Strengthening of Tapered Beam using CFRP

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ABSTRACT— ***Tapered beam is a type of prismatic beam that has different dimension at the end of the beam and the mid-span. End of tapered beam has a larger dimension than the middle span. Tapered beams serve as Intermediate Moment Resisting Frame System (SRPMM) in reinforced concrete building that is one of the structural methods to resist forces caused by the earthquake load for intermediate seismic risk category. The purpose of this research was to improve the nominal shear strength in existing tapered beam on the X building using CFRP (Carbon Fiber Reinforced Polymer). The X Building is an office building that has 14 floors and tapered beams as moment resisting frame system. Tapered beams located on the 3rd floor and serves to support transfer columns that support 9 floors above. Tapered beams structure in X Building has dimensions of 120x210-180 cm. Tapered beam's structural strength must be considered, especially the shear force prediction from seismic loads threats that might come. The building structure modeling was designed and analyzed using ETABS program. Given design seismic loading is in the form of spectrum response of dynamic seismic load procdure. Structural analysis results shows the maximum shear force factored value on the tapered beam is greater than the value of nominal shear strength. Recommended strengthening is the installation of CFRP (Carbon Fiber Reinforced Polymer) layers. Analysis of tapered beam structure strengthening used ACI 440.2R-08 method.***

Keywords— building, earthquake, tapered beam, strengthening

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1. INTRODUCTION

Jakarta is one of area in Indonesia which is belong in intermediate earthquake zone category. Jakarta as the center of Indonesia's capital city has numerous high-rise buildings. The structural design of earthquake resistant buildings required building design's standards and regulations to ensure the safety of occupants, avoid and minimize the structure damage and casualties against frequent earthquakes (Budiono and Supriatna, 2011). The structure of seimic resistant buildings must have the strength, rigidity and stability that is sufficient to prevent the collapse of the building. The failure of structure can be caused by: the calculation error in planning, the mismatch between planning and on field work execution implementation, change of building function, natural disasters such as strong earthquakes, and many others. Evaluation of building's structure performance could be done by analyzing the ultimate limit and serviceability limit performance according to SNI 03-1726-2002 (Christiawan et al, 2008).

Indonesia's latest regulation for seismic loading standards is SNI 03-1726-2012. SNI 03-1726-2012 contains earthquake resistance planning procedures and guidelines for buildings and non-buildings structure, which is a revision of SNI 03-1726-2002 (BSN, 2012). SNI 03-1726-2012 has been using the latest earthquake history map since 2010, so the building that was built before 2010 need to be evaluated to determine the structure's safety according to the new standards. The differences in planning guidelines for building's earthquake resistance between SNI 03-1726-2002 and SNI 03-1726-2012 is the seismic spectral acceleration design in SNI 03-1726-2012 in some parts of Indonesia experienced an increase in medium and hard soil site class type and a decrease in soft ground site class types (Arfiandi and Satyarno, 2013).

Building elements such as beams and columns require further research about its strengthening study. This study discusses strengthening studies on tapered beams of the X building in Jakarta. The X Building is an office building that has 14 floors and tapered beams as a supporting structure element. Tapered beams located on the 3rd floor and serves to support transfer columns that support 9 floors above. This is caused by the 2nd floor that functioned as a hall. Tapered beams in X Building has dimensions of 120x210-180 cm. Tapered beam's structural strength must be considered, especially the shear force prediction from seismic loads threats that might come. Natural disasters like earthquakes have repeatedly demonstrated the susceptibility of existing structures to seismic effect and hence implements like retrofitting and rehabilitation of deteriorated structures are important in high seismic regions (Raju and Mathew, 2013). The purpose of this research to improve the nominal shear strength in existing tapered beam on the X building using CFRP (Carbon Fiber Reinforced Polymer).

The building structure modeling can be designed and analyzed using ETABS program. The program can show the structure analysis results data in the form of internal forces that can be used to evaluate the building structure's performance due to gravity and earthquake loading. Seismic loading method for a high-rise building or irregular building can be done using spectrum response dynamic analysis (Priyono et al, 2014). Seismic loading method can also be performed by pushover analysis (Yalciner et al, 2015).

