.20	261732.62	42065.12
	S.S	45200.89	45200.89	60803.57	108432.08	112117.12	18027.90
G+15	M.S	133593.75	133593.75	179708.33	514187.6	531918.2	79064.11
	S.S	57254.46	57254.46	77017.86	220366.1	227965.0	33884.62
G+20	M.S	133593.8	133593.8	179708.3	514187.6	531918.2	163088.4
	S.S	57254.46	57254.46	77017.86	220366.1	227965	69895.01
G+25	M.S	138867.2	138867.2	186802.1	577513.5	594727.7	209948.5
	S.S	59514.51	59514.51	80058.04	247505.8	256040.5	89977.93

3. Parametric study

Variation in base conditions of structure are consider viz. infinitely rigid fixed base with modulus of elasticity E=∞ kN/m², medium soil with E=35,000 kN/m² and for soft soil with E=15,000 kN/m². Total numbers of frames considered in this study are five, G+5 stories to G+25 stories at an interval of 5 stories.

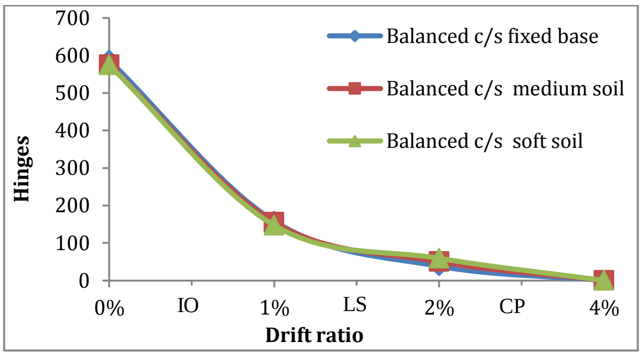
For the sake of comparison, fixed base condition is assumed to be datum and other two base conditions viz. medium soil and soft soil are varying accordingly. Structural members like beams and columns are assigned in a group of floors as shown in Table.3. In this B1 shows beam sizes, geometry of beams are kept constant throughout the structure. C1 to C6 shows various column sizes and they are assigned in a group of floors to various structures.

4. Results and Discussion

In this study number of hinges versus drift ratio graphs are plotted to observe performance of structure according to various base conditions. For analysis purpose structures are considered at an interval of 5 stories from G+5 stories up to G+25 stories. Fixed base condition of structure is kept as a datum and to evaluate soil structure interaction phenomenon fixed base of structure is replaced by flexible base viz. medium soil and soft soil. Results obtained assuming fixed base and using flexible base are compared for various structures and they are as follows.

4.1 Hinge variations in G+5 structure

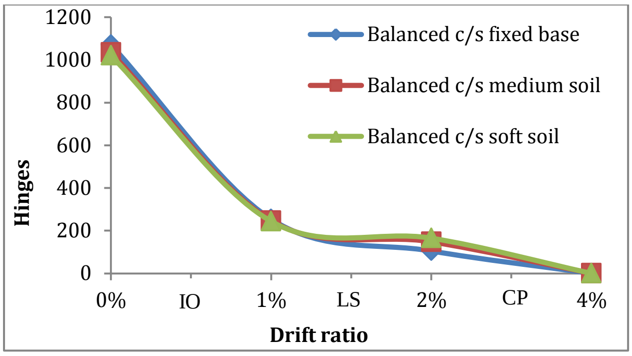
Graph.1 shows variation in number of hinge failures according to base condition of structure, fixed base of structure is kept as a datum and other two cases viz. medium soil and soft soil are compared with fixed base. For fixed base number of hinges is in life safety (LS) zone [ATC-40, 1996] and it is 38, as base condition of structure changes to medium soil structure is in LS zone but number of hinges is 50 and it is increased by 31.57% with respect to fixed base. As base condition of structure changes to soft soil, number of hinges is 59 and it is increased by 55.26% with respect to fixed base. All above shows that as the soil flexibility increase, there is increase in number of hinges which leads to more vulnerable performance of structure.



