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RETROFITTING DESIGN AND CONSTRUCTION OF MIXED TYPE STRUCTURE WITH RC FRAME AND MASONRY IN DHAKA, BANGLADESH

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Abstract

The model building considered for seismic assessment and retrofitting was utilizing as a fire service and civil defense station. The fire station building is a mixed type structure with RC frame and brick masonry. The building is located at Dhaka city. It was designed and constructed in 1963 without considering seismic load. Bangladesh National Building Code (BNBC) 1993 and also recent BNBC 2015 Final Draft don't cover the regulations of seismic assessment and retrofitting design of existing building. The fire station building has been retrofitted with the concept and practices of Japanese guideline and using seismic parameters of BNBC. Seismic evaluation, retrofitting design and construction steps have been introduced in this paper. This is the first project of seismic retrofitting of public building in Bangladesh. The total work has been done as part of the technical cooperation project namely CNCRP between Public Works Department (PWD) of Bangladesh and Japan International Cooperation Agency (JICA).

Before performing computation for seismic assessment and retrofitting design, as-built construction drawings were developed. Concrete core sampling and tests were performed. On-site direct shear test at joint of brick masonry wall was done. Seismic evaluation of existing building was performed and found inadequate. Strength oriented retrofitting design was prepared with the concept of column jacketing, brick wall laminating, RC shear wall, steel framed brace. Construction work with post-installed anchor and pressured grouting were maintained with engineering supervision at the site.

Keywords: Mixed type structure; seismic evaluation; retrofit design; brick wall lamination; steel framed brace

1. Introduction and background

Bangladesh is located near the boundary of Indian and Eurasian tectonic plates. Due to this geographical location and existence of many non-engineered building, Bangladesh is in the risk of potential danger of earthquake disaster resulting huge building collapse and human casualties. To overcome this vulnerable situation Government of Bangladesh entrusted some responsibilities to the Public Works Department (PWD). Since there is no guideline on seismic assessment and retrofitting design of existing structure in Bangladesh National Building Code (BNBC) [1], PWD requested to The Government of Japan for technical assistance in this arena. With the cooperation of JICA, PWD successfully completed a capacity development project namely 'Project for Capacity Development on Natural Disaster-Resistant Techniques of Construction and Retrofitting of Public Buildings in the People's Republic of Bangladesh (CNCRP)' from 2011 to 2015. As a part of this project, a pilot scheme was taken for retrofitting design and construction of a fire station building. The two storied building is a mixed type structure; partly frame structure and partly brick masonry structure. The focus of CNCRP project was on seismic assessment and retrofitting of frame structure. But this mixed type building was considered for retrofitting due to its importance and budget limitation for construction. The retrofitting construction work has been done in 2014 - 2015.

2. Brief description of the building

The two storied fire station building was constructed in 1963 without the consideration of seismic load. In this masonry building middle part is RC frame structure to facilitate parking at ground floor. The beam of middle part just rest on brick wall on both sides, but the single rigid diaphragm of RC slab covers whole floor area. At ground floor other than middle part two sides are used for official purpose and first floor is used as family quarter for officers on emergency duty. After use of more than 50 years the building was in poor condition including doors, windows and other finishing materials and the Department of Fire Service and Civil Defense welcome this remediation work.

3. Seismic evaluation of the structure

3.1 Evaluation method

Seismic evaluation and retrofitting design of fire station building was done in 2013. Since there is no method described in Bangladesh National Building Code (BNBC) for seismic evaluation of existing structure, Japanese 2nd level seismic evaluation method was followed with some modification for local seismicity and sub-soil characteristics. Some engineering judgment was also applied for brick masonry wall. It has to be noted that in 2015 three manuals on seismic vulnerability assessment [2], retrofitting design [3] and retrofitting construction have been published under CNCRP project.

3.2 Methodology for seismic evaluation

The standard for seismic evaluation and guidelines for seismic retrofitting design of existing reinforced concrete building was published in 2001 by The Japan Building Disaster Prevention Association. According to that standard seismic index of structure, I_s shall be calculated by following equation at each story and each principal direction of a building.

$$I_s = E_0 \,.\, S_D \,.\, T$$

Where: E_0 = Basic seismic index of structure ∞ C $\times$ F

C = Strength index, which is a ratio coefficient of lateral load carrying capacity divided by building weight

F = Ductility index, which is a function of ductility factor

S_D = Irregularity index and

T = Time index

The basic seismic index of structure E_0 is calculated at different stage of deflection of the structure and at each stage of deflection effective shear strength of individual vertical member is considered based on their ductility. E_0 of i-th story in a n-story building shall have to be modified by story shear modification factor, $(n+1)/(n+i)$.