2. METHODOLOGY

The building structure modeling was conducted using ETABS (Extended Three Dimensional Analysis of Building System) version 9.7.2 program. The addition of seismic load analysis was conducted using response spectrum chart from variance response spectrum analysis procedure. The response spectrum is a graph that shows the relation between structure acceleration response's peak values due to earthquake excitation as a function of structure system's natural period. Earthquake spectrum was based on 2010 Indonesian earthquake map. Earthquake spectrum determination is adjusted for geographic location and building soil site class category. The location which is the object of this study is Jakarta. Based on soil classification map of Jakarta, the research object location (X Building) belongs to soft ground site class type category (Asrurifak et al, 2013). According to SNI 03-1726-2012 about earthquake zoning map, 1 second bedrock acceleration value (S_1) for Jakarta area were ranged from 0.25 to 0.3 g and 0.2 seconds bedrock acceleration value (S_s) for Jakarta were ranged from 0.6 to 0.7 g. Loading combination was included into modeling according to PPPURG 1987 (Loading Regulation Guidelines for Home and Building) (DPU, 1987). Seismic loading that given response spectrum analysis according to SNI 03-1726-2012. The Seismic Design Categories (SDC) of the research object of D category. The seismic loading for SDC-D Categories must fullfill requirements according to SNI 03-1726-2012 code 7.5.4. The combination was inserted in modeling, are as follows:

1) 1.4DL
2) 1.2DL + 1.6LL + 0,5Lr
3) 1.2DL + 1.6Lr + 1LL
4) 1.2DL + 1WL + 1LL + 0,5Lr
5) 0.9DL + 1WL
6) $1.2DL + 1.1LL \pm 0.3(\rho QE + 0.2S_{DS}DL) \pm 1(\rho QE + 0.2S_{DS} DL)$.
7) $1.2DL + 1.1LL \pm 1(\rho QE + 0.2S_{DS}DL) \pm 0.3(\rho QE + 0.2S_{DS}DL)$.
8) $0.9DL \pm 0.3(\rho QE – 0.2S_{DS}DL) \pm 1 (\rho QE- 0.2S_{DS}DL)$.
9) $0.9DL \pm 1(\rho QE - 0.2S_{DS}DL) \pm 0.3(\rho QE- 0.2S_{DS}DL)$.

where : DL = dead load, LL = live load, Lr = live load in the roof, WL = wind load
QE = effect of horizontal seismic forces, ρ= reliability factor

This study has calculated dead load, live load according to PPPURG 1987 that published by Agency Public Works Indonesia are presented in Table 1-2.

Table 1: Dead load according to PPPURG 1987

Dead Load – Occupancy or Use	Load
Concrete Reinforcement	2,400 Kg/m^2
Concrete	2,200 Kg/m^2
Steel	7,850 Kg/m^2
Wall, known as batu bata merah	250 Kg/m^2
Plafond	18 Kg/m^2
Ceramics	24 Kg/m^2
Space of cement layer for plate floor	21 Kg/m^2
Parking in the ground story	800 Kg/m^2
Parking in upper story	400 Kg/m^2

Table 2: Live load according to PPPURG 1987

Live Load – Occupancy or Use	Load
Office buildings	250 Kg/m^2
Stairs	300 Kg/m^2
Roof top	100 Kg/m^2
Meeting room	400 Kg/m^2
Worker	100 Kg

The structural analysis results could be used, if the mass participation control up to 90%, which is in accordance with SNI 03-1726-2012 code 7.9.1. The seismic loading in this study should meet the requirements of SNI 03-1726-2012 code 7.9.4.1, if the value of response spectrum variance analysis seismic base shear force (Vt) is less than 85% of the first variety response seismic base shear force through equivalent lateral force analysis (V_1), then the value of Vt force must be multiplied by (0,85V1)/Vt (force scale factor).

Variance response spectrum seismic base shear force loading (Vt) should consider the redundancy factor (ρ) that required by SNI 03-1726-2012 Article 7.3.4.2. The article explained that when Vt values on each level does not meet the 35% of x and y directional Vt, then the Vt value must be multiplied by redudancy factor (ρ) of 1.3. If each floor has fulfilled 35% of Vt, then the permitted value of ρ = 1. In ETABS program, the redundancy factor value can be given by multiplying the redundancy factor value into scale factor for the U1 value in the x-direction and U2 value in the y-direction.

Results of structure analysis will determine the internal forces, which are: moment, shear, torsion and axial forces. The purpose of this research to increase the nominal shear strength in existing tapered beam on the X building using CFRP (Carbon Fiber Reinforced Polymer). It was important to know how to prevent shear failure due to the maximum shear force factored for ultimate loading combination.

