EFFECT OF CREATING LARGE OPENING IN THE EXISTING RC BUILDING AND IT'S REMEDIAL MEASURE

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ABSTRACT

The continuous growth of clients' demand for aesthetics and advanced facilities in modern houses is creating challenges for engineers to generate large openings in a newly constructed RC building or an existing RC building nowadays. In newly constructed buildings it is possible to design with a large opening but for existing RC buildings a detailed analysis of all the components of the structure is required before creating a large opening. This study uses ETABS 2018 to investigate the effect of opening in the existing RC building and analyze the axial force, bending moment, shear resistance variation in columns and moment and shear resistance variation in beams of an existing building where an extra lift shaft core with a dimension of 8 ft × 7.25 ft and an opening in the slab of story 6 with a dimension of 6.56 ft × 6.56 ft. After analyzing the generated model in ETABS, the study found that the negative axial force in columns nearer to the openingdecreases whereas in columns far from the opening the axial force increases after the opening is done. The study also found that there is a 2.05% increase in the negative moment in the beam nearer to the slab opening and a 21.40% increase in the negative moment in the beam that is far from the slab opening in the same slab area. The study observed an alarmingly high increase of negative moment in the beam connecting the old and new lift shaft core after opening which is 204.98%. Therefore, the study established that openings in the slab considerably impact the structural behavior of the components of the structure. The study suggests remedial measures such as placing extra reinforcement bars or beams around the opening to create an opening in an existing RC building.

Keywords:Largeopening, RC building, Structural behavior, ETABS2018, Lift shaft*

1. INTRODUCTION

Due to the client's demand for adding extra facilities to an existing building or for aesthetics, an opening in an existing floor is done. Sometimes, for repair purposes,an opening can be done too.According to dimensions, the openings can be classified as either round, rectangular, or square (Prentzas, E.G. (1968). However, when it comes to size, the openings can be classified as small or large by researchers without any exact definition (Mansur, 2006; Somes & Corley, 1974). According to a researcher, defining an aperture as small or large is dependent on its impact on the structural behavior of the beam (M. A. Mansur, n.d.). A little aperture preserves the beam type, whereas a large one changes it to a frame type(M. A. Mansur, n.d.). ACI 318 building code permits any size of the aperture in a new slab(ACI 318; Mota, n.d.).

The client's demand for adding an extra elevator shaft or staircase to an existing building often leads to a large opening in the existing floor.Sometimes for aesthetics, a large opening can be done in existing RC slabs. However, making an additional aperture in an existing floor, especially one with a confined construction, is quite difficult. A competent building modification is required to make a realistic change while keeping the structural integrity of the current structure. Many experimental researches have been conducted on different sizes of openings in RC slabs and found that opening in the RC structure has a significant effect on the RC structure (Khajehdehi & Panahshahi, 2016; Yaseen et al., 2022; Yılmaz et al., 2022). After an opening is created, the residual segment of the cutting section can function as a cantilever. In the meantime, the RC building departs from its integrity, reducing the structure's rigidity. Due to this, the structure's stress distribution may be impaired. Irregular moment distribution may also have an impact on the total structure. Unbalanced loads may induce torsional forces at the beam-column connection. The floor opening may decrease the structure's integrity and stiffness, reducing earthquake resistance and reducing the surrounding floor's ability to support weight.