Graph 1 variation in hinges for G+5 structure

4.2 Hinge variations in G+10 structure

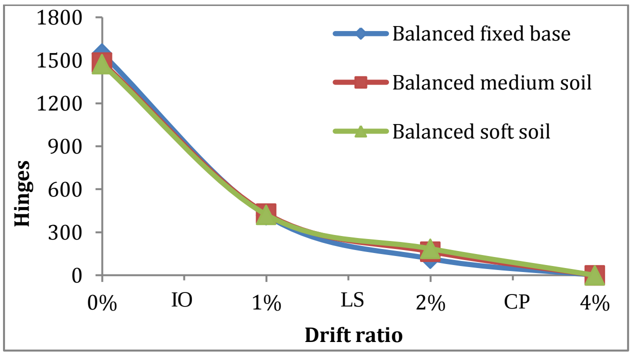
In the present study Graph.2 shows variation in number of hinge failures according to base condition of structure, fixed base of structure is kept as a datum and other two cases viz. medium soil and soft soil are compared with fixed base. For fixed base number of hinges is in LS zone and it is 105, as base condition of structure changes to medium soil structure is in LS zone but number of hinges is 148 and it is increased by 40.95% with respect to fixed base. As base condition of structure changes to soft soil, number of hinges is 165 and it is increased by 57.14% with respect to fixed base. From the above facts, we can conclude that there is increase in number of hinges with increase in soil flexibility, and performance of structure is more vulnerable towards danger.



Graph 2 variation in hinges for G+10 structure

4.3 Hinge variations in G+15 structure

Graph.3 shows variation in number of hinge failures according to base condition of structure, fixed base of structure is kept as a datum case and other two cases viz. medium soil and soft soil are compared with fixed base. For fixed base case number of hinges is in LS zone and it is 115, as base condition of structure changes to medium soil structure is in LS zone but number of hinges is 165 and it is increased by 43.47% with respect to fixed base.

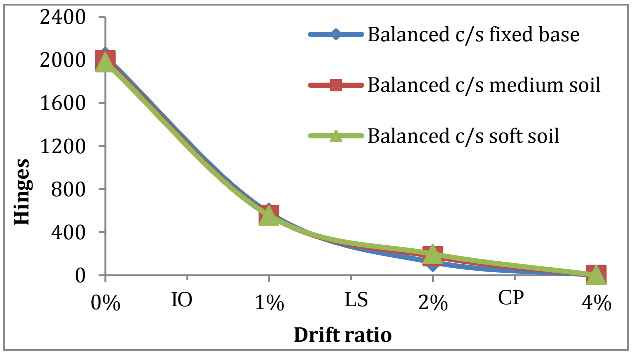


Graph 3 variation in hinges for G+15 structure

As base condition of structure changes to soft soil, number of hinges is 185 and it is increased by 60.86% with respect to fixed base. All above concludes that as the soil flexibility increases, there is increase in number of hinges which leads to more vulnerable performance of structure.

4.4 Hinge variations in G+20 structure

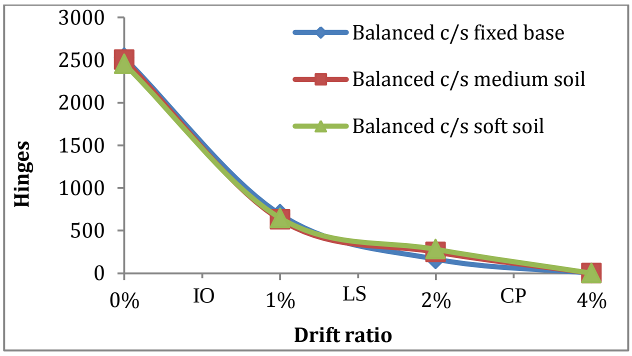
In this Graph.4 shows variations in number of hinge failures according to base condition of structure, fixed base of structure is kept as a datum case and other two cases viz. medium soil and soft soil are compared with fixed base. For fixed base case number of hinges is in LS zone and it is 121, as base condition of structure changes to medium soil structure is in LS zone but number of hinges is 175 and it is increased by 44.62% with respect to fixed base. As base condition of structure changes to soft soil, number of hinges is 197 and it is increased by 62.80% with respect to fixed base. All above discussion shows that as the soil flexibility increases, there is increase in number of hinges which leads to more vulnerable performance of structure.



