



COMPARATIVE STUDY OF PROGRESSIVE COLLAPSE ON RCC MULTISTORY BUILDING

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Abstract : *The progressive collapse resistance of seismically designed RCC 4 storey building is investigated using computational simulation models.. Two types of models were analyzed : SMRF & OMRF buildings with & without masonry infill wall. The study is conducted on previously designed 4-storey prototype buildings by applying the alternate path method. In this methodology, critical columns and if present, are instantaneously removed from an analysis model and the ability of the model to successfully absorb member loss is investigated. Member removal in this manner is intended to represent a situation where an extreme event or abnormal load destroys the member. The simulation results show that while both systems benefit from placement of the Infill wall on frame members of the building, the frame with infill walls is less vulnerable to progressive collapse than the frame without Infill wall. Improvement in behavior is due to improved system due to Infill wall acts as compression strut and resists the deformation of the frame.*

Keywords : OMRF, SMRF, Flexure, Shear, DCR

I INTRODUCTION

A progressive collapse involves a series of failures that lead to partial or total collapse of a structure. In the 'Best practice for reducing the potential for progressive collapse in buildings' published by NIST [1] the potential abnormal load hazards that can trigger progressive collapse are categorized as: aircraft impact, design/construction error, fire, gas explosions, accidental overload, hazardous materials, vehicular collision, bomb explosions, etc. As these hazards have low probability of occurrence, they are either not considered in structural design or addressed indirectly by passive protective measures. Most of them have characteristics of acting over a relatively short period of time and result in dynamic responses. In the United States the General Services Administration (GSA) [2] and the Department of Defense (DoD) [3] provide detailed information and guidelines regarding methodologies to resist progressive collapse of building structures. Among many different approaches to designing structures against progressive collapse, the guidelines generally recommend the alternate path method. In this approach, the structure is designed such that if one component fails, alternate paths are available for the load and a general collapse does not occur. This approach has the benefit of simplicity and directness. In its most common application, design for redundancy requires that a building structure be able to tolerate loss of any one column without collapse.

The analysis procedures recommended by the guidelines for alternate path method are linear elastic static (LS), linear dynamic (LD), nonlinear static (NS), and nonlinear dynamic (ND) methods, which were also recommended for seismic analysis and design for structures in FEMA 274 [4]. Kaewkulchai and Williamson [5] investigated the analysis procedures using a two-dimensional frame analysis. They found that linear static analysis might result in non-conservative results since it cannot reflect the dynamic effect by sudden exclusion of columns. Marjanishvili [6] studied the advantage and disadvantage of each analysis procedure for progressive collapse analysis. Powell [7] compared the LS, NS, and ND analyses and found that the impact factor of 2 regulated in the LS analysis can display very conservative result, and insisted that basically the nonlinear analysis should be used. Ruth et al. [8] found that a factor of 1.5 better represents the dynamic effect especially for steel moment frames. Marjanishvili and Agnew [9] compared the four procedures using an example building, and indicated that as the four procedures had their own merits the static and the dynamic analyses need to be incorporated properly to get the best results for progressive analysis. The results of previous research mentioned above showed that the analysis procedures presented in the guidelines possess both advantage and disadvantage.

The objective of this study is to assess the progressive collapse potential of steel moment frames designed per Korean Building Code [10] and the AISC Load and Resistance Factor Design [11]. The results of the linear step-by-step analysis procedure recommended by the GSA 2003 and the DoD 2005 guidelines were compared between SMRF & OMRF building with & without masonry Infill wall. The effect of the parameters such as the location of column removal and the number of story were also investigated.

II ANALYSIS PROCEDURE

2.1. Acceptance criterion for progressive collapse

The GSA 2003 proposed the use of the Demand-Capacity Ratio (DCR), the ratio of the member force and the member strength, as a criterion to determine the failure of main structural members by the linear analysis procedure:

$$DCR = Q_{UD} / Q_{CE}$$

where Q_{UD} is the acting force (demand) determined in component(moment, axial force, and shear etc.); and Q_{CE} is the expected ultimate, unfactored capacity of the component (moment, axial force, shear etc.); In the GSA 2003 the inherent strength is obtained by multiplying the nominal strength with the over strength factor of 1.1, and the strength reduction factor is not applied. The acceptance criteria for DCR vary from 1.25 to 3.0 depending on the width/thickness ratio of the member.

