PROGRESSIVE COLLAPSE ANALYSIS OF STEEL BUILDING WITH AND WITHOUT BRACING

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Abstract: Progressive collapse is a disastrous structural event that occur because of human-made and natural hazards. Damage can be in form of loss of non-structural element, structural components and collapse of structural element leading to progressive failure of part or whole building. The failure of a member in the primary load resisting system leads to redistribution of forces to the adjoining members and if redistributed load exceeds member capacity it fails. This process continues in the structure and eventually the building collapses. In this research paper, the authors investigates the effect of concentric bracing on the progressive collapse potential of steel building. Linear static analysis of building model with and without bracing are carried out using the alternate path method recommended by the General Service Administration (GSA guideline) using software SAP-2000. The building model would be of 5 and 8 storey steel building which includes "X" and "V" type bracing system with different arrangement. Both types of bracing system is evaluated with different arrangement of bracing and the demand capacity ratio of building is evaluated by GSA guidelines and is compared with different models which include building with and without bracing. Effect of removal of columns at different locations which include forces, moments and displacement are studied and compared. The study shows that moment frame with concentric bracing exhibited desirable strength against progressive collapse.

***IndexTerms*–Progressive collapse, Steel structure, Alternate path method, concentric bracing, Linear static analysis.**
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I. INTRODUCTION

During the recent years, a lot of attention has been paid to probable progressive collapse among the building owners in every parts of the world. This is because of the fact that progressive collapse is a potentially destructive event for huge buildings leading to serious number of casualties and injuries for their residing people and also may lead to significant damage to properties. The progressive collapse of structures is commenced when the primary component(s), usually columns, is eliminated. When a column is suddenly removed as a result of a vehicle collision, explosion, terrorist attacks, earthquake and other natural or artificial hazards, gravity loads (Dead Load and Live Load) gets transmitted to adjoining columns in the structure. If these primary elements are not appropriately designed to bear and redistribute the overloading, that portion of the structure or the whole of the structure may collapse. Because of that, a portion of the building may get damaged and fall down because of the larger and superior damage to the building than the preliminary impact.

Although progressive collapse is generally a very rare phenomena in developed countries, but its effect on buildings is very dangerous and costly. Without significant consideration of adequate continuity, ductility and redundancy, the progressive collapse cannot be prevented. Some past example of progressive collapse are Ronan point apartment tower in East London blast on eighteenth floor which destructed load-bearing precast concrete plates adjoining the junction of the building. There was support lost at the eighteen floor due to which the above structure to collapse. The impact of these collapsing resulted in to destruction of whole structure till ground. The other example of progress of consecutive damage during the progressive collapse, which occurred in Alfred P Murrah building in Oklahoma City, in 1995 resulted in 168 fatalities [6]. Due to this failure, several exploratory documents on the destruction and progression of collapse were transcribed. After the collapse of World Trade Centre due to terrorist attacks, many government organization and local agencies have worked on developing guidelines for designing structure to resist progressive collapse. The General Service Administration (GSA) guideline and Unified Facilities Criteria (UFC) by Department of Defense guideline developed by USA are used because they give analysis procedure and design requirements of structures to survive the collapse. According to GSA guidelines, progressive collapse is a situation where local failure of a primary structural component leads to the collapse of adjoining members which, in turn, leads to additional collapse. Once a column is failed the building weight transfers to neighboring members in the structure. If these members are not properly designed to resist and redistribute the additional load that part of the structure fails [10]. So to redistribute additional load the bracing are provided in this study. The bracing are of two types concentric and eccentric. The concentric bracing consists of diagonal braces located in the plane of frame and both the ends of the brace join at the end points of other framing members to form a truss, creating a stiff frame.

II. GUIDELINES AND METHODOLOGY

The US General Service Administration (GSA) commonly recommend the Alternate Path method especially for buildings with maximum 10 stories high, based on a feasible framework [10]. In this method, the probability of progressive collapse is reduced by providing redundancy in the structure. The structure is designed such that if any one member fails, alternate load paths are available for the load that was in that component 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 key element without collapse. There are four methods for analysis of progressive collapse in buildings: 1) Linear static method (LSM). 2) Non-Linear static method (NLSM). 3) Linear Dynamic method (LDM). 4) Non-Linear Dynamic method (NLDM) [2]. For current study linear static method is used for progressive collapse analysis.

2.1 Linear Static Analysis Loading

According to GSA guidelines [10], for static analysis procedures the below mentioned vertical load should be used:

$$\text{Load} = 2(1.2DL + 0.25LL)$$

Where DL= Dead load, LL = Live load and 2 is dynamic amplification factor

2.2 Calculation of Demand Capacity Ratio (DCR) and Acceptance Criteria

In order to determine the susceptibility of the building to Progressive Collapse, Demand Capacity Ratio should be calculated based on the following equation [10]:

$$DCR = Q_{ud}/Q_{ce}$$

Where,
Q_{ud}= Acting force (Demand) determined or computed in element or connection/joint.
Q_{ce} = Probable ultimate capacity (Capacity) of the component and/or connection/joint.

Referring to DCR criteria defined through linear static approach, different elements in the structures and connections with quantities value less than 1.5 or 2 are considered not collapsed as follows:

$DCR < 2.0$: for typical structural configuration
$DCR < 1.5$: for atypical structural configuration

The model which is used have typical structural configuration so the $DCR < 2$.Since the loading pattern used in this study for analysis is based on just gravity (amplified dead and live load), computation of DCR values for braces are neglected, DCR has been calculated only for beams and columns. In this study, Demand Capacity Ratio should be computed for moment, axial force and shear [10].

2.3 Procedure of Linear Static Analysis

The modelling and analysis are performed in the very well know software SAP2000 and the analysis procedure consists of following steps:
Step 1: Prepare three dimensional model in computer. Perform steel design and determine the steel sections.
Step 2: Based on the steel sections provided, calculate the capacity of member in flexure, shear and axial.
Step 3: Create the column loss scenario according to the GSA guidelines.
Step 4: Perform the static analysis and determine DCR ratios.
Step 5: Evaluate results as per acceptance criteria provided by the GSA guideline.

