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A STUDY ON STRUCTURAL RISK ASSESSMENT AND REHABILITATION OF AN EXISTING RCC INDUSTRIAL BUILDING IN BANGLADESH

Kamal Hosen*[1], Abdullah All Noman[2] and Md. Abul Kalam Azad[3]

[1]*Postgraduate Student, Department of Civil Engineering, Southeast University, Nanjing, China*
kamalcivilsub@gmail.com
[2]*Lecturer, Department of Civil Engineering, European University of Bangladesh, Dhaka, Bangladesh*
allnoman1994@gmail.com
[3]*Professor, Department of Civil Engineering, European University of Bangladesh, Dhaka, Bangladesh*
azad58@eub.edu.bd

***Corresponding Author**

ABSTRACT

In the time of recent years, probabilistic structural risk analysis tools were used to evaluate the performance of proposed and existing building structural systems. Many existing structures do not fulfil requirements of currently valid standards, they need to assess properly and the building need not be deteriorated or demolished. The retrofit is intended to mitigate the effect of a future structural disaster. This study performed a structural risk assessment on an existing six-story reinforced concrete industrial building built in 2010 to gain information regarding the building's current condition against operational and standard load. As built survey was done to prepare as built architectural and as built structural drawing. In addition, core test was conducted to obtain the concrete strength, ferro scan was done to know reinforcement detailing and rebar test has been conducted to know the tensile strength test of reinforcements. A preliminary assessment was performed for the members of the structure to examine any damage in the existing structure. Visual observation was carried out by sketches, photos, and video recording of any concrete deterioration during the survey. In general, there was no excessive damage in the structure members. Dead load and live load were carried out and lateral load was calculated according to zone and BNBC-2006 code. The structural analysis is performed based on actual material strength data and as built drawing. It shows that the structural capacity is lower than the actual operational load. Adequacy checking was done for existing foundation and Serviceability was evaluated. Based on these structural analysis report, a detailed scheme of column retrofitting is proposed to meet structure requirements. Concrete column jacketing was done to strengthening of existing inadequate column.

Keywords: *Readymade garment, lateral load, RCC column strengthening technique, concrete jacketing, drift and deflection*

1. INTRODUCTION

Within the ultimate twenty years of urbanization in Dhaka, fast development while not legitimate arrangement has been a serious concern. Most buildings were erected without the oversight of a proper earthquake disaster prevention system (Ahmed et al., 2010). Wind and earthquake loadings are the two major types of lateral dynamic excitations experienced by RCC buildings (Shilpa et al., 2017). In recent years, business owners' empowerment certificate of building structure should be hooked up once they need to increase business permits. Without workplace safety compliance, it is almost impossible to ensure business sustainability and thus to survive in global competitive market (Rajon, 2014). Many RCC factory buildings or facilities that are over twenty years recent in unstable regions are lean supported current seismic codes. Some studies have concentrated on the structural assessment of existing RMG factory buildings (Ansary and Barua, 2015; Hodgson et al., 2016). The quantity of major earthquakes in Bangladesh has shown that mitigation to scale back seismic risk is essential (Fahad et al., 2021). In order to, decrease this risk, structural risk assessment and the seismic retrofitting of the structure is one amongst the foremost effective techniques. In buildings, columns are the important structural members that transfer the load of the higher floors to the ground or foundations. In general, columns will sustain two main varieties of loads, the axial–flexural load and therefore the lateral shear load. Columns have a high axial load capability compared to their lateral load capacity. Buildings and columns are designed to face up to internal and lateral loads appreciate an earthquake. In some cases, wherever buildings are designed as per the previous unstable requirements, columns are additional vulnerable and weak. Underneath lateral loads, weak columns can exhibit severe damages or collapse and fail drastically (Julio et al., 2005). In alternative cases, columns are deteriorated thanks to environmental effects, aging of concrete, or adding new floors. All told cases, weak or broken columns need structural intervention to retrofit and strengthen the affected columns. Reinforced Cement Concrete is a versatile construction material that is strong in compression as well as tension. The use of reinforcement in concrete not only increases its strength but also helps in preventing temperature and shrinkage stresses. At some stages RCC structure become weak for design fault, construction fault or with ages of the structure become inadequate for natural hazard like as earthquake effect, wind load effect, cyclones etc. Researcher Tanaya and Sutapa conducted research on seismic vulnerability assessment for RCC structure (Tanaya and sutapa, 2017). Recently, a new decision support system was proposed to find the most optimized solution in terms of the trade-off between improved quality and investing cost for existing buildings renovation (Bianca-Elena et al., 2020). Researcher Praveen Anand and Ajay Kumar Sinha conducted research on Effect of Reinforced Concrete Jacketing on Axial Load Capacity of Reinforced Concrete Column (Praveen and Ajay, 2020). To conduct this study several visual investigations was done for settlement, foundation design check and settlement calculation were done to assess the foundation stability and settlement (Baraja, 2015). Detailed Engineering Assessment, Structural analysis and modification was done for vulnerability considering earthquake load and wind load effect as per BNBC-2006, NTPA and ACCORD standard. Existing structure was analysed to evaluate the stability of existing structural members. Existing structural analysis was done considering ACCORD and NTPA load combination and modified structural analysis was done according to BNBC load combination (BNBC-2006). Developed deflection and floor drift was checked against lateral load to evaluate the serviceability. Found inadequate members have retrofitted and concrete column jacketing was done. In this study column sizes were increased and new re-bars were inserted. The common practices consist of increasing the roughness of the interface surface and applying a bonding agent, normally an epoxy resin. Steel connectors are also occasionally applied. After completion of all remedial works ACCORD was inspected this RMG industrial building and gave approval that this building is structurally safe.

