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Application of N2 Method for Performance Evaluation of Reinforced Concrete Framed Asymmetric Edifices

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Authors' contributions

This work was carried out in collaboration between all authors. Author CNG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AG and SK managed the analyses of the study. Author BGNK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

As urban population is expanding constantly, the construction of edifices on the earthquake active area is also increasing. Due to aesthetic appearance, most of the edifices in the present era are asymmetric in nature. But when symmetric edifices are subjected to earthquake, their behaviors are not complex as compared to asymmetric edifices. Hence, for safety purpose, there is need to study the complex behavior of asymmetric edifices by conducting performance evaluation. In the present study, the performance evaluation of four RC edifices is done using N2 method. An effort is made to calculate the correction factors for displacements to account for the effect of torsion. The displacements of asymmetric edifices of all the joints, corners and center of mass are not same.

Keywords: Performance evaluation; pushover scrutiny; N2 method; joint displacements; asymmetric edifices; correction factors.

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1. INTRODUCTION

For safety of human life and edifices, there is a necessity to study the performance of old and new edifices which are built on earthquake active regions. Many of the researchers have worked in this regard and proposed the simplified method of performance evaluation as nonlinear pushover scrutiny [1]. In pushover scrutiny the demand spectrum obtained by earlier earthquake data, will be in single degree of freedom[SDOF] system and the capacity spectrum [1,2] obtained by conducting the pushover scrutiny on edifices will be in multi degree of freedom [MDOF] system. One of the main drawbacks of nonlinear pushover scrutiny is, the demand spectra is in SDOF system and the capacity spectrum is in MDOF system.

In order to overcome this drawback, Peter Fajfar and his team developed a new method, for performance evaluation of the edifices which is known as N2 method [3,4]. In N2 method N stands for nonlinear and 2 stands for two mathematical models. N2 method is an easy nonlinear method that can be used for performance evaluation of edifices. In this method both the capacity and the demand spectrums will be in SDOF system. In N2 method, first we have to obtain force displacement relationship by conducting the pushover scrutiny of MDOF system with respect to the center of mass [5]. Later it will be converted to SDOF force displacement relationship [3,4]. By using this SDOF force displacement relationship, the capacity spectrum of SDOF system will be obtained. The applicability of N2 method is with respect to the center of mass. In case of symmetric edifices the displacements of different joints, corners and at the center will be approximately same and there will be no torsional effect.

But in case of asymmetric edifices the displacement of the different joints and corners will be different as compared with the displacement of the center of mass. Hence the behavior of asymmetric edifices is quite complex during earthquake compared to symmetric edifices [6,7,8]. As the displacements of all the joints and corners are different in asymmetric edifices, they will undergo torsional movement under lateral loads. In order to account for this torsional effect some correction factors have to be applied to the results of pushover scrutiny in the N2 method [5,6,9,10]. In the present study, an exertion is made to analyse this complex behavior of the asymmetric edifices subjecting to lateral loads and to propose the enhanced displacement capacity to meet the demand criteria using N2 method. In order to determine the enhanced displacement capacity, correction factors are proposed to account for torsional effect.

2. METHODOLOGY

In the present study the method used for performance evaluation of edifices is N2 method [3]. In N2 method there are seven steps. In the first step the data required to perform N2 method are collected. In the second step the seismic demand in terms of acceleration-displacement pattern is determined. In the third step pushover scrutiny of MDOF system is preformed and force displacement relationship is obtained. This MDOF system force displacement relationship is converted to SDOF system force displacement relationship with the help of transformation constant [3] and from this SDOF system force displacement relationship the capacity spectrum of SDOF system is obtained [3]. In the fourth step the displacement demand of SDOF system is calculated. In the fifth step the target roof displacement of SDOF system is calculated [3]. In the sixth step correction factor to account for torsional effects is calculated. In the seventh step the performance evaluation of edifices is done by comparing local and global demands [3].