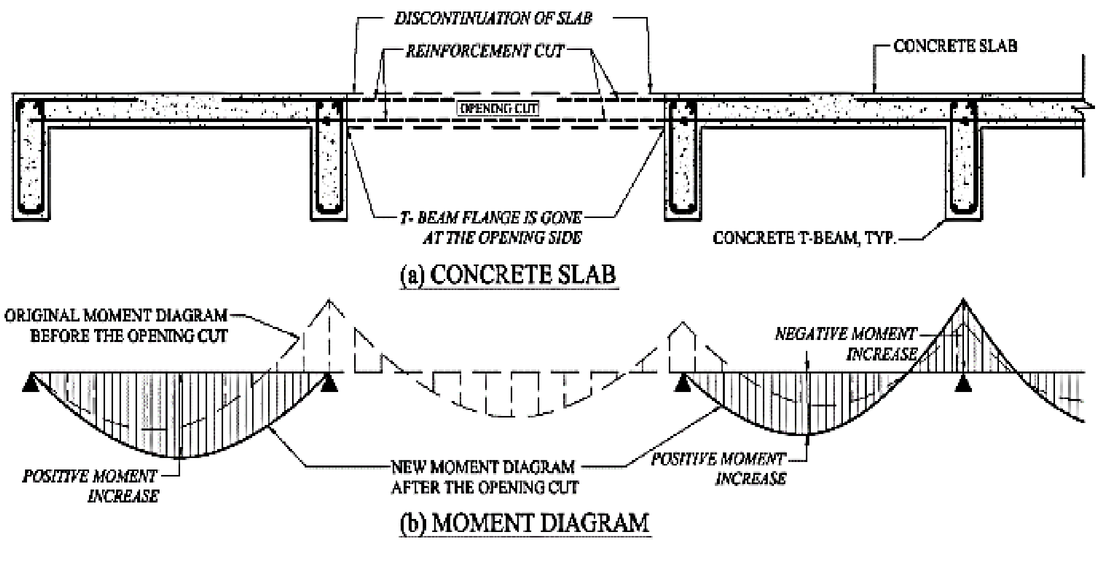

Figure 1: Effect of making an opening

To successfully implement a change that can be made while preserving the structural integrity of the current structure, an expert analysis is required before doing any opening. However, performing experimental analysis on the whole structure is not easy and is also time-consuming.So numerical methods have to be followed to perform the analysis of the whole structure easily and timely.Through numerical analysis, a study found that the beam’s and block flooring’s strength and resistance decreased against lateral load while showing more fragile behavior (Aminitabar et al., 2021).

Openings in newly constructed buildings can be handled by supplementary steel reinforcement in slabs or beams, beams spanning among columns, or strengthening parts of the slab surrounding apertures. There are several standard methods of reinforcement, but externally bonded and bolted plate methods are the most cost-effective(Hollaway & Leeming, 1999). The dimensions of the plates are determined according to the minimum design moments under combined loads. The surface shear forces between steel plates and concrete are provided by bonding agents and anchor bolts. Adding steel plates to the exterior of a slab with either anchor bolts or post-installed anchors is one of the most popular ways of increasing its moment capacity. Fiber-reinforced polymer and steel-reinforced polymer segments can also be used to reinforce the slab.Installing new transfer beams around an opening is also an effective method of fortification.Retrofitting both the beam and the column is yet another method that can be employed for strengthening.Reinforcing with only carbon-fiber fabric or steel plate is limited when there is a large, concentrated load in the hole and the main rib of the prefabricated plate is cut off.To enhance the outermost portion of the critical region for punching shear, concrete or steel collars are often installed around the columns while shear strengthening is necessary. The reinforcement of the frame beam, primary and secondary beams, frame columns and slabs, cross-sectional size, concrete strength level, and other parameters should be reviewed with the original structural design and construction drawings to determine whether to carry out construction. Reinforcement treatment is needed to ensure the bearing capacity of the original structure after the opening of the floor slab. This study investigates the effect of creating a large opening in the existing RC building and its remedial measures.

2. METHODOLOGY

The first step of the entire work was to create a six-story building model using AutoCAD. The model was then established in ETABS software. Before cutting an opening in the floor, a thorough model analysis was done using ETABS software. Then the model was evaluated while building an opening in a floor. After that, considering opening into the existing building to add a new elevator was evaluated. The construction of the opening on the current floor to accommodate a duplex and an additional elevator was the subject of a final investigation. The workflow diagram of the entire study is shown in Fig. 2 below:

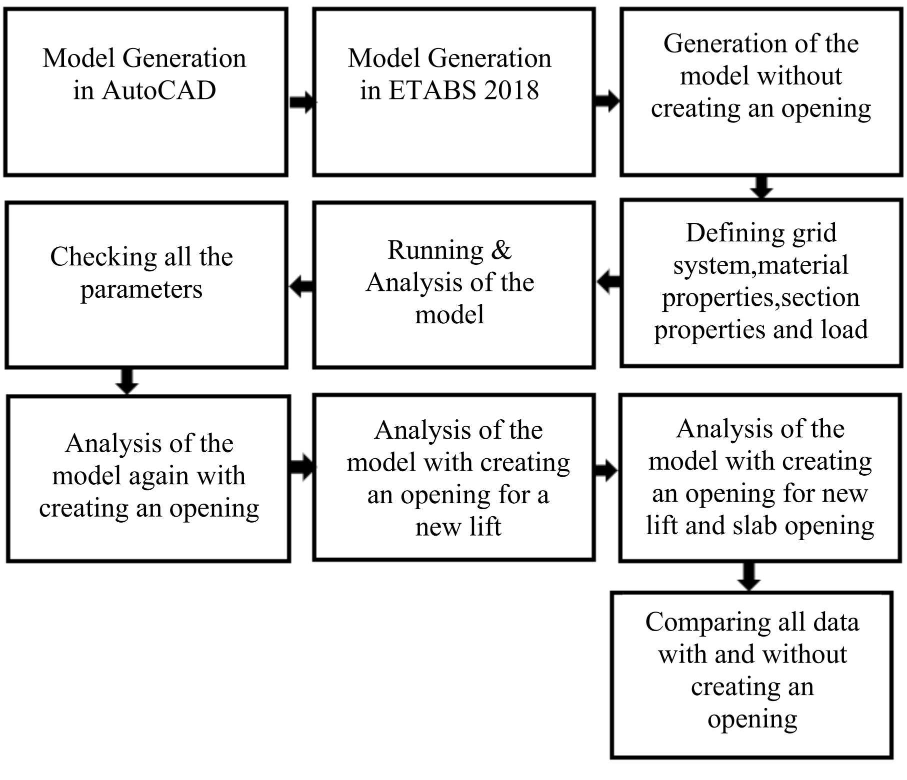

Figure 2: Workflow diagram

2.1 Model Generation

To carry out this investigation, a six-story RC building of 67.33 ft (length) by 68.25 ft (width) that satisfies all of the relevant specifications was considered.ETABS 2018 was used to analyze and designthe structure. The floor plan and its different ETABS modelsof a six-story RC structure are shown in Figures3-8.

