Dissipating the earthquake lateral base force of structure using sliding plate and link beam base isolation

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ABSTRACT

Link beam and sliding plates is used to isolate structure against lateral base shear of the foundation due to earthquake forces, the link beam element made from steel wide flange act as a metallic damper, combined with sliding plates become as base isolation. Analysis with the Etabs program results in significant differences in internal moment, shear and axial forces between structures that using link beam base isolation and those without, as well as the results for drift and deformation of the structure. The first step of analysis is estimate the dimensions of the structural elements. Base on the loads of the structure, the lateral base force of the structure can be calculated manually, so that, by applying the dynamic balance equation, the size of steel wide flange that will be used as the link beam. can be found. Furthermore, the analysis of internal forces, deformation, and structural drifts are calculated using the Etabs program for structural systems that with or without base isolation. The both results are compared so that it can be concluded that by using the base isolation link beam there is a significant decrease in the magnitude of the internal forces, drift and displacement, so that by using this base isolation, the elements of the structure will be reduced significantly, and the cost of structure can be saved[1], the safety and comfort of the building can be further improved too.

Keywords: link beam; base shear; metallic damper; seismic resistant system.

INTRODUCTION

The magnitude of the lateral base force due to the earthquake cannot be estimated with accuracy. Structural planning is usually based on the probability of occurring in an estimated time period, for example, a 2% chance of occurring in 50 years[2][3], but it does not rule out that the lateral force of the earthquake that occurs exceeds the above estimates, resulting in severe damage due to the lateral base force[4][5]. To anticipate this, the structure is planned to increase its ductility[6], with the hope that a structure can withstand through excessive lateral forces with the ability of the structure to carry out large displacement, due to the ductility of the structure elements[7]. There are various ways to increase the ductility of the structure, among others, by designing structural elements with the principle of yield strength and inelastic structures[8][9].

For the lower structure (substructure), a damping system (base isolation) can be applied[6], which functions to reduce lateral shear forces due to earthquake forces[10], by allowing large lateral movement of foundation, the vibration time of the structure will be increase[11], so that the earthquake energy can be absorbed by the base isolation[7][12][9]. There are several types of base isolation, including the type of Lead Rubber, Sliding or Viscous Damping[13][14], but the weakness of the base isolation above is the high price and maintenance costs.

In this research, the above matters can be overcome by using materials that can be made easily and locally supply[6][7], namely using wide flange (WF) profiles use as link beam and steel plates use as sliding plate[6]. Besides being cheap, this system can also be used for tall structures, which in other base isolation systems can only be used for low structures (smaller than 5 floors).

A structure that is subjected to a lateral earthquake force will provide dynamic balance[15], assuming the floor has infinite stiffness (Figure 1) , then the equation $fs = k\,u$ is obtained, where fs is the column reaction force, k is the column stiffness, u is the floor displacement[9]. This idea is applied to the link beam isolation system[16], where the structure is considered to be one unit with

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infinite stiffness supported by the link beam which functions as a column[8], so when the link beam receives the lateral force of the earthquake, the above equation also can be applied. Considering that the link beam is designed to only accept lateral loads[7], the vertical load of the structure must be able to be resisted by other elements that are able to accept these axial loads, in this case a concrete column is taken to support the weight of the structure as shown in Figure 2.

In actual fact, a structure that resisted a lateral force, will give a reaction consisting of the column stiffness reaction (*fS*), the damping structure (*fD*) and mass inertia of the structure (*fI*), so that the overall dynamic equilibrium [6][17] is as in Figure 1, and the balance equation as follows:

$$(m\ddot{u} + m\ddot{u}_g) + c\dot{u} + ku = 0 \qquad (1)$$

$$m\ddot{u} + c\dot{u} + ku = m\ddot{u}_g \qquad (2)$$

where: m is the mass of the structure
$\ddot{u}$ is the acceleration of the structure
$\ddot{u}_g$ is the acceleration of the soil subgrade
$\dot{u}$ is the velocity of the structure
u is the displacement of the structure
c is the structure damping
k is the stiffness of the column.

