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Seismic Responses in Isolated Steel Structures for Near and Far-Field Accelerograms

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Abstract:- Seismic responses of fixed-base and isolated steel structures were compared using near and far-field accelerograms. Accordingly, four, eight, and twelve-story steel structure models were created in SAP2000 for a time history analysis. Seismic responses, including relative floor displacement, base shear, potential energy, and plastic hinges were also considered for evaluation.

The results showed that seismic isolators reduced the seismic responses of far-field excitation by 80, 60, and 45% in the four, eight, and twelve-story buildings, respectively. However, near-field results were drastically different. Using the TABAS earthquake record on the eight-story building increased seismic responses by 25% on average. Moreover, some accelerograms showed seismic isolators to be ineffective in mitigating seismic responses of the twelve-story building.

Keywords*: Steel Structures, Seismic Isolators, Near-Field, Seismic Response, Accelerogram.*

1. Introduction

Seismic isolation of moment frames was evaluated in comparison with fixed-base steel structures using near and far-field earthquake records. Accordingly, five near-field and five far-field records were selected from the PEER database to be applied to four, eight, and twelve-story steel structures. A Lead-Rubber Bearing (LRB) was designed step-by-step according to the UBC-97 code of procedure and by 3D modeling using SAP2000. A time history analysis was used in light of the particular nature of near-field earthquakes. In the end, the seismic responses of isolated and fixed-based structures were compared in terms of relative floor displacement, potential energy, base shear, and the location of plastic hinges.

1.1. Three important characteristics of near-field earthquakes are as follows:

- Forward directivity: At this point in time, the released waves can be seen at the start of the accelerogram as a strong pulse moving normally to the slip direction.
- Fling step: a result of faulting that takes place within seconds from the slip and parallel to the fault direction.
- Hanging wall effects can be due to the vicinity of the site to the fault surface compared to other sites on the footwall side at a similar distance from the fault ($R_2<R_1$) (SOMERVILE, 2005).

Seismic isolators have risen in popularity, notably following the disastrous 1994 Northridge and 1995 Kobe earthquakes, for mitigating the destructive force of earthquakes by isolating structures from the ground. Naeim (1995), Chopra and Chintanup Akdee (2001) were the first to address the near-field elastic and non-elastic behavior of structures.

Relying on LRBs to dissipate the seismic energy and reduce the superstructure's seismic responses, base isolation can effectively extend the natural period of a structure's oscillation (Pan et al., 2019).

1.2. Lead-Rubber Bearings

LRBs can withstand the vertical load from the structure's weight while offering flexibility and reversibility in the horizontal direction.

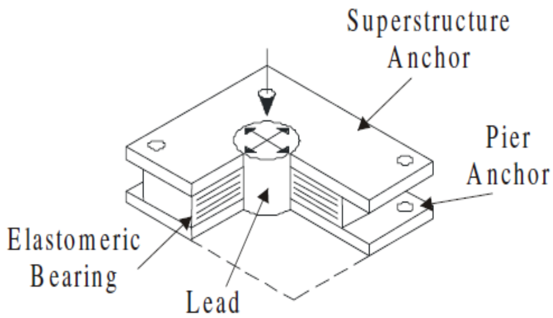

Figure 1. Lead-rubber bearings.

2. Computational Methods

Four, eight, and twelve-story steel moment-frame structures with fixed and isolated bases were considered for evaluation. The steel structures had regular plans with a 5 m span length and a 3.2 m floor-to-floor height and were modeled using steel box columns and steel I-beams or plate girders in SAP2000.

The four, eight, and twelve-story models of isolated and fixed-based buildings were loaded similarly.

Floor dead load = 600 kg.m^{-2} Floor live load = 200 kg.m^{-2}.

Roof dead load = 150 kg.m^{-2} Roof live load = 500 kg.m^{-2}.

Snow load = = 200 kg.m^{-2} Peripheral wall load = 350 kg.m^{-1}.