III. Building models and Configurations

The model considered is of 5 floor and 8 floor steel building which is designed according to the IS800 and IS 1893-2007. The bracing used for this study is "X" type bracing and "V" type bracing and are arranged in two different arraignment namely alternate arraignment and neighbor arraignment.

3.1 Model Data

- Storey : G+4 Storey building and G+7 Storey building
- Usage : Residential Structure
- Location : zone IV
- Structural System : Moment Resisting frame
- Area : 37.5m X 24m
- Total Height of Building : 17.5m (G+4) & 28m (G+7)
- Typical Bay width : 7.5m width in x-direction (5 bays) and 8.0m width in y-direction (3 bays)
- Typical storey height : 3.5m
- Thickness of Slab : 90mm
- Beam Size : ISMB-500
- Secondary Beam Size : ISMB-450
- Column Size : ISHB-450-I With Plates of (400mm*32mm)on both side of flanges

- Bracing : ISNB-300H

3.2 Material Properties

The material properties used in the models are as follows:

- Modulus of Elasticity: E = 210000 N/mm^2
- Poisson's Ratio: u = 0.3
- Weight per Unit Volume: 7.697E-05 N/mm^3
- Mass per Unit Volume: 7.849E-09 N/mm^3
- Minimum Yield Stress: 250 N/mm^2

3.3 Loading Data

The loads which are considered for this analysis are Dead loads, Live loads & Earthquake loads.

- The dead load include the self-weight of sections and slab.
- Floor finish = 1kN/m^2
- Terrace water proofing = 1kN/m^2
- Wall load on periphery beams = 20.5kN/m
- Live load on all floor except roof = 2.5kN/m^2
- Zone = IV
- Importance factor = 1
- Response reduction factor =5
- Type of soil = Medium

3.4 Location of Column removal

Three representative column removal locations were considered according to GSA guideline in this analysis example as shown in figure below:
Removal 1 – Long side column condition (D-1).
Removal 2 – Short side column condition (A-3).
Removal 3 – Corner column condition (A-1).

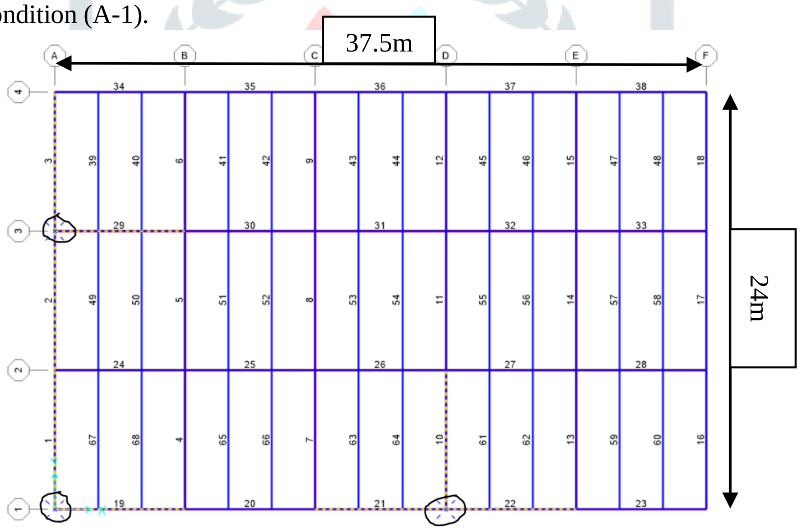
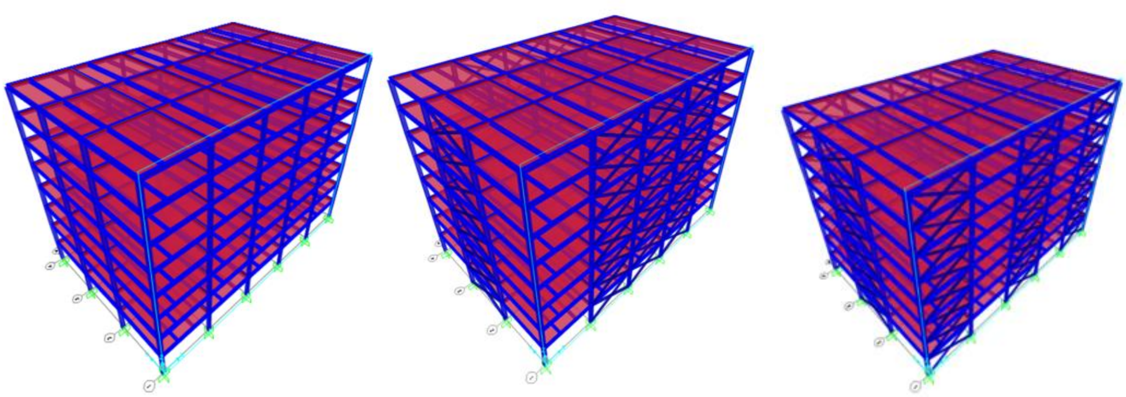


Fig.1: Plan and the location of column removal.

3.5 Three Dimensional model

The 3D models of 5 and 8 storey building with and without bracing with bracing at different position are shown below. The 5 storey models are also similar which are shown below.