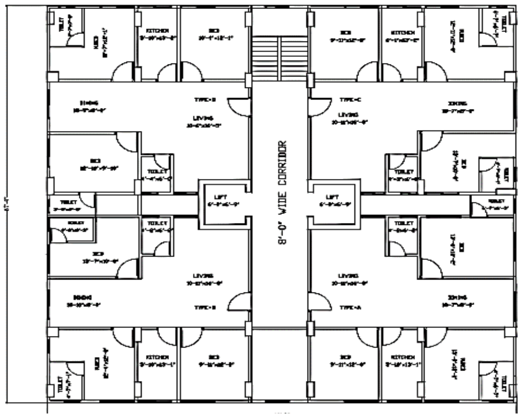

Figure 3: Plan view of six-story building

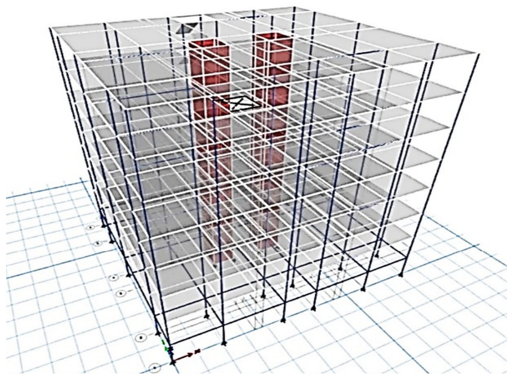

Figure 4: 3D view of six-story building

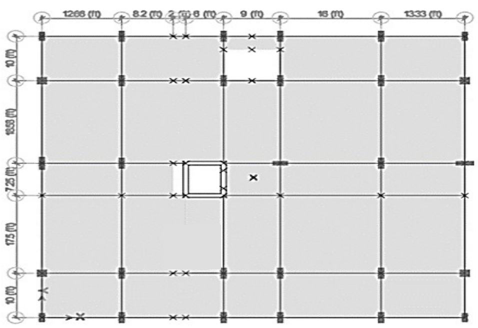

Figure 5: Model with no opening

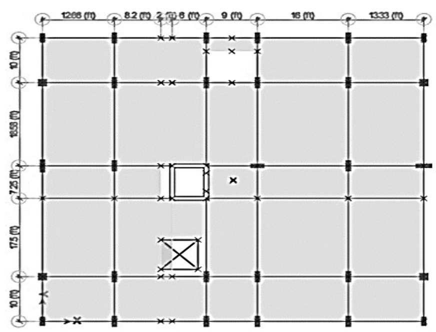

Figure 6: Model with a slab opening of 6.56 ft × 6.56 ft

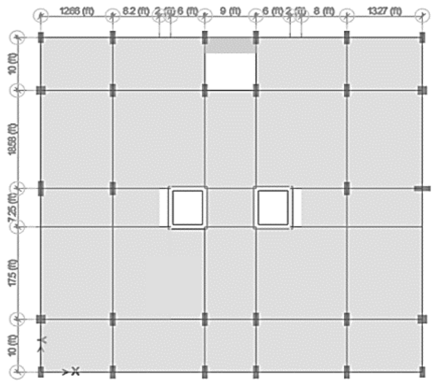

Figure7: Model with an opening for a new lift of size 8 ft by 7.25 ft

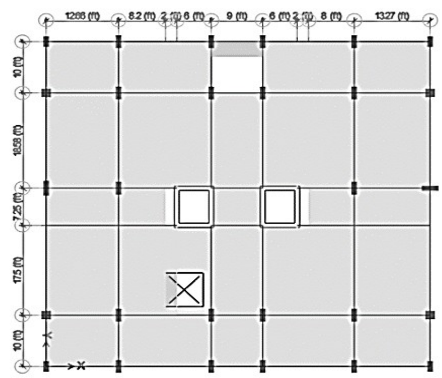

Figure 8: Model with an opening and a new lift shaft

3. RESULT AND DISCUSSION

3.1 AxialLoads and Bending Moments in Columns:

The analytical results for the following columns: C18, C19, C29 & C30 are presented because the following columns are nearer to the openings and havea significant effect on them while creating openings. The comparison of axial load and moment in columns, before and after creating a space in the existing slab is investigated.Fig. 9 to Fig. 12 shows the graphical variation of axial loads in different stories of columns 18, 19, 29, and 30 before and after creating openings.

