Seismic Evaluation of Existing I.I.T. Kanpur Library Building and its Strengthening with Proposed Extension

B. Tech Project (2003-2004)

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Project Guide:

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In this Presentation….

- Introduction
- About the Building
- Analysis of The Model
- Ambient Vibration Testing
- Methods of Retrofitting
- Conclusion

About the Building …

- Three Storey RC Ordinary Moment Resisting Frame Building
- 62.17 m along North-South & 41.45 m along East-West Direction (Rectangular, Aspect Ratio 1.5 : 1)
- Partly Stilt Structure
  - Dimensions of Stilted Part: 41.5 m X 20.72 m
- Square Shaped Opening: 15.54 mX15.54 m
- Un-reinforced Masonry walls out of plane of the frame

View from South, showing the partly stilt structure

View from South-East

Showing the slender corner column

View from North side showing the out of plane masonry walls

About the Software

- ETABS

  (Extended Three Dimensional Analysis of Building Systems)
- Creating and modifying a model, executing the analysis, design and optimizing the design can be done through a single interface
- Comprises the following modules
  - Modeling
  - Load Generation
  - Analyzing
  - Output display and Result Generation

Modeling Procedure

- Getting started with the software
- Assigning the grid lines
- Defining the frame, wall and slab sections
- Assigning the members to the grid lines i.e. erecting the structure
- Defining load combinations and assigning the loads

Modeling Procedure….

- Defining Different Sections

  - 28 different column sections
  - 131 different Beam Sections
  - 19 different slab sections
  - 1 wall section

- Columns need to be defined as having same size Reinforcement Bars
- Properties of different materials specified, are as follows

Properties of Materials

Concrete

Mass Per Unit Volume	2.40
Weight Per Unit Volume	23.56
Modulus Of Elasticity	24821128
Poisson's Ratio	0.20
Coefficient Of Thermal Expansion	9.900E-06

Masonry

Mass Per Unit Volume	1.733
Weight Per Unit Volume	17
Modulus Of Elasticity	4000000
Poisson's Ratio	0.1
Coefficient Of Thermal Expansion	5.500E-03

Steel

Mass Per Unit Volume	7.8271
Weight Per Unit Volume	76.8195
Modulus Of Elasticity	1.999E+08
Poisson's Ratio	0.3
Coefficient Of Thermal Expansion	1.170E-05

Defining Load Combinations and Assigning Loads

- 1.5 (DL+IL)
- 1.2 (DL +IL±EL)
- 1.5 (DL±EL)
- 0.9 DL±1.5 EL

DL: Dead Load
IL: Imposed or Live Load
EL: Earthquake Load

- Roof Load
  - DL Due to Water Proofing=1.5 kPa
  - Imposed Load= 0.75 kPa
- Live Load for other floors = 5 kPa