Tables 1, 2, 3, and 4 list the beam and column sections used in the four, eight, and twelve-story steel structures, and Table 5 presents the specifications of the LRBs installed in these structures.

Table 1. Beam and column sections in the four-story steel structure (kg.m^{-1}).

	ST1	ST2	ST3	ROOF
COLUMN	TUBO220*220*16	TUBO220*220*16	TUBO200*200*20	TUBO200*200*16
BEAM	IPE270	IPE270	IPE270	IPE220

Table 2. Beam and column sections in the eight-story steel structure (kg.m^{-1}).

	ST1	ST2	ST3,4	ST5,6	ST7	ROOF
COLUMN	TUBO400*400*25	TUBO380*380*25	TUBO300*300*20	TUBO300*300*16	TUBO280*280*16	TUBO260*260*16
BEAM	2IP24	2IP24	2IP24	2IP22	2IP22	2IP22

Table 3. Beam and column sections in the twelve-story steel structure (kg.m^{-1}).

	ST12	ST34	ST5	ST6	ST78910	ST11	STR
COLUMN	TUBO380*380*25	TUBO340*340*25	TUBO340*380*20	TUBO300*300*20	TUBO300*300*16	TUBO260*260*16	TUBO340*240*16

Table 4. LRBs used in the four, eight, and twelve-story structures (t.m^{-1}).

	EFFECTIVE STIFFNESS	STIFFNESS (TON.M)	YIELD STRENGHT	POST YIELD STIFFNESS RATIO
ISO 4	40	400	11	0.1
ISO 8	80	1000	30	0.1
ISO 12	100	1300	50	0.1

Table 5 presents details on the suitable near-field accelerograms along the normal component.

Table 5. Five near-field accelerograms.

RECORD	EARTHQUAKE MAGNITUDE	DISTANCE (KM)
TABAS,1998	7.4	1.2
ERZICAN.1992	6.7	2
LANDERS,1992	6.7	2
KOBE,1995	6.9	3.4
ELYSIAM PARK	7.1	17.5

Table 6. Five far-field accelerograms.

Records	Earthquake Magnitude	Distance (KM)	Scale Factor	Duration (sec)	PGA (cm/sec2)
West. Washington, Olympia, 1949	6.5	56	1.86	79.98	378.68
West.washington,seattle army,1948	6.5	80	5.34	66.68	289.19
Puget sound,olympia,1949	7.1	80	4.3	81.82	737.82
Simulation Hanging wall	6.5	30	0.39	29.99	121.97
Seguenary 1988palm	5.9	132	3.34	33.24	172.96

3. Near-Field Seismic Responses

Five records, namely the ERIZCAN, KOBE, LANDRES, TABAS, and SCLREL, were used on the four, eight, and twelve-story isolated and fixed-based steel structures. The evaluation considered relative floor displacement, potential energy, and base shear.

Table 7. Seismic responses of the four-story steel structure with near-field records.

DISPLACMENT(mm)	FIX-BASED	ISOLATED	RATIO
ERIZCAN	0.0122	0.0093	24%
KOBE	0.0318	0.0188	40%
LANDERS	0.0143	0.0111	22%
TABAS	0.0301	0.0174	42%
SCLREL	0.0432	0.0172	60%
POTENTIAL(kg)			
ERIZCAN	2076.78	1782.11	14%
KOBE	11960.23	6923.60	42%
LANDERS	5682.95	3796.77	33%
TABAS	7767.27	5119.72	34%
SCLREL	16420.29	5103.70	70%
BASE- SHEAR(kg)			
ERIZCAN	134294.88	119342.85	11%
KOBE	411958.11	119342.85	44%
LANDERS	289384.39	182762.95	36%
TABAS	282603.46	186151.69	34%
SCLREL	503908.7	193263.88	61%

The above table shows isolation to effectively reduce seismic response to near-field accelerograms in four-story buildings.

Table 8. Seismic responses of the eight-story steel structure with near-field records.

