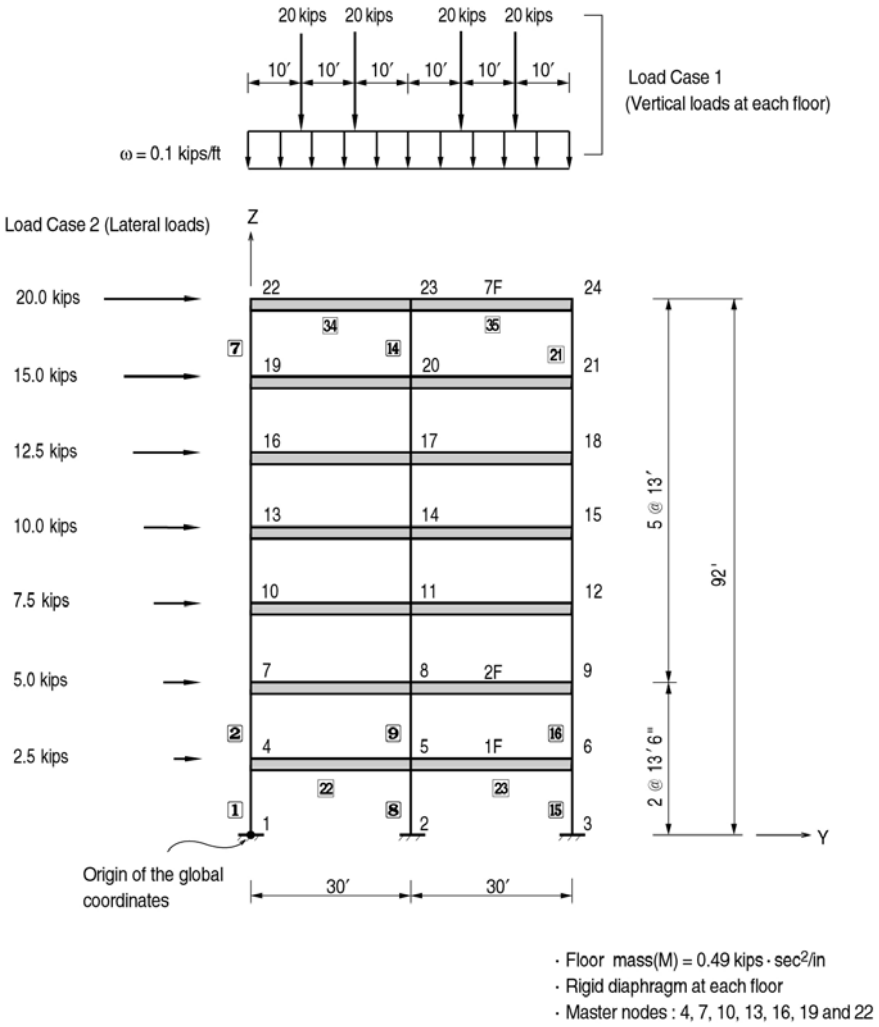
RS-2

Title

2-D, 7-story frame building under static and dynamic loads

Description

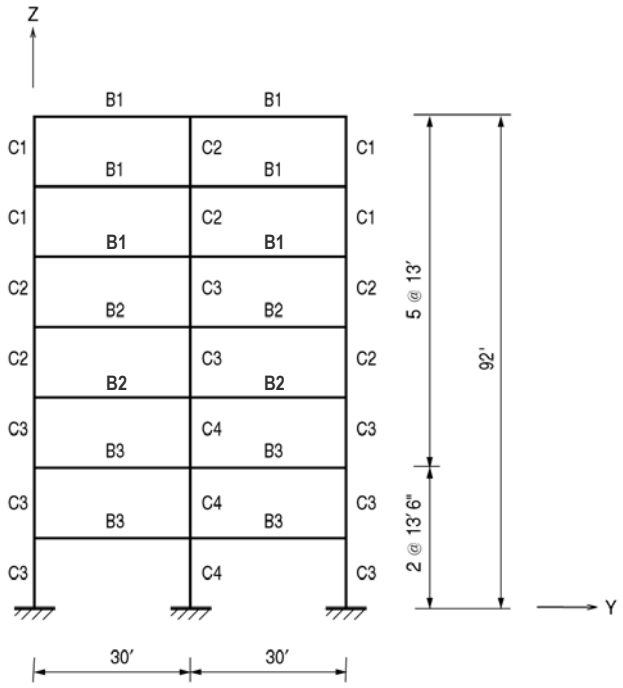
Assume that each floor of the structure illustrated below acts as a rigid diaphragm.
Calculate the natural frequencies.
Perform analyses for static lateral loads, earthquake loads specified as a response spectrum and earthquake loads specified as a base acceleration time history.
Calculate the axial forces and moments.