2. METHODOLOGY

In this study Automation Knitwear Ltd. located at BSCIC industrial estate, Narayanganj, Bangladesh, A six storied MRF RCC industrial building was used. A preliminary assessment was done to evaluate the condition of the existing buildings, and then different recommendations were made based on the evaluation result. Several visual inspections were done for collecting the detailed as built data of this building both architectural and structural. As built data was collected for all kind of structural members, vertical and lateral load carrying members, machineries load, dead load & live load producing equipment. Foundation was excavated to confirm the foundation type. In structural system it was found that the structural system is Moment Resisting Frame (MRF), Foundation system was pile and pile cap foundation system. RCC column, beam and slab is the main load carrying member, there was no shear wall or any others structural members to resist lateral load. Design analysis software CSI ETABS 2016 v16.2.2 was used for adequacy check of structural members.

2.1 Building Information

The frame type of this structure was moment resisting frame system. This structure is a mixed of RCC beam slab and flat plate slab system in different floor. The details of this industrial steel structure are given as follows: Height of the building= 66.5 ft, Length of the building = 76.5 ft, Width of the building= 42 ft, The Ground Floor accommodates the main entrance area, iron section and finishing section. First floor is finishing, drying, storage & official arrangement. Second Floor level accommodate general office, light operation. Other Floors level accommodating very light manufacturing, sewing section, finishing section, prayer hall, dining and water tanks on the roof. Pile foundation having pile length 75 ft and Pile cap level found at 6 ft below the plinth level. The Ground Floor Slab comprises a 6-inch thick in-situ reinforced concrete slab, spanning over ground beams. The first-floor structure was two-way spanning slabs, slabs of other floors is flat plate slab with 8-inch thickness. In the first floor, slab is connected with beam and beams are rigidly connected to columns. In other floors flat plate slabs are directly connected to columns. Figure 1 shows the existing front view of this industrial building, while figure 2 shows the floor plan of this structure. Figure 3 shows the main load carrying members in the first floor and figures 4 shows the main load carrying member in other floors.

2.2 Carried Out Existing Live Load and Dead Load

All floors, working sections, machines, water tank, toilet built up area, furniture, interior partition wall, exterior wall, ware house, fabrics section, storage and others work place of this building were checked and calculated the live load and dead load by taking consideration of these aspects. Dead load was taken as per calculation, 42 psf live load was used in normal working floor, while 30 psf and 84 psf were used in roof and stair zone, respectively for analysis (ACCORD-2013 and NTPA-2013, Guidelines for detailed engineering assessments).