RESEARCH METHOD

Idealization of the dynamic balance of the base isolation link beam is adopted from equation (2) by changing the force ($k\,u$) with yield strength of the link beam profile (Hp), ($c\,\dot{u}$) with the sliding plate friction force ($fD1$ and $fD2$), ($-m\,\ddot{u}_g$) with the earthquake lateral shear force ($Cs\,w$), then the balance of the forces is obtained as follows:

$$m\ddot{u} + fD + Hp = CsW \qquad (3)$$

where: m is the mass above the support column
fD is the plate sliding shear force
Hp is the plastic link beam shear capacity
Cs is the earthquake shear coefficient
W is total weight of the whole structure

The equation will be:

$$m\ddot{u} = CsW - fD - Hp \qquad (4)$$

by making the right side to be zero, $m\ddot{u} = 0$, then $\ddot{u} = 0$
so that when the link beam reaches its plastic equilibrium, the lateral forces that resisted by the structure (*m*) will be 0 (zero), in other words the building becomes stable.

Table1. The results analysis of element C16 using ETABS program.

Foundation type	**10^{th} floor max displacement - Y(mm)**	**10th floor drift**	**Mode Shape (90 %)**
Using Link Beam	11.81	0.000001	5^{th} mode
Without Link Beam	69.23	0.001463	50^{th} mode
Difference	-57.42	-0.001462	0

Foundation type	**Design M_{u2} kN-m**	**Shear V_u kN (Minor, V_{u3})**	**Design P_u kN**
Using *Link Beam*	-9.2767	3.4801	3483.2403
Without *Link Beam*	3205.4322	1188.5548	3408.7597
Difference	-3214.7089	-1185.0747	74.4806

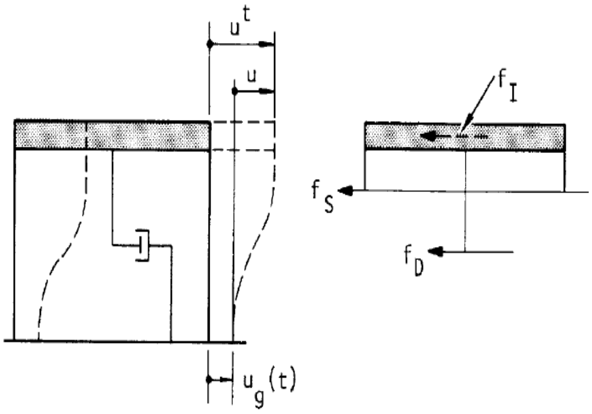

Figure 1. Dynamic equilibrium of the structure which gets the lateral earthquake force. Source: Anil K. Chopra – Dynamics of structures a primer

