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Evaluation of Fixed Base vs. Base Isolated Building Systems

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Abstract:- The earthquake causes a great damage to the structure. It is very important to protect the structure from earthquake forces and it can be done by various methods. One of the methods is seismic base isolation. The modeling procedure of not only fixed base but also of base isolated building in ETAB software is carried out and also manual. Also the design steps of isolators and linear static analysis using UBC 97 for isolated building has been discussed in the present work. Analytical seismic response of (G+14) storied building supported on base isolation system is investigated and compared with fixed base building.

Keywords:- ETABS and Manual

I. INTRODUCTION

As part of a National Science Foundation project, the cost and performance effects of a building with and without a sliding friction pendulum base isolation system were compared. A base isolation system works as a damper to decrease the seismic lateral forces on a structure by inserting a Teflon-steel sliding system at the structure's foundation. This system isolates the shaking of the ground from the shaking of the structure and minimizes damage to the structure (http://www.nist.gov/public_affairs/releases/n97-06.htm). The first step in the development of a comparison was to design a six-story RCC frame building with a fixed base.

Fixed base:

The fixed-base building was designed to use as the "control" building to compare with the isolated building. Using ETABS, the three-story building was modelled and the lateral and gravity loads were applied per the International Building Code (2000). From the output, axial loads, bending moments, and story drift were used as design criteria and it was determined that story drift was the controlling factor. A trial and error process was used until members were found that satisfied the axial, shear, moment, and story drift demands. The shape used for the columns was a modified C45x45 that had another C50x50. An adequate beam was determined to be a B45x35.

Design calculation fixed base building:

Mapped Spectral Response Acceleration:
The price of the Ss (- mapped maximum considered earthquake spectral response
acceleration at short periods) and S1 (mapped maximum considered earthquake spectral response acceleration at a period of 1s) should consider seismic maps that have already been prepared by competent authorities is determined. Manual design for 6 storey building.

S_s= 1.3 } form code
S_1= 0.5

Site Class
Site Class = D …….

Occupancy Category (OC)
OC = III ….. 1.1 ASCE (Types of Occupancy)
Importance Factor (I)
I = 1.25 ….

Site Coefficients (F_a and F_v)

S_S = 1.3 And Site Class D
F_a = 1 ….. table 1613.5.3 (1) IBC
$S_{1=}$ 0.5Site Class D
$F_{v\,=}$ 1.5….. table 1613.5.3 (2) IBC

S_{MS} - maximum considered earthquake spectral response acceleration for short periods.
SM1 - maximum considered earthquake spectral acceleration for 1s period.

$S_{MS} = F_a*S_S$ …. ASCE Equation 11.4.1
$S_{MS} = 1* 1.3 = 1.3$
$S_{M1} = F_V *S_1$…. ASCE Equation 11.4.2
$S_{M1} = 1.5 * 0.5=0.7$
SD1 - design spectral response acceleration at a period of 1s.
SDS - design spectra response acceleration in the short period range .

$S_{DS} = 2/3*S_{MS}$ …. ASCE Equation 11.4.3
$S_{DS} = 2/3* 1.3 = 0.867$
$S_{D1} = 2/3 *S_{M1}$…. ASCE Equation 11.4.4
$S_{D1} = 2/3* 0.75 =0.5$

Seismic Design Category (SDC)

SDC= D ….. Table ASCE 11.6.1 and ASCE 11.6.2
Response Modification Coefficient (R)

If the building are in the SDs zone there are need for moment resistant frame

R= 8 …… ASCE Table 12.2.1

Fundamental Period of Structure

T_a= 0.1* number of storey …..ASCE Equation 12.8.8
T_a= 0.1* 6 = 0.6 sec
$T_a = C_t*(h_n)^x$ ………. ASCE Equation 12.8.7
h = height of building
Table 12.8.2 ASCE Ct prices and x are determined according to the type building
$C_t = 0.0466$
x = 0.9
$T_a = 0.0466*19.8^{0.9} = 0.684$ sec
T_a=0.684 s