2.1 Analysis of Nominal Shear Strength in Beam Structure

BSN (2013) according to SNI 03-2847-2013 code 11.1.1, the design of beams for shear is to be based on the relation Eq (1), The design shear strength should be calculated by multiplying the nominal shear strength by the strength reduction factor (ϕ) = 0.75, as specied by SNI 03-2847-2013 code 9.3.2.3.

$$\phi Vn \geq Vu \quad (1)$$

where Vu is the total shear force applied at a given section of the beam due to factored loads and Vn = Vc + Vs is nominal shear strength, equal to the sum of the contributions of the concrete and the web steel if present. Thus vertical strirrups (Eq.2).

$$Vu \leq \phi\ (Vc + \frac{Av.fy.d}{S}) \quad (2)$$

BSN (2013) according to SNI 03-2847-2013 code 11.2.1.1, the nominal shear strength contribution of the concrete (Vc) that was required (Eq.3),

$$Vc = 0{,}17.\lambda.(f'c)^{1/2}.b_w.d \quad (3)$$

where :

Av = total cross-sectional area of web reinforcement within a distance *s* steel (mm)
fy = yield strength of web reinforceemnt steel (mm)
s = center-to-center spacing of shear reinforcement in a direction parallel to the longitudinal reinforcement (mm)
d = effective depth of beam (mm)
f'c = specified compressive strength of concrete (MPa)
bw = width of web (mm)
λ = 1 (normal weight concrete).

2.2 Retroffiting Structure Method

Retrofitting method selection to the building structures that suffered structural failures need to be reviewed in terms of damage levels, which are structural damage and non-structural damage. The example of structural damages are beams or plates deflection, comprehensive cracks that causing concrete cover being peeled, cracks in the column-beam joint, and foundation settlement. Types of non-structural damages e.g. hairline cracks on the beams, walls or other structural elements. If the hairline cracks value less than 0.20 mm, then the repair method can be done by grouting.

2.3 Strengthening Structure Method for Shear Failure

Christiawan et al, (2008) recommends existing structural elements strengthening with FRP (Fiber Reinforcement Polymer) layer of as effort to improve the concrete structures shear strength performance on the beam. The flexural strengthening by external bonding of fiber reinforced polymer (FRP) to the tension face of reinforced concrete (RC) beams has proven to play similar role as that of the internal longitudinal reinforcement in increasing flexural strength and stiffness of the beams (El-Sayed, 2014). The use of FRP (Fiber Reinforced Polymer) can be considered as structure strengthening. ACI 440.2R-08 Guidelines has explained that the nominal shear strengthening using FRP can be calculated by adding the contribution value of shear forces that can be supported by FRP layer (Vf) (ACI, 1998). Installation of FRP layers is shown in Figure 1.

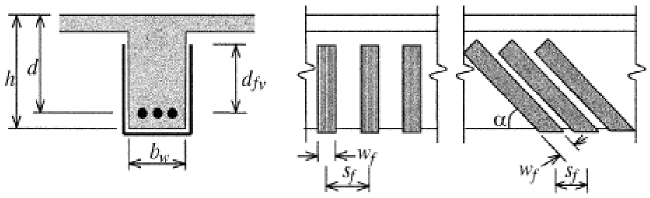


Figure 1: Illustration of the dimensional variables used in shear strengthening calculations for repair, retrofit or strengthening using FRP laminates according to ACI 440.2R-08

The design shear strength of concrete member strengthened with an FRP system should exceed the required shear strength (Eq. 4). The design shear strength should be calculated by multiplying the nominal shear strength by the strength reduction factor (ϕ) = 0.75, as specied by SNI 03-2847-2013.

$$\phi Vn > Vu \quad (4)$$

The nominal shear strength of an FRP-strengthened concrete member can be determined by adding the contribution of the FRP external shear reinforcement to contributions from reinforcin steel (striipus, ties or spiral) and the concrete. (Eq. 5).

$$\phi Vn = \phi(Vc + Vs + \psi f V_f) \quad (5)$$

The design shear contribution of the FRP shear reinforcement should be calculated by the FRP strength reduction factor (ψf). Recommended additional reduction factors for FRP shear reinforcement using completely wrapped member, ψf = 0.95 and recommended additional reduction factors for FRP shear reinforcement using theree-side or two-opposite-sides schemes, ψf = 0.85 (Figure 2).