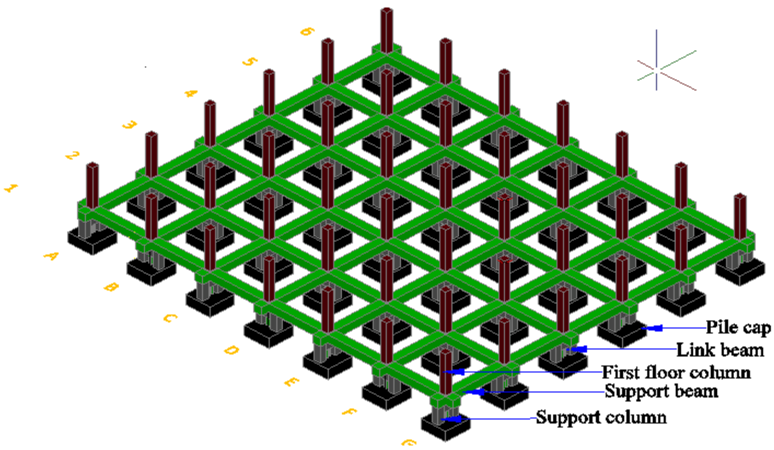

Figure 2. 3D Link Beam base isolation

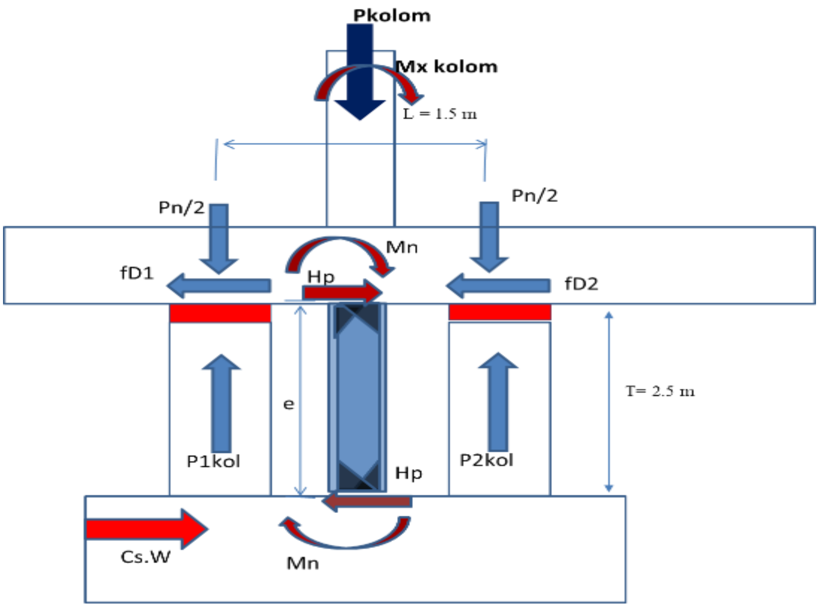

Figure 3. Idealization of the forces that occur on link beam isolation

Description and Technical

The 10-story concrete structure with dead, live and lateral loads due to the earthquake was analyzed using the Etabs program, in this study the analysis was carried out only in the Y direction, where the analysis was carried out on structure using base isolation and on structure without using base isolation.

The analysis results in the form of moment, shear, axial and deformation as well as drift are compared between the two systems, so that the difference of the above values can be obtained.

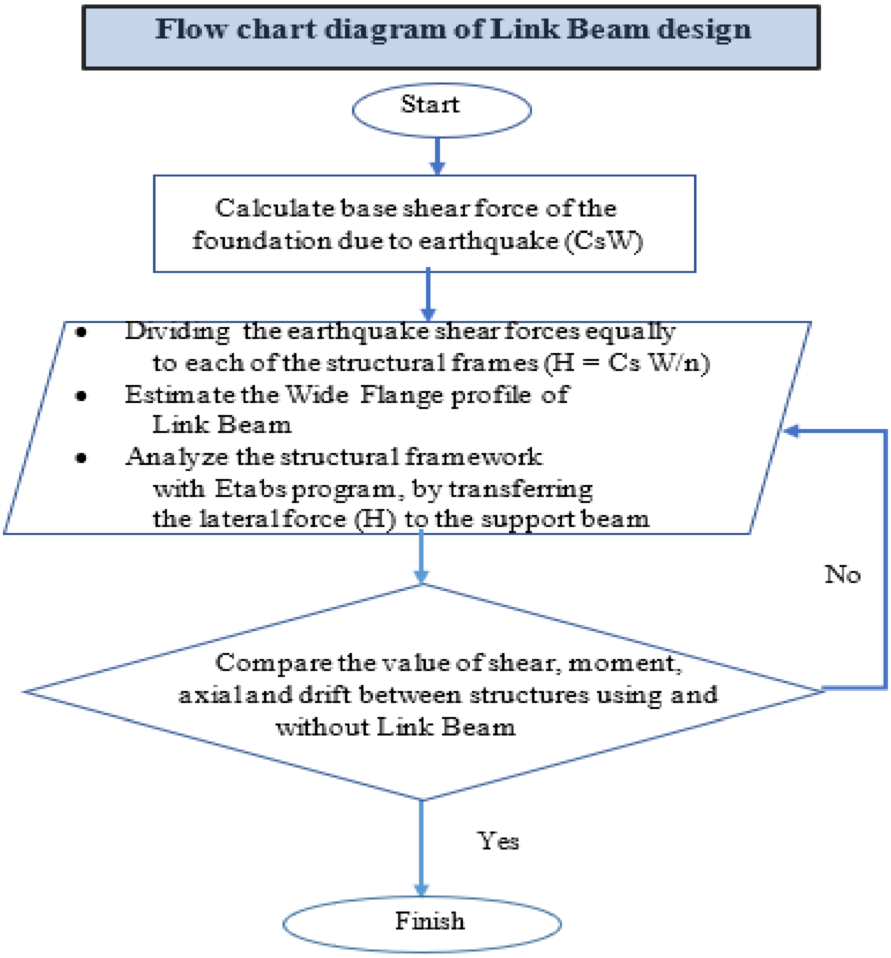

Figure 4. Flowchart Link Beam design

Structure specifications

In the structural design here, the location of the building is determined in Padang West Sumatra, with the building specifications as follows:

1. The concrete structure is a special moment-frame reinforced concrete
2. frame, with a total building height of 34 m.
3. The height between the ground floor and the base beam is 2.50 m.
4. The height between the base beam and the 1st floor is 4.50 m.
5. The height between the next floors, from the 2nd - 10th floors is 3.00 m.
6. The number of columns is 42, with the distance on the X axis: 6 x 6 m and the Y direction: 5 x 6 m
7. Analyse structure using the ETABS program.

8. Link beam design is taken on the column with the largest lateral force, that is point C-4

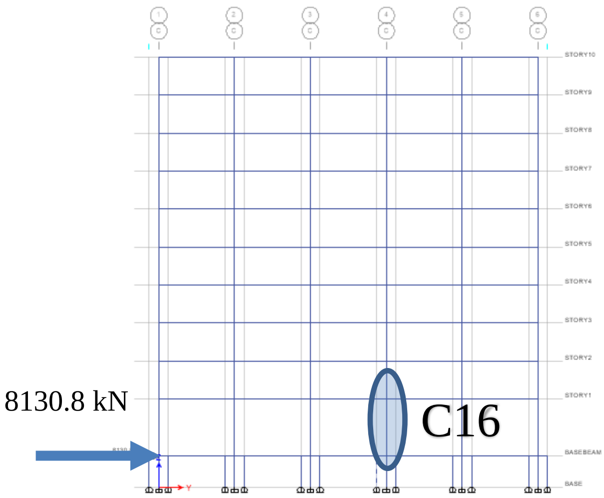

Figure 5 The frame C axis Source: ETABS software

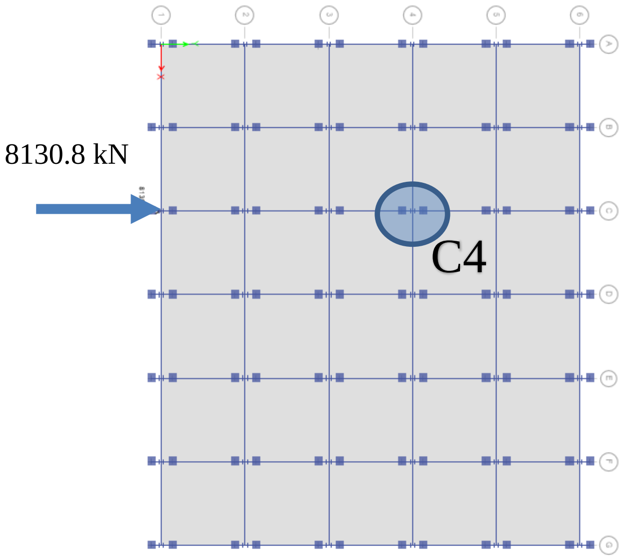

Figure 6. Base isolation plan

Table 2. Floors data

Floor level	10^{th} Floor	9^{th} Floor	8^{th} Floor	7^{th} Floor	6^{th} Floor	5^{th} Floor	4^{th} Floor	3^{th} Floor	2^{nd} Floor	1^{st} Floor	Base Beam	Base
Length (m)	3	3	3	3	3	3	3	3	3	4.5	2.5	
Elevation (m)	34	31	28	25	22	19	16	13	10	7	2.5	0

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Table 3. X and Y axis data

X Axis	A	B	C	D	E	F	G
Ordinate	0	6	12	18	24	30	36
Y Axis	1	2	3	4	5	6	
Ordinate	0	6	12	18	24	30	

Table 4. Sizes of structural beams

C	Size
Main beam	(250x500)
Joist beam	(250x400)
Support beam	(800x1500)

Table 5. Sizes of structural columns

Floor Level	Column dimension
10th Floor	250x250
9th Floor	350x350
8th Floor	350x350
7th Floor	350x350
6th Floor	350x350
5th Floor	500x500
4th Floor	500x500
Third Floor	500x500
Second Floor	500x500
First Floor`	500x500
Support column	600X600
Link beam	WF12.65

RESULTS AND DISCUSSIONS

Analysis by the Etabs program is carried out on the structural frame on the C axis to obtain values of defonation, drift, internal forces (moment, shear, axial) of elements, and reactions force of structure, the value of the analysis results above is compared between structures using the link beam base isolation system, with those who do not use isolation, as shown in Table 1.