DISPLACMENT(MM)	FIX-BASED	ISOLATED	RATIO
ERIZCAN	0.0193	0.0159	17%
KOBE	0.0539	0.0377	30%
LANDERS	0.0315	0.0309	1%
TABAS	0.0166	0.0176	-5%
SCLREL	0.0368	0.0349	5%
POTENTIAL(kg)			

DISPLACMENT(MM)	FIX-BASED	ISOLATED	RATIO
ERIZCAN	18960.74	12336.37	35%
KOBE	181722.72	70737.83	60%
LANDERS	53976.32	47612.14	11%
TABAS	11427.51	19379.60	-69%
SCLREL	72716.26	56279.44	22%
BASE- SHEAR(kg)			
ERIZCAN	497072.7	412192	17%
KOBE	1508484	918120	39%
LANDERS	953137.3	783913.03	17%
TABAS	489601.4	524985.4	-7%
SCLREL	990323.9	848104.66	17%

According to Table 8, integrating seismic isolators in eight-story buildings would generally mitigate their seismic response to near-field accelerograms in comparison with a fixed-based configuration. However, the opposite is true in the case of the TABAS record.

Table 9. Seismic responses of the twelve-story steel structure with near-field records.

DISPLACMENT(MM)	FIX-BASED	ISOLATED	RATIO
ERIZCAN	0.011	0.0112	-2%
KOBE	0.0491	0.0389	20%
LANDERS	0.0355	0.0292	17%
TABAS	0.0202	0.0236	-16%
SCLREL	0.0378	0.0327	13%
POTENTIAL(kg)			
ERIZCAN	17507.7	19024.76	-8%
KOBE	340106.29	190451	44%
LANDERS	168411.04	117887.02	30%
TABAS	57902.35	57392.7	0.8%
SCLREL	190214.47	142248.18	25%
BASE- SHEAR(kg)			
ERIZCAN	463682.24	470225.83	-1%
KOBE	2042355.07	1529144	25%
LANDERS	1596537	1295164.7	18%
TABAS	991323.9	1002288.5	-1%

DISPLACMENT(MM)	FIX-BASED	ISOLATED	RATIO
SCLREL	1494797.4	1308699.6	12%

According to Table 9, seismic isolators reduced the seismic response of the twelve-story steel structure with three near-field accelerograms. However, the isolators can be said to be ineffective in doing the same with TABAS and ERIZCAN records.

Table 10. Mean near-field seismic responses of the isolated buildings relative to fixed-based buildings.

STORY	DISPLACMENT(MM)	BASE-SHEAR(kg)	POTENTIAL	RATIO
4	40%	40%	40%	40%
8	10%	11.8%	16.6%	38%
12	6.4%	18.36%	10.6%	35%

Overall, isolators reduced the near-field seismic response of the four, eight, and twelve-story steel structures by 0.4, 38, and 35% from the fixed-base level, respectively.

4. Far-Field Seismic Responses

Five far-field records, namely the MATCHED, PALM, PUGET, OLYMPIA, and SEATTLE, were used on the four, eight, and twelve-story isolated and fixed-based steel structures. The corresponding decrease in seismic responses of the isolated structures is illustrated in Tables 11, 12, and 13.

Table 11. Seismic responses of the four-story steel structure with far-field records.

DISPLACEMENT	FIX-BASED	ISOLATED	RATIO
MATCH	0.08425	0.02729	0.67
PALM	0.0557	0.0249	0.55
OLYMPIA	0.3994	0.0083	0.79
PUGET	0.0883	0.0130	0.85
SEATTLE	0.0601	0.0061	0.90
POTENTIAL			
MATCH	74557.78	13755.7169	0.8
PALM	32604.587	12236.6685	0.6
OLYMPIA	168908.642	14293.1742	0.9
PUGET	94512.464	3702.6767	0.95
SEATTLE	57773.962	595.40117	0.95
BASE SHEAR			
MATCH	918253.6	281053.2	0.7
PALM	580899.35	288168.92	0.5

DISPLACEMENT	FIX-BASED	ISOLATED	RATIO
OLYMPIA	395936.91	92406.985	0.8
PUGET	1013945.38	146357.28	0.85
SEATTLE	787927.43	60825.212	0.9

Table 12. Seismic responses of the eight-story steel structure with far-field records.

