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CONTRIBUTION OF RC SLABS TOWARDS COLLAPSE RESISTANCE OF BUILDING STRUCTURES

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Abstract: Progressive collapse of RC buildings can be studied using sudden column loss scenarios by removal of column one at a time as mentioned in the GSA guidelines. Removal of column causes the deformation in the structural members at removal location and location above. Deformation causes the membrane tensile action in the slabs which helps the structure to resist the collapse under column removal scenario. Mixed behaviour of concrete slabs as compression and tension region, represents an important line of key aspect against progressive collapse. Provided Negative steel at the corners of slabs helps to greater tensile membrane forces, whereas the compression causes by hogging moment, strengthen the concrete. Hence, overall collapse load resisting capacity of structures enhanced. In present study, attempt have been focused on the contribution of slabs on resistance of collapse of building with different height to width aspect ratio. In present study, 4-storey, 7-storey and 10-storey building structure with removal cases of four columns on at a time have been considered.
Keywords: Progressive Collapse, Equivalent Beam Modelling, Non-Linear Analysis, Collapse Assessment, Catenary effect, Tensile Membrane Action

1. INTRODUCTION

Sudden Removal of Column causes the axial compressive forces in columns above the removed column and the same is redistributed quickly within a few seconds to the adjacent elements. As a result, all floors above the first floor or slab at removal location will deflect identically and dynamically under gravity loads to achieve the new equilibrium. Structure will progressively collapse until the desire equilibrium not achieved. Two simultaneous changes have been caused increase the internal forces as, “double-span effect” which cause spans of slabs and beams bridging over the removed column will double the initial ones and “dynamic effect” which cause existing gravity loads are amplified by a dynamic amplification factor up to 2.0 as prescribed in GSA guideline. Removal of column causes the deformation of the beams-columns and slabs assembly in catenary shape, hence the adjacent elements get pulled in towards removed column side which leads to the increasing in the unbalance equilibrium of forces. Effective Lateral restraint from adjacent elements cause the reduction in catenary action to arrest progressive collapse. When column is removed, adjacent slabs may form a very strong in-plane diaphragm action which are able to contribute in the catenary tension forces occurs in the beams (Figure 1) and reduce the demand of catenary action. Hence enable the structures to sustain the amplified gravity applied loads longer before the progressive collapse.

SMRF structural system have been considered for formulation of space frame and the same have been design as per IS code. The slabs are design as per IS:456-2000 and reinforcement mesh have been considered as 8T-150 c/c for both ways as well as on all four edges of slabs as top negative reinforcement for all slab panels. Assessment of collapse resistance have been calculated by non-linear pushdown analysis, considering contribution of slabs and without contribution of slabs and presented in the charts as load attempt by structure vs displacement.

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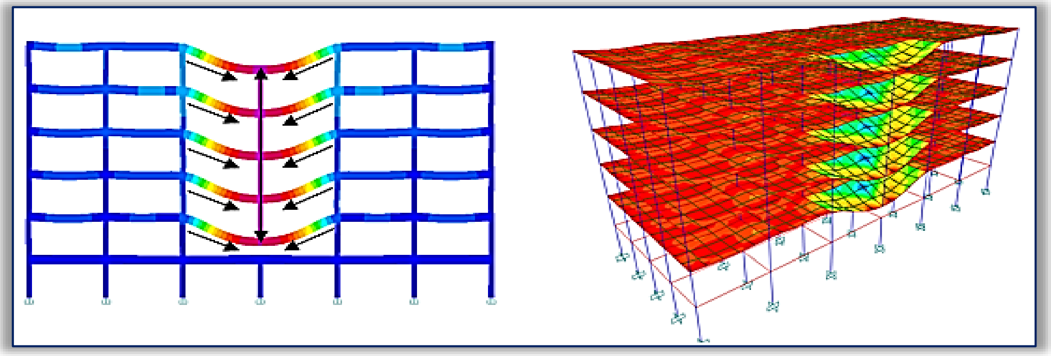

Figure 1. Catenary Action in the Beams and in plane forces in the slabs

2. STRUCTURAL CONFIGURATION & DESIGN PARAMETERS

The considered models in the present study is rectangular in plan with 3m storey height with 6 bay of 5m spacing in X-direction & 4 bay of 3m spacing in Y-direction. A sample of typical plan and 3-D model of the structural model are as shown in Figure 2. The structure have been analysed and design for Gravity and Lateral load as per IS Code. The structural member sizes of beams, columns & slabs are mention in the table-1 in detail and Loading parameters are mentioned in table-2. The structure is considered as situated in seismic zone III founded on a medium soil in accordance with IS 1893:2016 (Part I).