· Floor mass(M) = 0.49 kips · sec²/in
· Rigid diaphragm at each floor
· Master nodes : 4, 7, 10, 13, 16, 19 and 22

Structural geometry and analysis model

· Section properties of columns : C1, C2, C3 and C4
· Section properties of beams : B1, B2 and B3



Section properties of 7- story plane frame building

Model

Analysis Type

Response spectrum and time history analyses

Unit System

in, kip

Dimension

Length	$L = 60 \times 12$ in
Level height	$H_1 = 13 \times 12 + 6$ in ($1^{st} \sim 2^{nd}$ floor)
	$H_2 = 13 \times 12$ in ($3^{rd} \sim 7^{th}$ floor)
Floor mass	$M = 0.49$ kips·sec^2/in
Damping ratio	$\xi = 0.05$ (5 %)
Gravitational acceleration	$g = 386.4$ in/sec^2
Response spectrum data	1941 El Centro N-S component

Element

Beam element

Material

Modulus of elasticity $E = 29500$ ksi

Section Property

Refer to the figure shown above.

Areas and moments of inertia for columns

C1 : $A = 51.17$ in^2 $I_{yy} = 2150$ in^4

C2 : $A = 62.10$ in^2 $I_{yy} = 2670$ in^4

C3 : $A = 72.30$ in^2 $I_{yy} = 3230$ in^4

C4 : $A = 84.40$ in^2 $I_{yy} = 3910$ in^4

Areas and moments of inertia for beams

B1 : A = 50 in^2 I_{yy} = 3330 in^4
B2 : A = 50 in^2 I_{yy} = 4020 in^4
B3 : A = 50 in^2 I_{yy} = 5120 in^4

Boundary Condition

Nodes 1 ~ 3 ; Constrain Dy, Dz and Rx.
Nodes 4 ~ 22 (at an increment of 3) ; Constrain Dy of all nodes at each floor to these nodes. (Master nodes)

Load Case

Static vertical loads ;

The following loads are applied to each floor in the -Z direction.:
Uniform line load = 0.1 kips/ft = 0.1/12 kips/in
Each span is subjected to two concentrated loads, 20.0 kips each

Static lateral loads ;

The following loads are applied to the master nodes on each floor in the Y direction.
Node 4 (2^{nd} level) : 2.5 kips
Node 7 (3^{rd} level) : 5.0 kips
Node 10 (4^{th} level) : 7.5 kips
Node 13 (5^{th} level) : 10.0 kips
Node 16 (6^{th} level) : 12.5 kips
Node 19 (7^{th} level) : 15.0 kips
Node 22 (Roof level) : 20.0 kips

Dynamic loads ;

Floor masses are assigned to the master nodes at each floor in the Y direction.
The response spectrum data of the El Centro N-S component are applied in the Y direction.
Number of natural frequencies to be computed = 7

Earthquake loads ;

The N-S acceleration component of the EL Centro is applied to the entire structure in the Y direction.

Load Case
- RS-02-1
  - Load Case 1 : Static vertical loads
  - Load Case 2 : Static lateral loads
  - Load Case 3 : Dynamic loads
  - Load Combination 1 : Static vertical loads + Static lateral loads
  - Load Combination 2 : Static vertical loads + (+)Dynamic loads
  - Load Combination 3 : Static vertical loads + (-) Dynamic loads
- RS-02-2
  - Load Case 1 : Time history loads (Earthquake loads)