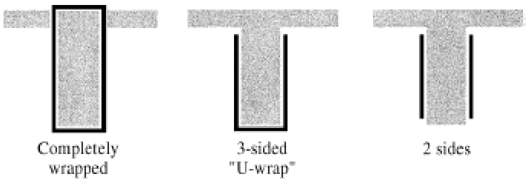


Figure 2: Typical wrapping schemes for strengthening using FRP laminates according to ACI 440.2R-08

Given strengthening using FRP laminates is in the form of width of each sheet (wf) and span between each sheet (sf) are shown in Figure 3.

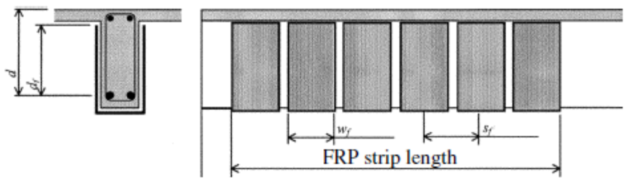


Figure 3: Configuration of the supplemental FRP shear reinforcement according to ACI 440.2R-08

3. RESULT AND DISCUSSION

3.1 Spectral response acceleration design

The seismic load was designed using dynamic response spectrum method according to SNI 03-1726-2012. The response spectrum parameter was taken from the website of Ministry of Public Works of Republic Indonesia by entering the coordinates of the location and category of site soil condition on the website. In this study was located in East Jakarta, with result of soil investigation was category soft soil (E) (Asrurifak et al, 2013). The website of application spectra design had generated the data of parameter of spectral response (Table 3).

Table 3: Spectral response graphic design parameter

Parameter	Value
S_s	0.667 g
S_1	0.293 g
S_{MS}	0.991 g
S_{M1}	0.929 g
S_{DS}	0.607 g
S_{D1}	0.553 g
Ts	0.901 second
To	0.182 second

where:

Ss	=	Spectral response acceleration parameter of earthquake MCE_R mapped on a short period
S_1	=	Spectral response acceleration parameter of earthquake MCE_R mapped on a 1 sec period.
S_{MS}	=	Spectral response acceleration parameter of earthquake MCE_R on a short period which has already been adjusted to the site class
S_{M1}	=	Spectral response acceleration parameter MCE_R on a 1 second period which has already been adjusted to the site class
S_{DS}	=	Spectral response acceleration parameter on a short period, 5% damping
S_{D1}	=	Spectral response acceleration parameter design on a 1 sec period
To and Ts	=	Fundamental structural vibration period

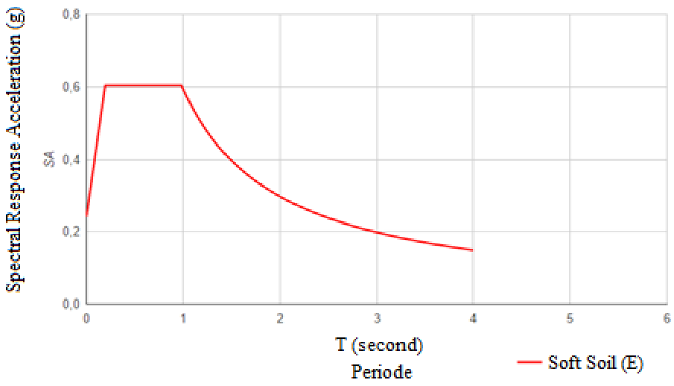


Figure 4: Typical design spectrum at area object study

3.2 Building Model

The supporting data in this research are as built drawings, architectural drawings and references about soil type site class map. The description of the building model are as follows; the buiding function is an office building; the building material structure used concrete material, but roof structure is the 12th floor used steel construction; there are not shear wall and core wall systems; the highest elevation is +56.50 m and lowest elevation is -6.40 m; 12 primary stories, 2 base stories, adding l penthouse story and penthouse roof story; typical floor height of 4.00 m and the height of basement floor is 3.20 m. The building area is 4,735.71 m^2. The quality of steels used for concrete reinforcement (fy) of 240 MPa for reinforcing steel diameters smaller than 12 mm and 390 MPa for reinforcing steel diameter greater than 12 mm. Specification of concrete compressive strength of 29.05 Mpa.