Figure. 1: Photo of Existing Building

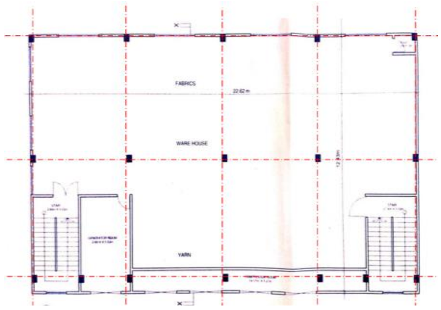


Figure. 2: Plan view of a 6 stroied RCC Building

Figure 3: Main Load carrying member in 1st floor

Figure 4: Main Load carrying member in other floors

2.3 Materials Test

Drilled concrete core was collected and Core test was conducted (BRTC, BUET) to assess the strength of the concrete, re-bar test performed (BRTC, BUET) to assess the strength of reinforcement. In addition, Ferro scan was conducted to check the provided reinforcement of RCC members. ACI-562 method was used to evaluate the concrete strength which was found 1913 psi. 60000 psi was used as rebar tensile strength.

2.4 Foundation and Soil Investigation

Soil test report was collected from the industry authority. The soil test report reveals, the structure was built on brown med. dense fine sand in zone 2 (moderate seismic zone) of Bangladesh seismic map. Foundation type, size and thickness was confirmed by existing foundation documents and verbal statement of the building owner. Foundation system is pile and pile cap foundation. Pile diameter is 20 inch with length of 75 ft. Pile cap level foundation is found at 6 ft below from the plinth level. equation 1 and equation 2 which were given by researcher Wayne C. Teng (1988)
Load combination for punching and flexure check: 1.4 DL + 1.7 LL
Load combination for pile diameter, length and total number of pile: DL + LL
Pile capacity check: Q_{ult}: $\pi R2 \ (1.3cNc + {}_{\Upsilon}DNq + 0.6_{\Upsilon}RN_{\Upsilon}$ ……………………………………..(1)
Pile cap check: $Q_m = Q/n \pm M_y x / \sum(x^2) \pm M_x y / \sum(y^2)$……………………………………………(2)
Pile capacity: 791 kn, Factor of Safety: 2.5

2.5 Structural Analysis

After as built structural and materials data collection a number of analyses were used to assess the response of the foundation for the Structure. The main design model was developed using a Finite Element (FE) program ETABS. Soil is considered as continuum medium. While modelling, base support was considered as fixed. Applied as a body load to the structure foundation elements, in a direction to coincide with the appropriate wind action assumed. Floor slab was considered semi-rigid diaphragm and modelled as shell elements. Stiffness is modified. Membrane stiffness was used full scale, while bending stiffness almost ignored. Finite element structural model was done considering actual as built condition. Figure 5 shows the three-dimensional finite element model of this structure. Demand capacity ratio of steel members was collected from design software ETABS.

The Existing structural system of this building was modelled using ETABS Software considering dead load, live load, wind load and earth quake load according to BNBC-2006 and NTPA load combination.