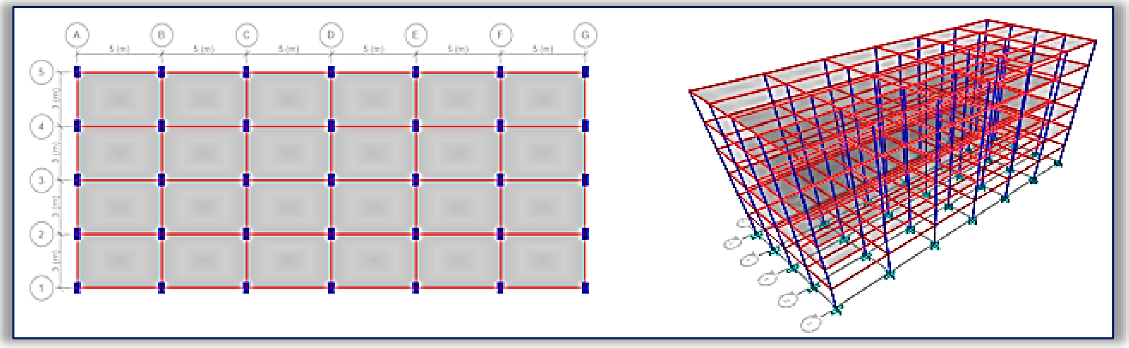

Figure 2. Plan and 3D model of Building Structure

Table 1 – Geometrical Parameters

<table>
<tr><th>Nos. of Storeys</th><th>H/B ratio of Building</th><th>Height of Building (m)</th><th>Plan Dimension at Plinth Level (m)</th><th>Column Sizes (mm)</th><th>Beam Sizes (mm)</th><th>Slab Thk. (mm)</th></tr>
<tr><td>4-Storey</td><td>1.25</td><td>15.00</td><td rowspan="3">Dx=30.00m
Dy=12.00m</td><td rowspan="3">350x650</td><td rowspan="3">230x600</td><td rowspan="3">150</td></tr>
<tr><td>7-Storey</td><td>2.00</td><td>24.00</td></tr>
<tr><td>10-Storey</td><td>2.75</td><td>33.00</td></tr>
</table>

*Concrete Grade M30, Steel Grade Fe500 for all structural members

Table 2 – Loading Parameters

<table>
<tr><th>Load Type</th><th>Description</th></tr>
<tr><td>Dead Load</td><td>Cross section x Material density</td></tr>
<tr><td>Live Load</td><td>LL=4.0kN/m² as area load on slab</td></tr>
<tr><td>SDL Load</td><td>1.2kN/m² as area load on slab</td></tr>
<tr><td>Wall Load</td><td>6.9kN/m (UDL on Beams) (i.e-0.115x3x20=6.9kN/m)</td></tr>
<tr><td rowspan="4">Seismic Parameters & Natural Periods (sec) (IS:1893-2016)</td><td>Z=0.16 (Zone-3), Soil Type-2 (Medium Soil), Importance factor (I=1.2), Response reduction factor (R=5.0),</td></tr>
<tr><td>Natural Period of 4-Storey - Tx=0.25, Ty=0.39</td></tr>
<tr><td>Natural Period of 7-Storey - Tx=0.39, Ty=0.62</td></tr>
<tr><td>Natural Period of 10-Storey - Tx=0.54, Ty=0.86</td></tr>
</table>

*Seismic Co-efficient method used for Lateral load analysis as per IS:1893-2016.

3. COLLAPSE LOADING AND COLUMN REMOVAL CASES (BARE FRAME)

For Design of Structure, load combination mentioned in IS:456-2000 & IS:1893-2016 have been considered. Collapse loading have been adopted from reference of GSA guidelines and modified accordingly as per Indian Codal Provision requirement. Collapse load is considered as 2.4DL+2.0LL at & above all floors for particular column removal location, whereas, 1.2DL+1.0LL at other than removal locations. Marked four columns locations are considered for column removal cases one at a time. Figure 3 shows the schematic collapse loading arrangement and column removal cases with circle marks for present study.