T_a=0.684 s

T_L
T_L = 12 sec ……… assumed for Kabul city
Seismic Response Coefficient C_S

$$C_S = \frac{S_{DS}}{\frac{R}{I}}$$ …. ASCE Equation 12.8.2

$$C_S = \frac{0.867}{\frac{8}{1.25}} = 0.135$$

Since $T< T_L$ the value of C_S shall not exceed

$$C_S = \frac{S_{D1}}{T_a\frac{R}{I}}$$ …. ASCE Equation 12.8.3

$$C_S = \frac{0.5}{0.684\frac{8}{1.25}} = 0.115$$

C_S=0.115

Effective Weight of the Building
According to ASCE Code of repair or Effective Weight is calculated as follows To fix the weight, W, in addition to Dead Load, other times their hospitality is calculated as following
A) in whose place it is used as a warehouse to add at least 25% live load)
B) the weight of all items that are available in permanent repair)
C) the weight of snow in the neighborhoods of N / m2 144 more, plus 20% of the weight of the snow)
D) Where in accordance with section 4.2.2 is required to Partition, Partition and the actual weight of 0.48 KN /) m2 multiplied by the area of the floor, the choice is yours Using project plans and calculations were carried out previously for the content of the Project Design, are summarized in the table below represents an Effective Weight is the weight or repair

$W_{Eff} = W_{Roof} + \sum W_{Floor} + W_{Basement}$
$W_{Eff} = 517.2\ T + 4*773.7\ T + 666.9\ T = 4118.75$ Tons

Base Shear (V)

$V = C_S*W$ ……….ASCE Equation 12.8.1
$V = 0.115*4118.75 = 473.7$ Tons

Lateral Seismic on each Story (F_X)

$$C_{VX} = \frac{W_i*h_i^k}{\sum_{i=1}^{n}(W_i*h_i^k)}$$ …… ASCE Equation 12.8.12

K constant prices using linear interpolation obtains

$$\frac{2-1}{2.5-0.5} = \frac{2-x}{2.5-0.684}$$

k = x = 1.092

$F_X = C_{VX}*V$……… ASCE Equation 12.8.11
F_X = Lateral Seismic Force on each story
V = Base Shear
C_{VX}= Seismic Response Coefficient of each story
The force calculation in Excel computer program has been summarized in the table below has been calculated and are shown here have a flashlight.

$$C_{V1} = \frac{773.7*3.3^{1.09}}{773.7*3.3^{1.09}+773.7*6.6^{1.09}+7773.7*9.9^{1.09}+773.7*13.2^{1.09}+773.7*16.5^{1.09}+773.7*19.8^{1.09}}$$

$$C_{V1} = \frac{2689.6}{57514.68} = 0.047$$

Story	W_x (T)		$w_x*(h_x^{1.09})$	C_{vx}	F_x (T)	$V_{x\,(T)}$
1	w1	732	2689.6	0.047	22.2	473.8
2	w2	732	5725.5	0.100	47.2	451.6
3	w3	732	8907.5	0.155	73.4	404.4
4	w4	732	12188.1	0.212	100.4	331.1
5	w5	732	15544.2	0.270	128.0	230.7
6	w6	481	12459.8	0.217	102.6	102.6
	$\sum[wx*(h_x^{1.09})]$		57514.68	$\sum(F_x)$		

F_1 = 0.047* 473.75T = 22.2 Tons

Overturning Moment

$$O.M = \sum_{i=1}^{n} F_i(h_i - h_x)$$

Overturning moment of the first floor run here and calculation examples of this moment for the rest of the houses in the table below have been incorporated. O.M for First Floor

O. M_1 = 22.2*3.3+47.2*6.6+73.4*9.9+100.4*13.2+100.4*16.5+102.6*19.8
O.M_1 = 6780.7 Ton*m

Story	hx (m)		Fx (T)		Mx=∑Fi(hi-hx) (T-m)	
1	h1	3.3	F1	22.2	M1	6580.7
2	h2	6.6	F2	47.2	M2	5017.3
3	h3	9.9	F3	73.4	M3	3527.0
4	h4	13.2	F4	100.4	M4	2192.4
5	h5	16.5	F5	128.0	M5	1099.9
6	h6	19.8	F6	102.6	M6	338.7

Story Drift

$$\delta_x = \frac{C_d * \delta_{xe}}{I}$$

I = Importance Factor =1.25
C_d = Deflection Amplification Factor = 5.5 … ASCE Table 12.2.1
We need to get to get the price Story Drift δxe price we've achieved that the price of the program ETABS: All calculations in this section are implemented in Microsoft Excel program and this is the first example of Story Drift receive our house.