3. RC EDIFICES CONSIDERED FOR SCRUTINY

A reinforced concrete framed edifices with the height 16 m (G+3) and with dimension of plan as 5 m X 5 m located in seismic zone 4 is selected for analysis purpose. The grade of concrete & steel used for construction of the edifice is M20 and Fe415 respectively. The edifices are located on hard soil. The edifices consist of a slab of thickness 130 mm. Since the edifices are located in seismic zone 4 from IS 1893 (part 1): 2002 the zone factor is 0.24, importance factor is 1 and response reduction factor is 3. For scrutiny purpose, we selected 4 edifices, whose plan of the selected edifices is as shown in Figs. 1 to 7. The above specification is same for all 4 edifices. The mass of the all the four edifices remains same and the only change is the orientation of the columns.

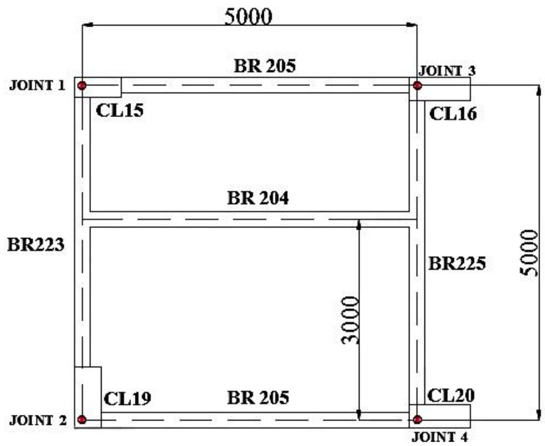

Fig. 1. Floor plan of edifice 1

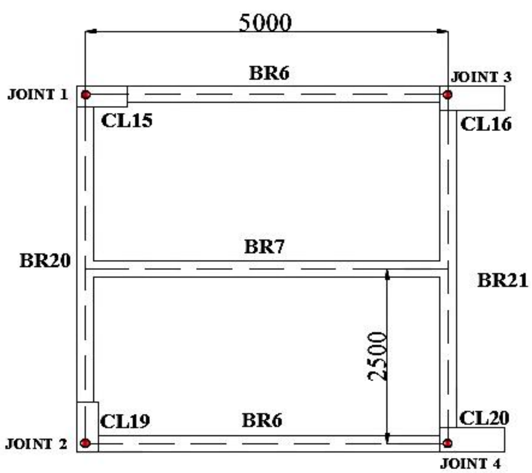

Fig. 2. Roof plan of edifice 1

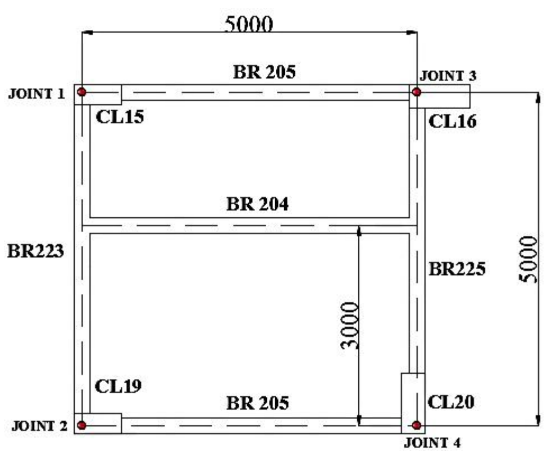

Fig. 3. Floor plan of edifice 2

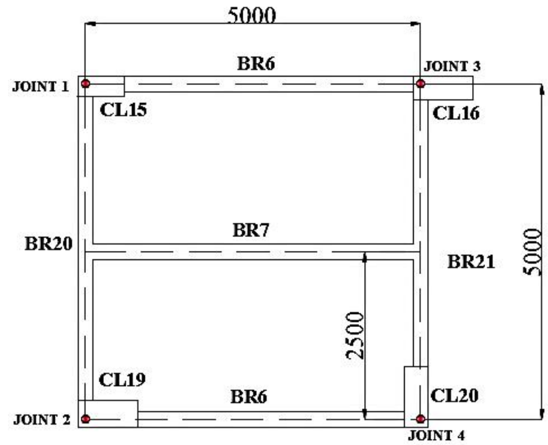

Fig. 4. Roof plan of edifice 2

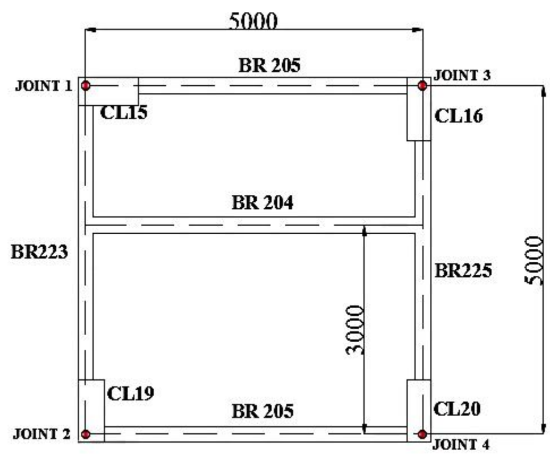

Fig. 5. Floor and roof plan of edifice 3

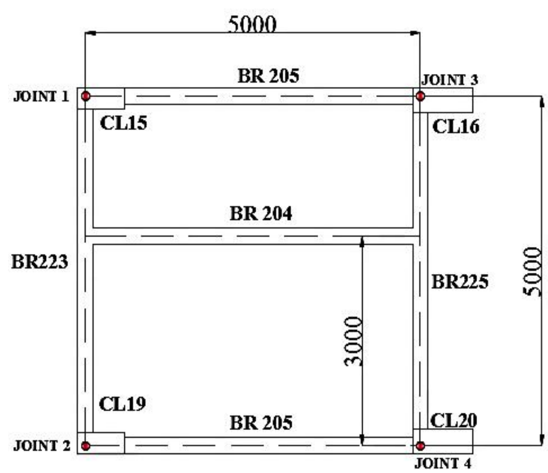

Fig. 6. Floor Plan of edifice 4

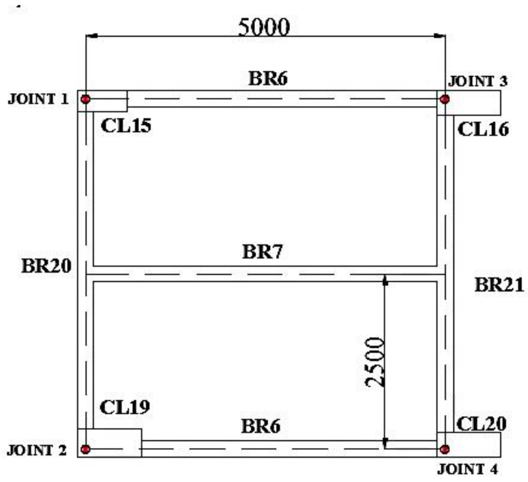

Fig. 7. Roof Plan of edifice 4