2.2 Methodology for progressive collapse analysis using alternate load path method

The detailed procedure for linear static analysis method is given in the GSA. In this study same procedure is followed. The steps are as:

1. Analyze and design of the building for the seismic loading
2. Create a column lost by removing a column from the location
3. Carry out linear static analysis with the gravity loading on the structure
4. Check demand capacity ratios for flexure and shear at critical locations

III CONFIGURATION AND ANALYTICAL MODELING OF MODEL STRUCTURES

3.1. Model structures

One typical building as shown in Figure 3 is taken for the study of progressive collapse analysis. Bay width in both the plan direction is taken as 5m. Height of storey is 3.2m having 150 mm slab thickness. In Infill wall models peripheral & internal wall having thickness 230mm & 115mm respectively. Building is modeled in the ETABS 2015 software. Building is designed considering seismic load first and after that studied for progressive collapse analysis. Here, total 4 models are considered for seismic design & progressive collapse analysis :

1. SMRF (without infill wall)
2. OMRF (without infill wall)
3. SMRF (with infill wall)
4. OMRF (with infill wall)

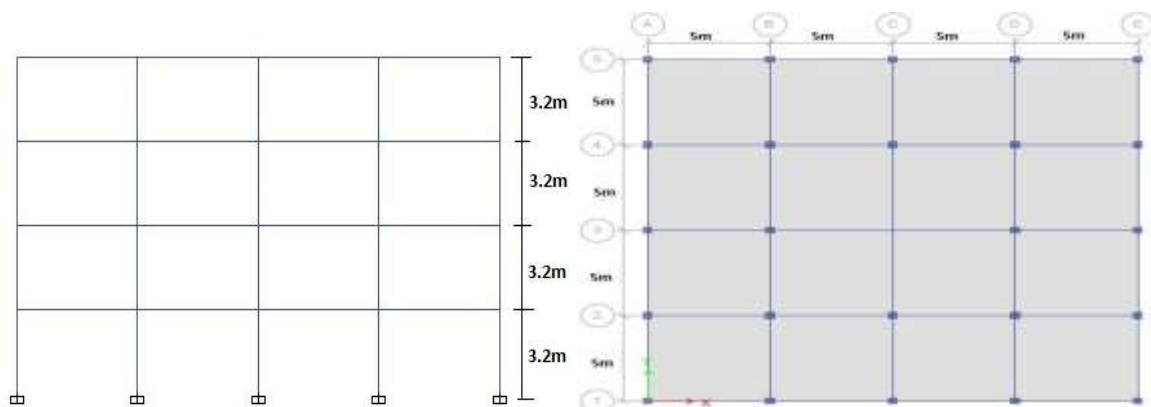


Fig.1 Elevation of the 4-storey model structure.

Fig.2 Plan of the 4-storey model structure.

Table 1 Element Sizes

Storey	Beam size(mm)	Column size(mm)
1	230*425	400*400
2	230*400	375*375
3	230*375	350*350
4	230*350	300*300

Table 2 Load condition & material properties

Dead load	13.00 KN/m (on peripheral beam) 6.5KN/m (on Internal beam)
Live load	3 KN/m ²
Floor finish load	1 KN/m ²
f_{ck} (concrete)	25Mpa
f_m (masonry)	3.45Mpa
F_y (steel)	415N/mm ²

Table 3 Parameters considered for seismic loading

Seismic zone	V
Soil type	II
Importance factor	1
Response reduction factor	5 (SMRF) 3(OMRF)

Load combinations considered for seismic design :

1. 1.5 (DL+LL)
2. 1.2 (DL + LL $\pm$ EQ_x) And 1.2 (DL + LL $\pm$ EQ_y)
3. 1.5 (DL $\pm$ EQ_x) And 1.5 (DL $\pm$ EQ_y)
4. 0.9DL $\pm$ 1.5EQ_x And 0.9DL $\pm$ 1.5EQ_y

IV ANALYSIS OF MODEL STRUCTURES FOR PROGRESSIVE COLLAPSE

Here, In each model three cases are considered as per the GSA guidelines as shown in figure 3.