Graph 4 variation in hinges for G+20 structure

4.5 Hinge variations in G+25 structure

In present study Graph.5 shows variation in number of hinge failures according to base condition of structure, fixed base of structure is kept as a datum case and other two cases viz. medium soil and soft soil are compared with fixed base.



Graph 5 variation in hinges for G+25 structure

For fixed base number of hinges is in LS zone and it is 165, as base condition of structure changes to medium soil structure is in LS zone but number of hinges is 248 and it is increased by 53.30% with respect to fixed base. As base condition of structure changes to soft soil, number of hinges is 280 and it is increased by 69.69% with respect to fixed base. From the above facts, we can conclude that as the soil flexibility increases, there is increase in number of hinges which leads to more vulnerable performance of structure.

From all above cases it is observed that base condition of structure changes from fixed base to flexible base, nature of hinge failure goes on increasing and performance of structure goes on decreasing.

Conclusions

While assessing the seismic behaviour of structure in the form of hinge failure employing the pushover analysis, it is observed that base condition influences the most on structural behaviour. The following conclusions are drawn on the basis of above study.

- The percentage hinge failure goes on increasing with increasing number of storey, and it is varying in the range of 5% to 16% for each five stories rise.
- As base condition of structure changes from fix base to medium soil percentage increase in hinge failure increases by 1.2% to 9%.
- As base condition of structure changes from medium soil to soft soil percentage increase in hinge failure is increased by 16% to 23%.
- The effect of change of base condition is observed to be of paramount importance. It is seen that as the base condition become more flexible the formulation of number of failure hinges are increasing. With increasing flexibility of base, the failure hinge increases, therefore it leads to deterioration of structural performance.

Therefore the incorporation of soil structure interaction for seismic analysis purpose will be more realistic as compared to the conventionally consider fixed base beneath the structure.

References

Sekhar Chandra dutta, Rana roy (2002), A critical review on idealization and modeling for interaction among soil-foundation-structure system, *Computer and structures,* 80,pp 1579-1594.

Koushik Bhattacharya, Sekhar Chandra Dutta (2004), Assessing lateral period of building frames incorporating soil-flexibility, *Journal of Sound and Vibration*, 269,pp 795-821.

A. kadid and A. Boumrkik (2008), Pushover analysis of reinforced concrete frame structures, *Asian journal of civil engineering*, 9, pp 75-83.

M. Hakan Arslan (2009), Application of ANN to evaluate effective parameters affecting failure load and displacement of RC buildings, *Nat. hazards earth*, pp 967-977.

V.S.R Pavan Kumar.Rayaprolu, P.Polu Raju (2012), A non-linear static analysis of multi storied building, *International Journal of Emerging trends in Engineering and Development*, 4(2)

M.Mouzzoun, O.Moustachi, A.Taleb, S.Jalal (2013), Seismic performance assessment of reinforced concrete buildings using pushover analysis, *IOSR Journal of Mechanical and Civil Engineering,* 5, PP 44-49.

Mourad Belgasmia and Sabah Moussaoui (2014), Comparison of static pushover analysis in the case of small and large deformation with time history analysis using flexibility based model for an existing structure, *IJCET -ISSN*, 3

S. A. Halkude, M. G. Kalyanshetti, S. H. Kalyani (2014), Soil Structure Interaction Effect on Seismic Response of R.C. Frames with Isolated Footing, *International Journal of Engineering Research & Technology,* 3(1).

Applied Technology council-40 (1996).

Federal Emergency Management Agency-356 (2000).