The seismic demand index of the building is $I_{so} = 0.8 \times 2/3 \times Z \times I \times C$. To calculate the I_{so}, value, each parameter Z, I, C is taken from BNBC 2015 final draft. For judgment on seismic safety of structural component, seismic index of structure I_s is compared with seismic demand index of structure I_{so}. Seismic performance of the structure will be judged satisfactory if $I_s \geq I_{so}$. For ductile structure, a minimum strength is required in addition to this criterion. If the seismic performance is not satisfactory then retrofitting is required. An example of relationship between seismic demand and capacity of structure is shown in Fig. 1.

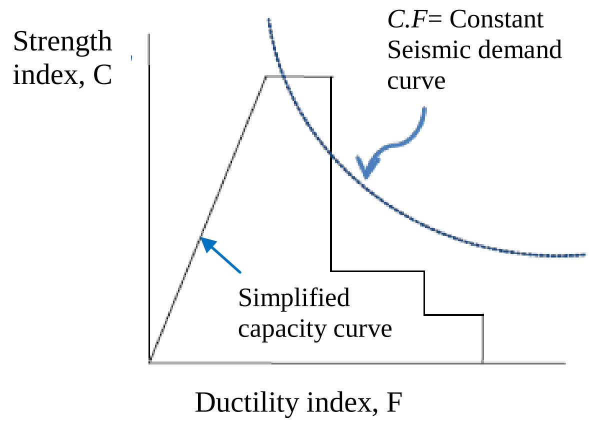

Fig. 1- Demand -capacity Relationship

3.3 Building data

Ground and first floor plan of existing building is shown in Fig. 2 to get an image of the structure. The stair blocks have been extended at roof. Following is the other details of the building.

i. Number of story: 2

ii. Floor area: Approximately 272 sqm in each floor

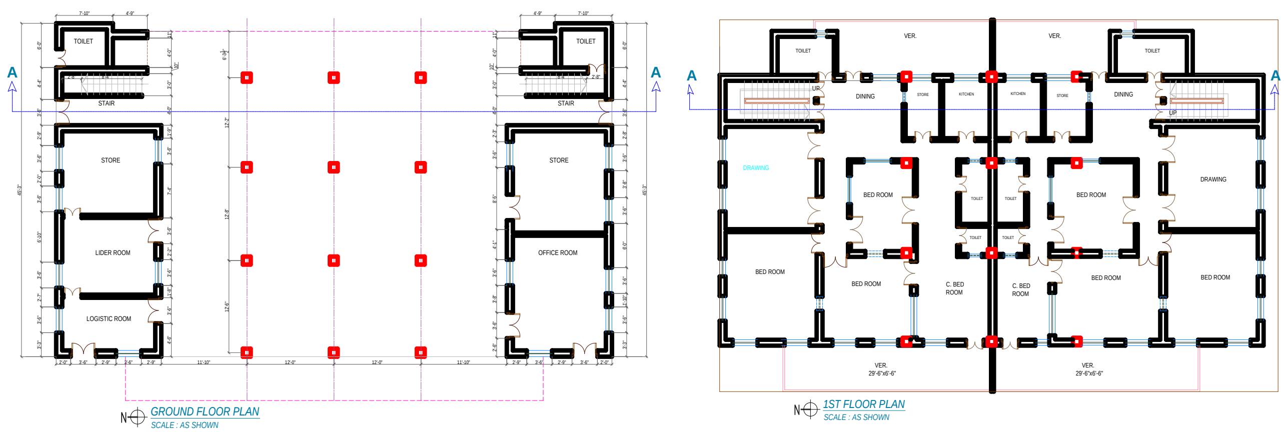

Fig. 2 – Ground and first floor plan of existing building

iii. Usage: Ground floor = Office cum car parking,
First floor = Residence, Stair portion continuous up to roof

iv. Occupancy type: IV (Since fire station building provide essential facilities at post disaster event)

v. Building height: Ground floor height = 3100 mm (Parking to beam bottom) + 400 mm beam
First floor height = 3000 mm

vi. Foundation level: Top of the footing 800 mm below parking level

vii. Structure type: Mixed type structure (Brick masonry + RC frame)

viii. Foundation type: Masonry part on continuous brick foundation and RC column on isolated footing

3.4 Properties of existing material

The building is very old and architectural or structural drawing of existing building was not available. As built architectural and structural drawings was prepared to use in seismic evaluation. Sub-soil investigation was also performed. Core sample was taken to get the concrete compressive strength. In situ shear strength of mortar joint of brick masonry wall has also been tested. Following is the summery of existing material.