Analysis of the model…

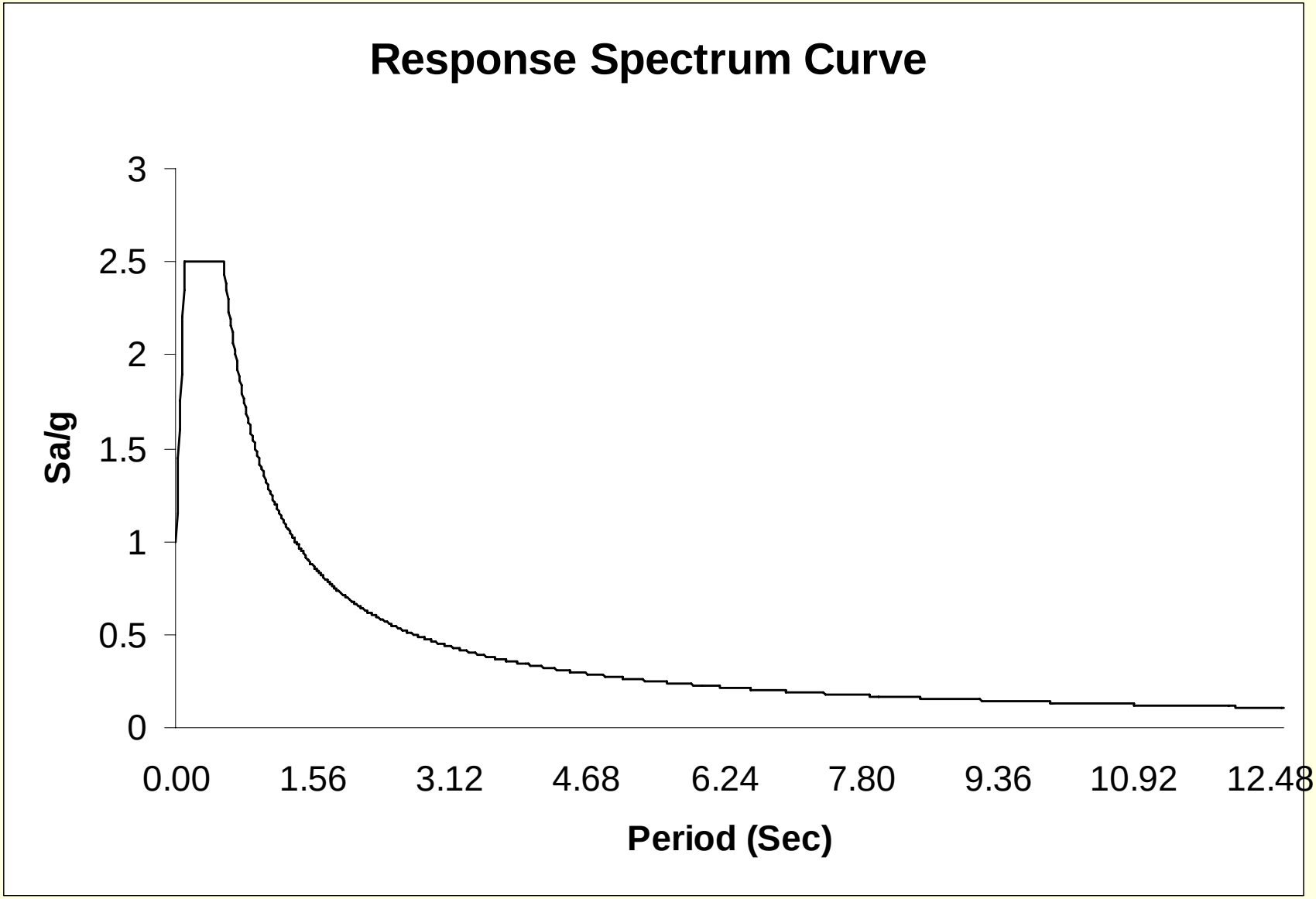
- Method adopted: *Response Spectrum Method*

- Steps Involved:
  - Defining the Response Spectrum Case
    - Spectrum Case Name: *Response*
    - Structural and Function Damping: *0.05*
    - Modal Combination: *CQC*

      (Complete Quadratic Combination)
    - Directional Combination: *SRSS*

      (Square root of sum of squares)

Response Spectrum Curve



Salient Features of the Analysis….

- 12 modes of vibration were captured
  - 90-98% mass participate in the first 12 modes
  - On adding further modes, no significant change in the mass participation
- Following three models of the building were analyzed
  - Bare Frame model
  - Model with solid walls and without openings
  - Model with openings in walls
- Natural Period values for the three models have been tabulated

Mode	Periods (seconds)				Nature of Mode
	Bare Frame	Walls (ithout Openings)	Walls (With Openings)	Experimental value	
1	1.1406	0.9563	1.0378	0.69	Torsional
2	0.9737	0.7100	0.8122	0.50	Translational (along X)
3	0.8447	0.6506	0.6813		Torsional
4	0.2564	0.5941	0.5195		Torsional
5	0.2485(Tr X)	0.3096	0.2464		Torsional
6	0.2206	0.2456	0.1952		Torsional
7	0.1857	0.1170	0.1810		Torsional
8	0.1613 Mixed..Tr X)	0.1160	0.1629		Torsional
9	0.1559(Torsional)	0.1066	0.1170(Trans Y)	0.40	Translational Y
10	0.1286(Torsional)		0.1160		
11	0.1191		0.1120		
12	0.1183		0.1039		

