

# REVIEW OF PROGRESSIVE COLLAPSE ANALYSIS OF REINFORCED CONCRETE STRUCTURES WITH FLAT SLAB CONSIDERING EFFECTS OF GEOMETRICAL (HORIZONTAL and VERTICAL) IRREGULARITIES.

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**Abstract** –This review paper presents Progressive Collapse analysis(PCA) of Reinforced Concrete Structures with Flat slab considering effects of geometrical (horizontal & vertical) Irregularities. Progressive collapse failure starts with local damage and extend up to whole structure. Flat slab buildings are more prone to progressive collapse than moment frame buildings, its behavior to resist progressive collapse must be examined, Since absence of beams to redistribute load due to get more effect after removing columns. to get more Clair idea about PCA purpose in review Some paper considered various model having geometrical irregularity by conducting Linear static progressive collapse analysis and dynamic PCA as per GSA guidelines (2016). mostly research papers explores the different locations for column removal situation in each model at ground storey and the results are analyzed for each case in terms of demand capacity ratio (DCR) at critical sections, vertical joint displacement and chord rotation at column removal locations and thus sensitivity of building to progressive collapse is calculated accordance with relevant acceptance criteria consigned in DOD guidelines (2009). Along with that in this review paper cover effects of geometrical irregularities as well flat slab effects in RCC structure.

**Key Words:** Progressive collapse, flat slab, vertical displacement, DCR, Chord rotation, GSA, DOD, local damage, static linear analysis, dynamic analysis, seismic forces, ETABS

## 1.INTRODUCTION

The collapse of load carrying structural element may lead to progressive collapse as a part or whole structure. According to GSA 2016 guidelines, progressive collapse is defined as extent of damage or collapse that is disproportionate to the magnitude of the initiating event. The progressive collapse initiates, when one or more load carrying members are removed. When one or more load carrying elements remove chain reaction of failures structure start. The guidelines of the GSA and DoD suggested the Alternate Path Method (APM) for progressive collapse analysis where a single column in the ground level is assumed to be unexpectedly missing and analyses are carried out to assess the ability of the weakened structure to pass through the missing column. The alternate load path method (APM) focuses on the

vertical deflection of the building after the column has been suddenly removed. The collapsing structure seeks for alternative load path continuously for prevent progressive attention collapse and survive. Traditional design work not considered extreme loading conditions. Previously some experiences grab of structural engineer's attention Ronan point apartment building, Alfred.P. Murrah building, skyline plaza, world trade Centre. Based on the type of collapse occur, progressive collapse divided into pancake-type, zipper-type, domino-type, section-type, instability-type and mixed type collapse. The purpose of this study is to analyze the effect of geometrical irregular RC flat slabs for progressive collapse. progressive collapse analysis where a single column in the ground level is assumed to be unexpectedly missing and analyses are carried out to assess the ability of the weakened structure to pass through the missing column. PCA is classified as PRESSURE LOAD- Internal gas explosion, Blast load, Extreme wind pressure and another type is IMPACT LOAD- Aircraft impact, Vehicular collision, Earthquake in this study analyses behavior of building under column loss at ground floor.

## 1.2 OBJECTIVE OF WORK

1. To study PCA structural behaviour using GSA and DOD guidelines.
- 2.
3. And understand phenomena of flat slab building under critical column loss scenarios in PCA for static as well dynamic analysis.

## 2. LITERATURE REVIEW

Sivq naveen, Nimmy Mariam Abraham, anitha kumari,[3] they analyzed irregular structure under earthquake loads and the results of structural response in the form of story displacement, story drift, base shear and overturning moment. And for validation response is compared with regular building. In this paper they not only study single irregularity but also combinations taken in design. In vertical irregularities mass, stiffness, and geometrical vertical irregularities and for horizontal torsional, re-entered corners considered. total 54 irregular frames are analyzed out of witch 34 configuration have

single irregularity and 20 have combine and finally they study critical combination of irregularity. And result is the combination of stiffness and vertical geometrical irregularities has given maximum displacement response where's the combination of re-entered corners and vertical geometrical irregularities has shown less displacement response.