Results

Eigenvalue Analysis Results

EIGENVALUE ANALYSIS													
	Mode No	Frequency (rad/sec)	Frequency (cycle/sec)	Period (sec)	Tolerance								
	1	4,934908	0,785415	1,273212	4,3765e-016								
	2	14,568672	2,318676	0,431281	7,7667e-015								
	3	25,958788	4,131469	0,242045	4,7610e-013								
	4	39,225914	6,242998	0,160179	2,7560e-013								
	5	52,804465	8,404092	0,118990	2,1707e-013								
	6	66,094387	10,519248	0,095064	1,9637e-012								
	7	79,019124	12,576284	0,079515	2,8268e-011								
MODAL PARTICIPATION MASSES(%) PRINTOUT													
	Mode No	TRAN-X		TRAN-Y		TRAN-Z		ROTN-X		ROTN-Y		ROTN-Z	
		MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM	MASS	SUM
	1	0,00	0,00	79,96	79,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	2	0,00	0,00	11,34	91,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	3	0,00	0,00	4,18	95,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	4	0,00	0,00	2,12	97,59	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	5	0,00	0,00	1,41	99,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	6	0,00	0,00	0,68	99,69	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	7	0,00	0,00	0,31	100,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
EIGENVECTOR													

Displacements of RS-02-1

	Node	Load	DX (in)	DY (in)	DZ (in)	RX ([rad])	RY ([rad])	RZ ([rad])
▶	22	LCB1	0.000000	1.450764	-0.028999	-0.001012	0.000000	0.000000
	22	LCB2	0.000000	5.436736	0.022768	0.001434	0.000000	0.000000
	22	LCB3	0.000000	-5.436736	-0.116221	-0.002654	0.000000	0.000000

Member Forces of RS-02-2

	Elem	Load	Part	Axial (kip)	Shear-y (kip)	Shear-z (kip)	Torsion (kip·in)	Moment-y (kip·in)	Moment-z (kip·in)
▶	1	CASE2	i	69.99	0.00	20.67	0.00	2324.68	0.00
	1	CASE2	1/4	69.99	0.00	20.67	0.00	1487.46	0.00
	1	CASE2	2/4	69.99	0.00	20.67	0.00	650.24	0.00
	1	CASE2	3/4	69.99	0.00	20.67	0.00	-186.98	0.00
	1	CASE2	j	69.99	0.00	20.67	0.00	-1024.20	0.00

Displacements of RS-02-2

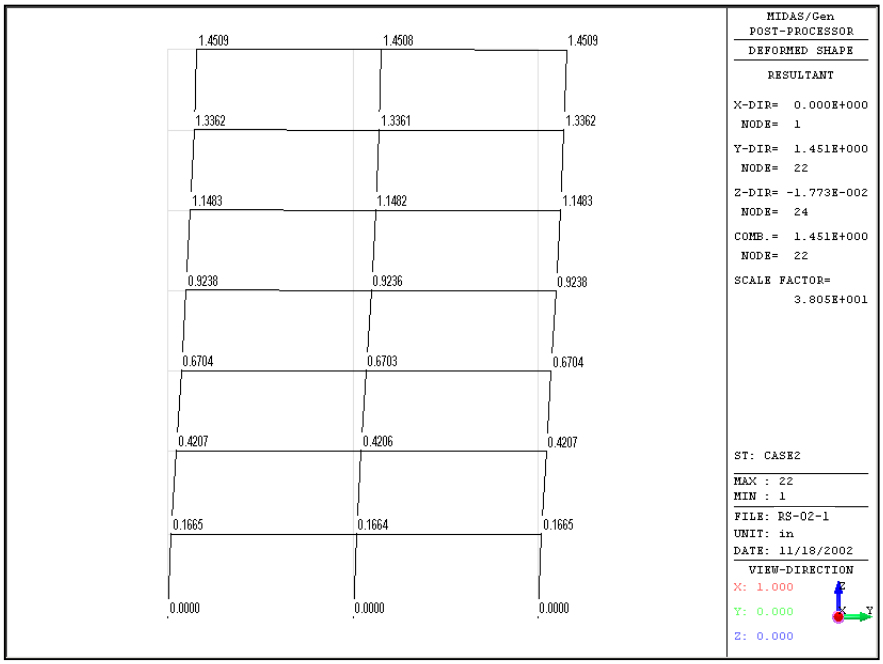
	Node	Load	DX (in)	DY (in)	DZ (in)	RX ([rad])	RY ([rad])	RZ ([rad])
▶	22	Time(max)	0.000000	5.487354	0.069371	0.002202	0.000000	0.000000
	23	Time(max)	0.000000	5.487354	0.000000	0.001660	0.000000	0.000000
	24	Time(max)	0.000000	5.487354	0.061678	0.002202	0.000000	0.000000
	22	Time(min)	0.000000	-4.465072	-0.061678	-0.002357	0.000000	0.000000
	23	Time(min)	0.000000	-4.465072	0.000000	-0.001768	0.000000	0.000000
	24	Time(min)	0.000000	-4.465072	-0.069371	-0.002357	0.000000	0.000000
	22	Time(all)	0.000000	5.487354	0.069371	0.002357	0.000000	0.000000
	23	Time(all)	0.000000	5.487354	0.000000	0.001768	0.000000	0.000000
	24	Time(all)	0.000000	5.487354	0.069371	0.002357	0.000000	0.000000