First step analyses is calculate to obtain the base lateral force, and the force obtained is 48784.6 kN, so frame C resist 8130.8 kN lateral force as shown on figure 5. From the above value the estimated profile of link beam that match with the lateral force above is WF 12.65. then this profile apply for Etabs data.

The strength of the link beam against the lateral force

Using ETABS analyses, the lateral force on point C16 due to the earthquake is

Cs W = 267.6 kN

The estimated yield strength of Link Beam (WF 12.65), Hp = 566.8 kN

Δ_{max} Link Beam = 3.04 in (deviation of the link beam profile allowed) is greater than the deviation that occurs in the support beam (10.02 mm = 0.4 in), which means that the deviation value can be accepted.

Dynamic balance requirements:

Cs W < (fD1+fD2+Hp) Eq (4)

Cs W < 7.28+7.72+566.8

Cs W < 581.8 kN
267.6 < 581.28 kN (OK)
where: fD1 and fD2 is μ.Pn1 and μ.Pn2
μ is friction coeffisien of sliding plates.
Pn1 is axial force of column 1
Pn2 is axial force of column 2

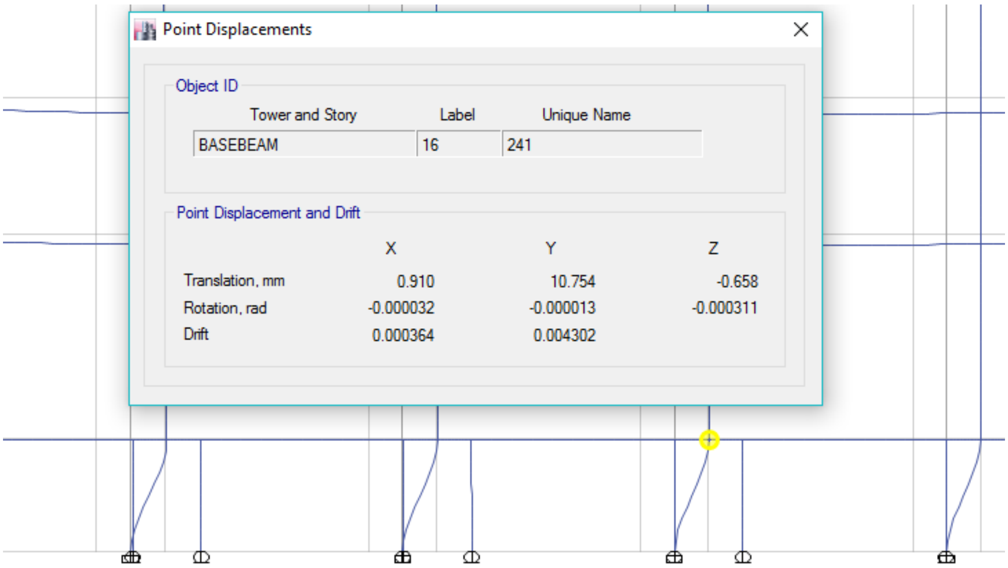
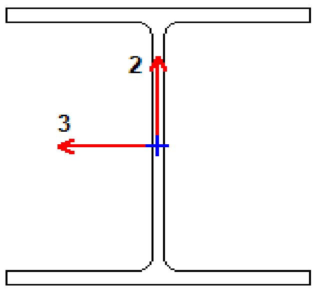


Figure 7. Deformation of link beam during Earthquake

Table 6. Link beam data

ETABS Steel Frame Design

AISC LRFD 93 Steel Section Check (Strength Summary)



Element Details (Part 1 of 2)

Level	Element	Unique Name	Location (mm)	Combo	Element Type	L (mm)	Section
BASEBEAM	C16	1746	0	WITHISOLATION	Moment Resisting Frame	2500.0	W12X65

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Element Details (Part 2 of 2)