- **Ravindra nagar, Vinay Agrawal, Suyash Garge., [4]** studied the effects of progressive collapse of RC flat slab building 8 floor by static analysis with or without periphery beam layout as per GSA 2016 guidelines and result is analyzed in term of joint vertical displacement, chord rotation at column removal locations. And result showed incorporation of perimeter beams in flat slab building improved PC resistance and reduces joint displacements, chord rotation at column removal locations by providing sufficient stiffness and load path. And result is get that more prone to progressive collapse in case of corner column removal than any other column removal conditions. for interior column removal locations addition of external periphery beam not resulted good resistance than another locations column removal results get. Also to enhance progressive collapse potential retrofitting tools along with partial beams in frame layout is grate option as per this study.
  - **Zabihullah, Priyanka singh, Mohammad zamir.,[5]** studied seismic response of RC structures of G+7 story having vertical and horizontal irregularities analyzed and compared by using response speculum method as per IS codes. The comparison of this models are carried out by base shear, fundamental period, story stiffness, lateral displacement, story drift, eccentricity, torsional irregularity. Out of the building models horizontal irregular model is most susceptible during considered earthquake. They discussed most imp seismic parameters of all the models to get idea of irregular building performance. Idea is get Clair that the more asymmetrical the building more will be its lateral displacement and story displacement and story drift. The more asymmetrical building, more will eccentricity as well as torsional irregularities.
  - **Suyash Garg, Vinay Agarwal, Ravindra nagar., [6]** in this paper progressive collapse behavior of five story RC flat slab building is assessed by removing column from first story and dynamic analysis is conducted as per GSA guidelines. In this paper sustainably point of view also touches means the construction of new houses, often required form of energy and creates harmful gases, the CO<sub>2</sub> emission factors rate is 236.8kg co<sub>2</sub>/cubic meter for M25 concrete and 424.2kg-CO<sub>2</sub> /ton for Fe500 rebar. Therefore, author considered money of protect the environment also considered. result is analyzed in term of joint vertical displacement, chord rotation at column removal locations in three cases at column removal first story, edge and corner column removal.
  - **P. olmati, J. sagseta, D.cormie, A.E.K. jones.,[7]** . This paper presents a framework for a simplified reliability analysis and derivation of safety factors for computing the probability of punching of flat slab concrete buildings subjected to accidental loads such as column removal, slab falling from above or blast load. approach in study is proposed to take into account uncertainty in the gravity load in the slab. This study is done by using advanced dynamic software's and get ideas that The response of the slab in the blast load scenario is more impulsive compared to the column removal and falling slab scenarios, although the slab rotation outside the column at failure is of similar magnitude. And, the variability in the gravity loads in the slab influences the inertial effects and demand capacity ratio of the slab-column connections after extreme events. The uncertainty in the load applied in the slab was found to have a less critical role in the falling slab and blast load cases considered due to the high shear demand compared to the column removal scenario.
  - **Suyash Garg, Vinay Agrawal, Ravindra Nagar[8]** this study focuses on building strengthened by using shear wall, perimeter beam and did PCA by removing corner column, interior column, edge column and results compared with static and dynamic analysis methods it contains column remove alternatively, simultaneously, sequentially by using GSA and DOD guidelines.
  - **Suyash Garg, Vinay Agrawal, Ravindra Nagar[9]** this paper gives improved PCA results of RCC flat slab building under different corner column failures analytical research examines for failure criteria and improvement in the progressive collapse resistance using static analysis of five and ten-storey irregular R.C flat slab building by incorporating perimeter beams along with strengthened perimeter columns in the building. The progressive collapse study is conducted by removing different corner columns on the ground floor as per the GSA guidelines.
  - **D. z. yankelevsky, Y.s.karinski, V.r.feldgun[10]** this study focus on the numerical detailed simulations of a connection under impact conditions and study of dynamic response of RC connection between slab and column due to falling of upper slab. And points cover in studies like shear reinforcement, reinforced ductility on connections and type of failures. Entire analysis done by FEM in ANSYS AUTODYN commercial software. In this work they used fine mesh of three dimensional solid elements used in concrete slab domain.
- Flat slab fails in punching issue between rebar and surrounding concrete has included top and bottom meshes with rebar's in both directions. And for column strengthening

longitudinal rebar's and stirrups in connection structural system. And this short duration response slip during bond action between a rebar and solid intact concrete is ignored and the rebar's ideal perfect bond connection to the concrete.