Concrete strength = 7.8 N/mm^2, (average – standard dev./2) of test result of 3 core sample (size 50mm x 100mm)

Yield strength of reinforcing bar = 275 N/mm^2 plain bar have been assumed considering construction period

Shear strength of brick masonry = 0.2 N/mm^2 from in-situ direct shear test, E = 0.60x10^4 N/mm^2

Allowable bearing capacity of soil = 150 kN/m^2

3.5 Building weight

Unfactored unit weight and floor area is given in Table 1. Unit load of specific floor level is calculated considering 50% load from upper floor and 50% load from lower floor. Live load is considered as 1.45 kN/m2.

Table 1 – Unit load and floor area

	Brick Masonry Part		RC frame part	
	Unit weight	Floor area	Unit weight	Floor area
Staircase at roof	3.59 kN/m^2	17.8m^2		
Roof	10.27kN/m^2	102.8m^2	6.87 kN/m^2	168.8m^2
1st floor	12.47 kN/m^2	102.8m^2	7.21 kN/m^2	168.8m^2

Building weight at roof level, W = 2280 kN

Building weight at 1st floor level, W = 2502 kN

Total weight, ΣW = 4782 kN

3.6 Seismic index of the structure

3.6.1 Strength of existing column

Dimension and reinforcement details of existing column are shown in Fig. 3.

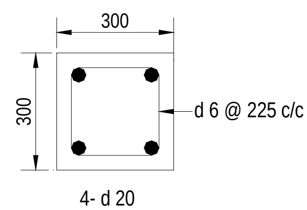

Fig. 3 – Existing column section

Axial force on inner column, N = 177.4 kN

Flexural strength of column = 61.3×10^6 N-mm

Shear force at flexural strength, Q_{mu} = 31.4 kN

Ultimate shear strength, Q_{su} = 49.3 kN [reduction factor (K_r = 0.68) for low strength concrete is used]

Since, $Q_{mu} < Q_{su}$, $\therefore$ Shear strength of each column = 31.4 kN

Total shear strength of columns at ground floor = 12 × 31.4 = 377 kN

3.6.2 Strength of existing brick wall

Following are the considerations for calculation of brick wall strength:

i) Brick walls with 250 mm thickness at window level are estimated for strength calculation.

ii) Brick walls located out side of projected line of RC frame portion are excluded.

iii) Brick walls length less than 400 mm are excluded due to flexural behavior.

X-direction total section area of brick wall is 4,925,000 mm^2.

So, shear strength of brick wall = 4,925,000 × 0.2/1000 = 985 kN.

3.6.3 Calculation of I_S at ground floor

Time index, T = 0.8 (For age > 30 years)

Irregularity index S = 0.9 (For soft ground floor)

Considering allowable deflection angle of brick masonry is 1/500.

Ductility index, F = 0.8 and effective strength factor of column, α = 0.5

Building weight at middle of the ground floor = 4782 kN

∴ Strength index,

$$C = \frac{Q}{\sum W} = \frac{\text{Strength of brick wall in X-direction} + \text{Strength of all column}}{\text{Building Weight}} = \frac{985 + 0.5 \times 377}{4782} = 0.245$$

$$\therefore I_s = \frac{n+1}{n+i} \times C \times F \times T \times S$$

$$= 1 \times 0.245 \times 0.8 \times 0.8 \times 0.9 = 0.14$$

3.7 Seismic demand index

Using building and subsoil characteristic according to 'BNBC 2015 Final Draft' seismic demand index, I_{so} for 2nd level screening is calculated as follows and this value have been applied for assessment and retrofitting design.

$$I_{SO} = 0.80 \times \frac{2}{3} \times Z \times I \times C_S$$

Where: Z = Zone co-efficient = 0.2

I = Importance factor = 1.5

C_S = Normalized response spectrum = 2.875

Therefore, $I_{SO} = 0.80 \times \frac{2}{3} \times 0.2 \times 1.5 \times 2.875 = 0.46$

Table 2 - Result of Seismic Evaluation

Storey	X direction (Longitudinal direction)				Y direction (Transverse direction)			
	C	E	I_s	I_{so}	C	E	I_s	I_{so}
2	0.69	0.41	0.30	< 0.46	0.87	0.52	0.38	< 0.46
1	0.25	0.20	0.14	< 0.46	0.36	0.29	0.21	< 0.46

Table 2 shows summery of the assessment for two floors and two directions of the building. It is easily understandable from Table 2 that the building is vulnerable to earthquake both way and both story since seismic index, I_s of the structure is less than seismic demand index, I_{so}. So, the structure needs to be retrofitted.