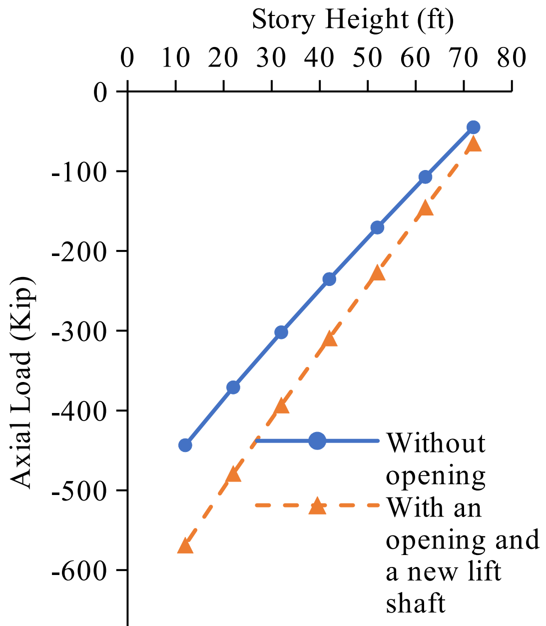

Figure 9: Variation in Axial Load of Column 18

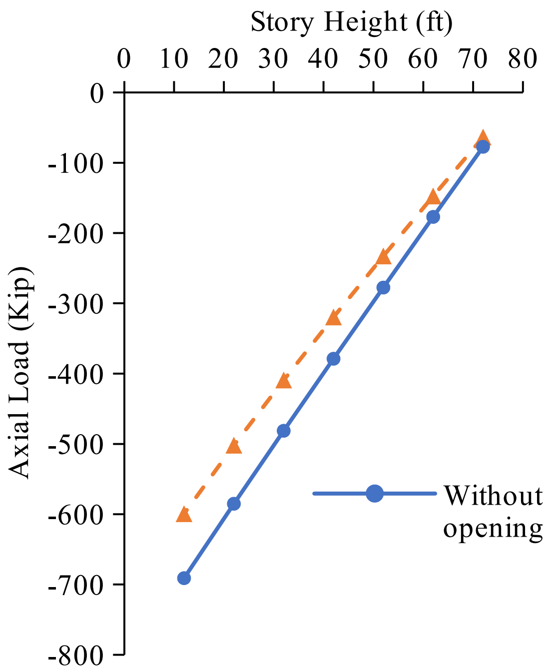

Figure 10: Variation in Axial Loadof Column 19

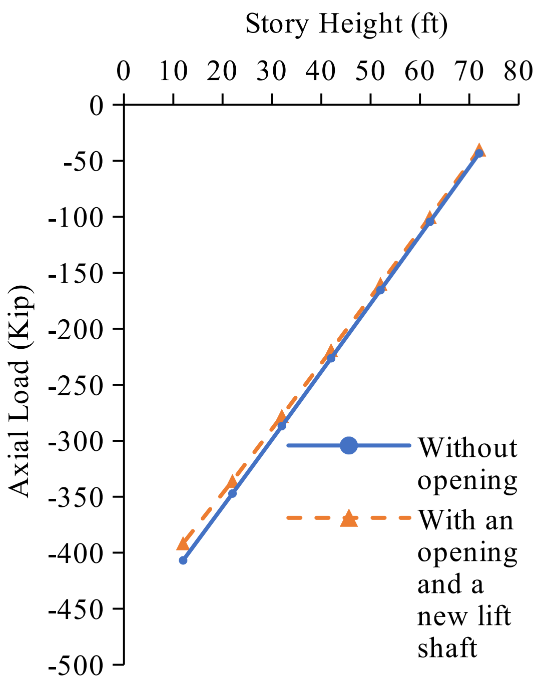

Figure 4: Variation in Axial Load of Column 29

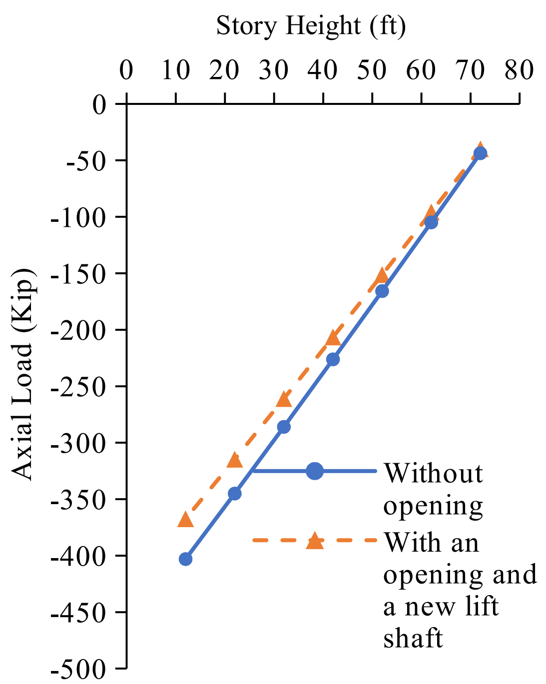

Figure 12: Variation in Axial Load of Column 30

Fig.9indicates that the negative axial force of column 18 should be noted that the column 18 is not in the area of opening.From Fig.10, it can be seen that by creating an opening in the existing slab the negative axial force in column 19 decreases.Column 19 is nearer to the area of the opening. Fig.11 shows that the negative axial force of column 29 slightly decreases with the creation of an opening in an existing slab. Column 29 is also in the location of the opening. Column 30**,** which is also in the location of the opening,has a decreased negative axial load with the creation of the opening (Ref: Fig 12).

Therefore, it can be seen that the negative axial force of columns nearer to the opening decreases whereas as columns far from the opening the negative axial force increases in the column after the opening is done.When the aperture has been produced, there is a redistribution of axial forces as a result of the change in load directions. As the load moves to the parts of the slab around the opening, the axial forces typically decrease down in the region around the hole. This happens because the opening is a stress-gathering point that moves a portion of the load out of the area.Fig 13 to Fig 16 shows the variation in the bending moment of columns: C18, C19, C29, and C30 at different stories when openings are done.