Interpretation of Results

- As the stiffness of the building decreases period value increases
  - Verified from : $T = 2*\prod* \sqrt{(m/k)}$
- The results have been interpreted for the model which has walls with openings
  - Modal Participation Factors and
  - Maximum Storey Drifts Were Verified

Modal Participation Factors (%)

Mode	UX	UY	SumUX	SumUY	RX	RY	RZ	SumRX	SumRY	SumRZ
1	0.09	0.00	0.09	0.00	0.00	0.00	0.01	0.00	0.00	0.01
2	0.01	70.79	0.10	70.79	96.75	0.01	0.23	96.75	0.01	0.24
3	0.05	0.00	0.15	70.79	0.00	0.00	0.00	96.75	0.01	0.24
4	32.87	0.18	33.02	70.97	0.21	45.73	40.41	96.97	45.74	40.65
5	36.24	0.07	69.26	71.04	0.08	50.59	36.30	97.04	96.33	76.95
12	0.00	0.00	90.94	90.49	0.00	0.00	0.00	98.85	98.88	84.93

Maximum Storey Drift…

Story	Item	X	Y	Z	DriftX (mm)	DriftY (mm)	**Permissible Drift (IS:1893) (mm)**
ROOF	Max Drift X	-0.762	34.29	15.686	0.252		15.24
ROOF	Max Drift Y	58.979	-0.762	15.686		0. 343	15.24
STORY2	Max Drift X	36.271	41.453	11.876	1.564		17.64
STORY2	Max Drift Y	62.179	0	11.876		2.72	17.64
STORY1	Max Drift X	46.634	41.453	7.466	3.509		15.64
STORY1	Max Drift Y	62.179	5.182	7.466		6.629	15.64
G FLOOR	Max Drift X	22.453	10.363	3.556	5.945		11.04
G FLOOR	Max Drift Y	62.179	31.09	3.556		9.098	11.04
PLINTH	Max Drift X	10.363	31.09	0.8	8.388		3.2
PLINTH	Max Drift Y	56.998	41.453	0.8		7.66	3.2

Interpretation of Results…

- Prominent Mode of Vibration
  - Second Mode (from modal participation)
  - Translational in X direction with period of 0.8122 s.

- Adequacy of Columns
  - The adequacy of the columns was checked on the basis of the value of the expression:

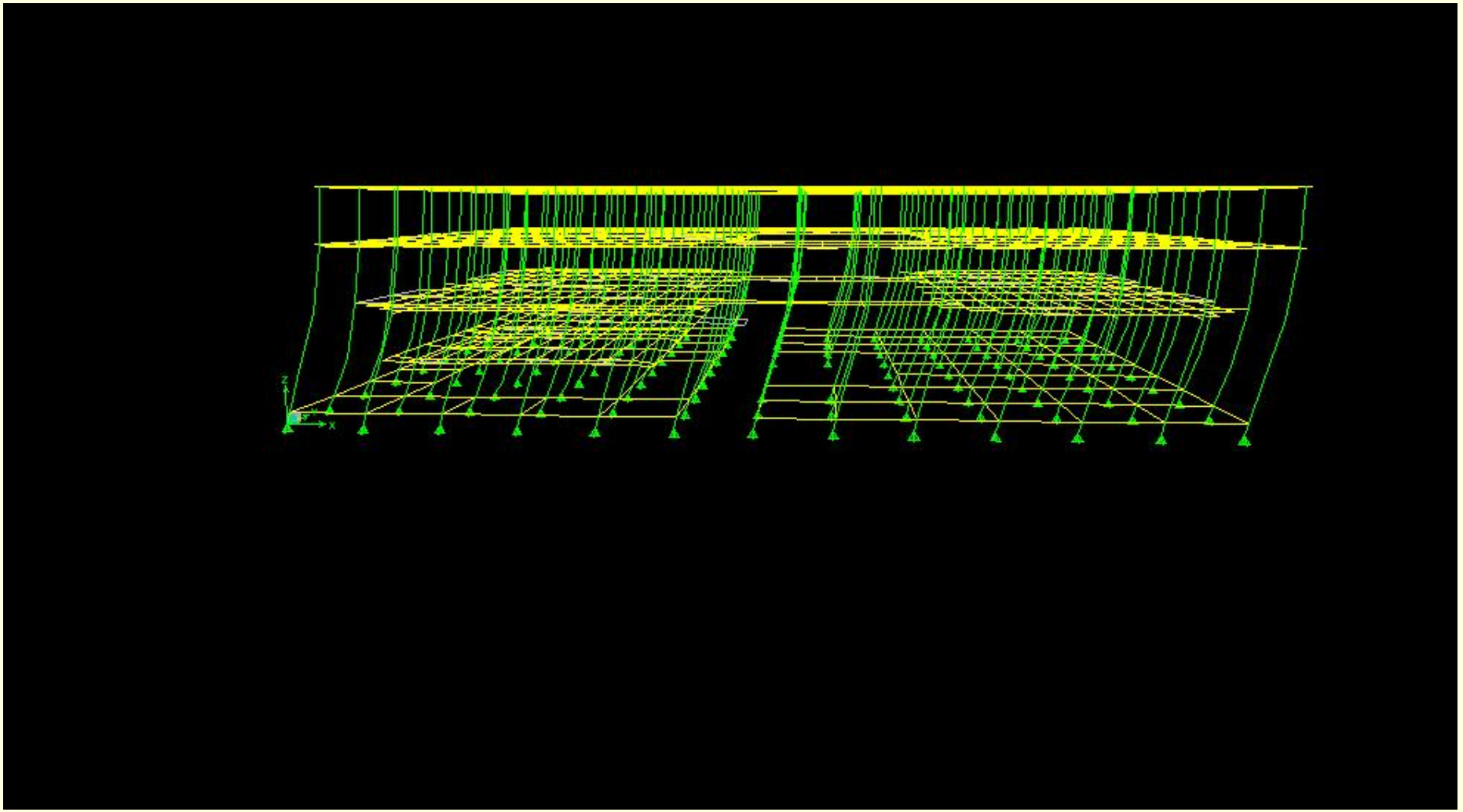
$$(Mux/Mux1)^{\alpha} + (Muy/Muy1)^{\alpha}$$