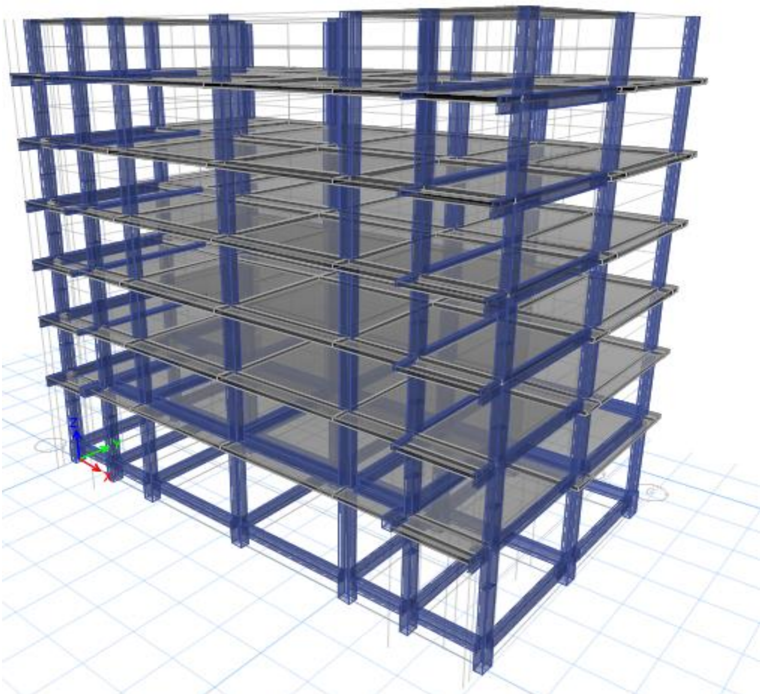


Figure 5: 3D Finite Element Model of the 6 stroied RCC Industrial Building

Table 1: Data and Equation of wind load and seismic load

Equation used for wind load calculation	**Equation used for Earthquake load calculation**
Wind Pressure, $P = C_g C_p q$ Sustainable wind pressure, $qz = C_c C_I C_z V_b^2$ Basic wind Speed V_b (Kmph)= 210 C_c= velocity-to-pressure conversion coefficient = 47.2x10-6 C_g = gust coefficient C_p = pressure coefficient C_I = structure importance coefficient = 1 C_z = combined height and exposure coefficient.	Base Shear, V= (ZIC/R)W total load from ETABS, W= 70660 KN seismic zone coefficient, Z = 0.15 structural importance coefficient, I = 1 response modification factor, R = 6 soil characteristic coefficient, S = 1.5 Ct = 0.083 fundamental period of vibration, T = 0.23184827 sec numerical coefficients, C = 4.96819575 sec C = 2.75 sec

3. RESULT AND DISCUSSIONS

Performed finite element analysis in ETABS, it was found that several RCC columns of the existing structure were inadequate. All existing pile and pile cap were found safe. It was found that the existing structure gave excessive value of deflection. Destabilizing forces are likely to arise from lateral wind & seismic loading and under gravity loading due to lack of verticality in the structural frame. After design check it was observed that capacity of beam slabs and flat plate slabs are very good. All beams found safe. But the capacity of interior columns under wind loading as per BNBC-2006, ACOORD as well as NTPA is not satisfactory. From serviceability consideration structure did not comply with the serviceability requirement. Displacement is not within the allowable limit while drift of existing structure was not within the allowable limit. After modification of existing building, it was found that all structural members were safe, deflection and lateral drift were in satisfactory.

3.1 Foundation Adequacy

The adequacy of pile, size of pile cap, area of pile cap, reinforcements of pile cap and punching shear were checked. Axial force and shear force were in consideration to check the adequacy of foundation. All pile and pile cap were found adequate under code of BNBC-2006. Over all stability is safe. Predicted settlement was also within the allowable limit. Table 2 shows the adequacy checking of existing foundation system.

Table 2: Adequacy check of pile & pile cap foundation

Grid id	**Pile Nos**	**Maximum Axial load from each column (KN)**	**Capacity of each pile (KN)**	**Maximum reinforcements required for pile cap (mm^2)**	**Provided reinforcements for pile cap (mm^2)**	**Remarks**
01-a, b, c, d, e, f & g	2,2,3,3,3,3,2&2	1383	791	2298	2613	Safe
02-a, c, d, e, & g	3,4,4,4&2	2222	791	2298	2613	Safe
03-a, c, d, e, & g	2,3,3,3&2	1433	791	2298	2613	Safe

3.2 Demand capacity ratio

Given demand capacity ratio (p-m-m) in table 3 shows adequacy check of all RCC column. All of these analysis data were collected from structural analysis and design software application ETABS.

Structural members which has p-m-m ratio more than 1 is considered as inadequate. Figure 6 shows the demand capacity ratio of columns and figure 7 shows the column interaction diagram for axial and bending moment. Table 3 reveals the evaluation of column capacity.

Table 3: Adequacy check of RCC column

Demand capacity ratio of steel column			Remarks
Grid id	**Members name**	**P-M-M Ratio**	Red marked values which contain greater than 1 considered as Unsafe column
01-a, b, c, d & e	Column (Sizes 12"X20" & 20" X20")	1.11, 1.40, 0.84, 0.99, 0.84, 1.19, 1.12	marked values which contain greater than 1 considered as Unsafe column
02-a, b, c, d & e	Column (Sizes 16"X20" & 20" X20")	1.34, 0.99, 0.92, 1.04, 1.39	marked values which contain greater than 1 considered as Unsafe column
03-a, b, c, d & e	Column (Sizes 16"X20" & 20" X20")	1.08, 1.05, 1.03, 1.10	marked values which contain greater than 1 considered as Unsafe column