Structure material modeled as reinforced concrete for beams, columns and slabs based on execution drawing data (as built drawings) and for the foundation structure was modeled as pedestal flops with ETABS program (Extended Three Dimensional Analysis of Building System) version 9.7.2. (Figure 5).

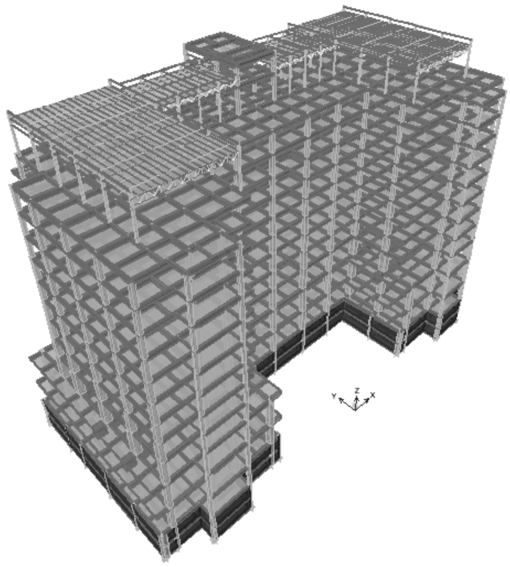


Figure 5: Building model in ETABS program

Tapered beams located on the 3rd floor and serves to support transfer columns that support 9 floors above. Tapered beams in X Building has dimensions of 120x210-180 cm and has a length of 21 meters, which serves to support the transfer column so the second floor room could be utilized as hall without middle column (Figure 6).

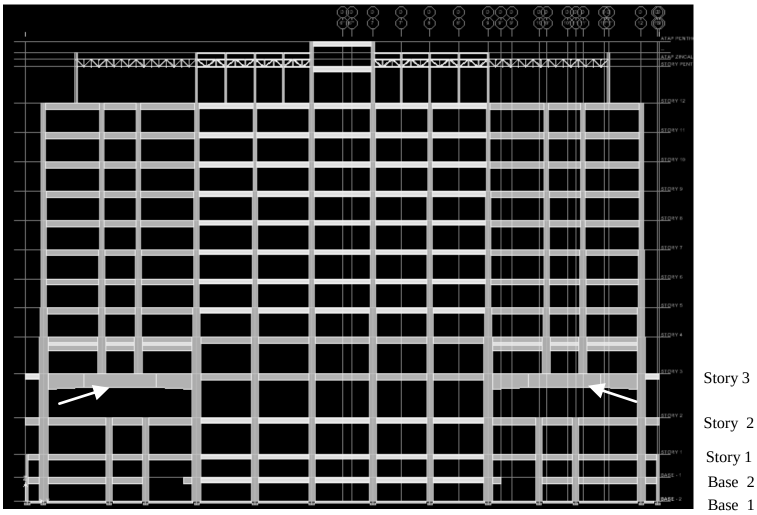


Figure 6: Located of tapered beam on the X bulding

Structure of tapered beam on the X building has a length of span is 21 meters. Details length of span existing tapered beam is shown in the Figure 7. Details of dimension and steel reinforcement of existing tapered beam is shown in the Table 4.

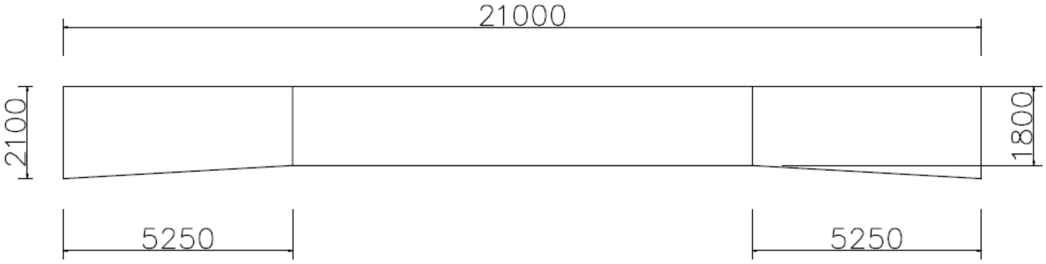
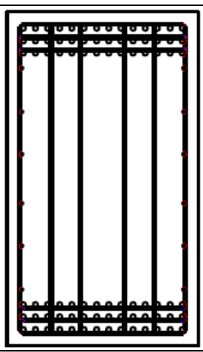
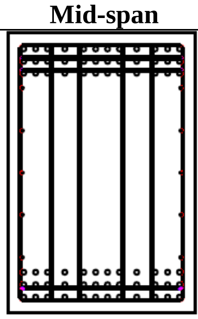
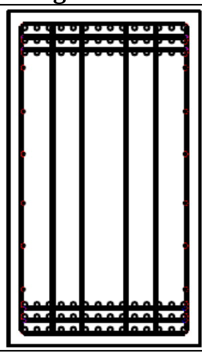