- Demand Vs Capacity for storey shear

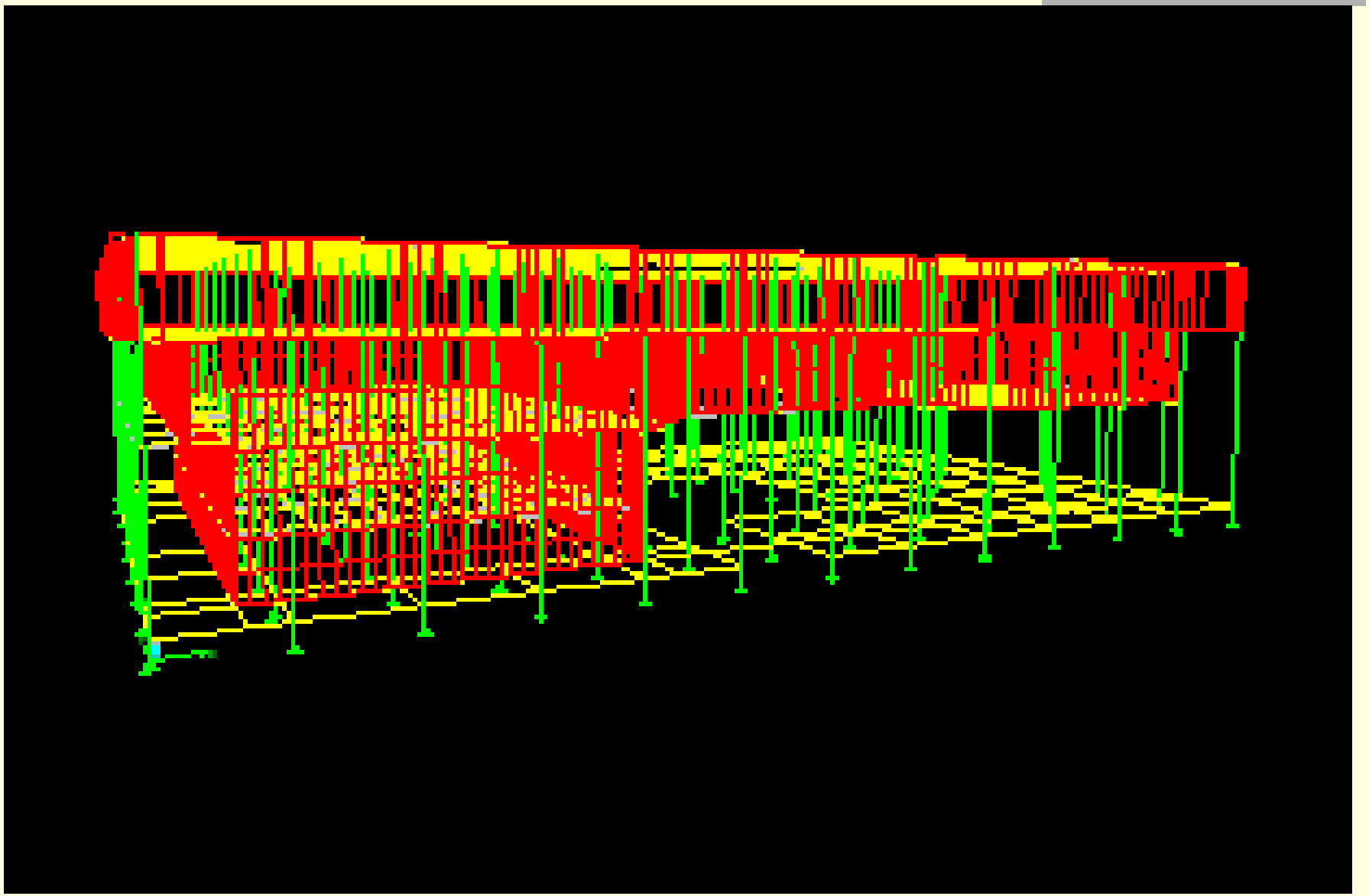
Column	Pu (KN)	Mux (KNm)	Muy	Mux1	Muy1	Value
C74	663.01	290.19	82.41	279.18	279.18	1.33
C90	861.48	354.93	128.40	314.08	314.08	1.52
C82	1227.48	426.02	219.36	314.08	314.08	2.11
C85	879.03	357.48	132.46	296.63	296.63	1.64
C86	1027.07	462.36	141.70	314.08	314.08	1.97
C104	1197.62	454.27	220.12	296.63	296.63	2.40
C105	874.10	446.44	27.24	296.63	296.63	1.65
C50	940.96	453.65	78.16	296.63	296.63	1.84
C63	597.90	293.56	55.26	279.18	279.18	1.25
C70	528.14	292.19	26.97	244.29	244.29	1.31
C62	555.53	321.86	50.50	261.73	261.73	1.42
C61	580.27	355.92	52.56	261.73	261.73	1.56
C69	510.54	321.52	25.49	251.26	251.26	1.38
C60	563.56	356.45	26.15	261.73	261.73	1.46
C44	479.20	342.30	77.92	261.73	261.73	1.61
C54	952.71	356.60	58.34	279.18	279.18	1.49
C76	624.05	271.04	36.65	296.63	296.63	1.04
C24	487.00	338.19	35.73	244.29	244.29	1.53
C72	540.67	293.29	3.70	296.63	296.63	1.00
C71	526.49	323.56	0.97	314.08	314.08	1.03
C59	562.29	340.11	4.23	296.63	296.63	1.16
C22	457.25	269.64	13.75	279.18	279.18	1.02