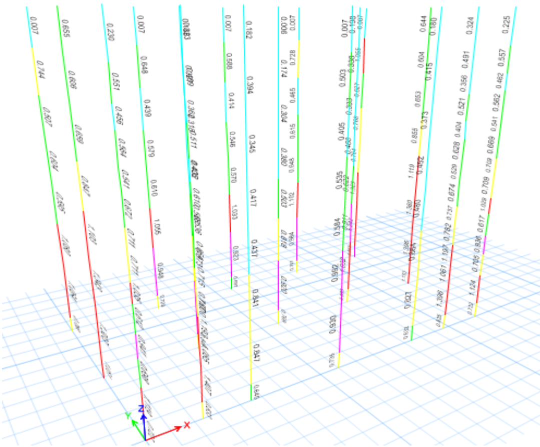


Figure. 6: Demand capacity ratio of column

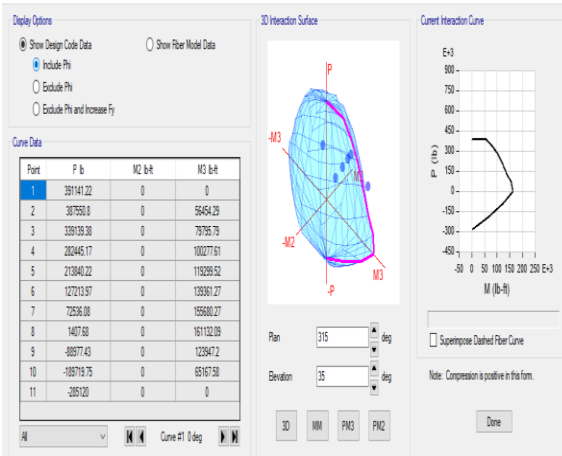


Figure. 7: Column interaction diagram

3.3 Serviceability check

From ETABS the values of deflection given by the structure was collected. From the deflection checked it was found that the structure is failed in deflection. Floor Drift of this existing structure within the allowable limit. Maximum displacement in Y direction against wind load while Maximum displacement in X direction against seismic load. Figure 8 and 9 show the maximum displacement against wind load and maximum drift against earthquake load respectively. Table 4 indicates the evaluation of serviceability (BNBC- 2006, table 6.6.4 and chapter 1.5.6).

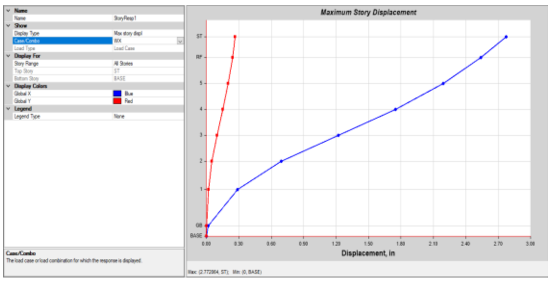


Figure 8: Maximum displacement

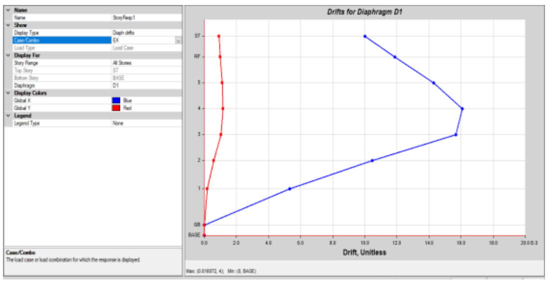


Figure 9: Maximum drift

Table 4: Serviceability checking of existing structure.

Evaluation of story displacements					**Evaluation of story drift**				
Direction	Load	Developed story displacement (inch)	Allowable story displacement (inch)	Remarks	Direction	Load	Developed story dirft	Allowable story drift	Remarks
Y	Wind Load	4.55	1.995	Unsafe	X	Seismic	0.016	3.19	Safe

3.4 Retrofitting of Existing Building

Model of retrofitting industrial building was done by modification of existing model considering BNBC-2006 load combination for RCC structure. Earthquake load also revised after retrofitting. After retrofitting analysis all structural members were found adequate against all kind of lateral load and gravity load. Table 5 shows the demand capacity ratio, ratio of all columns found under 1.00. Figure 10 shows the demand capacity ratio of columns and column interaction diagram for axial and bending moment after concrete jacketing of existing column. Table 5 reveals the evaluation of column capacity.