.$\delta_{e1} = 8.51\,mm$ … … .. From ETABS

$$\delta_1 = \frac{5.5 * 8.51}{1.25} = 37.44\,mm$$

$\delta_{e2} = 23.56\,mm$ … … .. From ETABS

$$\delta_2 = \frac{5.5 * 23.56}{1.25} = 103.66\,mm$$

Using Deflection and prices can be calculated using the following formula:

$$\Delta_n = \delta_n - \delta_{n-1}$$
$$\Delta_1 = \delta_1 = 37.44\,mm$$
$$\Delta_2 = \delta_2 - \delta_1 = 103.66 - 37.44 = 66.22\,mm$$

Now we calculate the price limit Story Drift or Δa Use the following formula to achieve this further cooperation.

Allowable Story Drift

$\Delta_a = 0.015 * h_{sx}$ ……. ASCE Table 12.12.1

$$\Delta_a = 0.015 * 3300mm = 49.5\,mm$$

The following table illustrates the calculation is to Story Drift

Isolated Base:

Story Drift Calculation					
Story	**(δ_{xe})avg (mm)**	**δ_x (mm)**	**Δ_x (cm)**	**Δ_{xa}=0.020h_{sx} (cm)**	**Is $\Delta_x \le \Delta_{xa}$**
1	8.51	37.44	3.7	6.6	Yes
2	23.56	103.66	6.6	6.6	Yes
3	37.82	166.41	6.3	6.6	Yes
4	49.57	218.11	5.2	6.6	Yes
5	57.77	254.19	3.6	6.6	Yes
6	61.87	272.23	1.8	6.6	Yes

To design the isolated building, response spectra analysis was used for seismically isolated structures as detailed in section 1623 of the International Building Code (2000).And (ASCE) Assumptions regarding effective damping and effective period were determined in order to carry out the design process. Lateral story forces were determined to be much less than those applied to the fixed-base building due to the isolation system, as expected. The building was modeled in ETABS and the gravity and reduced lateral loads were applied. A trial and error approach was used to find steel sections that satisfied axial, shear, moment, and drift demands The shape used for the columns was a modified C45x45 that had another C50x50. An adequate beam was determined to be a B45x35.

Design calculation isolated base building:

Spectral Response analysis

The price of the Ss and S1 should consider seismic maps that have already been prepared by competent authorities is determined. Manual design for 6 storey building

S_s= 1.3 } form code

S_1= 0.5

Site Class

Site Class = D …….

Occupancy Category (OC)

OC = III ….. 1.1 ASCE (Types of Occupancy)

Importance Factor (I)

I = 1.25 ….

Site Coefficients (F_a and F_v)

S_S = 1.3 And Site Class D

F_a = 1 ….. Table 1613.5.3 (1)

S_1= 0.5 site class

F_v = 1.5….. Table 1613.5.3 (2) IBC

S_{MS} , S_{M1}

$S_{MS} = F_a*S_S$ …. ASCE Equation 11.4.1

S_{MS} = 1* 1.3 =1.3

$S_{M1} = F_V *S_1$…. ASCE Equation 11.4.2

S_{M1} = 1.5 * 0.5=0.7

S_{DS} , S_{D1}

S_{DS} = 2/3*S_{MS} …. ASCE Equation 11.4.3

S_{DS} = 2/3* 1.3 = 0.867

S_{D1} = 2/3 *S_{M1}…. ASCE Equation 11.4.4

S_{D1} = 2/3* 0.75 =0.5

Seismic Design Category (SDC)

SDC= D ….. Table ASCE 11.6.1 and ASCE 11.6.2

Response Modification Coefficient (R)

If the building are in the SDs zone there are need for moment resistant frame
R= 8 …… ASCE Table 12.2.1
R1= 3/8R
R1=3 Rmax =2 there for R1=2