- Case 1. Corner column removal
 Case 2. Side column removal
 Case 3. Central column removal

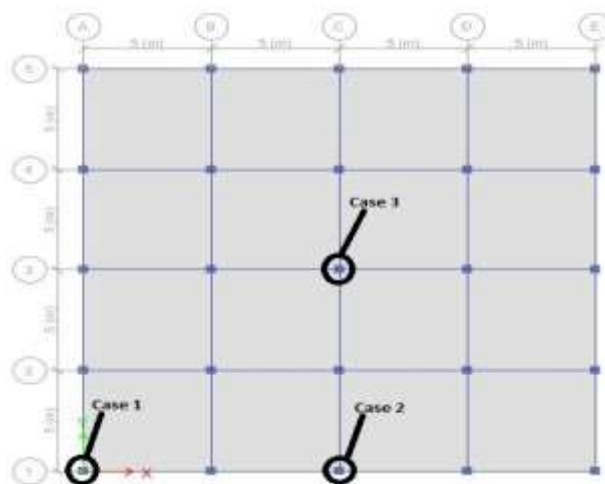


Fig.3 Plan of the building with column removal cases

V RESULTS

DCR for flexure & shear are found at critical location after removal of various column. In below figures DCR values are shown, here values having red color indicates that exceeds the permissible limit given by GSA.

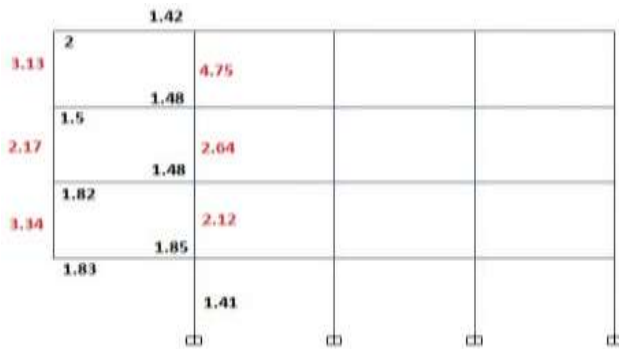


Fig.4 DCR(flexure) for case1(SMRF, without Infill wall)

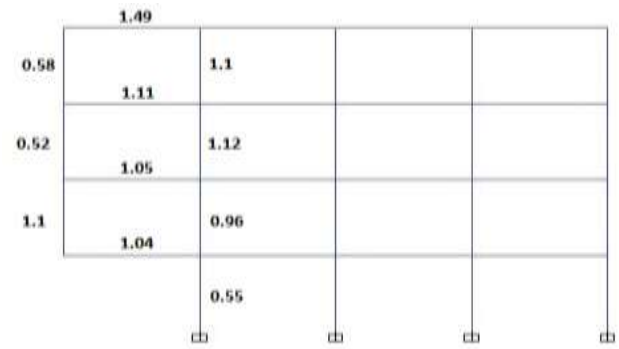


Fig.5 DCR(shear) for case1(SMRF, without Infill wall)



Fig.6 DCR(flexure) for case 2(SMRF, without Infill wall)