In order to perform N2 method, two important things required are demand and capacity spectrum. The demand spectrum is taken from IS 1893 (part 1): 2002, which will be in SDOF system. The capacity spectrum is obtained from pushover scrutiny [11,12,13]. To perform pushover scrutiny, the modeling of edifices is done using ETABS Version 16.0.3. The pushover scrutiny is done with respect to the center of mass of edifices.

4. CORRECTION FACTORS

In order to account for the effect of torsion, the obtained seismic demand needs to be increased. So in order to increase the demand the obtained results of pushover scrutiny in N2 method has to be multiplied by some factors which are known as correction factors. This correction factor is calculated by using below equation.

Correction factor = Normalized displacement of response spectrum scrutiny/Normalized displacement of pushover scrutiny

The maximum roof displacements of various joints and center of mass of the edifices are obtained by conducting response spectrum scrutiny with respect to the center of mass in both X & Y directions and pushover scrutiny with respect to the center of mass in both positive & negative X & Y directions. Later, normalize the roof displacements values of response spectrum scrutiny of considered joints with respect to roof displacements values of response spectrum scrutiny with respect to the center of mass. Also normalize the roof displacements values of pushover scrutiny of considered joints with respect to roof displacements values of pushover scrutiny with respect to the center of mass. If the obtained normalized roof displacements of response spectrum scrutiny are less than one, then we have to take it as 1. Table 1 shows the correction factors of four edifices.