Effective Weight of the Building

According to ASCE Code of repair or Effective Weight is calculated as follows To fix the weight, W, in addition to Dead Load, other times their hospitality is calculated as following
A) in whose place it is used as a warehouse to add at least 25% live load)
B) the weight of all items that are available in permanent repair)
(C) the weight of snow in the neighbour hoods of N / m2 144 more, plus 20% of the weight of the snow
(D) Where in accordance with section 4.2.2 is required to Partition, Partition and the actual weight of 0.48 KN / m2 multiplied by the area of the floor, the choice is yours Using project plans and calculations were carried out previously for the content of the Project Design, are summarized in the table below represents an Effective Weight is the weight or repair

$W_{Ef\,f} = W_{Roof} + \sum W_{Floor} + W_{Basement}$
W_{Eff}= 517.2 T+ 4*773.7 T+ 666.9 T = 4118.75 Tons
Assumed effective damping
BD = 15%
BD factor =1.35
Assumed effective period at design displacement
TD= 2.5 sec
TM = 3.0 sec

Maximum effective stiffness Kd max

Kd max = 4 Wπ^2/TD^2 g = 4* 4118.75 π^2/2.5^2*9.81= 264.932kN/m
DD = (g/4*π^2)(SD1*TD/BD) =(9.81/4*π^2)(0.5*2.5/1.35)
= 2.2m

Design displacement DD

DD =(g/4π^2)(SD1*TD/BD) = (9.81/4π^2)(0.5*2.5/1.35) = 0.23m

Maximum displacement DM

DM =g/4π^2*SM1*TM/BM= 9.81*1.3 *0.7/4π^2/1.35= 16.7m
Real damping value for sliding system radiuses of curvature
r= TD^2 *g/2π^2 =(2.5)^2*9.81/2*3.14^2= 3.1m
Damping
Damping = 2/π[Mu/Mu+DD/r] = where Mu is 0.049
Damping =39,9%
Use linear interpolation and continued iteration
BD= 1.35
DD= 2.2
DM= 17

Base Shear (V)

Structure elements above the isolation system

$$vs = Kd\ max * DD/R1$$

= 264.932kN/m* 2.2/2 = 291.42 ton

Lateral Seismic on each Story (F_X)

$$C_{VX} = \frac{W_i * h_i^k}{\sum_{i=1}^{n}(W_i * h_i^k)}$$ …… ASCE Equation 12.8.12

K constant prices using linear interpolation obtains

$$\frac{2-1}{2.5-0.5} = \frac{2-x}{2.5-0.684}$$

k = x = 1.092

FX =CVX*V……… ASCE Equation 12.8.11

FX = Lateral Seismic Force on each story

V = Base Shear

CVX= Seismic Response Coefficient of each story

The force calculation in Excel computer program has been summarized in the table below have been calculated and are shown here have a flashlight.

$$C_{V1} = \frac{773.7*3.3^{1.09}}{773.7*3.3^{1.09}+773.7*6.6^{1.09}+7773.7*9.9^{1.09}+773.7*13.2^{1.09}+773.7*16.5^{1.09}+773.7*19.8^{1.09}}$$

$$C_{V1} = \frac{2689.6}{57514.68} = 0.047$$

Story	W_x (T)		$w_x*(h_x^{1.09})$	C_{vx}	F_x (T)	$V_{x\ (T)}$
1	w1	732	2689.6	0.047	12.2	364.275
2	w2	732	5725.5	0.100	27.2	348.96
3	w3	732	8907.5	0.155	44.6	313.1
4	w4	732	12188.1	0.212	61..1	257.3
5	w5	732	15544.2	0.270	77.9	181.0
6	w6	481	12459.8	0.217	67.0	83.7
	$\sum[wx*(h_x^{1.09})]$		57514.68	$\sum(F_x)$		

F_1 = 0.047*291.42 T = 12.2 Tons

Overturning Moment

$$O.M = \sum_{i=1}^{n} F_i(h_i - h_x)$$

Overturning moment of the first floor run here and calculation examples of this moment for the rest of the houses in the table below have been incorporated. O.M for First Floor