Classification
Non-Compact

Design Code Parameters

Φ_b	Φ_c	Φ_t	Φ_v	$\Phi_{c,Angle}$
0.9	0.85	0.9	0.9	0.9

Section Properties

A (cm^2)	I_{33} (cm^4)	r_{33} (mm)	S_{33} (cm^3)	A_{v3} (cm^2)	Z_{33} (cm^3)
123.2	22185.1	134.2	1443.7	78.1	1586.3

J (cm^4)	I_{22} (cm^4)	r_{22} (mm)	S_{22} (cm^3)	A_{v2} (cm^2)	Z_{22} (cm^3)	C_w (cm^6)
90.7	7242.4	76.7	475.2	30.4	722.7	1545639.2

Material Properties

E (MPa)	f_y (MPa)	α
199900.03	344.74	

Demand/Capacity (D/C) Ratio (H1-1b)

D/C Ratio	Axial Ratio	Flexural $Ratio_{Major}$	Flexural $Ratio_{Minor}$
0.835	0.087 +	0.691 +	0.056

Stress Check Forces and Moments (H1-1b) (Combo WITHISOLATION)

Location (mm)	P_u (kN)	M_{u33} (kN-m)	M_{u22} (kN-m)	V_{u2} (kN)	V_{u3} (kN)
0	-617.3652	335.0589	-12.2313	267.5981	-9.8472

Axial Force & Biaxial Moment Design Factors

	L Factor	K	C_m	B_1	B_2	C_b
Major Bending	0.4	1.157	0.681	1	1	1.469
Minor Bending	0.4	1.16	0.678	1	1	

Axial Force and Capacities

P_u Force (kN)	ϕP_{nc} Capacity (kN)	ϕP_{nt} Capacity (kN)
617.3652	3545.8457	3823.2467

Moments and Capacities

	M_u Moment (kN-m)	ϕM_n Capacity (kN-m)
Major Bending	335.0589	484.757
Minor Bending	12.2313	217.0885

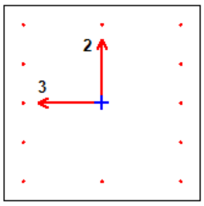
Shear Design

	V_u Force (kN)	ϕV_n Capacity (kN)	Stress Ratio
Major Shear	267.5981	566.7613	0.472
Minor Shear	9.8472	1453.2341	0.007

Table 7. Design C16 element of structure using Link Beam

ETABS Concrete Frame Design

ACI 318-08 Column Section Design



Column Element Details (Summary)

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF	Type
STORY1	C16	58	KOLOM500x500	WITHISOLATION	0	4500	0.4	Sway Special

Section Properties

b (mm)	h (mm)	dc (mm)	Cover (Torsion) (mm)
500	500	49.6	27.3

Material Properties

E_c (MPa)	f'_c (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{ys} (MPa)
25743	30	1	413.69	413.69

Design Code Parameters

Φ_T	Φ_{CTied}	$\Phi_{CSpiral}$	Φ_{Vns}	Φ_{Vs}	Φ_{Vjoint}
0.9	0.65	0.7	0.75	0.6	0.85

Axial Force and Biaxial Moment Design For P_u , M_{u2} , M_{u3}

Design P_u kN	Design M_{u2} kN-m	Design M_{u3} kN-m	Minimum M2 kN-m	Minimum M3 kN-m	Rebar Area mm^2	Rebar % %
3483.2403	-9.2767	140.8879	105.3332	105.3332	2500	1

Axial Force and Biaxial Moment Factors

	C_m Factor Unitless	δ_{ns} Factor Unitless	δ_s Factor Unitless	K Factor Unitless	Effective Length mm
Major Bend(M3)	0.973853	1.337545	1	1	4000
Minor Bend(M2)	0.399766	1	1	1	4000

Shear Design for V_{u2} , V_{u3}

	Shear V_u kN	Shear ΦV_c kN	Shear ΦV_s kN	Shear ΦV_p kN	Rebar A_v /s mm^2/m
Major, V_{u2}	0.0229	308.8518	0	0	0
Minor, V_{u3}	3.4801	308.8518	0	0	0

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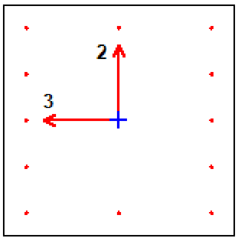
Table 8. Design C16 element of structure without Link Beam