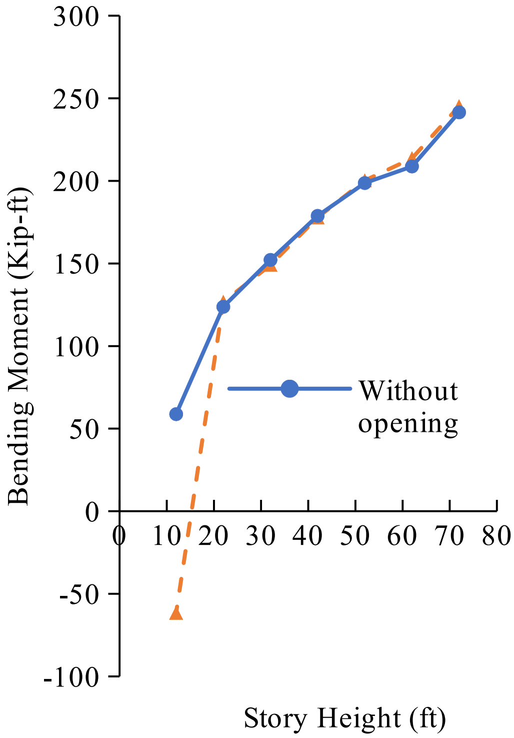

Figure 13: Variation in Bending Moment of Column 18

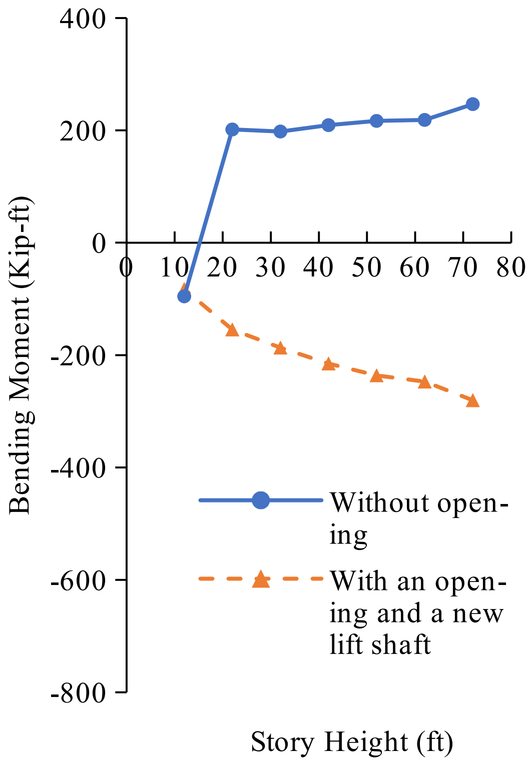

Figure 14: Variation in Bending Moment of Column 19

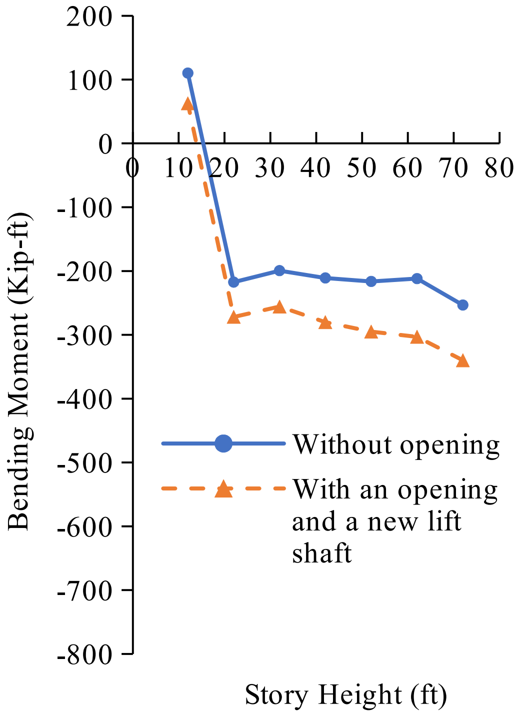

Figure 15: Variation in Bending Moment of Column 29

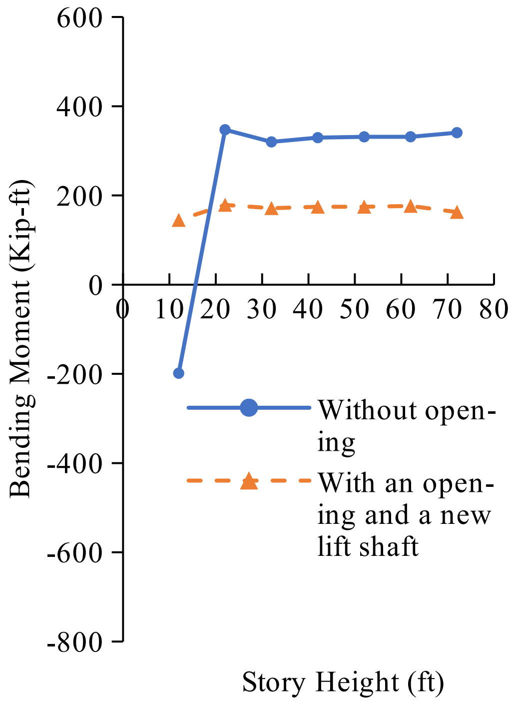

Figure 16: Variation in Bending Moment of Column 30

3.2 Shear Force and Bending Moment of Beams:

Fig.17 and Fig.18 show the shear force diagram (SFD) of beams of story 6 with and without openings.