O. M_1 = 12.2*3.3+27.2*6.6+44.4*9.9+61.1*13.2+77.9*16.5+67.0*19.8

O.M_1 = 6780.7 Ton*m

Story	hx (m)		Fx (T)		Mx=∑Fi(hi-hx) (T-m)	
1	h1	3.3	F1	12.2	M1	4079.79
2	h2	6.6	F2	27.2	M2	3102.69
3	h3	9.9	F3	44.6	M3	2206.05
4	h4	13.2	F4	61.1	M4	1379.0
5	h5	16.5	F5	77.9	M5	699.27
6	h6	19.8	F6	67.0	M6	221.1

Story Drift

$$\delta_x = \frac{C_d * \delta_{xe}}{I}$$

I = Importance Factor =1.25
C_d = Deflection Amplification Factor = 5.5 … ASCE Table 12.2.1
We need to get the price Story Drift δxe price we've achieved that the price of the program ETABS. All calculations in this section are implemented in Microsoft Excel program and this is the first example of Story Drift receive our house.

.$\delta_{e1} = 6.51\, mm$ … …. From ETABS

$$\delta_1 = \frac{5.5 * 6.51}{1.25} = 28.6\, mm$$

$\delta_{e2} = 19.56\, mm$ … …. From ETABS

$$\delta_2 = \frac{5.5 * 19.56}{1.25} = 86.06\, mm$$

Using Deflection and prices can be calculated using the following formula:

$$\Delta_n = \delta_n - \delta_{n-1}$$
$$\Delta_1 = \delta_1 = 28.6\, mm$$
$$\Delta_2 = \delta_2 - \delta_1 = 86.06 - 28.6 = 57.46\, mm$$

Now we calculate the price limit Story Drift or Δa Use the following formula to achieve this further cooperation.

Allowable Story Drift

$\Delta_a = 0.015 * h_{sx}$ ……. ASCE Table 12.12.1

$$\Delta_a = 0.015 * 3300mm = 49.5\, mm$$

The following table illustrates the calculation is to Story Drift

story drift calculation					
Story	(δ_{xe})avg (mm)	δ_x (mm)	Δ_x (cm)	$\Delta_{xa}=0.020h_{sx}$ (cm)	Is $\Delta_x \le \Delta_{xa}$
1	6.51	28.64	2.9	6.6	Yes
2	19.56	86.06	5.7	6.6	Yes
3	30.82	135.61	5.0	6.6	Yes
4	42.08	185.15	5.0	6.6	Yes
5	52.77	232.19	4.7	6.6	Yes
6	59.07	259.91	2.8	6.6	Yes

RESULT

Analytical seismic response of (G+6) storied building is supported on base isolation system is investigated and compared with fixed base building. The variation in maximum storey displacement, maximum storey drift, lateral loads to stories, and storey overturning moment and storey shear of isolated building is studied under different parameters. By using software and manually Using base isolation system at (G+6) storied, it is found that the base isolation technique was protected and better for structure more than 4 storey. It was observed that the variation in maximum displacement of stories in base isolated model is very low while compared with fixed base model. It was also observed that storey overturning moment & storey shear are also found to be reduced in base isolated building.

Lateral Seismic Force on each story (ton)

Story	Fixed base		Isolated base	
	Manually	Software	Manually	Software
1	22.2	20.2	12.2	12
2	47.2	45.2	27.2	26.9
3	73.4	71.8	44.6	44.1
4	100.4	99.4	61.1	59.1
5	128.0	126.0	77.9	76.9
6	102.6	100.6	67.0	59.8

Story shear in each story (ton)

Story	Fixed base		Isolated base	
	Manually	Software	Manually	Software
1	473.8	470.8	364.275	363.075
2	451.6	450.2	348.96	347.26
3	404.4	402.1	313.1	312.1
4	331.1	330.	257.3	252.3
5	230.7	230.3	181.0	180
6	102.6	100.09	83.7	82.2

Storey Overturning Moment (ton-m)