- **Silpag, Yamini sreevalli.,[11]** This paper discusses the existing researchers on the analytical study, experimental study, and numerical simulations of flat slab structures along with various load resisting mechanisms to mitigate progressive collapse. Further, various strengthening techniques available in the literature for the flat slab structures have been discussed.
- **Justin M Russell , John S Owen and Iman Hajirasouliha ., [12]** In this study, finite element analysis is used to replicate column loss scenarios on a range of reinforced concrete flat slab floor models. The model was validated against the results of scaled-slab experiments and then used to investigate the influence of different geometric and material variables. And basically result get that is the most critical removal location depends on the slab geometry with an internal column removal case causing the largest nonlinear behavior for stiffer slabs and a corner column removal for more flexible slabs. In addition, the use of low-strength concrete results in structures more prone to progressive collapse, even after accounting for an increase in flexural reinforcement.
- **S. M. Marjanishvili, P.E., M. ASCE.,[13]** in this study detailed information or guidelines about to protect existing and new building from PCA by DOD and GSA is gives after world trade center collapse. By linear-elastic static; nonlinear static; linear-elastic dynamic; and nonlinear dynamic. they discuss the advantages and disadvantages of each method. And conclude that the most effective analysis procedure for progressive collapse evaluation incorporates the advantageous parts of all four procedures by systematically applying increasingly comprehensive analysis procedures to confirm that the possibility of progressive collapse is high.
- **Dario Coronelli a, Marco Lamperti Tornaghi b, Luca Martinelli a, Francisco-Javier Molina b, Aurelio Muttoni....etc and all.,[14]** this group of people did experimental work on full-scale flat slab building for gravity and lateral loads undertaken in Slab STRESS research project carried by ELSA laboratory of European commission joint research Centre. They considered two different longitudinal reinforcements. Work is done basically focusing on two things that is primary wall and flat slabs. Varies devices are used to measure inclination of column and cyclic loading tests.
- **Saeed Sarvari, M. Reza Esfahani.,[15]** they did experimental work on post-punching behavior of flat slab means changes in diameter of reinforcement, changes in shear reinforcement pattern in flat slab, example-truss type, sometime provided additional bent up bars than required, around column slab connection polar or crossover arrangement of steel and so on 17 slab with cover variations. The effects of integrity, compressive, shear, truss, and bent-up reinforcements, diameter of tensile reinforcement, and concrete cover of tensile reinforcement on the post punching behavior of slab-column connections were studied. The results of the experiments indicate that the integrity reinforcement significantly improves the post-punching strength. The increase of the concrete cover of the tensile reinforcement and decrease of the diameter of the tensile reinforcement result in an increase of the post-punching strength.
- **Rasha T.S. Mabrouk , Amr Bakr, Hany Abdalla.,[16]** their ongoing research seven half scale specimens are cast and tested to know Effect of flexural and shear reinforcement on the punching behavior of reinforced concrete flat slab. They considered parameters spacing between vertical stirrups, width of the stirrups, number of stirrups branches and the ratio of the horizontal flexural reinforcement. During testing, ultimate capacity, steel strain, cracking pattern and deformation were recorded. The experimental results were analyzed and compared against values estimated from different international design codes.
- **Szczepan wolinski.,[17]** this article name is Robustness and vulnerability of flat slab structure. In this paper the importance of assessing both the structural robustness and vulnerability of flat slab structure to catastrophic and unforeseen events is highlighted and analyzed and the risk is evaluated. The vague nature of possible hazards and their consequences, semi-quantitative approaches to risk eliminated by fuzzy numbers has been used.
- **J.M. Russella, J.S. Owenb , I. Hajirasouliha ., [18]** Has analyzed The nonlinear dynamic response of a structure after dynamic column loss event is considered, including the redistribution of loads and displacement profile. These results are then compared to equivalent static cases in order to determine the Dynamic Amplification Factor (DAF). For the range of structures, they considered, the DAF was calculated as between 1.39 and 1.62 for displacements, with lower factors associated with a higher nonlinear response or slower column removal. Additionally, the shear forces in remaining columns may exceed 200% of their fully supported condition, with a different associated DAF. The effects of increasing the tensile strength of concrete due to high strain rates are also considered. They did experiment on FE displacements results against time with different removal times compared to the experimental results. Four different times (0, 20, 50 and 100 MS) are used to reduce the reaction force provided by the temporary



support. In this work study is applied experimentally The dynamic response of RC flat slab structures after a column loss demonstrates that a sudden removal can considerably increase the peak displacements and the shear forces compared to the static condition. The DAF for displacement values is related to the extent of damage and nonlinearity within the force displacement response.