Member Forces of RS-02-2

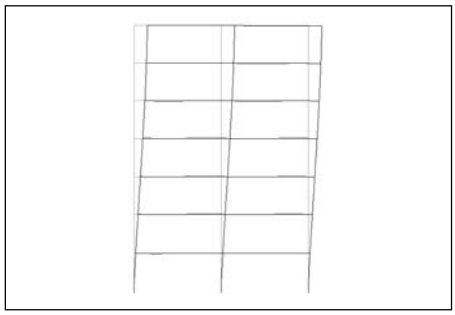
	Elem	Load	Part	Axial (kip)	Shear-y (kip)	Shear-z (kip)	Torsion (kip·in)	Moment-y (kip·in)	Moment-z (kip·in)
▶	1	Time(max)	i	263.11	0.00	81.21	0.00	9115.18	0.00
	1	Time(max)	1/4	263.11	0.00	81.21	0.00	5826.09	0.00
	1	Time(max)	2/4	263.11	0.00	81.21	0.00	2536.99	0.00
	1	Time(max)	3/4	263.11	0.00	81.21	0.00	868.26	0.00
	1	Time(max)	j	263.11	0.00	81.21	0.00	3870.02	0.00
	1	Time(min)	i	-215.14	0.00	-74.12	0.00	-8158.17	0.00
	1	Time(min)	1/4	-215.14	0.00	-74.12	0.00	-5158.12	0.00
	1	Time(min)	2/4	-215.14	0.00	-74.12	0.00	-2166.66	0.00
	1	Time(min)	3/4	-215.14	0.00	-74.12	0.00	-780.23	0.00
	1	Time(min)	j	-215.14	0.00	-74.12	0.00	-4049.75	0.00
	1	Time(all)	i	263.11	0.00	81.21	0.00	9115.18	0.00
	1	Time(all)	1/4	263.11	0.00	81.21	0.00	5826.09	0.00
	1	Time(all)	2/4	263.11	0.00	81.21	0.00	2536.99	0.00
	1	Time(all)	3/4	263.11	0.00	81.21	0.00	868.26	0.00
	1	Time(all)	j	263.11	0.00	81.21	0.00	4049.75	0.00

Reaction Forces of RS-02-2

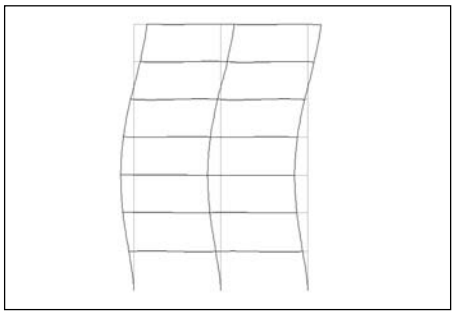
	Node	Load	FX (kip)	FY (kip)	FZ (kip)	MX (kip-in)	MY (kip-in)	MZ (kip-in)
▶	1	Time(max)	0.000000	74.117449	215.143958	9115.183952	0.000000	0.000000
	2	Time(max)	0.000000	110.412712	0.000000	12333.753338	0.000000	0.000000
	3	Time(max)	0.000000	74.117449	263.107026	9115.183952	0.000000	0.000000
	1	Time(min)	0.000000	-81.212285	-263.107026	-8158.169754	0.000000	0.000000
	2	Time(min)	0.000000	-122.375965	0.000000	-10995.78548	0.000000	0.000000
	3	Time(min)	0.000000	-81.212285	-215.143958	-8158.169754	0.000000	0.000000
	1	Time(all)	0.000000	81.212285	263.107026	9115.183952	0.000000	0.000000
	2	Time(all)	0.000000	122.375965	0.000000	12333.753338	0.000000	0.000000
	3	Time(all)	0.000000	81.212285	263.107026	9115.183952	0.000000	0.000000
	SUMMATION OF REACTION FORCES PRINTOUT							
		Load	FX (kip)	FY (kip)	FZ (kip)			
		Time(all)	0.000000	284.800534	0.000000			
		Time(max)	0.000000	258.563150	0.000000			
		Time(min)	0.000000	-284.800534	0.000000			