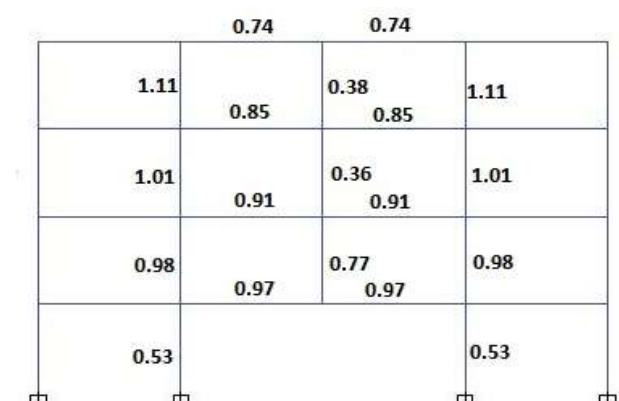


Fig.7 DCR(shear) for case 2(SMRF,without Infill wall)



Fig.8 DCR(flexure) for case 3(SMRF, without Infill wall)

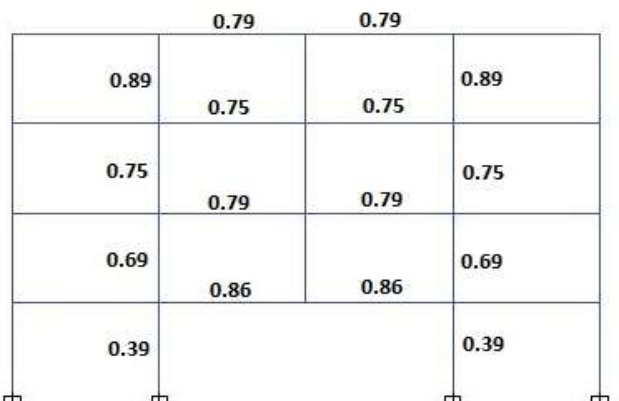


Fig.9 DCR(shear) for case 3(SMRF, without Infill wall)



Fig.10DCR(flexure)for case1(OMRF, without Infill wall)

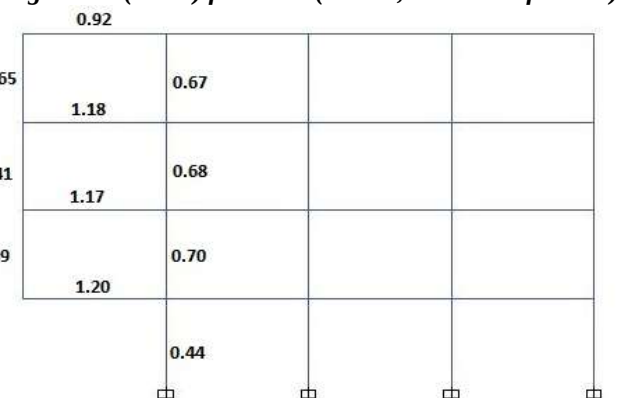


Fig.11DCR(shear)for case1(OMRF,without Infill wall)

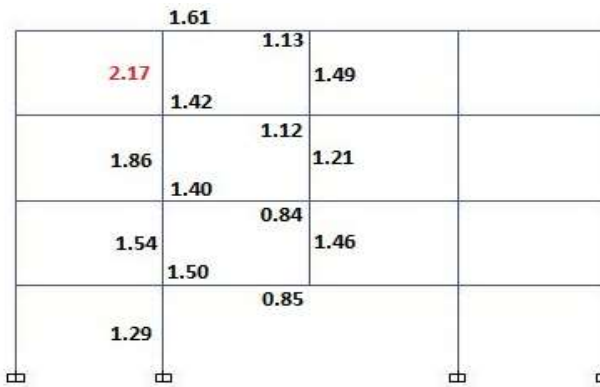


Fig.12 DCR(flexure) for case 2(OMRF, without Infill wall)

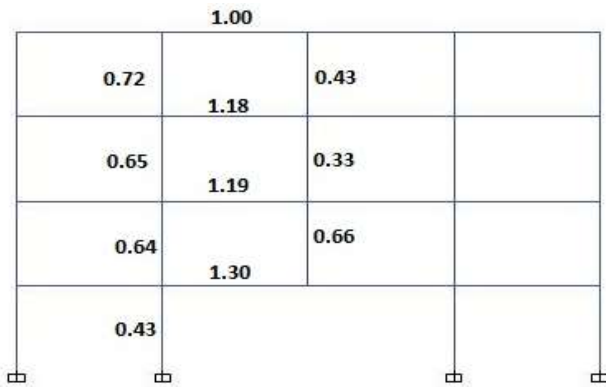


Fig.13 DCR(shear) for case 2(OMRF, without Infill wall)