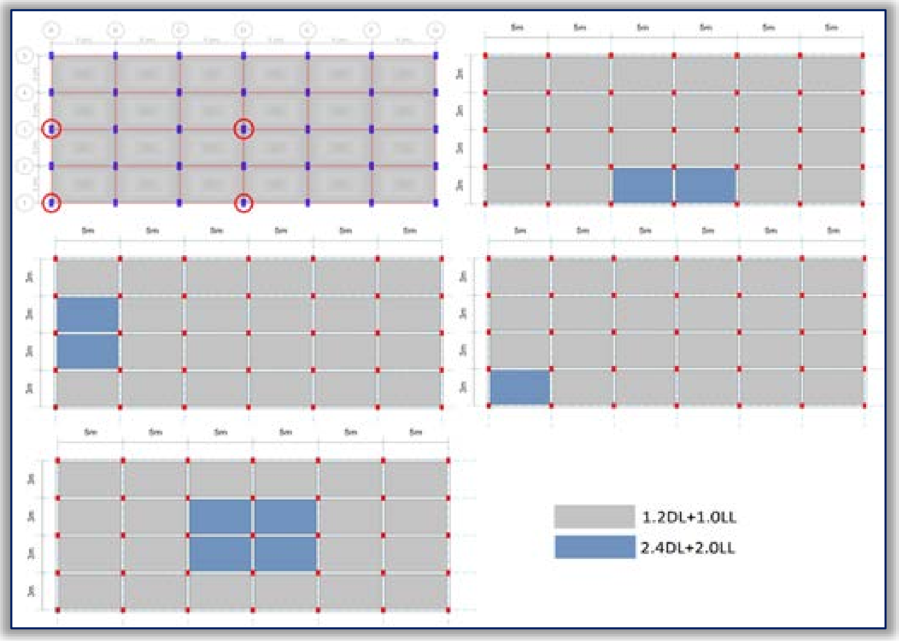

Figure 3.(i) Column Removal Case (ii) Long Bay Column Removal (iii) Short Bay Column Removal (iv) Corner Column Removal (v) Centre Column Removal (vi) Legend for Collapse Loading Marks

— Modelling Details

ETABS has been used for modelling, analysis & design of structure and for collapse assessment, nonlinear static analysis have been performed. A 3D computer model is created and user defined plastic hinges are incorporated to the beams, columns and also to equivalent beams which represent slabs. Equivalent beams have been modelled as per ASCE 41-17 to represent the slabs. User defined hinges and moment-rotation data was generated using the Engissol tool for reinforcement arrangements in cross section and presence of axial loads. A set of moment-rotations relationships have been calculated for beams, columns and equivalent beams (for slabs) considering the basics of cross section properties. Equivalent beams have assigned same properties as considered for slabs. The moment of inertia and the weight of equivalent beams get scaled to match with the inertia and weight of slabs.

— Sample Calculation of Moment Capacity and Axial Capacity of Equivalent Beams and Its M-θ relationship (IS:456-2000)

The equivalent beam to represent the slab have been discretised as 1000mm x 150 mm cross section. 1000mm represent the width of equivalent beam, whereas 150mm represent thickness of slab. Provided reinforcement in both directions in slab as 8T-150 c/c at mid span and edge of slab panel (figure 4), hence the 1000mm width beam having 6.6nos equivalent reinforcing bars of 8T of bottom face at mid of equivalent beam, whereas 6.6nos equivalent bars of top & bottom face at both ends of equivalent beam.

$A_{st} = (a_{st}/spacing) \times 1000 = [(\pi/4 * 8^2)/150] \times 1000 = 335mm^2$.

Depth of neutral axis $x_u = [(0.87 f_y A_{st}) - \{f_{sc} - f_{cc}\} A_{sc}]/(0.36 f_{ck} b) = 2.22mm$

Max. Depth of neutral axis $x_{u\,max} = 0.48 x d = 55.20mm$

Moment capacity, $M_{u\,capacity} = 0.36 f_{ck} b d x_u [\{d-(0.42 x_u)\}/d] + [(f_{sc}-f_{cc}) A_{sc}(d-d')] = 13.68$ kN.m ≈ 14.00 kN.m (Calculated at both end of equivalent beam),