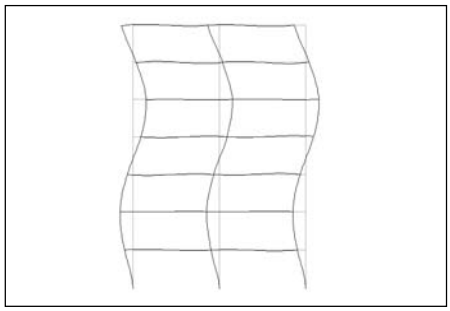
Deformed shape of the structure : Load Case 2



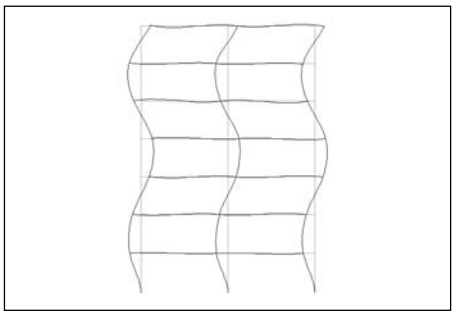
(a) 1st vibration mode



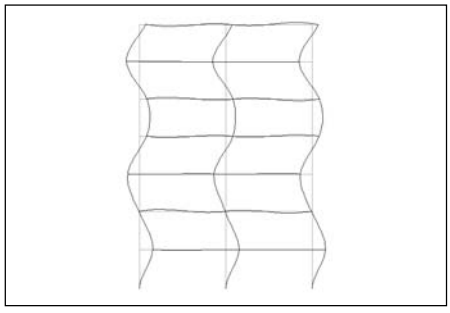
(b) 2nd vibration mode



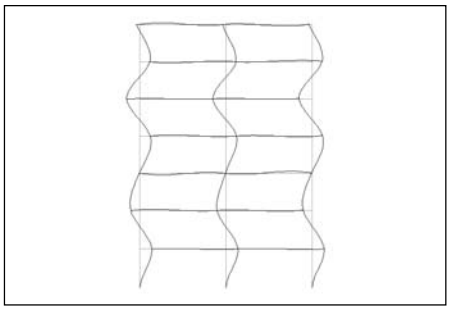
(c) 3rd vibration mode



(d) 4th vibration mode

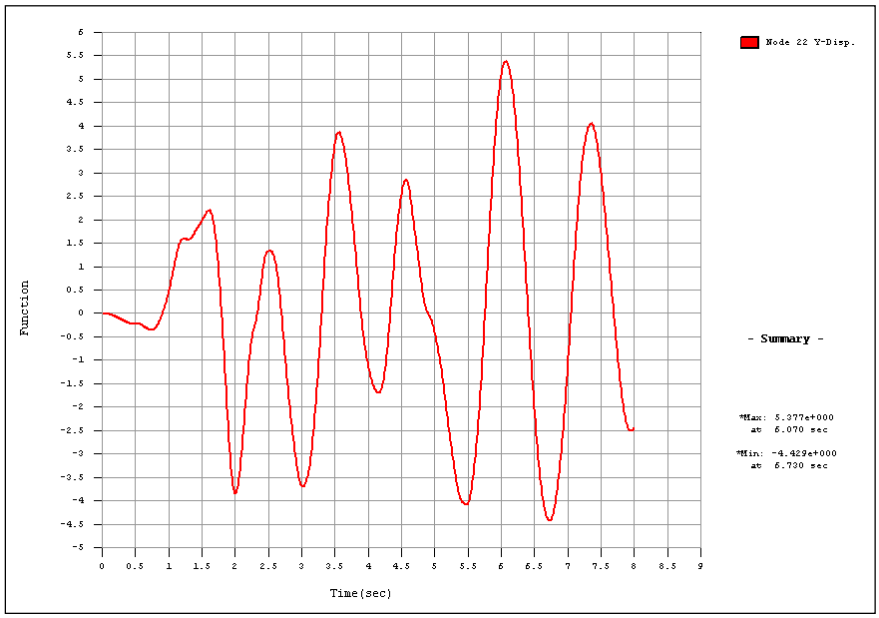


(e) 5th vibration mode

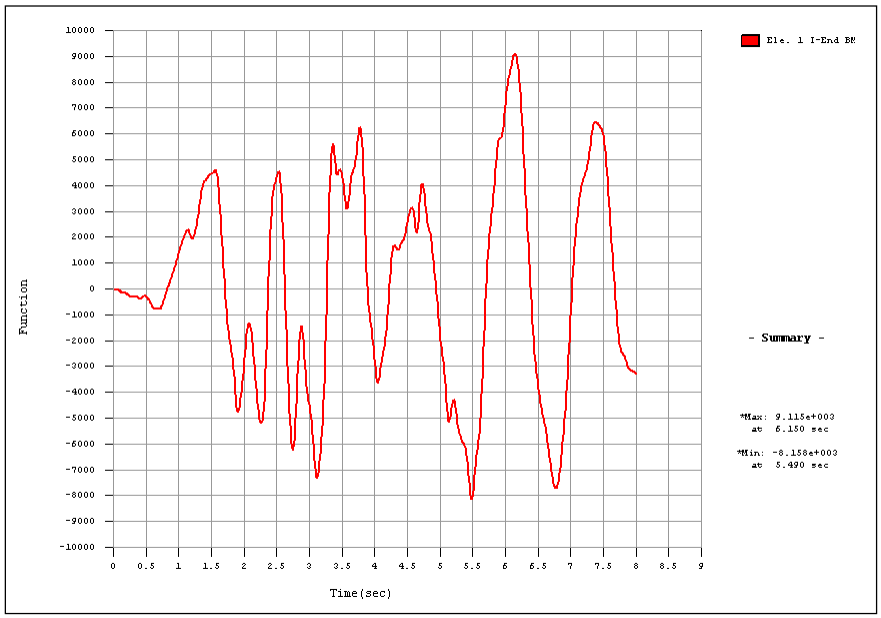


(f) 6th vibration mode

Vibration modes of the structure



(a) Lateral displacements at the node 22



(b) Bending moments at the I-end of the element 1

Time history analysis results due to earthquake loads

Comparison of Results

Results due to Lateral Loads

Unit : in, kip-in

Result	Ref. 1	SAP2000	ETABS	MIDAS/Gen
Lateral displacement at the node 22	1.450764	1.450764	1.4508	1.450764
Axial force of the element 1	69.99	69.99	69.99	69.99
Bending moment of the element 1	2324.68	2324.68	2324.68	2324.68

Natural Periods

Unit : sec

Mode	Natural period			
	Ref. 1	SAP2000	ETABS	MIDAS/Gen
1 *st*	1.2732	1.2732	1.2732	1.2732
2 *nd*	0.4313	0.4313	0.4313	0.4313
3 *rd*	0.2420	0.2420	0.2420	0.2420
4 *th*	0.1602	0.1602	0.1602	0.1602
5 *th*	0.1190	0.1190	0.1190	0.1190