4. Seismic retrofit design of the building

4.1 Methodology for seismic retrofitting

When seismic performance of existing structure is not satisfactory, retrofitting is done by column jacketing, insertion of shear wall or steel framed bracing, RC wing wall, fiber reinforced polymer or any other method. I_s of the structure is calculated including the retrofitted element and compared with I_{so} until $I_s \geq I_{so}$.

In Japanese method of retrofitting capacity of each member is calculated separately and total capacity is checked against demand index. Strength oriented retrofitting or ductility oriented retrofitting is chosen depending on deficiency of existing structure. The concept of retrofit design of an existing structure is shown in Fig. 4 [4]. Vertical axis is the ratio between lateral strength of vertical members and building weight. Lateral strength of a member is considered as the minimum between shear strength as per shear reinforcement and shear force at ultimate flexural strength of that member. Horizontal axis is story drift or story deflection angle. The objective of retrofit design of a deficient structure is to reach right upper side of the hyperbolic line, i.e. demand line. It can be achieved by increasing strength (line S) or by increasing ductility (line D) or by increasing both strength and ductility (line B). It is also possible to reach to the safe zone with the change of usage; that is by reducing the seismic demand index.

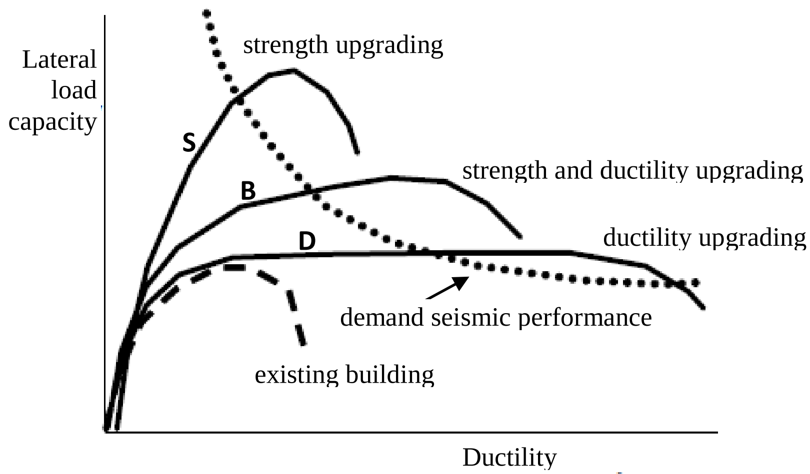

Fig. 4 – Different retrofitting concept [4]

4.2 Basic design concept

Since the structure is a mixed type with low strength masonry wall, so performance objective is to limit the deflection. Strength based retrofitting was used to reduce the horizontal deflection. Followings are the basic idea for retrofitting design and retrofitting items are shown in Fig. 5.

4.2.1 Brick masonry portion

(i) To increase shear strength, concrete jacketing with thickness of 100mm with single layer of reinforcing bars at outside of perimeter walls is provided. RC floor slab as well as brick wall is connected to RC jacketed wall at perimeter by chemical anchors. Vertical load is supported by existing brick masonry walls and lateral load is resisted by RC jacketed walls. Lateral strength of brick masonry is also considered in retrofitting design.

(ii) To increase the shear strength of X direction (long direction) at ground floor, RC wall with thickness 150mm with double layer reinforcement is provided at grid 4 of both sides. This wall is connected to 1st floor slab by chemical anchors.

(iii) To increase the strength in X direction door opening at gird 1 is closed and laminated by RC wall. To increase the unity of frames, wall with 750mm ~1,350mm length is provided at grid C and grid G near grid 1.

4.2.2 RC frame portion

(i) Existing column concrete strength was very low and rebar was corroded. So, all RC columns are jacketed up to roof to increase its axial force capacity and durability.

(ii) Steel framed brace is added at grid E in Y-direction (transverse direction) to increase horizontal strength and to improve the irregularity related problem of Y-direction. RC wall is provided beneath steel framed brace.