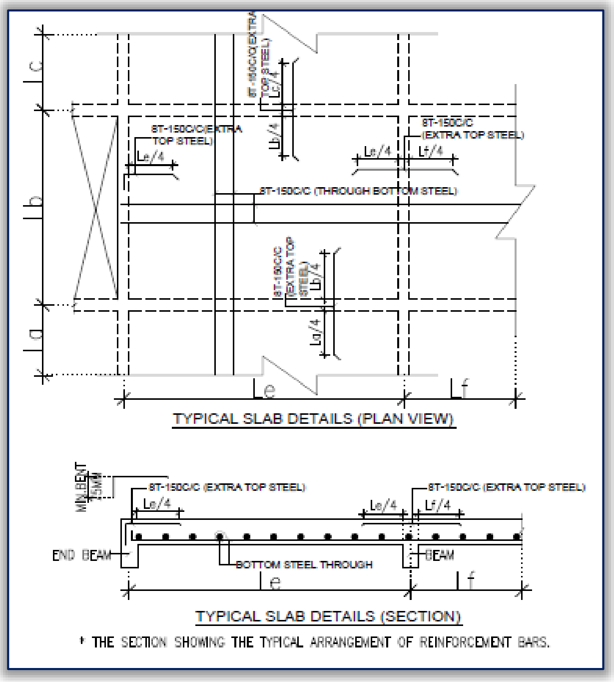

Figure 4. Typical Slab R/F Details

Axial Capacity = $0.87 f_y A_{st}$ = 145.72 kN (Calculated at mid of equivalent beam)

Here, A_{st} = Tension steel, A_{sc} = Compression steel, f_{sc} = Compressive stress in steel, f_{cc} = Compressive stress in concrete, f_{ck} = strength of concrete (30 N/mm^2), f_y = strength of steel (500 N/mm^2), d = effective depth as (over all depth – clear cover), b = width of member, d' = top cover (30mm)

4. RESULTS AND DISCUSSION

The results obtained for the models of bare frame (without considering contribution of slabs) and with considering contribution of slabs by non-linear static methods are compared and discussed as follows. The Pushdown curve for all four column removal case, have been carried out and plotted as collapse load attempt by Structure vs. removal node displacement for both the cases as with slabs and without slabs contribution. Figure 6 shows pushdown curves for bare frame (without contribution of slabs) models. For all four column removal cases the long bay column removal & center column removal cases the structures under goes elastoplastic range before failure, these is occurs because of the catenary effect of the more long span beams framing at a joint, Whereas for short bay and corner column removal cases the structures behave elastically more and little defamation observed beyond yield point, these is happens because of the more short span beams are farming into joint. Figure 7 shows pushdown curves for structure considering the contribution of slabs.