Table 1. Correction factors of four edifices

	Edifice 1	Edifice 2	Edifice 3	Edifice 4
Joint 1	1.007	1.192	1.009	1.005
Joint 2	1.257	1.192	1.173	1.005
Joint 3	1.205	1.039	1.009	1.043
Joint 4	1.187	1.039	1.173	1.043

5. RESULTS AND DISCUSSION

Figs. 8 and 9 represent the displacements of joints 1, 2, 3 and 4 of edifice 1 along X & Y directions after applying the correction factors respectively. The displacements of joints 1 and 2 are not uniform at all stories and the displacements of joints 3 and 4 are approximately uniform at all stories of edifice 1 along X & Y directions. This is because; the distribution of lateral strength of edifice 1 at every story is not equal.

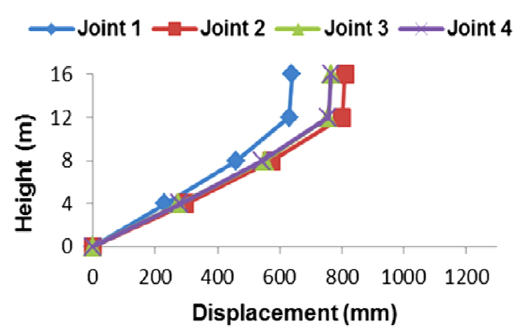

Fig. 8. Joint displacements of edifice 1 along X direction

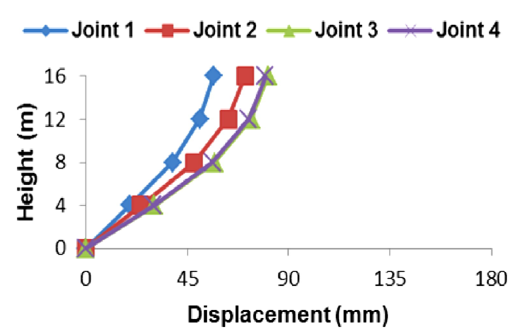

Fig. 9. Joint displacements of edifice 1 along Y direction

Figs. 10 and 11 represent the displacements of joints 1, 2, 3 and 4 of edifice 2 along X & Y directions after applying the correction factors respectively. The displacements of joints 1, 2, 3 and 4 along X direction are not uniform at all stories of edifice 2. The displacements of joints 1 and 2 & joint 3 and 4 along Y direction are approximately uniform at all stories of edifices 2. This is because; the distribution of lateral strength of edifice 2 at every story is not equal.

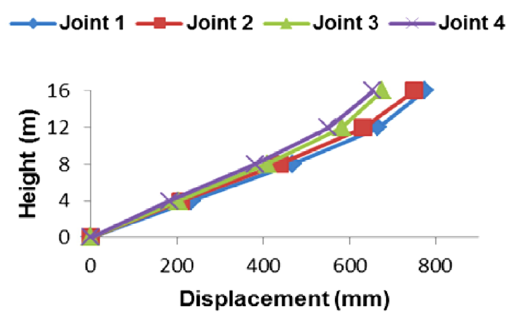

Fig. 10. Joint displacements of edifice 2 along X direction

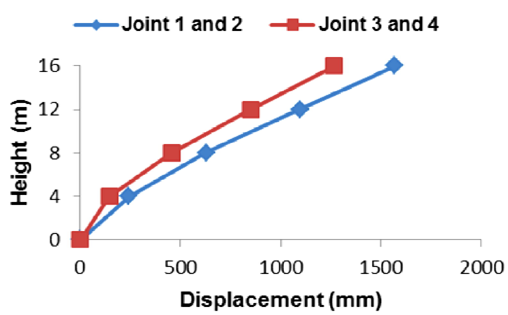

Fig. 11. Joint displacements of edifice 2 along Y direction

Figs. 12 and 13 represent the displacements of joints 1, 2, 3 and 4 of edifice 3 along X & Y directions after applying the correction factors respectively. The displacements of joints 1 and 3 & joints 2 and 4 along X direction are uniform at all stories of edifices 3. The displacements of joints 1, 2, 3 and 4 along Y direction are not uniform at all stories of edifices 3. This is because; the distribution of lateral strength of edifice 3 at every story is not equal.