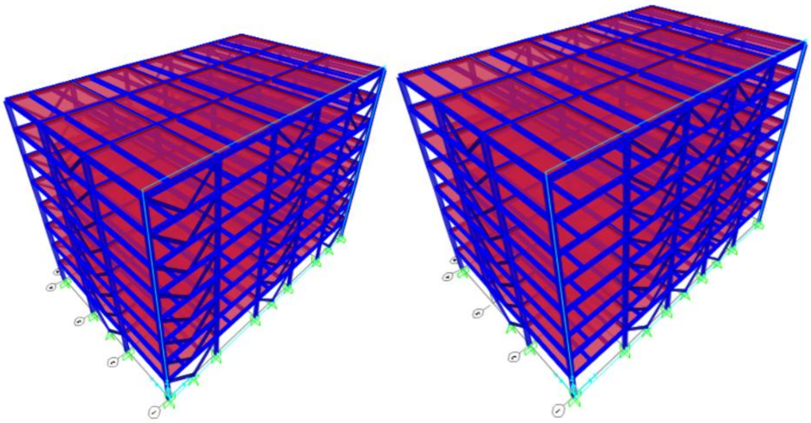


Fig.2: 3D models of 8 storey building model

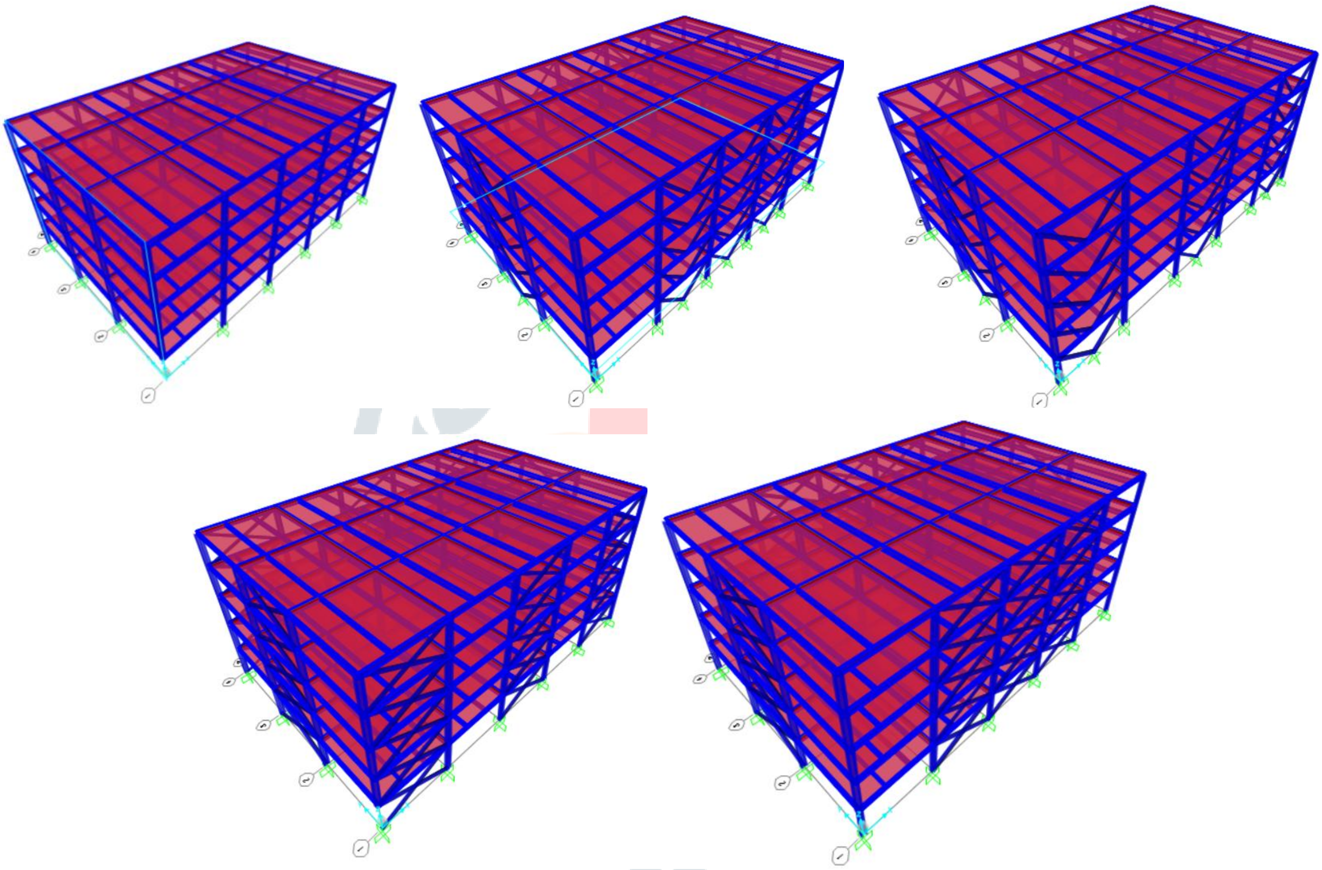
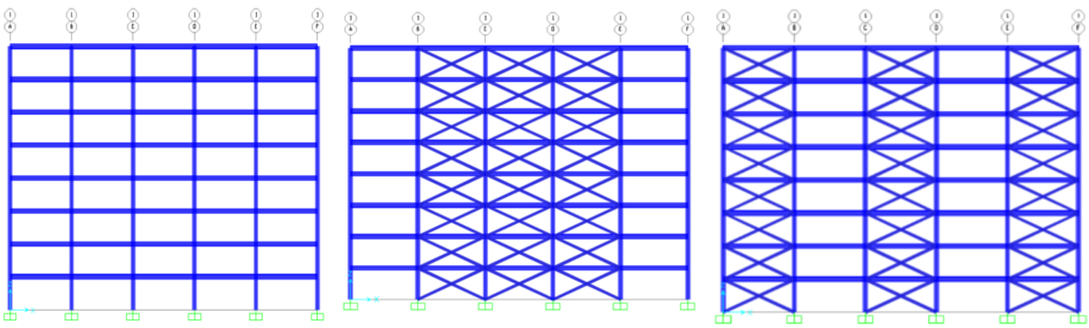


Fig.3: 3D models of 5 storey building model

The arrangement of bracing is changed only in the longitudinal direction (x-direction). The models of 5 floor and 8 floor are same except the number of storys.The elevation of all the models are below:



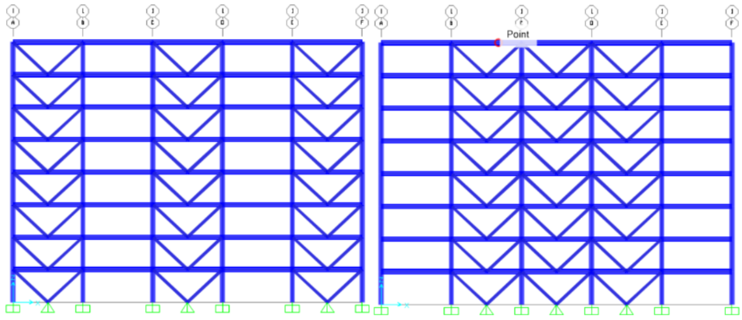


Fig.4: Arrangement of bracing in longitudinal direction for 8 storey model 1) without bracing. 2) X bracing neighbor. 3) X bracing alternate. 4) V bracing alternate. 5) V bracing neighbor.

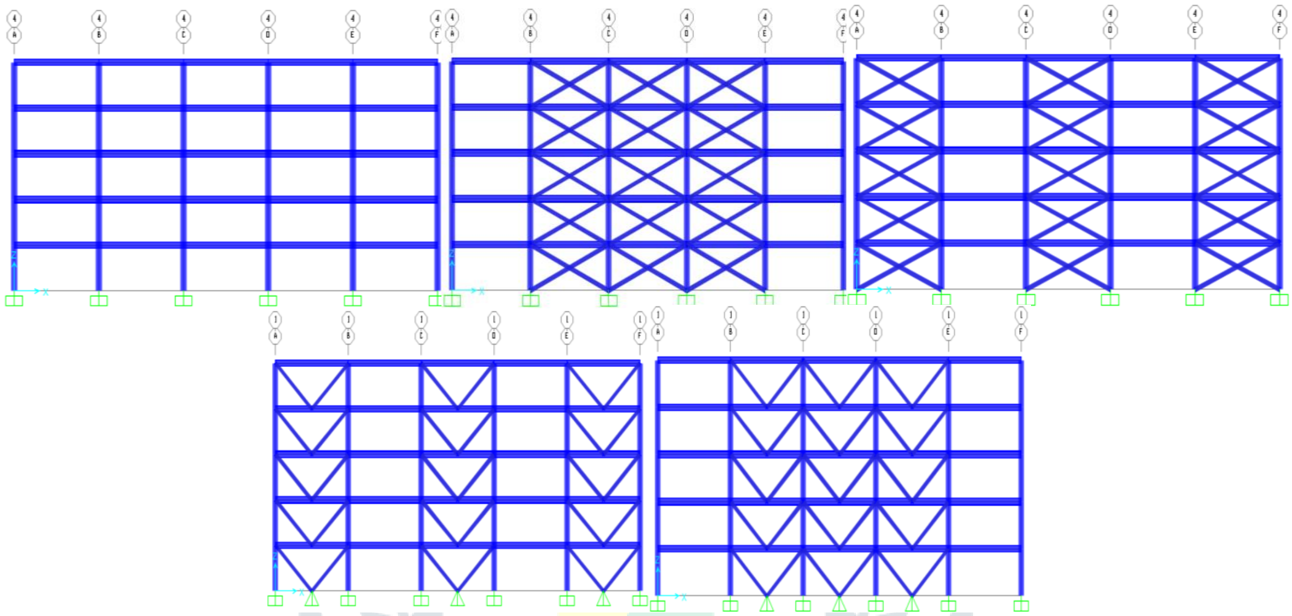


Fig.5: Arrangement of bracing in longitudinal direction for 5 storey models 1) without bracing. 2) X bracing neighbor. 3) X bracing alternate. 4) V bracing alternate. 5) V bracing neighbor

IV. Results Discussion and Comparison

The linear static analysis is carried out for all the models including all column removal case. The value of Demand Capacity Ratio (DCR) for moment, shear and axial force are obtained for all models and then the values are compared. The absolute displacement values are also compared for all the models. The comparison of DCR_m is represented in graphically form below:

4.1 Results of DCR_m for 8 storey model.

The eight floor model with and without bracing is analyzed considering all the column loss scenario. The results of this model is shown in the graphs below:

Fig.4: 8 storey DCR_m values of affected elements for all column removal case.

The above graphs shows the DCR_m value of the affected elements by all the column removal cases. From the graphs it is clear that the progressive collapse potential of structure drastically decrease when the bracings are provided. The V bracing gives better result to resist progressive collapse compared to the X type of bracing.

4.2 Results of DCR_m for 5 storey model.

The eight floor model with and without bracing is analyzed considering all the column loss scenario. The results of this model is shown in the graphs below:

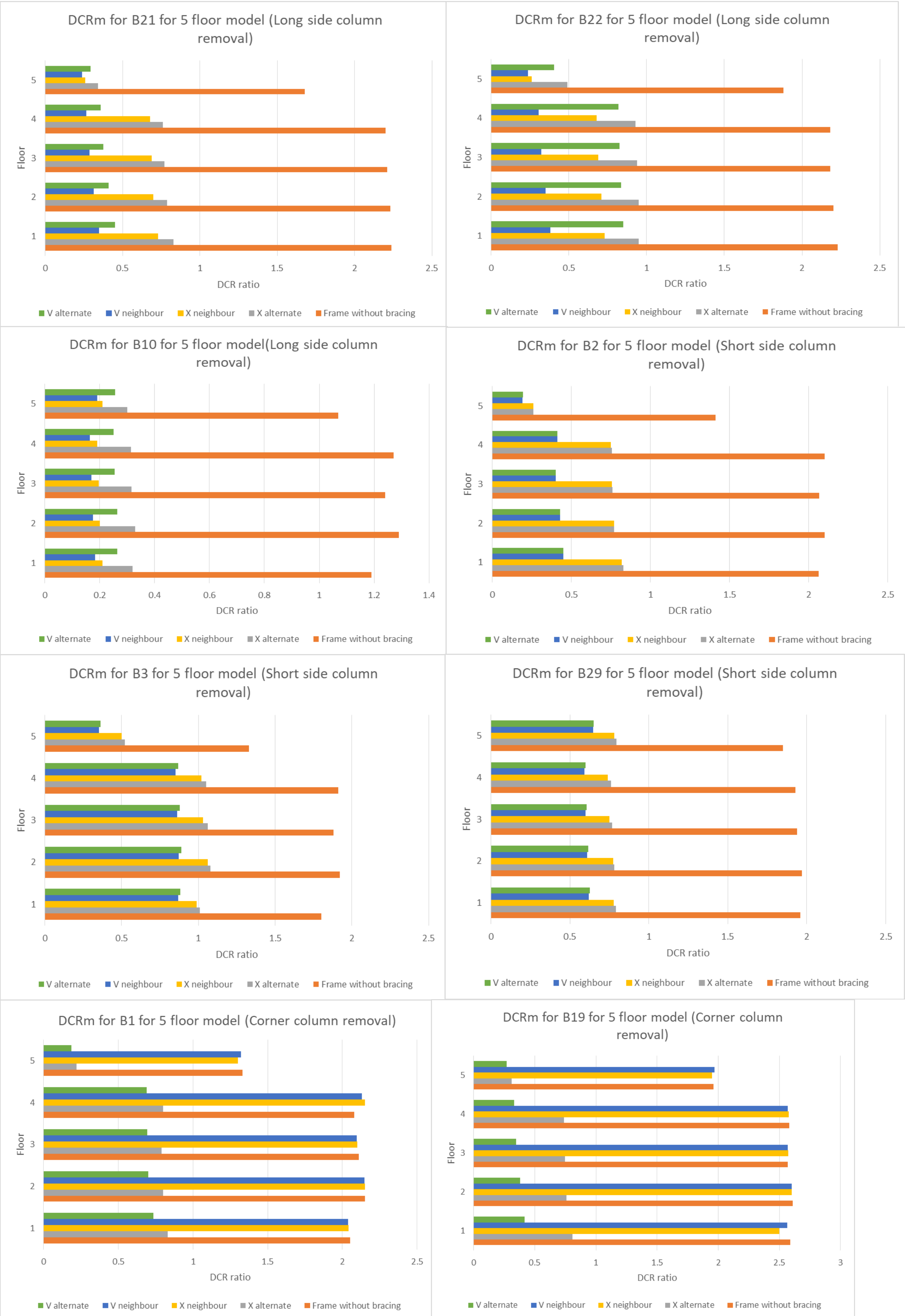


Fig.4: 5 Storey DCR_m values of affected elements for all column removal case.

Table-A: Summary of DCR_{shear} for Beams Adjacent to Eliminated Columns

	DCR_{shear}	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	**B21**	**B22**	**B10**	**B2**	**B3**	**B29**	**B1**	**B19**
Without Bracing	**1**	0.660	0.660	0.240	0.594	0.569	0.465	0.574	0.724
	2	0.650	0.650	0.270	0.596	0.570	0.472	0.603	0.732
	3	0.649	0.640	0.265	0.588	0.564	0.461	0.590	0.720
	4	0.642	0.636	0.261	0.583	0.560	0.454	0.586	0.713
	5	0.637	0.631	0.258	0.579	0.557	0.449	0.582	0.707
	6	0.632	0.627	0.254	0.575	0.553	0.444	0.577	0.702
	7	0.631	0.626	0.259	0.579	0.556	0.444	0.589	0.703
	8	0.380	0.375	0.220	0.280	0.260	0.447	0.253	0.426
X Bracing Alternate	**1**	0.380	0.413	0.102	0.362	0.410	0.251	0.365	0.380
	2	0.369	0.411	0.105	0.345	0.422	0.250	0.358	0.365
	3	0.361	0.406	0.100	0.341	0.414	0.243	0.355	0.358
	4	0.355	0.403	0.097	0.337	0.410	0.239	0.351	0.353
	5	0.351	0.400	0.095	0.334	0.406	0.235	0.349	0.349
	6	0.348	0.398	0.093	0.332	0.403	0.232	0.347	0.346
	7	0.346	0.397	0.093	0.331	0.402	0.231	0.349	0.345
	8	0.110	0.150	0.100	0.075	0.129	0.257	0.067	0.106
X Bracing Neighbour	**1**	0.359	0.359	0.079	0.359	0.404	0.247	0.570	0.720
	2	0.350	0.351	0.077	0.343	0.414	0.245	0.604	0.730
	3	0.344	0.345	0.074	0.339	0.406	0.239	0.590	0.720
	4	0.339	0.340	0.071	0.335	0.401	0.234	0.585	0.710
	5	0.336	0.337	0.070	0.332	0.397	0.231	0.581	0.708
	6	0.334	0.335	0.068	0.330	0.394	0.228	0.576	0.703
	7	0.330	0.330	0.067	0.330	0.393	0.226	0.586	0.704
	8	0.098	0.098	0.080	0.070	0.120	0.253	0.251	0.427
V Bracing Alternate	**1**	0.262	0.393	0.0903	0.2436	0.3868	0.2188	0.3498	0.2523
	2	0.247	0.389	0.0918	0.2386	0.3859	0.2167	0.3400	0.2398
	3	0.236	0.385	0.0883	0.2298	0.3815	0.2126	0.3378	0.2285
	4	0.225	0.382	0.0863	0.2219	0.3788	0.2094	0.3348	0.2186
	5	0.216	0.380	0.0847	0.2150	0.3766	0.2068	0.3328	0.2098
	6	0.207	0.379	0.0834	0.2073	0.3751	0.2048	0.3307	0.2018
	7	0.201	0.378	0.0829	0.2088	0.3749	0.2035	0.3320	0.1962
	8	0.107	0.139	0.0924	0.0648	0.1012	0.2333	0.0594	0.1018
V Bracing Neighbour	**1**	0.235	0.242	0.0721	0.2435	0.3829	0.2166	0.5739	0.7212
	2	0.224	0.231	0.0705	0.2382	0.3813	0.2143	0.6039	0.7316
	3	0.214	0.222	0.0683	0.2293	0.3767	0.2102	0.5900	0.7210
	4	0.206	0.213	0.0668	0.2214	0.3738	0.2070	0.5853	0.7140
	5	0.198	0.205	0.0657	0.2144	0.3715	0.2044	0.5807	0.7082
	6	0.190	0.198	0.0649	0.2065	0.3701	0.2024	0.5751	0.7035
	7	0.184	0.192	0.0641	0.2081	0.3698	0.2010	0.5845	0.7038
	8	0.095	0.094	0.0781	0.0634	0.0973	0.2311	0.2529	0.4292