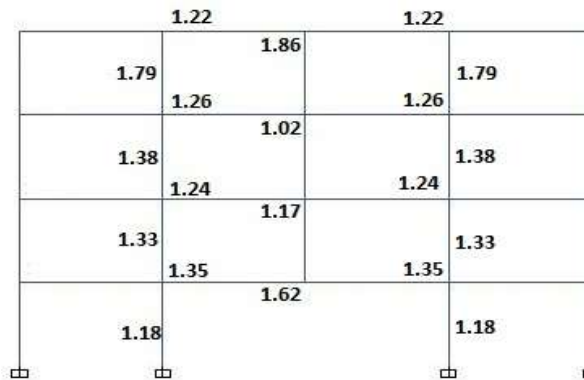


Fig.14 DCR(flexure) for case 3(OMRF, without Infill wall)

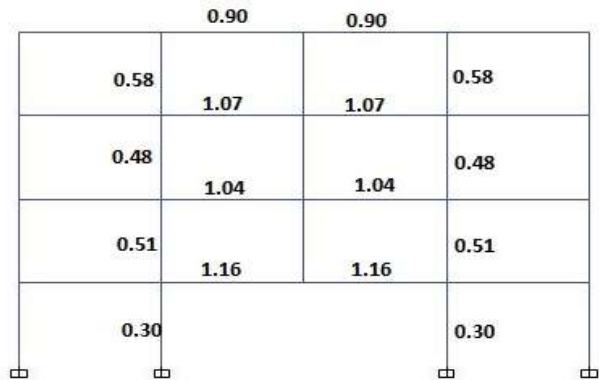


Fig.15 DCR(shear) for case 3(OMRF, without Infill wall)

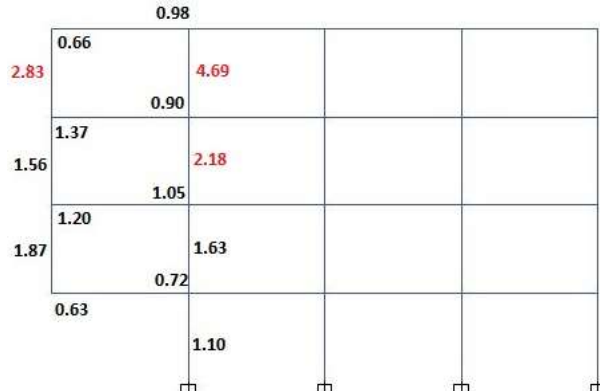


Fig.16 DCR(flexure) for case 1 (SMRF, with Infill wall)

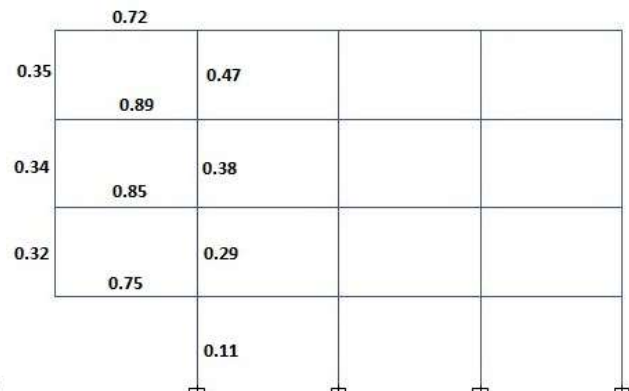


Fig.17 DCR(shear) for case 1 (SMRF, with Infill wall)



Fig.18 DCR(flexure) for case 2 (SMRF, with Infill wall)