Figs. 14 and 15 represent the displacements of joints 1, 2, 3 and 4 of edifice 4 along X & Y directions after applying the correction factors respectively. The displacements of joints 1 and 2 & joint 3 and 4 along X & Y directions are approximately uniform at all stories of edifices 4. This is because; the distribution of lateral strength of edifice 4 at every story is not equal.

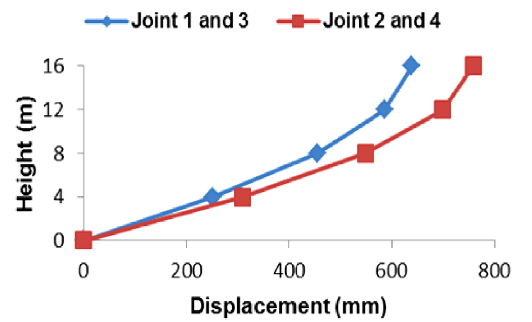

Fig. 12. Joint displacements of edifice 3 along X direction

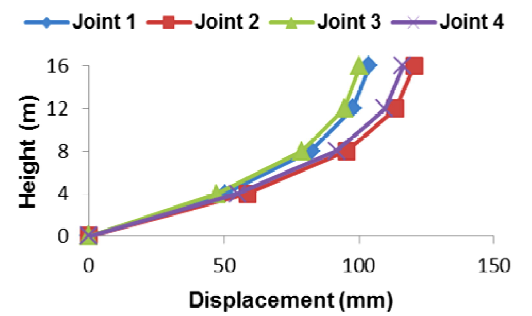

Fig. 13. Joint displacements of edifice 3 along Y direction

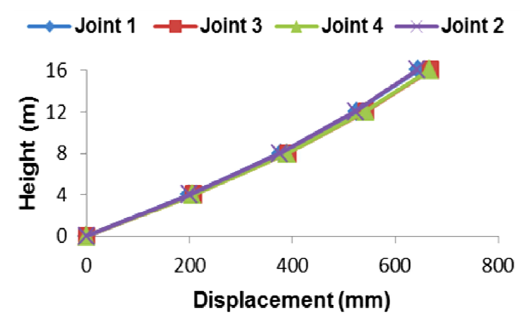

Fig. 14. Joint displacements of edifice 4 along X direction

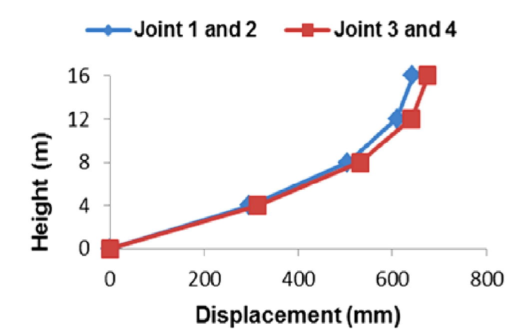

Fig. 15. Joint displacements of edifice 4 along Y direction

6. CONCLUSION

When edifices are subjected to lateral loads, performance of these edifices are done based on N2 method of performance evaluation, some of the conclusions drawn are; The joint displacements of edifices 1 and 3 along X direction are more when compared to Y direction. This is because the strength of edifices 1 and 3 along X direction is less when compared to Y direction. The joint displacements of edifices 2 and 4 along Y direction are more when compared to X direction. This is because the strength of edifices 2 and 4 along Y direction is less when compared to X direction. In order to account for the effect of torsion the obtained seismic demand has to be increased. Displacements of various joints are different when comparing to the displacements at center of mass, which needs to be corrected in the design process.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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