Table-B: Summary of DCR_m for Beams Adjacent to Eliminated Columns

	DCR_m	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	**B21**	**B22**	**B10**	**B2**	**B3**	**B29**	**B1**	**B19**
Without Bracing	1	2.38	2.36	1.28	2.17	1.979	2.088	2.17	2.763
	2	2.34	2.32	1.37	2.19	2.01	2.089	2.27	2.765
	3	2.3	2.27	1.32	2.15	1.975	2.033	2.21	2.7
	4	2.27	2.24	1.3	2.12	1.95	1.99	2.18	2.66
	5	2.24	2.21	1.28	2.1	1.94	1.96	2.16	2.63
	6	2.22	2.19	1.26	2.07	1.91	1.944	2.14	2.611
	7	2.21	2.18	1.28	2.1	1.94	1.941	2.18	2.613
	8	1.68	1.66	1.08	1.37	1.24	1.85	1.34	1.99
X Bracing Alternate	1	0.91	1.07	0.39	0.89	1.15	0.91	0.9	0.89
	2	0.84	1.06	0.4	0.81	1.23	0.9	0.88	0.81
	3	0.79	1.04	0.37	0.78	1.18	0.87	0.86	0.77
	4	0.76	1.02	0.35	0.76	1.16	0.84	0.84	0.74
	5	0.74	1	0.34	0.74	1.14	0.82	0.83	0.72
	6	0.729	0.998	0.336	0.735	1.129	0.81	0.81	0.71
	7	0.721	0.994	0.335	0.736	1.22	0.8	0.82	0.7
	8	0.31	0.54	0.32	0.24	0.57	0.83	0.24	0.28
X Bracing Neighbour	1	0.79	0.79	0.25	0.88	1.12	0.89	2.16	2.73
	2	0.74	0.74	0.24	0.8	1.19	0.88	2.27	2.75
	3	0.71	0.71	0.22	0.78	1.14	0.84	2.21	2.7
	4	0.68	0.69	0.21	0.75	1.11	0.82	2.18	2.67
	5	0.67	0.67	0.2	0.74	1.09	0.8	2.16	2.64
	6	0.66	0.66	0.196	0.73	1.079	0.788	2.13	2.61
	7	0.65	0.65	0.192	0.73	1.07	0.781	2.17	2.62
	8	0.24	0.23	0.21	0.23	0.53	0.81	1.32	1.99
V Bracing Alternate	1	0.557	0.962	0.326	0.526	1.024	0.743	0.812	0.520
	2	0.500	0.940	0.326	0.505	1.020	0.727	0.775	0.467
	3	0.453	0.920	0.308	0.470	0.995	0.706	0.757	0.423
	4	0.413	0.906	0.297	0.440	0.980	0.689	0.741	0.386
	5	0.380	0.894	0.287	0.415	0.967	0.675	0.728	0.355
	6	0.351	0.886	0.280	0.387	0.960	0.664	0.718	0.328
	7	0.334	0.880	0.278	0.400	0.952	0.658	0.714	0.312
	8	0.276	0.460	0.279	0.192	0.425	0.705	0.208	0.253
V Bracing Neighbour	1	0.436	0.465	0.216	0.524	1.002	0.731	2.171	2.741
	2	0.391	0.421	0.206	0.502	0.994	0.715	2.273	2.761
	3	0.354	0.384	0.194	0.467	0.968	0.693	2.208	2.708
	4	0.322	0.353	0.185	0.437	0.952	0.676	2.177	2.670
	5	0.294	0.327	0.179	0.412	0.939	0.662	2.150	2.638
	6	0.270	0.303	0.174	0.384	0.932	0.651	2.121	2.613
	7	0.250	0.289	0.171	0.396	0.923	0.645	2.155	2.612
	8	0.227	0.219	0.195	0.183	0.404	0.693	1.341	2.008