Figure 7: Length of tapered beam span in milimeter unit

Table 4: Details of dimension and reinforcement of existing of tapered beam

Floor Position	**Left end**	**Mid-span**	**Right end**
Lantai 3			
Dimension	120 x 210 cm	120 x180 cm	120 x 210 cm
Top of reinforcing bars	42D32mm	38D32 mm	42D32 mm
Bottom of reinforcing bars	42D32 mm	38D32 mm	42D32 mm
Steel stirrups	4D13-100 mm	4D13-150 mm	4D13-100 mm
Adding reinforcing bars	12D19 mm	12D19 mm	12D19 mm
Concrete cover (ds)	50 mm	50 mm	50 mm

3.3 Structure Analysis

Shear force diagrams of tapered beam on the X Building was analyzed by ETABS program, as shown in Figure 8.

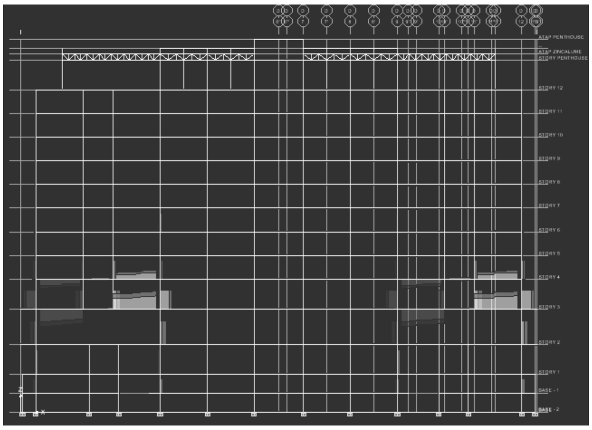


Figure 8: Shear 2-2 force diagrams in the X building on ETABS program

Figure 8 shows a tapered beam's shear force diagrams on the X building. The shear force factored value of tapered beam looks great enough on the 3th floor. It also makes tapered beam unsafe towards ultimate shear force due to loading combination. It was important to know how to prevent shear failure due to the maximum shear force factored for ultimate loading combination. The tapered beams position that weak against shear are shown in Figure 9.

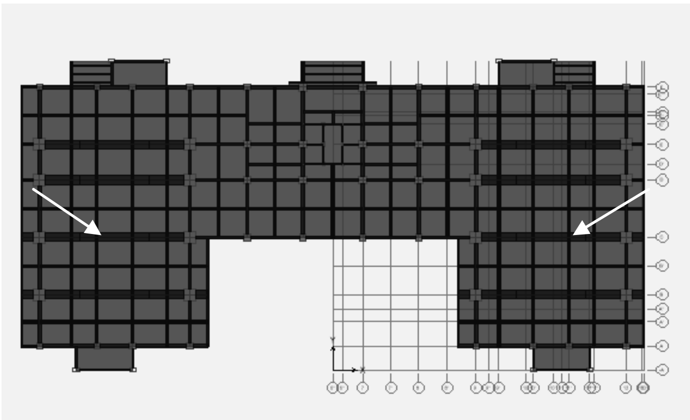


Figure 9: The tapered beam position that weak against shear on the 3rd floor at grid C

Figure 9 shows shape of building modeling in ETABS program is symmetrical form. Structure analysis result showed that the maximum shear force factored of tapered beam left and right part are similar, due to the building symmetrical form. The reviewed structure analysis results were tapered beam on the right part. The reviewed shear force diagrams value of 2-2 direction. The values of nominal shear strength and maximum shear force factored from tapered beam is shown in Table 5.