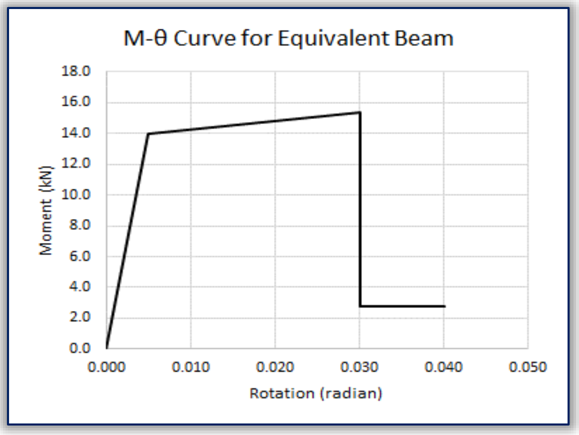

Figure 5. Moment-Rotation Curve for Equivalent Beam

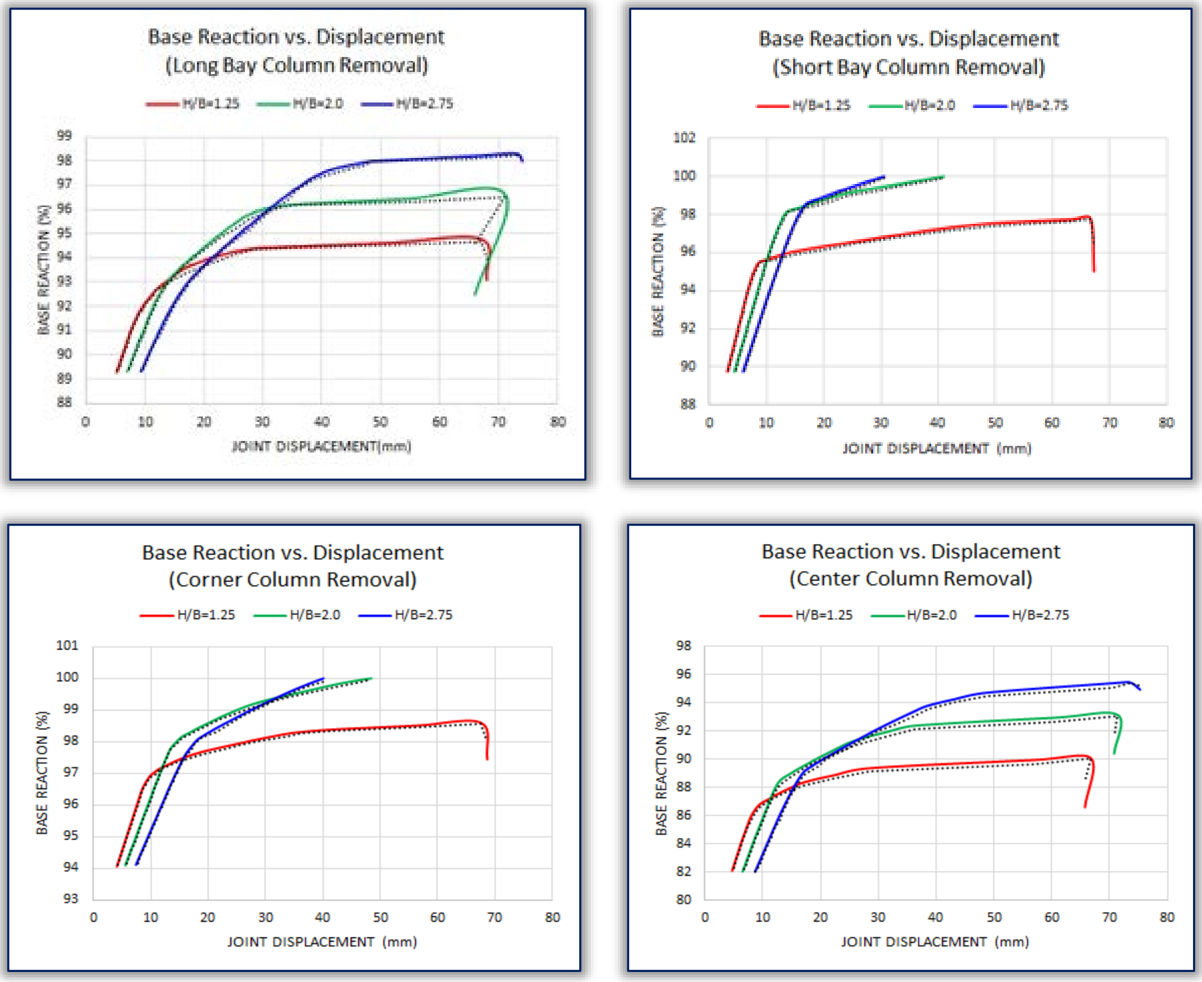

Figure 6. Pushdown curve for Bare Frame (Without Contribution of Slabs): (i) Long Bay Column Removal, (ii) Short Bay Column Removal; (iii) Corner Column Removal; (iv) Center Column Removal