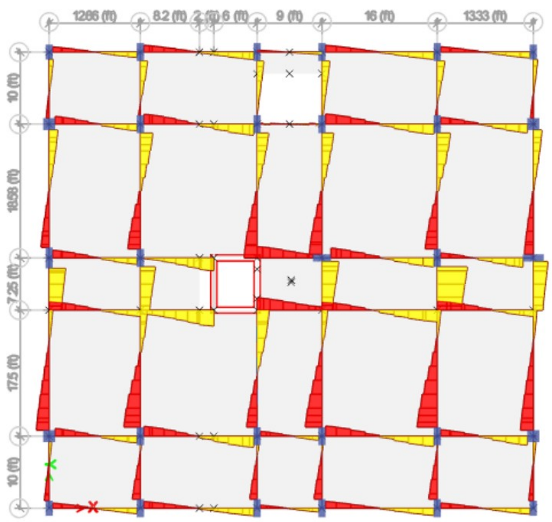

Figure 17: SFD of beams without opening

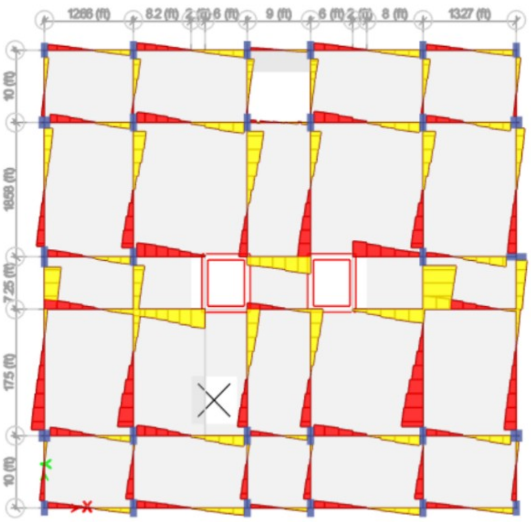

Figure 18: SFD of beams with openings

Fig.19 and Fig.20 show the bending moment diagram (BMD) of the beams of story 6. It can be seen that there are moment distribution irregularities in the AB beam that is close to the openings. There is a 2.05% increase in the bending moment for cutting a hole in the existing slab. The increase is almost negligible but care must be taken into account for safety purposes.

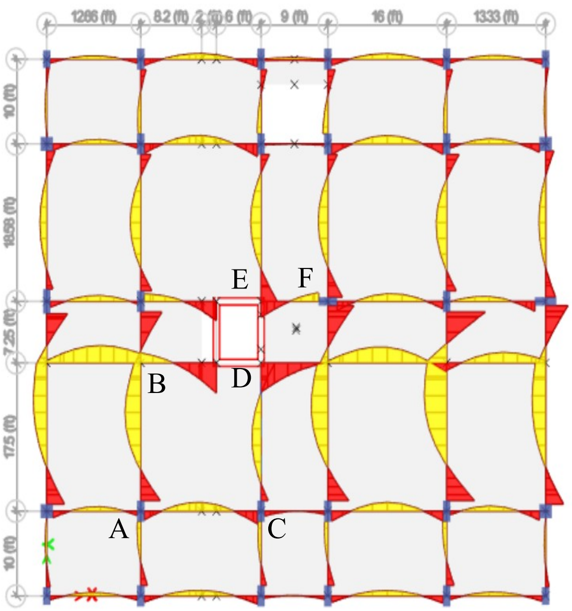

Figure 19: BMD of beams without opening

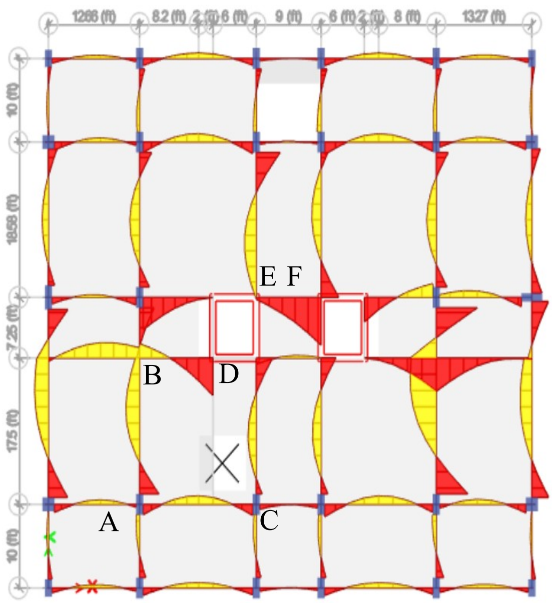

Figure 20: BMD of Beams with opening

From Fig.19 and Fig.20, it can be seen that the bending moment increases by 21.40%. for the creation of a new opening in the existing building.Fig.19 and 20also show the moment differences in the EF beam which is connecting two lift shafts after creating an opening in the existing slab for the new lift shaft. There is a 204.98% increase at the bending moment, which is alarmingly high. Thisincrease in bending moment is because of creating an opening in the existing building floor and an extra lift shaft. Therefore, extra care must be taken in the EF beam before creating openings.

Before creating the opening, the slab distributes loads uniformly throughout its surface. This homogeneous moment distribution allows the slab to easily transfer loads to supporting beams. However, openings weaken slab structural stability. Removing the part that makes up the slab becomes weaker (bending and shear resistance). Thus, moments near the entrance change significantly.

Opening a slab redistributes moments. Due to load concentration, moments are higher around the opening and lower away from it which can be seen from the analysis. This redistribution can cause localized stress and structural failure.

3.3 Remedial Measures:

After a careful analysis of the moment difference before and after creating an opening in a slab, it has been established that openings have a significant impact on the structural behavior of the slab. This impact can be seen in force distribution and load capacity. To mitigate the negative consequences of moment variation, it is recommended to place steel bars or beams around the opening. This solution restores structural integrity and load-carrying capacity. In addition, proper load transmission systems, opening sizing, and positioning are necessary to minimize moment differences and ensure surface stability.