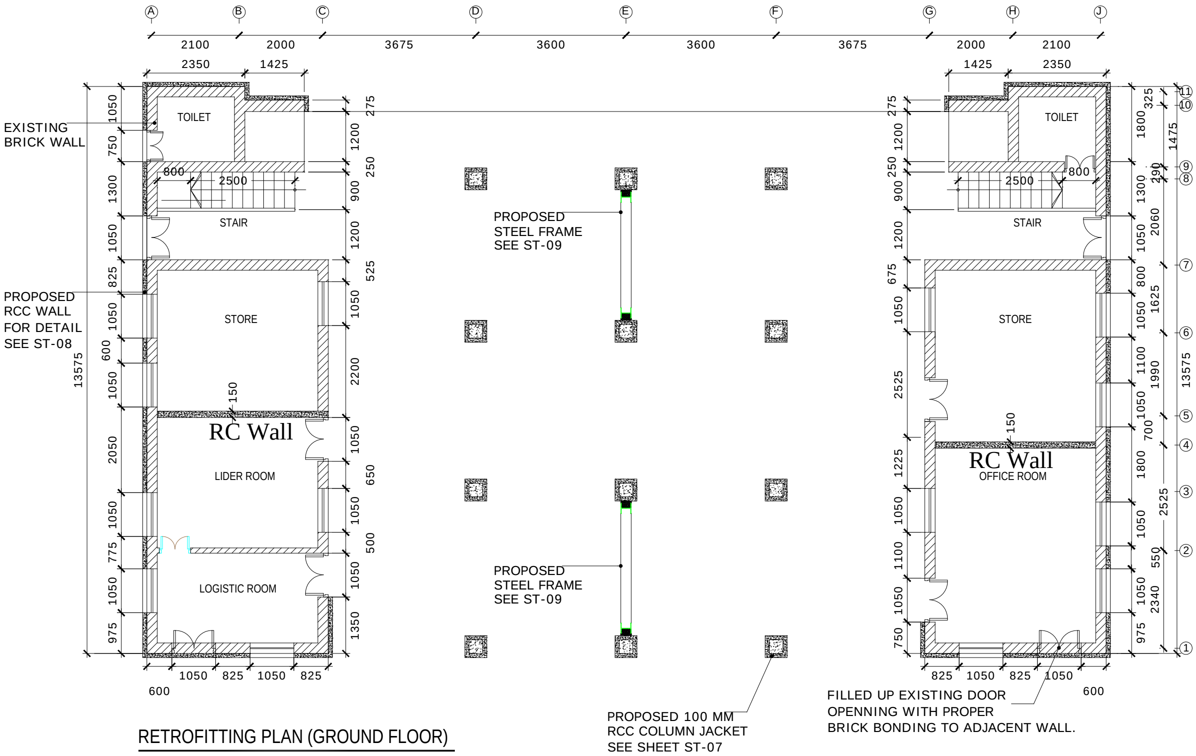

Fig. 5 – Retrofitting plan at ground floor

4.2.3 Material property for retrofitting members

Material property of existing concrete, reinforcing bar and brick wall is given in section 3.4. For retrofitting following material property was considered.

Concrete f'_c = 25 N/mm^2, non-shrink grout f'_c = 30 N/mm^2, concrete reinforcing bar σ_y = 400 N/mm^2, Structural steel σ_y = 345 N/mm^2. Related material specification as described in BNBC was applied.

4.2.4 Load-deflection relationship of the retrofitting members and effective strength factor α

Assumed load-deflection characteristics of structural elements are shown in Fig. 6. A characteristic of steel framed brace is added on the figure of reference [5].

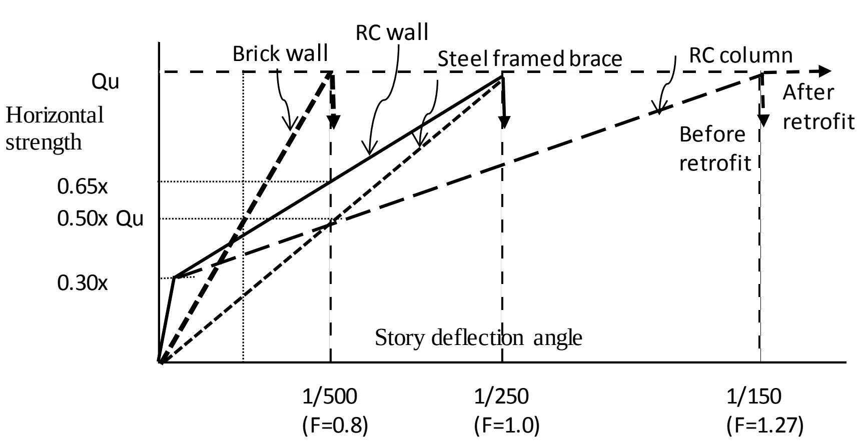

Fig. 6 - Load-deflection Characteristics [5]

Strength index C is evaluated incorporating the strength contribution factor α of RC shear wall, steel framed brace and RC column. For ductility index of brick masonry, F = 0.8 (storey deflection angle, 1/500 is assumed) following is the effective strength factor of various structural member.