Table-C: Summary of DCR_{axial} for Beams Adjacent to Eliminated Columns

	DCR_{axial}	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	**1C**	**1E**	**2D**	**2A**	**4A**	**3B**	**1B**	**2A**
Without Bracing	1	0.908	0.910	0.807	0.913	0.628	0.899	0.978	0.928
	2	0.786	0.787	0.707	0.791	0.531	0.785	0.849	0.807
	3	0.665	0.666	0.604	0.669	0.434	0.670	0.718	0.682
	4	0.546	0.546	0.503	0.548	0.337	0.558	0.589	0.559
	5	0.427	0.427	0.403	0.428	0.241	0.446	0.461	0.436
	6	0.309	0.309	0.303	0.309	0.145	0.336	0.334	0.315
	7	0.192	0.192	0.204	0.190	0.048	0.226	0.208	0.193
	8	0.075	0.075	0.105	0.072	0.725	0.117	0.081	0.071
X Bracing Alternate	1	1.118	0.545	0.667	1.095	0.465	0.712	1.044	0.670
	2	0.987	0.473	0.584	0.987	0.400	0.623	1.043	0.582
	3	0.801	0.407	0.501	0.813	0.332	0.534	0.920	0.496
	4	0.634	0.338	0.418	0.653	0.261	0.445	0.746	0.408
	5	0.481	0.267	0.336	0.501	0.187	0.357	0.590	0.320
	6	0.338	0.194	0.254	0.355	0.111	0.270	0.447	0.230
	7	0.201	0.119	0.172	0.214	0.033	0.182	0.314	0.139
	8	0.068	0.043	0.090	0.073	0.529	0.096	0.187	0.047
X Bracing Neighbour	1	0.866	0.926	0.648	1.101	0.504	0.706	0.927	0.932
	2	0.750	0.806	0.567	0.993	0.424	0.617	0.799	0.806
	3	0.607	0.656	0.486	0.820	0.345	0.529	0.672	0.678
	4	0.480	0.520	0.406	0.659	0.266	0.441	0.549	0.553
	5	0.364	0.395	0.327	0.506	0.188	0.354	0.429	0.430
	6	0.255	0.277	0.247	0.359	0.110	0.267	0.310	0.309
	7	0.152	0.165	0.167	0.152	0.165	0.167	0.194	0.190
	8	0.052	0.055	0.088	0.052	0.055	0.088	0.077	0.070
V Bracing Alternate	1	0.904	0.531	0.658	0.840	0.487	0.690	0.844	0.640
	2	0.896	0.502	0.577	0.880	0.420	0.604	0.832	0.593
	3	0.737	0.431	0.495	0.736	0.349	0.518	0.684	0.506
	4	0.592	0.358	0.413	0.598	0.276	0.432	0.549	0.417
	5	0.458	0.283	0.332	0.466	0.201	0.347	0.423	0.328
	6	0.330	0.206	0.251	0.338	0.124	0.262	0.305	0.238
	7	0.208	0.129	0.170	0.214	0.046	0.178	0.191	0.147
	8	0.089	0.050	0.089	0.090	0.506	0.093	0.081	0.055
V Bracing Neighbour	1	0.715	0.787	0.643	0.849	0.490	0.686	0.893	0.897
	2	0.721	0.749	0.563	0.886	0.413	0.600	0.815	0.815
	3	0.595	0.620	0.484	0.742	0.336	0.515	0.688	0.686
	4	0.480	0.500	0.404	0.603	0.259	0.430	0.564	0.561
	5	0.373	0.387	0.325	0.470	0.183	0.345	0.443	0.438
	6	0.272	0.280	0.246	0.341	0.107	0.261	0.323	0.317
	7	0.175	0.175	0.167	0.216	0.030	0.177	0.205	0.197
	8	0.080	0.073	0.088	0.091	0.567	0.093	0.086	0.077

Table-D: Summary of 5 storey DCR_m for Beams Adjacent to Eliminated Columns

	DCR_m	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	**B21**	**B22**	**B10**	**B2**	**B3**	**B29**	**B1**	**B19**
Without Bracing	1	2.24	2.23	1.19	2.06	1.80	1.96	2.05	2.59
	2	2.23	2.20	1.29	2.10	1.92	1.97	2.15	2.61
	3	2.21	2.18	1.24	2.07	1.88	1.94	2.11	2.57
	4	2.20	2.18	1.27	2.10	1.91	1.93	2.08	2.58
	5	1.68	1.88	1.07	1.41	1.33	1.85	1.33	1.96
X Bracing Alternate	1	0.83	0.95	0.32	0.83	1.01	0.79	0.83	0.81
	2	0.79	0.95	0.33	0.77	1.08	0.78	0.80	0.76
	3	0.77	0.94	0.32	0.76	1.06	0.77	0.79	0.75
	4	0.76	0.93	0.31	0.76	1.05	0.76	0.80	0.74
	5	0.34	0.49	0.30	0.26	0.52	0.80	0.22	0.31
X Bracing Neighbour	1	0.73	0.73	0.21	0.82	0.99	0.78	2.04	2.50
	2	0.70	0.71	0.20	0.77	1.06	0.77	2.15	2.60
	3	0.69	0.69	0.20	0.76	1.03	0.75	2.10	2.57
	4	0.68	0.68	0.19	0.75	1.02	0.74	2.15	2.58
	5	0.26	0.26	0.21	0.26	0.50	0.78	1.30	1.95
V Bracing Alternate	1	0.45	0.85	0.26	0.45	0.88	0.63	0.74	0.42
	2	0.41	0.84	0.26	0.43	0.89	0.62	0.70	0.38
	3	0.38	0.83	0.25	0.40	0.88	0.61	0.69	0.35
	4	0.36	0.82	0.25	0.41	0.87	0.60	0.69	0.33
	5	0.29	0.41	0.26	0.19	0.36	0.65	0.19	0.27
V Bracing Neighbour	1	0.35	0.38	0.18	0.45	0.87	0.62	2.04	2.57
	2	0.32	0.35	0.18	0.43	0.87	0.61	2.15	2.60
	3	0.29	0.32	0.17	0.40	0.86	0.60	2.10	2.57
	4	0.26	0.31	0.17	0.41	0.85	0.59	2.13	2.57
	5	0.24	0.24	0.19	0.19	0.35	0.65	1.32	1.97

Table-E: Summary of 5 storey DCR_{shear} for Beams Adjacent to Eliminated Columns