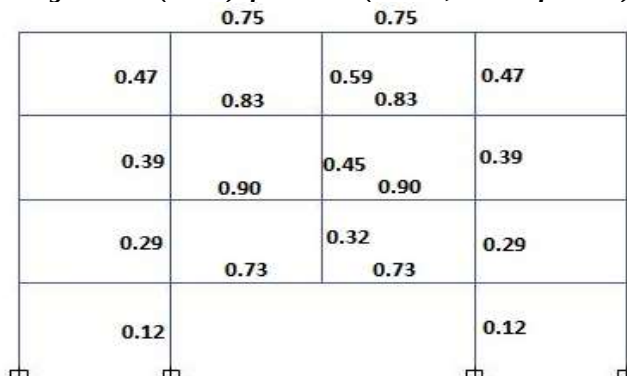


Fig.19 DCR(shear) for case 2 (SMRF, with Infill wall)

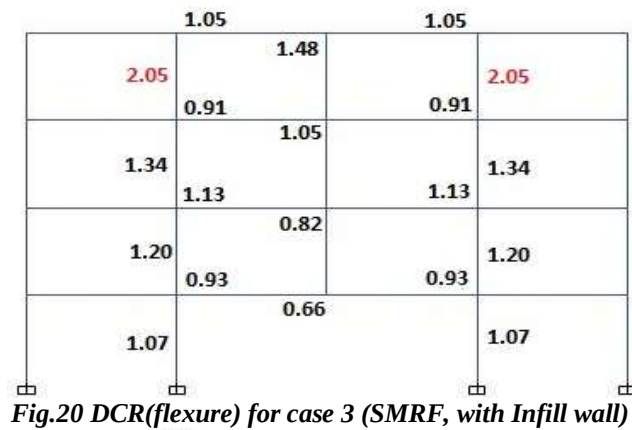


Fig.20 DCR(flexure) for case 3 (SMRF, with Infill wall)

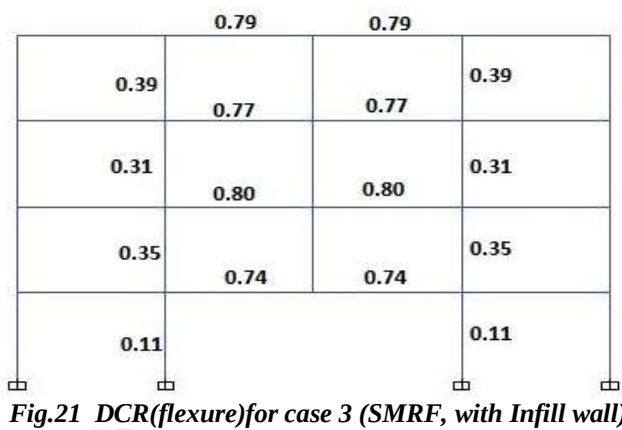


Fig.21 DCR(flexure) for case 3 (SMRF, with Infill wall)

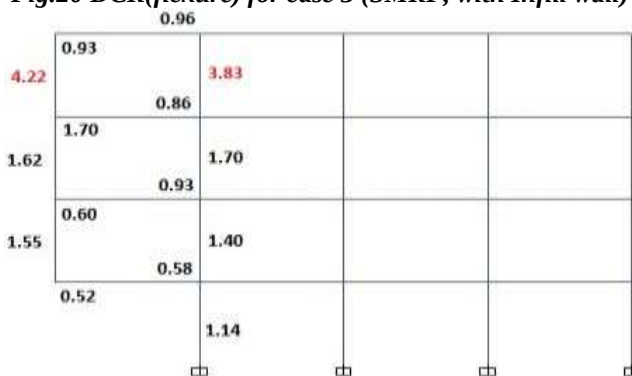


Fig.22 DCR(flexure) for case 1 (OMRF, with Infill wall)