4. CONCLUSION

The development of a large opening in an already existing slab has the potential to have a considerable impact on the distribution of axial forces and bending moments inside the structural elements such as columns, beams,and slab as found in the study. The finding of the study is summarized below:

- The compressiveaxial load of columns: C19, C29,and C30 decreases after creating the openings.
- In C18 columns the compressiveaxial load increases after creating the openings.
- Significant variation in bending moment of the columns after creating the opening.
- The bending moment of the CD beam increases by 21.40%. for the creation of a new opening in the existing building.
- A 204.98% increase in the bending momentafter creating an opening in the existing slab for the new lift shaft of the EF beam which connects two lift shafts.

The findings indicate that the structure can maintain stability following the creation of an opening, provided that an appropriate strengthening technique is implemented.

REFERENCES

M. A. Mansur, K.-H. T. (n.d.). Concrete Beams with Openings: Analysis and Design - M. A. Mansur, Kiang-Hwee Tan - Google Books. Retrieved October 17, 2023, from https://books.google.com.bd/books?hl=en&lr=&id=cDBk0MS4SrUC&oi=fnd&pg=PP15&dq=According+to+their+dimensions,+the+openings+can+be+classified+as+either+round,+rectangular,+or+square.+Size,+placement,+function,+and+moment+distribution+are+only+a+few+of+how+these+openings+vary&ots=2DCrvTwKne&sig=H_DG1l30i5lYz1hGF3EthPWC1kg&redir_esc=y#v=onepage&q&f=false

Aminitabar, M., Kanaani, O., & Eskenati, A. R. (2021). Numerical Evaluation of the Opening Effects on the Reinforced Concrete Slab Structural Performance. Shock and Vibration, 2021, 1–16. https://doi.org/10.1155/2021/1060841

Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary - ACI Committee 318, American Concrete Institute - Google Books. (n.d.). Retrieved October 17, 2023, from https://books.google.com.bd/books?hl=en&lr=&id=c6yQszMV2-

EC&oi=fnd&pg=PT10&dq=ACI+318+&ots=nYUrNTYENL&sig=9aISg7c262z5hG7gofAsVId0O6g&redir_esc=y#v=onepage&q=ACI%20318&f=false

Concrete Beams with Openings: Analysis and Design - M. A. Mansur, Kiang-Hwee Tan - Google Books. (n.d.). Retrieved October 16, 2023, from https://books.google.com.bd/books?hl=en&lr=&id=cDBk0MS4SrUC&oi=fnd&pg=PP15&dq=According+to+their+dimensions,+the+openings+can+be+classified+as+either+round,+rectangular,+or+square.+Size,+placement,+function,+and+moment+distribution+are+only+a+few+of+how+these+openings+vary&ots=2DCrvTwKne&sig=H_DG1l30i5lYz1hGF3EthPWC1kg&redir_esc=y#v=onepage&q&f=false

Hollaway, L. (Leonard), & Leeming, M. B. (Michael B.). (1999). Strengthening of reinforced concrete structures : using externally-bonded FRP composites in structural and civil engineering. 327. https://books.google.com/books/about/Strengthening_of_Reinforced_Concrete_Str.html?id=BLCjAgAAQBAJ

Khajehdehi, R., & Panahshahi, N. (2016). Effect of openings on in-plane structural behavior of reinforced concrete floor slabs. Journal of Building Engineering, 7, 1–11. https://doi.org/10.1016/J.JOBE.2016.04.011

Mansur, M. A. (2006). DESIGN OF REINFORCED CONCRETE BEAMS WITH WEB OPENINGS. 5–6.

Mota, M. (n.d.). Floor Openings in Two-Way Slabs.

Prentzas, E.G. (1968). Behaviour and reinforcement... - Google Scholar. (n.d.). Retrieved October 16, 2023, from https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=Prentzas%2C+E.G.+%281968%29.+Behaviour+and+reinforcement+of+concrete+beams+with+large+rectangular++apertures.+Ph.D.+Thesis%2C+University+of+Sheffield%2C+U.K.%2C+Sept.%2C+230+p.&btnG=

Somes, N. F., & Corley, W. G. (1974). Circular Openings in Webs of Continuous Beams. Special Publication, 42, 359–398. https://doi.org/10.14359/17293

Yaseen, A. N., Hussein, A., Al, A., & Al-Ahmed, A. (2022). Behaviour of One-Way Reinforcement Concrete Cantilever Slabs with Openings. IOP Conference Series: Earth and Environmental Science, 961(1), 012043. https://doi.org/10.1088/1755-1315/961/1/012043

Yılmaz, T., Anil, Ö., & Tuğrul Erdem, R. (2022). Experimental and numerical investigation of impact behavior of RC slab with different opening size and layout. Structures, 35, 818–832. https://doi.org/10.1016/J.ISTRUC.2021.11.057