Brick wall, α = 1.00; RC shear wall and jacketed wall, α = 0.65; Steel framed brace, α = 0.50; Jacketed RC column, α = 0.50.

4.3 Retrofit design of structural members

Weight of additional concrete wall = 412 kN, column jacketing = 203 kN, steel framed bracing = 29 kN. So, total additional weight of retrofitting elements= 645 kN

4.3.1 Strength of jacketed column:

Original column: Size = 300mm × 300mm

Main rebar = 4- d20 and Tie = 6d @ 225

F_c = 7.8 N/mm^2 and σ_y = 275 N/mm^2

Jacketed part (shown in Fig. 7):

Jacketed column size = 500mm × 500mm

Additional main rebar = 8- d16

Hoop spacing = d10 @ 150

F_c = 25 N/mm^2 and σ_{y2} = 400 N/mm^2

∴ Shear strength of each column at ground floor = 84.8 kN.

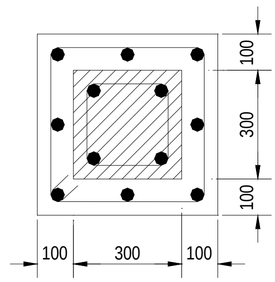

Fig. 7 - Section of Jacketed Column

4.3.2 Strength of RC jacketing over existing masonry wall.

Typical plan and sectional detail of brick wall lamination by RC wall is shown in Fig. 8 and Fig. 9 respectively.

Thickness of jacketing wall, t_w = 100mm.

Length of jacketing wall at grid-1= 7000 mm [Entrance opening is filled by brick wall and later jacketed by RC wall] and at grid-11 = 7950 mm

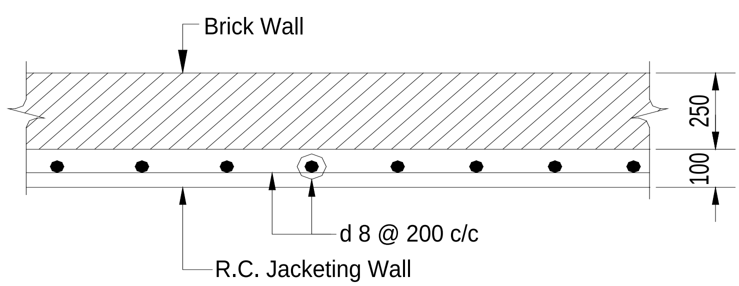

Fig. 8 – Plan of RC wall lamination

F_{cw} = Compressive strength of concrete of RC jacketing wall = 25 N/mm2.

σ_{wy} = Yield strength of reinforcement of jacketing wall.

= 400 N/mm^2.

Shear stress for RC shear wall, τ =1.5 N/mm^2

In X-direction, total shear strength of wall jacketing of grid 1 & 11, Q_{wi} = 2242 kN

In Y-direction, total shear strength of wall jacketing of grid A, C, G and J, Q_{wi} = 2790 kN

4.3.3 Strength of RC wall at Grid-4

Length of RC wall = 3850mm, Thickness of wall = 150mm.

Two new RC wall at each side of masonry block is provided (details shown in Fig. 10) to meet the shear demand at ground floor only. This new RC wall has a continuous footing at existing foundation level and is anchored to

1st floor slab by post installed anchor. Since the height of RC wall is low compared to its width, so it will fail in shear mode instead of flexure mode.

So, shear strength of RC wall = $\tau \times l \times t$ = 1.5 × 3850 × 150 × 2 nos. = 1732 kN.