Bare Frame Model

- Prominent Mode of Vibration- Translational along North-South direction with Time Period of 0.9737 s

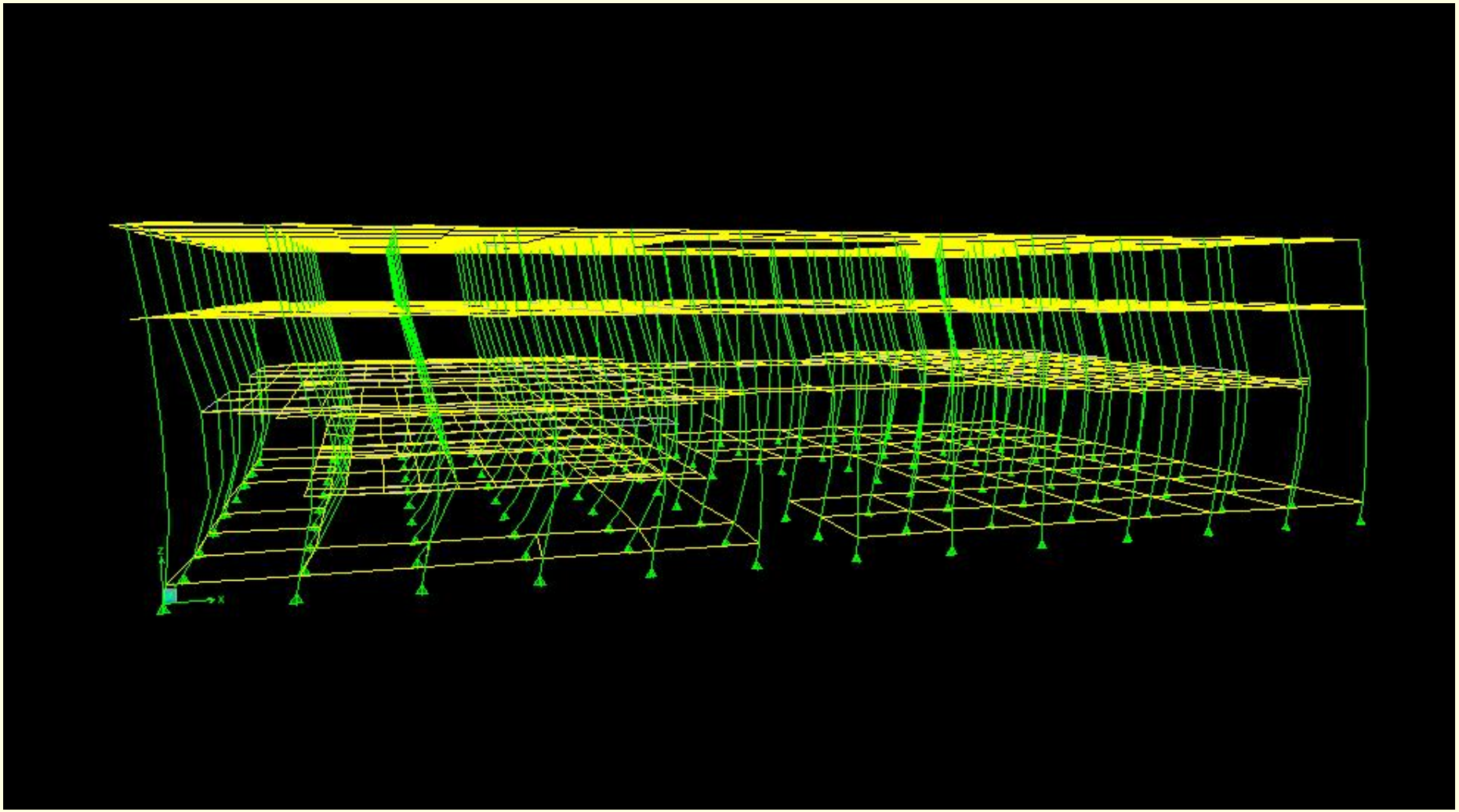


Translational along North-South

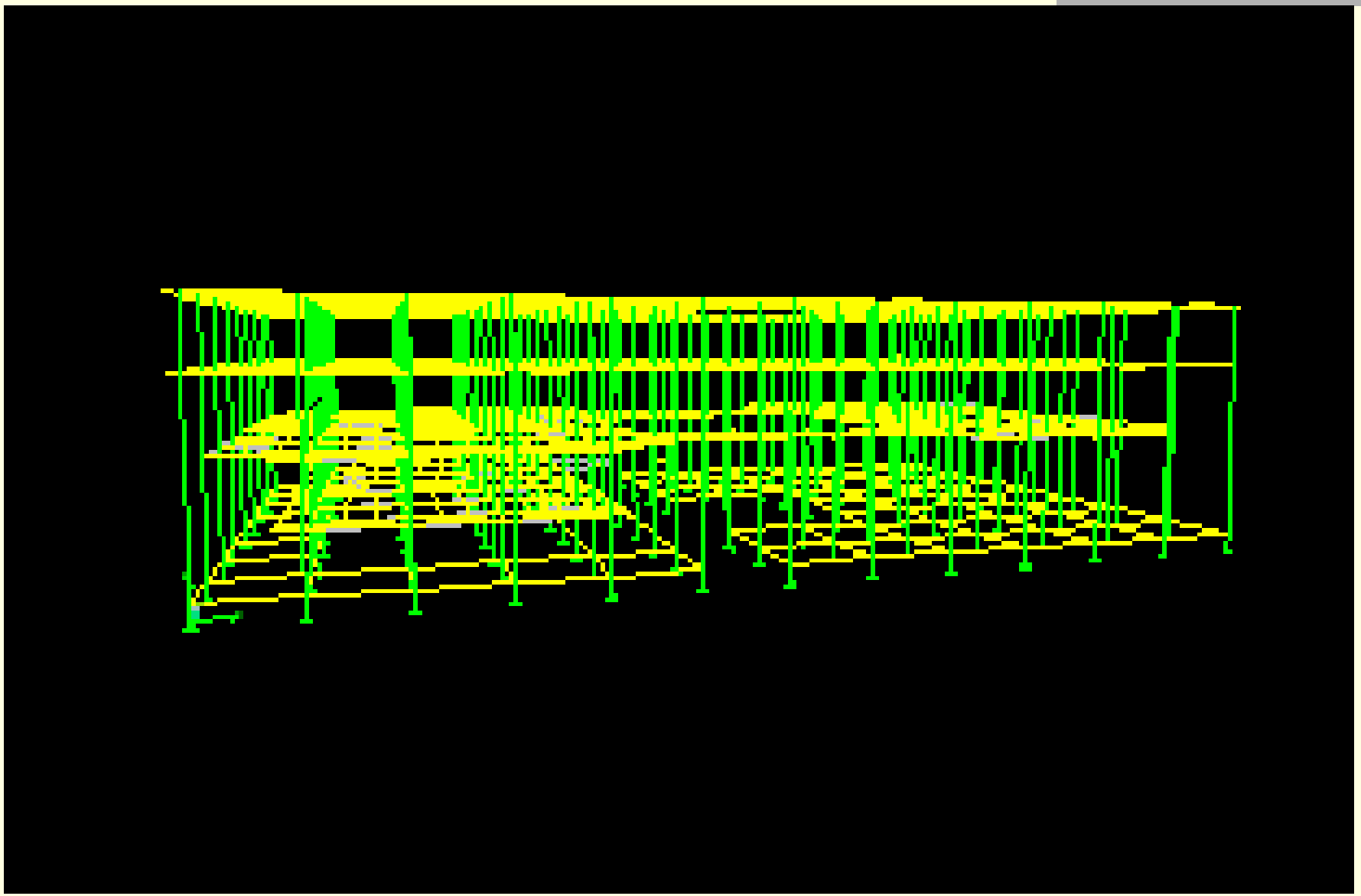


Bare Frame Model- Torsional Mode of Vibration