	DCR_{shear}	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	**B21**	**B22**	**B10**	**B2**	**B3**	**B29**	**B1**	**B19**
Without Bracing	1	2.24	2.23	1.19	2.06	1.80	1.96	2.05	2.59
	2	2.23	2.20	1.29	2.10	1.92	1.97	2.15	2.61
	3	2.21	2.18	1.24	2.07	1.88	1.94	2.11	2.57
	4	2.20	2.18	1.27	2.10	1.91	1.93	2.08	2.58
	5	1.68	1.88	1.07	1.41	1.33	1.85	1.33	1.96
X Bracing Alternate	1	0.83	0.95	0.32	0.83	1.01	0.79	0.83	0.81
	2	0.79	0.95	0.33	0.77	1.08	0.78	0.80	0.76
	3	0.77	0.94	0.32	0.76	1.06	0.77	0.79	0.75
	4	0.76	0.93	0.31	0.76	1.05	0.76	0.80	0.74
	5	0.34	0.49	0.30	0.26	0.52	0.80	0.22	0.31

	DCR_{shear}	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
X Bracing Neighbour	1	0.73	0.73	0.21	0.82	0.99	0.78	2.04	2.50
	2	0.70	0.71	0.20	0.77	1.06	0.77	2.15	2.60
	3	0.69	0.69	0.20	0.76	1.03	0.75	2.10	2.57
	4	0.68	0.68	0.19	0.75	1.02	0.74	2.15	2.58
	5	0.26	0.26	0.21	0.26	0.50	0.78	1.30	1.95
V Bracing Alternate	1	0.45	0.85	0.26	0.45	0.88	0.63	0.74	0.42
	2	0.41	0.84	0.26	0.43	0.89	0.62	0.70	0.38
	3	0.38	0.83	0.25	0.40	0.88	0.61	0.69	0.35
	4	0.36	0.82	0.25	0.41	0.87	0.60	0.69	0.33
	5	0.29	0.41	0.26	0.19	0.36	0.65	0.19	0.27
V Bracing Neighbour	1	0.35	0.38	0.18	0.45	0.87	0.62	2.04	2.57
	2	0.32	0.35	0.18	0.43	0.87	0.61	2.15	2.60
	3	0.29	0.32	0.17	0.40	0.86	0.60	2.10	2.57
	4	0.26	0.31	0.17	0.41	0.85	0.59	2.13	2.57
	5	0.24	0.24	0.19	0.19	0.35	0.65	1.32	1.97

Table-F: Summary of 5 storey DCR_{axial} for Beams Adjacent to Eliminated Columns

	DCR_{axial}	LONG SIDE COLUMN REMOVAL			SHORT SIDE COLUMN REMOVAL			CORNER COLUMN REMOVAL	
	Floor	1C	1E	2D	2A	4A	3B	1B	2A
Without Bracing	1	0.550	0.552	0.506	0.553	0.429	0.565	0.589	0.557
	2	0.431	0.433	0.408	0.433	0.335	0.453	0.463	0.438
	3	0.312	0.313	0.306	0.312	0.239	0.341	0.336	0.315
	4	0.194	0.194	0.206	0.193	0.144	0.229	0.209	0.194
	5	0.076	0.076	0.106	0.073	0.048	0.118	0.082	0.071
X Bracing Alternate	1	0.673	0.252	0.417	0.652	0.293	0.443	0.621	0.398
	2	0.551	0.182	0.335	0.545	0.228	0.355	0.506	0.309
	3	0.385	0.112	0.253	0.385	0.164	0.268	0.353	0.222
	4	0.229	0.040	0.172	0.231	0.097	0.182	0.210	0.134
	5	0.078	0.327	0.090	0.079	0.028	0.095	0.071	0.046
X Bracing Neighbour	1	0.529	0.446	0.407	0.548	0.340	0.440	0.573	0.449
	2	0.421	0.312	0.327	0.387	0.263	0.353	0.448	0.322
	3	0.293	0.185	0.247	0.233	0.186	0.267	0.323	0.197
	4	0.173	0.062	0.167	0.080	0.109	0.181	0.201	0.072
	5	0.059	0.557	0.088	0.655	0.032	0.095	0.079	0.572
V Bracing Alternate	1	0.532	0.275	0.411	0.480	0.280	0.430	0.500	0.380
	2	0.499	0.200	0.331	0.480	0.250	0.340	0.460	0.320
	3	0.360	0.125	0.250	0.350	0.180	0.260	0.330	0.230
	4	0.227	0.048	0.169	0.220	0.110	0.180	0.210	0.140
	5	0.098	0.320	0.089	0.090	0.040	0.090	0.090	0.050
V Bracing Neighbour	1	0.431	0.417	0.404	0.480	0.330	0.430	0.550	0.460
	2	0.411	0.301	0.325	0.350	0.250	0.340	0.460	0.330
	3	0.298	0.189	0.245	0.220	0.180	0.260	0.340	0.210
	4	0.190	0.079	0.166	0.090	0.100	0.180	0.210	0.080
	5	0.087	0.470	0.088	0.480	0.030	0.090	0.090	0.550

V. Conclusion

In structure with concentrically lateral seismic bracing system, by removing the critical elements determined by GSA progressive collapse guideline and by performing progressive collapse analysis by alternate path analysis on the steel building model the following results have been obtained:

(1)The DCR_m values are greater than 2 for building without bracing so according to the GSA guidelines the structure is considered to be collapsed. After providing the bracing the DCR_m values are less than 2 so the structure is now safe against collapse. The most critical column removal case is the column removed from the corner compared to the long side removal and short side removal. DCR values for moment, shear and axial decrease as the height of the building increase so the progressive collapse potential also decrease as the height increase.

(2) Concentric V type of bracing system provided better performance against progressive collapse because of providing more suitable alternate path to distribute additional loads. By changing the type of bracing system from "V" to "X" shaped bracing, significant decline was observed in the structures progressive collapse resisting capacity. By providing the bracing the progressive collapse potential of the steel building model is reduced by approximately by 65% because the bracing provide more suitable alternate paths and the ability of better distribution of loads by increasing in the redundancy of the structure.

(3) Among the type of arrangement of bracing, arrangement of alternate bracing supported more column removal compared to the neighbor arrangement against the progressive collapse and has performed better. So among the models the building with V bracing with alternate arraignment of bracing demonstrated the best performance compare to the other structure.

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