Story	Fixed base		Isolated base	
	Manually	Software	Manually	Software
1	6580.7	6560.27	4079.79	4072.09
2	5017.3	5013.3	3102.69	3100.39
3	3527.0	3521.0	2206.05	2200.25
4	2192.4	2189.17	1379.0	1376.09
5	1099.9	1094.12	699.27	692.07
6	338.7	336.23	221.1	291.19

Storey Drift (mm)

Story	***Fixed base***		***Isolated base***	
	Manually	Software	Manually	Software
1	37.44	36.89	28.64	27.3
2	103.66	102.43	86.06	84.78
3	166.41	164.41	135.61	132.45
4	218.11	216.11	185.15	183.34
5	254.19	253.89	232.19	230.89
6	272.23	267.34	259.91	257.23

Storey displacement (cm)

Story	Fixed base		Isolated base	
	Manually	Software	Manually	Software
1	3.7	3.6	2.8	2.7
2	6.6	6.5	4.9	4.3
3	6.3	6.1	4.9	4.7
4	5.2	5.4	4.9	5.0
5	3.6	3.7	4.7	4.7
6	1.8	1.3	2.7	2.6

Modelling in ETABS software

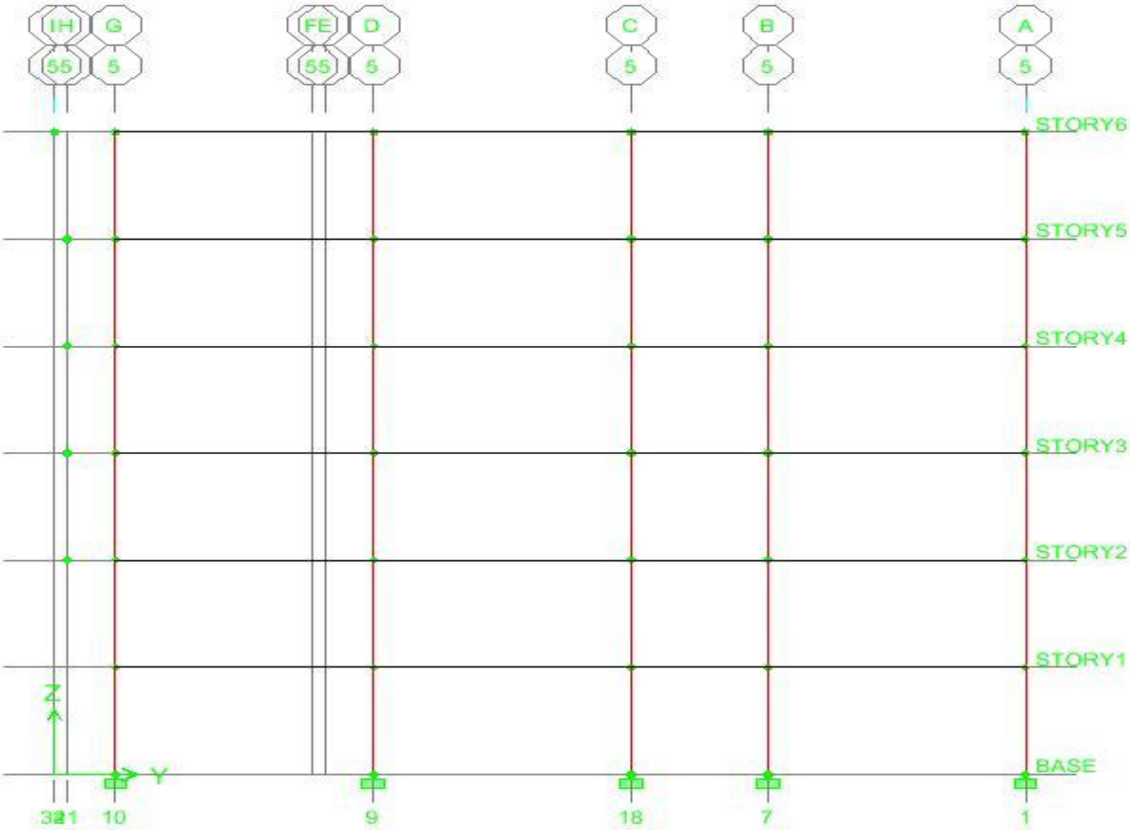

Fig modelling in Etabs software

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