DISPLACEMENT	FIXED-BASED	ISOLATED	RATIO
MATCHE	0.0973	0.0505	0.5
PALM	0.914	0.0431	0.5
OLYMPIA	0.0118	0.0046	0.6
PUGET	0.0154	0.0067	0.6
SEATTLE	0.0562	0.3752	0.3
POTENTIAL			
MATCHE	673575.29	120924.469	0.8
PALM	470740.84	109740.419	0.75
OLYMPIA	463052.34	323363.74	0.3
PUGET	5406359.5	534214.81	0.9
SEATTLE	1614508.77	719524.88	0.55
BASE SHEAR			
MATCHE	3522682.9	1048045.39	0.7
PALM	2558226.7	1251313.8	0.5
OLYMPIA	6846765	323363.74	0.95
PUGET	92660796	8500661.2	0.9
SEATTLE	13329362.5	8241897	0.4

Table 13. Seismic responses of the twelve-story steel structure with far-field records.

DISPLACEMENT	FIX-BASE	ISOLATED	RATIO
MATCHE	0.0671	0.0518	0.2
PALM	0.0780	0.0622	0.2
OLYMPIA	0.0297	0.0174	0.4
PUGET	0.05	0.02	0.6
SEATTLE	0.0337	0.0144	0.5
POTENTIAL			

DISPLACEMENT	FIX-BASE	ISOLATED	RATIO
MATCHE	495907.36	260604.302	0.45
PALM	826832.59	404997.12	0.5
OLYMPIA	7159387.2	3228954.5	0.5
PUGET	26220585.4	4308802.3	0.8
SEATTLE	4231265.2	1826655.93	0.55
BASE SHEAR			
MATCHE	2537765	1915440.6	0.25
PALM	3432506.3	2325467.9	0.3
OLYMPIA	8895669	7056728.3	0.2
PUGET	19430052.5	6499152	0.7
SEATTLE	7661033.2	3787412	0.5

Table 14. Mean far-field seismic responses of the isolated buildings relative to fixed-based buildings.

STORY	DISPLACEMENT	BASE SHEAR	POTENTIAL
4	75	75	85
8	50	70	65
12	40	40	60

Table 14 shows the percent reduction in seismic responses, including the potential energy, base shear, and relative floor displacement, after using seismic isolators. Base isolation was found to reduce the responses of steel structures to far-field accelerograms by 85, 65, and 60% in four, eight, and twelve-story buildings, respectively.

5. Results

A comparison between the seismic responses of isolated and fixed-based structures using far and near-field records arrives at the following conclusions:

I. Seismic isolation reduced the seismic response of the low-rise, four-story building with near-field earthquake records by 40% on average.

II. Seismic responses from the near-field records were mitigated by 38% on average in the medium-rise, eight-story isolated steel structure. Even though, the contrary holds for the Tabas record.

III. Isolation was also found to reduce the seismic responses of the high-rise, twelve-story steel structure by 35% on average when near-field records were used. Although, in the case of Tabas and Erzican records, the isolators proved ineffective. One disadvantage of passive structural control is its dependence on external excitation, which can mitigate, exacerbate, or have no effect on seismic responses.

IV. Using far-field records, seismic isolation was found to reduce seismic responses by 80, 60, and 45% in four, eight, and twelve-story buildings, showing that base isolation becomes less effective in far-field earthquakes as the building height increases.

V. A direct-integration analysis showed seismic isolation to prevent plastic hinge formation in four-story steel structures, maintaining the superstructure in the elastic range.

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