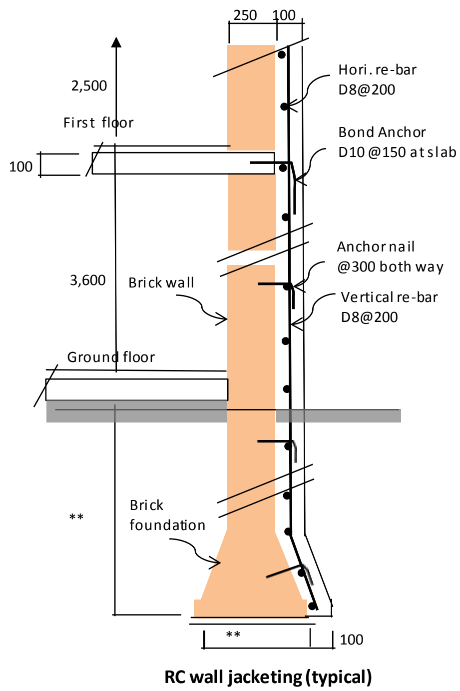

Fig. 9 – Section of RC wall lamination

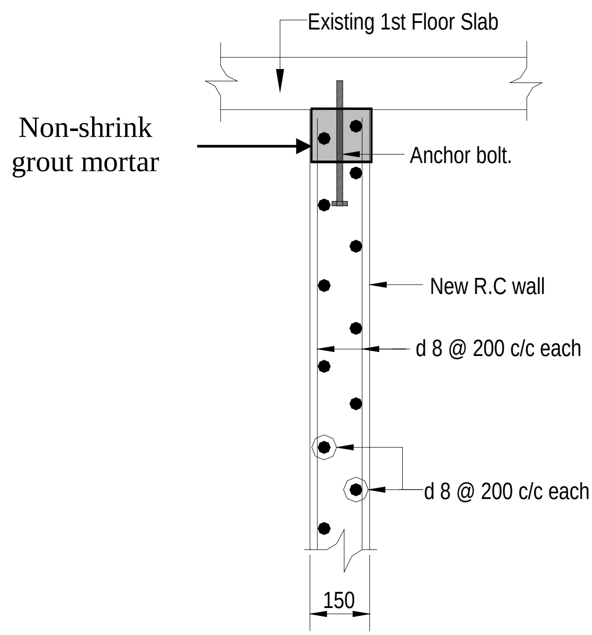

Fig. 10 – Section of new RC wall at grid -4

4.3.4 Strength of Steel Framed Brace

In transverse direction at center line (at grid E) of the building two steel framed bracings has been placed to increase stiffness and strength of the middle part. Typical elevation of the steel frame is given in Fig. 11.

Length of steel framed brace = 3010mm

Height of steel framed brace = 2650mm

Length of diagonal member = 3834mm

Section of brace (channel type) = ⊏ 225 × 125 × 10 (slenderness ratio = 41.6)

For tension side 20% reduction for bolt hole is assumed. Only main diagonal member will be considered for strength calculation. One braced frame will take load by compression and another will participate by tension. Inclination of this diagonal member is 41.4° with base.

$$\text{So, strength} = A_{s1}\, f_{cr}\, cos\theta + A_{S2}\, f_y \cos\theta$$

$$= (4550 \times 306 + 4550 \times 0.8 \times 345) \times \cos 41.4 \quad = 1986 \text{ kN.}$$

Table 3 - Result after Retrofit

Storey	X direction				Y direction			
	C	E	I_s	I_{so}	C	E	I_s	I_{so}
2	0.97	0.58	0.55	> 0.46	1.05	0.63	0.60	> 0.46
1	0.75	0.60	0.57	> 0.46	1.03	0.83	0.78	> 0.46