Table 5: Adequacy check of RCC column after retrofitting

Demand capacity ratio of steel column			**Remarks**
Grid id	Members name	P-M-M Ratio	Red marked values which contain greater than 1 considered as unsafe column
01-a, b, c, d & e	Column (Sizes 28”X20” & 20” X20”)	0.59, 0.79, 0.64, 0.79, 0.54, 0.87, 0.72	marked values which contain greater than 1 considered as unsafe column
02-a, b, c, d & e	Column (Sizes 28”X22” & 20” X20”)	0.64, 0.54, 0.54, 0.67, 0.77	marked values which contain greater than 1 considered as unsafe column
03-a, b, c, d & e	Column (Sizes 28”X20” & 20” X20”)	0.76, 0.88, 0.57, 0.65	marked values which contain greater than 1 considered as unsafe column

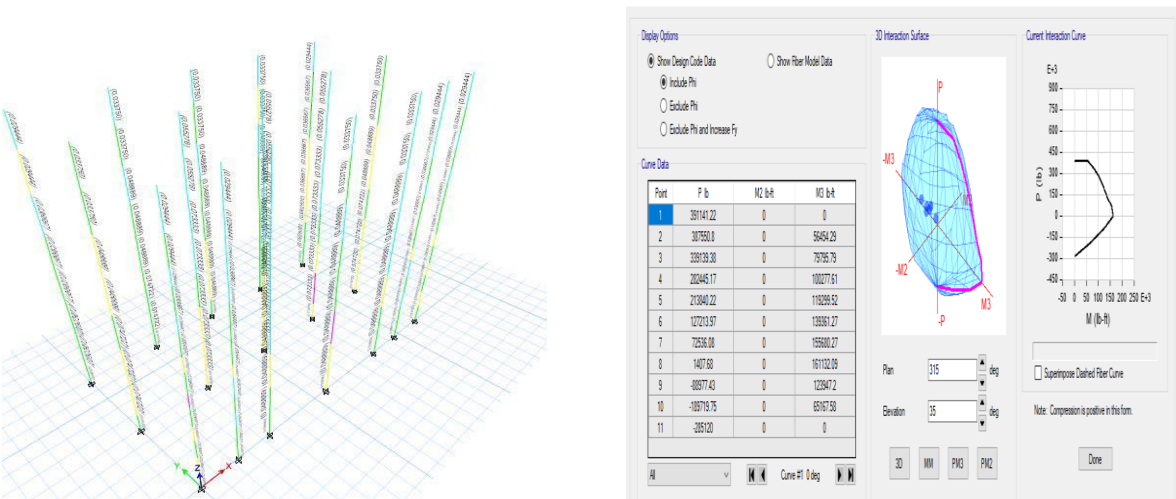


Figure. 10: Demand capacity ratio of column and interaction diagram after retrofitting

3.5 Serviceability check

From ETABS the values of deflection given by the structure was collected. From the deflection checked it was found that the structure is safe in deflection after retrofitting. Floor Drift of this modified structure within the allowable limit. Maximum displacement in Y direction against wind load while Maximum displacement in X direction against seismic load. Figure 11 and 12 show the maximum displacement against wind load and maximum drift against eartquake load respectively. Table 6 indicates the evalutaion of serviceability (BNBC- 2006, table 6.6.4 and chapter 1.5.6).