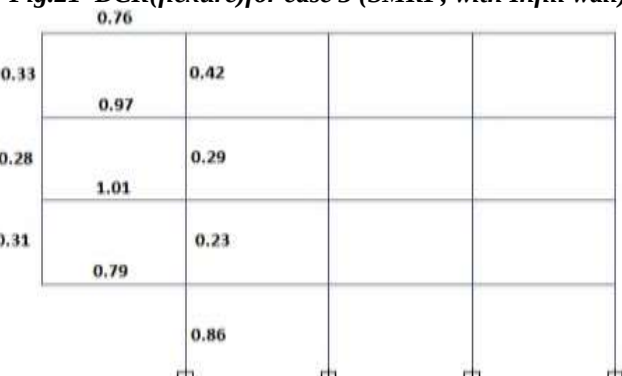


Fig.23 DCR(shear) for case 1 (OMRF, with Infill wall)



Fig.24 DCR(flexure) for case 2 (OMRF, with Infill wall)

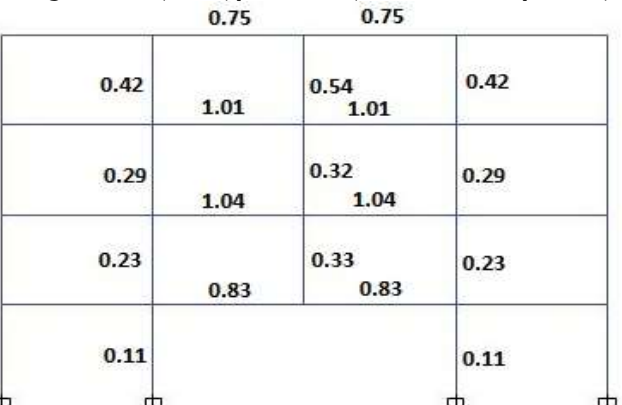


Fig.25 DCR(flexure) for case 2 (OMRF, with Infill wall)



Fig.26 DCR(flexure) for case 3 (OMRF, with Infill wall)

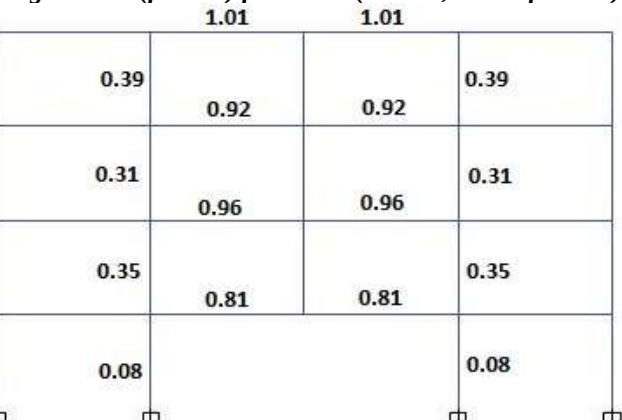


Fig.27 DCR(shear) for case 3 (OMRF, with Infill wall)

VI CONCLUSION

In this study the progressive collapse potential for SMRF & OMRF, with & without Infill walls was investigated using the linear static analysis procedures recommended in the GSA 2003 guidelines. The progressive collapse analyses were conducted using the computer program ETAB 2015. Even though the linear static step-by-step analysis procedure has advantage that not only it is theoretically simple but also analyzed without sophisticated nonlinear modeling, a lot of manual works were required to evaluate DCR in each analysis step and to remodel/reanalyze the structure until DCR of any member does not exceed a given limit state.

Linear static analysis of both the SMRF building and the OMRF building indicated that the columns in the top story were most significantly influenced by the column loss, likely due to smaller cross section and lower moment of inertia. It was also observed that the potential for progressive collapse was highest when a corner column was suddenly removed, It was also observed that beams at the lower storey were affected in flexure and columns at the upper stories. In all cases beams and columns were safe in shear as DCR values are within permissible limit for shear.

For central column removal case DCR values for flexure & shear are lower compared to corner & side column removal case as redistribution of load after column removal is much symmetrical in central column case.

In this study, it was also observed that frames having masonry Infill wall were less susceptible to progressive collapse as compared to bare frames because Infill wall offers diagonal compressive resistance after column removal, which lowers the DCR values, so we concludes that Infill walls decreases the vulnerability of progressive collapse.

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