Table 5: Nominal shear strength and ultimate shear force from existing of steel stirrups

Beam dimension (cm)	Position	Existing of Steel Stirrups	ϕVn (kN)	Vu (kN)
120 x 210-180	Left-end	4D13 mm -100 mm	4,159.44	5,134.23
	Mid-span	4D13 mm -150 mm	3,253.99	4,444.94
	Right-end	4D13 mm -100 mm	4,159.44	4,516.30

Table 5 shows the greatest maximum shear force factored value occurs in the left-end area is 5,134.23 kN, while the nominal shear strength value is 4,159.44 kN. This indicates that the maximum shear force factored value is greater than the nominal shear strength value. The same thing also happens in mid-span area which is maximum shear force factored values of 4,444.94 kN, while the nominal shear strength value is 3,253.99 kN. Results of evaluation stated that the amout of existing steel stirrups installed in all of span on tapered beam is not meet the requirement which is ϕVn > Vu.

3.4 Analysis of Strengthening of Tapered Beam using CFRP

Recommended strengthening is the installation of CFRP (Carbon Fiber Reinforced Polymer) layers with ACI 440.2R-08 method. Manufacturer's reported CFRP system properties; Ultimate tensile strength is 2,790 MPa; The modulus of elasticity of FRP laminates is 155,000 MPa; The density is 1.50 g/cm^3; Strengthening CFRP layers are installed with adhesive/epoxy with a strong adhesive concrete greater than 4 MPa and modulus of elasticity is 12,800 MPa. Structural strengthening analysis done to improve the ability of tapered beam in bearing the ultimate shear force due to maximum loading combination. High of beam taken as the calculation of the high beam at mid-span. Configuration data plan of CFRP materials are shown in Table 6.

Table 6: Configuration of supplemental FRP shear reinforcement

Effective depth of FRP shear reinforcement (dfv) = h - ds	1,800 – 50 = 1,750 mm
Width of each sheet (wf)	200 mm
Span between each sheet (sf)	300 mm
Nominal thickness of one ply of FRP reinforcement (tf)	1.40 mm

The stages of calculation to provide nominal shear strength strengthening using CFRP to tapered beam according to ACI 440.2R-08 are shown below.

3.4.1 Compute the design material properties

The beam is located in an interior space and a Carbon Fyber Reinforced Polymer (CFRP) material will be used. Environmental reduction factor for type of carbon interior exposure at 0,95 from ACI 440.2R-08 code 9.3.4, Table 9.1.

Design of ultimate tensile strength of FRP reinforcement (f_{fu})

f_{fu} = 0.95Fy = 0.95 x 2790 MPa = 2.651 kN/mm^2

Design of rupture strain of FRP reinforcement (Ɛfu)

ε_{fu} = 0.95Ɛfu = 0.95 x 0.017 = 0.016

3.4.2 Calculate the effective strain level in the CFRP shear reinforcement

The effective strain in CFRP U-wraps should be determined using the bond reduction coefficient (Kv). This coefficient can be computed using from ACI 440.2R-08 code 11.4.1.2, Eq (11-7) about to calculate the bond reduction coefficient (Kv). It is needed to calculated the active bond length of FRP laminate (Le), the modification factor applied to Kv account for concrete strength (K_1) and the modification factor applied to Kv to account for wrapping scheme (K_2).

Calculate the active bond length of FRP laminate (Le).

$$Le = \frac{23{,}300}{(n\ tf\ Ef)^{0.58}} = \frac{23{,}300}{(2 \times 1.4 \times 155{,}000)^{0.58}} = 54 \text{ mm}$$

Calculate the modification factor applied to Kv to account for concrete strength (K_1).

$$K_1 = \left[\frac{f'c}{27}\right]^{2/3} = \left[\frac{29.05}{27}\right]^{2/3} = 1.05$$

Calculate the modification factor applied to Kv to account for wrapping scheme (K_2).

$$K_2 = \frac{d_{fv} - 2L_e}{d_{fv}} \text{ (for U Wraps)} \qquad K_2 = \frac{1{,}750-(2 \times 54)}{1{,}750} = 0.938$$

Calculate the bond reduction coefficient (Kv)

$$Kv = \frac{(K_1 + K_2)\ Le}{11{,}910 \times \varepsilon fu} = \frac{(1.05+0.938)\ 54}{11{,}910 \times 0.016} = 0.275 \leq 0.75$$

Planning of typical wrapping scheme for strengthening analysis using bonded U-wraps. The effective strain can then be computed using from ACI 440.2R-08 code 11.4.1.2, Eq. (11-6b) as follows: ε_{fe} = Kv $\varepsilon_{fe} \leq$ 0.004.

ε_{fe} = 0.275 x 0.016 = 0.004

The effective strain is calculated using a bond-reduction coefficient Kv applicable to shear.