- **Kai Qiana , Yun-Hao Wengb , Bing Lic., [19]** Has analyzed impact of two columns missing on dynamic response of RC flat slab structure. These two specimens have identical dimensions and reinforcement details. One of the substructures suffered a loss of an interior column scenario while another one was subjected to a two columns one interior and other is edge column missing. It is found that although both specimens had exceeded their yield load capacity, no collapse occurred as considerable compressive membrane action developed in the RC slab to help redistribute the loads. With the drop panels, no punching shear failure was observed in the slab-column connections after removal of the column. The numerical results indicated that missing a single interior column achieves larger dynamic response than that of the loss of a single corner or an exterior column. And for missing two-column scenarios, the substructures under the loss of both a corner column and an adjacent exterior column simultaneously may experience more severe damage than that of the substructures subjected to the combined loss of an interior column and an adjacent exterior column.
- **Colin gurley.,[20]** gives information and differences between progressive collapse and earthquake resistance. Basically earthquake engineering focuses on sway mechanism in which building as a whole move sideways and may collect under its own weight and explosion may removes one or several load bearing column, walls or transfer structure loading to vertical collapse and double span mechanism.
- **Khaja ateequddin, waseemsohail.,[21]** has analyzed Effects of irregularity shape on flat slab multistory building under lateral loading using etabs. Horizontal and vertical irregular models are analyzed by using etab software and results plotted against wind load as well earthquake loads. And finely gives comparison between story shear, drift, displacement. Time and all properties behavior with model.
- **Niramjan Chaudhary, nitin verma.,[22]** they did work on seismic behavior of flat slab multistory building in plan irregularities considering T, U, PLUS shape G+13 floor by using E-tabs software considering column head, drop panels with and without both. nonlinear time history method used to get different parameters story displacement, story drift, base shear, time period by using is codes.

### 3. CONCLUSIONS

- The joint displacement and Chord rotation at column removal locations are evaluated when different locations of column on each building removes the finding indicates the studied flat slab is more vulnerable in case of corner Column remove than edge columns.
- Joint Displacement and Chord Rotation values are inversely proportional to progressive collapse resistance as chord rotation decreases, Progressive Collapse Resistance increases.
- The Irregular Structure also sustains progressive collapse effect after removal of columns Alternately, and the effect of flat slab on PCA is very influential because the existence of flat slab after removal of column does not experience overall collapse, but some structural elements collapse. Load distribution after removal of column through nearby critical column is done, Column DCR < 1.5 for irregular and DCR < 2 FOR regular structure. gives limit of safety member.
- The result values of vertical joint displacement and chord rotation and DCR is taken as per GSA load combination. building is designed for seismic forces hence seismically designed building columns have inherent ability to resist progressive collapse.
- The purely RC regular flat slab structural system is less vulnerable than irregular flat slab structure because the ductility of these structural system is generally limited by the deformation capacity of slab column connection. i.e., penetration force in the slab at the connections, which should retain its load bearing capacity when column removes adjacent column get additional load and this is related with maximum displacement and DCR are less than 2 as well chord rotation is less than 0.05 in all cases therefore adjacent all members are safe.
- DCR values for column adjacent to removal column maximum when central Internal column removes, then another Internal column, edge column of longer side, then edge column on shorter side, and finely corner column.
- As the structural response depends on degree of irregularity, type, location those factor need to be taken care while designing any structure. This would help in incorporating irregularities in structures without compromising their performance.
- Mostly Flat slab on the ground floor of a building when the critical column and inner sides of a building are removed collapsed but does not affect the floor above, because the load on the upper floor moves to a flat slab system on the ground floor of the building. The irregular

building structure did not collapse after the removal of the column.

- In general, if the structures are designed and detailed with an adequate level of continuity, redundancy, and ductility can develop alternative load paths which in return prevents the loss of an individual member and prevent progressive collapse.

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