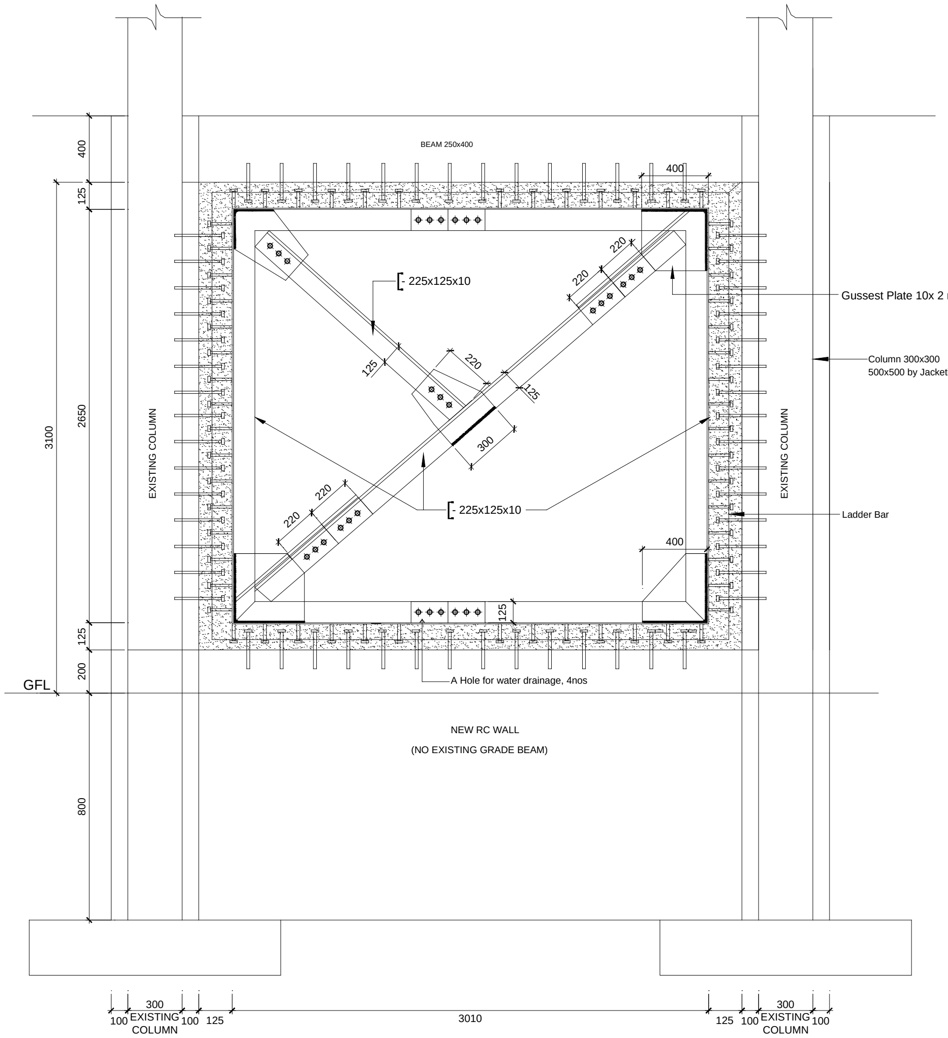

Fig. 11 – Elevation of steel framed brace

The building has been re-evaluated including the contribution of new retrofitting elements with the same method of seismic evaluation. The results are summarized in Table 3, where it is seen that I_s index of the structure is well above the seismic demand index, I_{so} in both story and both directions.

4.4 Retrofitting of non-structural components (elements)

i. Internal brick walls are investigated against possible horizontal acceleration for out of-plane movement. Horizontal acceleration of 0.63g and more was applied for walls of 125mm thickness at 1st floor and RC post (125mm x 125mm) was be provided at the free end of 125mm wall as a retrofit.

ii. Non-structural wall at perimeter of RC frame portion (grid 1 and grid 9) will be made by RC wall.

iii. Parapet wall at roof is brick wall and is jacketed by RC wall.

iv. Protrusion (protrude objects) such as staircase at roof is jacketed by RC wall.

v. Existing standing wall at veranda of 1st floor is RC wall.

5. Experience of retrofitting construction work

There are some experiences of re-strengthening work of private and public building in Bangladesh, but this pilot project is the first initiative of methodical retrofitting design and retrofitting construction work. This retrofitting work helped local engineers to understand applicability of retrofitting methods, cost of work, construction management etc. Some of the pictures of construction work are shown in Fig. 12. Following are the notable experience gathered during construction work.

i. Time schedule of retrofitting construction was finalized involving the building user, so that they can continue the everyday official job.

ii. Except retrofitting work many repair and maintenance work like; replacement door and windows, replacement of existing floor finish, replacement of roof lime concreting, relocation of toilets etc. was done since the building is 50 years old. The replacement work was more than the tender schedule.

iii. First floor residential plan was revised due to request of user since the old plan not suitable for the user. All most all partition walls at first floor was demolished and reconstructed as per new plan, which was not considered before starting of construction work.

iv. Due to this additional work, cost for non-retrofitting item was more than the retrofitting work. Total cost of this project was around 65% with compared to cost of new building of same floor area.

v. Since local construction company is no familiar with this type of specialized job, quality of work was not up to the mark, specially in case of steel framed bracing fabrication.

(a) Elevation before retrofitting

(b) Column jacketing

(c) Non-shrink grout mortar work at top of column, 1st story

(d) Chemical anchor at beam and column

(e) Placing of steel framed brace

(f) Connection of steel framed brace

Fig. - 12 Retrofitting construction work

(g) Construction of RC wall at grid -4

(h) Concreting work on perimeter brick wall

(i) New look of fire station building after retrofitting

Fig. - 12 Retrofitting construction work (cont.)

6. Conclusion

With the implementation of pilot retrofitting project Public Works Department, Bangladesh has achieved confidence on retrofitting design, construction and supervision of existing vulnerable structure, specially brick masonry structure. After successful completion of this project, another project (Yen loan project funded by JICA) has started to retrofit 9 other similar fire station buildings in and around Dhaka city. To increase the urban resilience in earthquake, some other private and public buildings are also being retrofitted following the manuals prepared under CNCRP project.

7. Acknowledgements

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