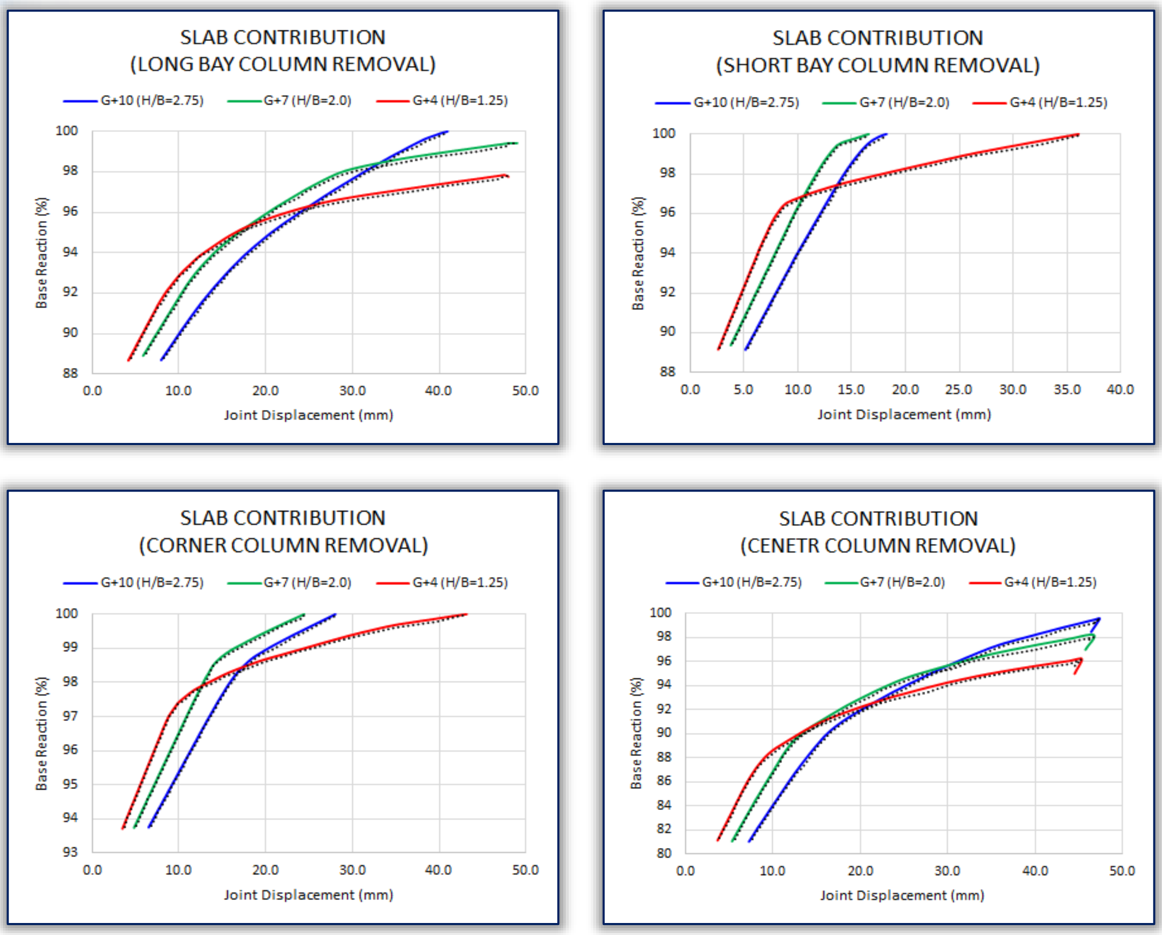

Figure 7. Pushdown curves for models (With Contribution of Slabs)

Pushdown curves with contribution of slabs indicates that the collapse resistance of building structure in increase, if contribution of slabs are considered as compare to bare frame. Table-3 shows the collapse load attempted by structure at failure of any structural member considering the contribution of slabs and without contribution of slabs (bare frame) towards collapse resistance.

Table 3 – Collapse Load Attempted by Structure with & without Contribution of Slabs

Column Removal Cases	(G+4 Storey) H/B=1.25		(G+7 Storey) H/B=2.00		(G+10 Storey) H/B=2.75	
	Without COS	With COS	Without COS	With COS	Without COS	With COS
Long Bay	93.11%	97.96%	96.63%	99.42%	98.31%	100.00%
Short Bay	95.02%	100.00%	100.00%	100.00%	100.00%	100.00%
Corner	97.44%	100.00%	100.00%	100.00%	100.00%	100.00%
Center	86.61%	94.99%	90.41%	96.98%	94.94%	98.46%

*COS = Contribution of Slabs

5. CONCLUSIONS & RECOMMENDATIONS

The load-carrying capacity of beam-slab substructures shown enhancement by membrane actions in slabs and reduction in catenary action in the double-span beams under removal of column. The enhanced capacity by contribution of slabs is a key feature to sustain the amplified collapse loads and thus to resist the progressive collapse of building structures. The following points can be drawn from the present analysis & study,

(1) Collapse resistance of structure are increase with increases of H/B ratio.
(2) Contribution of slabs shall not be ignore to predict the collapse resistance of structure as the slabs contribution are remarkable to resist progressive collapse
(3) Collapse resistance of structure have been increase by 10 to 12%, with considering the contribution of slabs as observed from the load attempted by structure.
(4) The contribution slabs for collapse resistance are affected by reinforcing ratio of slabs also, but that may vary in the difference of 2% to 5% only, based on the reinforcement detailing pattern in the slabs.

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