6 *th*	0.0951	0.0951	0.0951	0.0951
7 *th*	0.0795	0.0795	0.0795	0.0795

Response Spectrum Analysis Results (SRSS)

Unit : in, kip

Result	Ref. 1	SAP2000	ETABS	MIDAS/Gen
Lateral displacement at the node 22	5.438	5.437	5.431	5.437
Axial force of the element 1	261.8	261.7	261.5	261.7
Bending moment of the element 1	9868	9864	9916	9864

Time History Analysis Result due to Earthquake Loads

Unit : in, kip

Result	Ref. 1	SAP2000	ETABS	MIDAS/Gen
Lateral displacement at the top (22, 23and 24)	5.48	5.49	5.49	5.49
Base Shear Force	284.0	284.7	285.0	284.8
Axial force of the element 1	258.0	263.0	263.0	263.1
Bending moment of the element 1	8740	9104	9104	9115

References

"*Static and Dynamic Analysis of Multistory Frame Structure Using DYNAMIC/ EASE2*", Engineering Analysis Corporation and Computers and Structures, Inc., Berkeley, California.

"*SAP90, A Series of Computer Programs for the Finite Element Analysis of Structures, Structural Analysis Verification Manual*", Computer and Structures, Inc., 1992, Example 1.

"ETABS, Examples Manual", Version 6.0, Computers and Structures, Inc., Berkeley, California, 1994, Example 7.

Ground Acceleration Records