3.4.3 Calculate the contibution of the CFRP rinforcement to the shear strength (Vf)

Area of CFRP shear reinforcement with spacing (*s*) can be computed as follows:

A_{fv} = 2.n.tf.wf , where: n = number of plies of CFRP reinforcement

A_{fv} = 2 x 2 x 1.40 x 200 = 1,120 mm^2

The effective stress in the CFRP can be computed from Hooke's law.
$f_{fe} = \varepsilon_{fe}.Ef$ = 0.004 x 155,000 = 0.689 kN/mm^2

The shear contribution of the CFRP (Vf) can be then calculated from ACI 440.2R-08 code 11.4, Eq. (11-3).

$$V_f = \frac{A_{fv}\ f_{fe}\ (\sin\alpha + \cos\alpha)\ d_{fv}}{s_f} = \frac{1{,}120 \times 0.689 \times (1) \times 1{,}750}{300} = 4{,}498.94 \text{ kN}$$

3.4.4 Calculate nominal shear strength provided by concrete with steel flexural reinforcement (Vc)

Contribution of nominal shear strength provided by concrete with steel flexural reinforcement (Vc) can be computed using from SNI 03-2847-2013 code 11.2.1.1.

$$Vc = 0.17\ \lambda \sqrt{fc}\ bw\ d = 0.17 \times 1 \times \sqrt{29{,}05} \times 1{,}200 \times 1{,}750 = 1{,}924.16 \text{ kN}$$

where: the value λ using normal weight concrete, so λ = 1.

3.4.5 Calculate nominal shear strength provided by steel stirrups (Vs)

Contribution of nominal shear strength provided by steel stirrups (Vs) can be computed using from SNI 03-2847-2013 code 11.4.7.2.
Calculate area of vertical stirrups (Av)
Av = ¼ x π x D^2 x n, where the symbol of (D) is diameter of legged steel stirrups, (mm) and the symbol of (n) is number of legged steel stirrups.
Av = ¼ x π x 13^2 x 4 = 530.66 mm^2
Calculate nominal shear strength provided by steel stirrups (Vs)

$$Vs = \frac{A_v\ .fy.d}{s} = \frac{530.66 \times 390 \times 1{,}750}{150} = 2{,}416.70 \text{ kN}$$

3.4.6 Calculate the shear strength of the section

The design shear strength should be calculated by multiplying the nominal shear strength by the strength reduction factor (ϕ) = 0.75. The design shear strength can be computed from ACI 440.2R-08 code 11.3, Eq.(11-2), where: FRP strength reduction factor (ψf) is 0.85 for U-wraps and the value of maximum shear force factored (Vu) is 5,134.23 kN.
Design of nominal shear strength (ϕVn)
ϕ Vn = ϕ (Vc + Vs + ψf Vf)
ϕ Vn = 0.75 [1,924.16 + 2,416.70 + (0.85 x 4,498.94)]
ϕ Vn = 6,123.72 kN > Vu = 5,134.23 kN.

4. CONCLUSION

Results of analysis of existing tapered beam on X building indicates that the value of maximum shear force factored due to ultimate loading combination is greater than the value nominal shear strength. Tapered beams on the X building indicated a failure shear in the tapered beam based on analyzed by ETABS program.

Recommended tapered beam strengthening is the installation of CFRP layers using ACI 440.2R-08 method. Manufacturer's reported CFRP system properties: The CFRP thickness is 1.40 mm, Ultimate tensile strength is 2,790 MPa, modulus of elasticity is 155,000 MPa and density is 1.50 g/cm^3. Strengthening CFRP layers are installed with adhesive/epoxy with a strong adhesive concrete greater than 4 MPa and modulus of elasticity is 12,800 MPa.

The results of analysis shows that tapered beam is needed to install 2 CFRP layers of 21 meters. Planning of application CFRP using width of each sheet (wf) is 200 mm and span between each sheet (sf) is 300 mm. The value of nominal shear strength of tapered beam in the left and right end beam before given strengthening is 4,159.44 kN and after given strengthening of CFRP is 6,123.72 kN so this result shows that shear nominal strength could be increased is 32.08%. The value of nominal shear strength of tapered beam in mid-span before given strengthening is 3,253.99 kN and after given strengthening of CFRP is 6,123.72 kN so this result shows that nominal shear strength could be increased is 46.86%.

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