ETABS Concrete Frame Design

ACI 318-08 Column Section Design



Column Element Details (Summary)

Level	Element	Unique Name	Section ID	Combo ID	Station Loc	Length (mm)	LLRF	Type
STORY 1	C16	58	KOLOM500 x 500	NONISOLATION	0	4500	0.4	Sway Special

Section Properties

b (mm)	h (mm)	dc (mm)	Cover (Torsion) (mm)
500	500	49.6	27.3

Material Properties

E_c (MPa)	f'_c (MPa)	Lt.Wt Factor (Unitless)	f_y (MPa)	f_{ys} (MPa)
25743	30	1	413.69	413.69

Design Code Parameters

Φ_T	Φ_{CTied}	$\Phi_{CSpiral}$	Φ_{Vns}	Φ_{Vs}	Φ_{Vjoint}
0.9	0.65	0.7	0.75	0.6	0.85

Axial Force and Biaxial Moment Design For P_u , M_{u2} , M_{u3}

Design P_u kN	Design M_{u2} kN-m	Design M_{u3} kN-m	Minimum M2 kN-m	Minimum M3 kN-m	Rebar Area mm²	Rebar % %
3408.7597	3205.4322	103.0809	103.0809	103.0809	46316	18.53

Axial Force and Biaxial Moment Factors

	C_m Factor Unitless	δ_{ns} Factor Unitless	δ_s Factor Unitless	K Factor Unitless	Effective Length mm
Major Bend(M3)	0.561038	1	1	1	4000
Minor Bend(M2)	0.406741	1	1	1	4000

Shear Design for V_{u2} , V_{u3}

	Shear V_u kN	Shear ΦV_c kN	Shear ΦV_s kN	Shear ΦV_p kN	Rebar A_v /s mm²/m
Major, V_{u2}	15.768	312.2048	0	15.768	0

	Shear V_u kN	**Shear ΦV_c kN**	**Shear ΦV_s kN**	**Shear ΦV_p kN**	**Rebar A_v /s mm²/m**
Minor, V_{u3}	1188.5548	249.7638	0	0	

Support Column

Columns with the greatest moment and compressive force was selected to design the dimension and column reinforcement[5]:

Mu = 19.29 kN-m
Pu = 0 kN

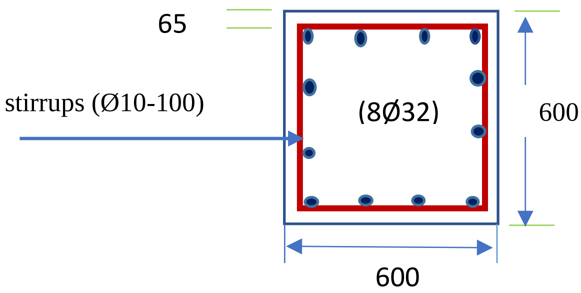


Figure 8. Details of column reinforcement

Table 9. The percentage decrease of C16 column area.

Foundation type	**Steel reinforced (mm²)**	**Size of C-16 column(mm²)**
Using Link Beam	2500 (1 %)	25e4 (500x500)
Without Link Beam	46316 [18.53 %	25e4 (500x500)
Difference	-95%	0%

Internal forces as well as deformation) and structure drift become much smaller when using this base isolation system, as shown on tabel 1

Base Isolation using Sliding Plate and Link Beam Systems is made with wide flange steel profiles, combined with steel friction plates mounted on reinforced concrete support columns, so that the manufacture can be done easily becaused the material can be found easily without imported and another advantage is the structure with this base isolation type, able to withstand the tensile force due to the over tuning force of the structure, so that it can be used for tall structures, which in other base isolator systems can only be applied to low structures, as shown on table 9 below.

Table 10. Comparation of stress allowed between base isolation types

Base Isolation type	**Compressive stress of element C16 (kN)**	**Element stress allowed**	**Overtunning moment**
Sliding plate and link beam	-2956.73 (see table 1)	Tension and shear	Allowed
Lead rubber, sliding and others	> 0 (compression)	Compression and shear	Not allowed

CONCLUSION

The results of the analysis using the Etabs program shows a significant difference between structures using a base isolation system and those without base isolation in anticipating the lateral base shear due

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to the earthquake as shown on table 6 and 7, the rebar area of C16 column can be reduce 95 % as shown below.

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