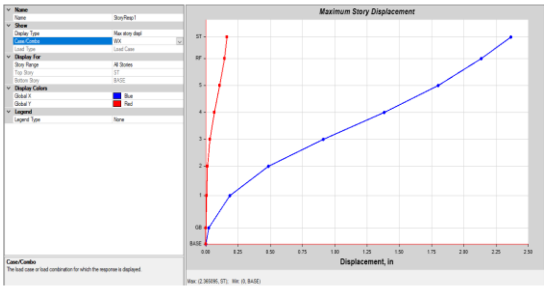


Figure 11: Maximum displacement

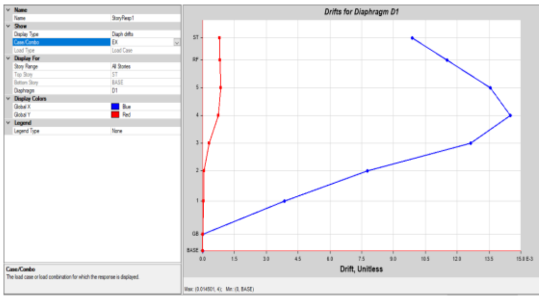


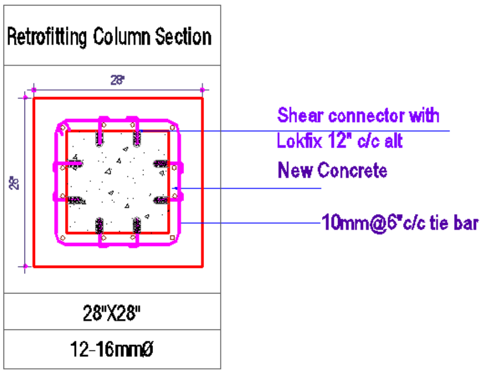
Figure 12: Maximum drift

Table 6: Serviceability checking of modified retrofit structure.

Evaluation of story displacements					**Evaluation of story drift**				
Direction	Load	Developed story displacement (inch)	Allowable story displacement (inch)	Remarks	Direction	Load	Developed story dirft	Allowable story drift	Remarks
Y	Wind Load	0.89	1.995	Safe	X	Seismic	0.014	3.19	Safe

3.6 Retrofitting Structural Drawing and Concrete Jacketing Procedure Check

After analysis of retrofitting structural model all structural members were found adequate against all types of lateral loads and gravity loads then retrofitting structural drawing was done according to retrofitting model for retrofitting construction of the existing building. Retrofitting construction was performed according to retrofitting structural design and drawing. Removed the RCC concrete cover of the column and expose all the longitudinal bars. Installed new rebars on all faces of Column using appropriate epoxy Grout. Provided sufficient anchoring of new concrete with the old concrete. Inserted new rebars on the corners of the column and connect with existing bars by welded Bent Bars. New bars should be provided in the corners to avoid puncturing the beams. For jacketing, concrete strength should be more than existing column concrete strength, or at least equal to it. Figure 13 shows the drawing of retrofitting column section while figure 14 reveals the rebar arrangements of beam column joint area. The rehabilitation of existing building was done for this study that will not make any hamper of working environment and space. Figure 15 shows the working procedure during column jacketing and figure 16 shows the photos after completion of retrofitting work.



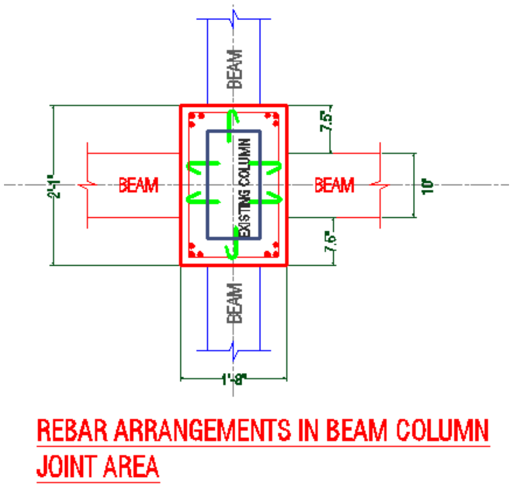


Figure 13: Drawing of Column Jacketing

Figure 14: Beam column joint area.

Figure 15: Photos of RCC column jacketing construction.

Figure 16: Photos of column after retrofitting.

4. CONCLUSIONS

Rehabilitation of a building means returning a building or a structure to a useful state by means of repair, modification, or alteration to create safer buildings for people to live and work. RC column strengthened by concrete jacketing have shown that this is a very easy and effective strengthening technique. In this regard, further studies should be encouraged to appropriate solutions considering the construction characteristics of Bangladesh and the availability of local building construction materials.

1. All of the beams, slabs and columns were checked for vulnerability due to all kind of gravity loads, dead loads, live loads and lateral loads. All beams and slabs found safe while some columns found over stressed and unsafe.
2. Story displacements was not within the allowable limit while story drift was within the allowable limit in existing condition. After modification of existing building story displacements found within the allowable limit.
3. After rehabilitation of existing building, all structural members were found safe against all kind of lateral load and vertical load according to BNBC-2006

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