- Torsional Mode of Vibration -Time Period of 0.2485 s

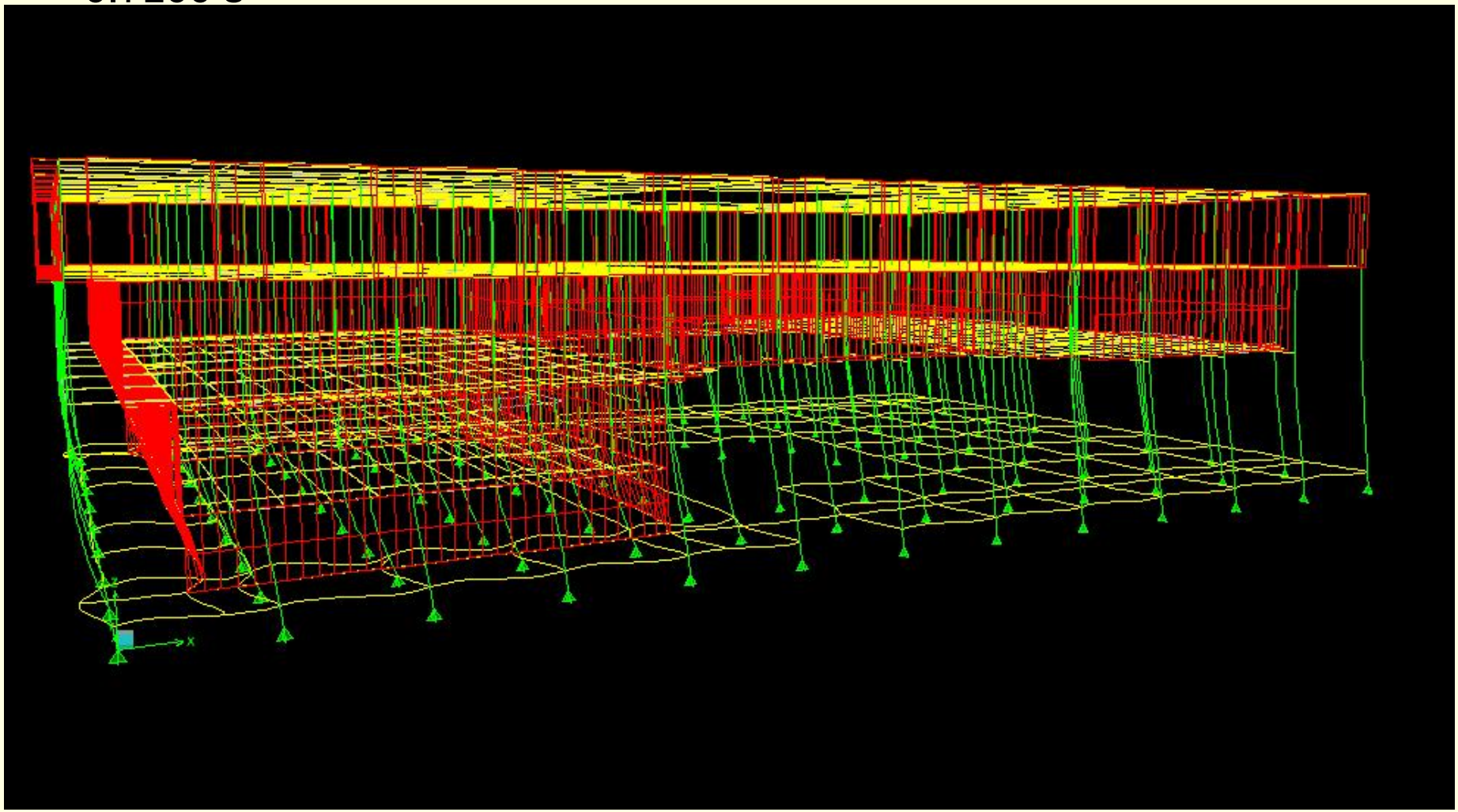


Torsional Mode of Vibration

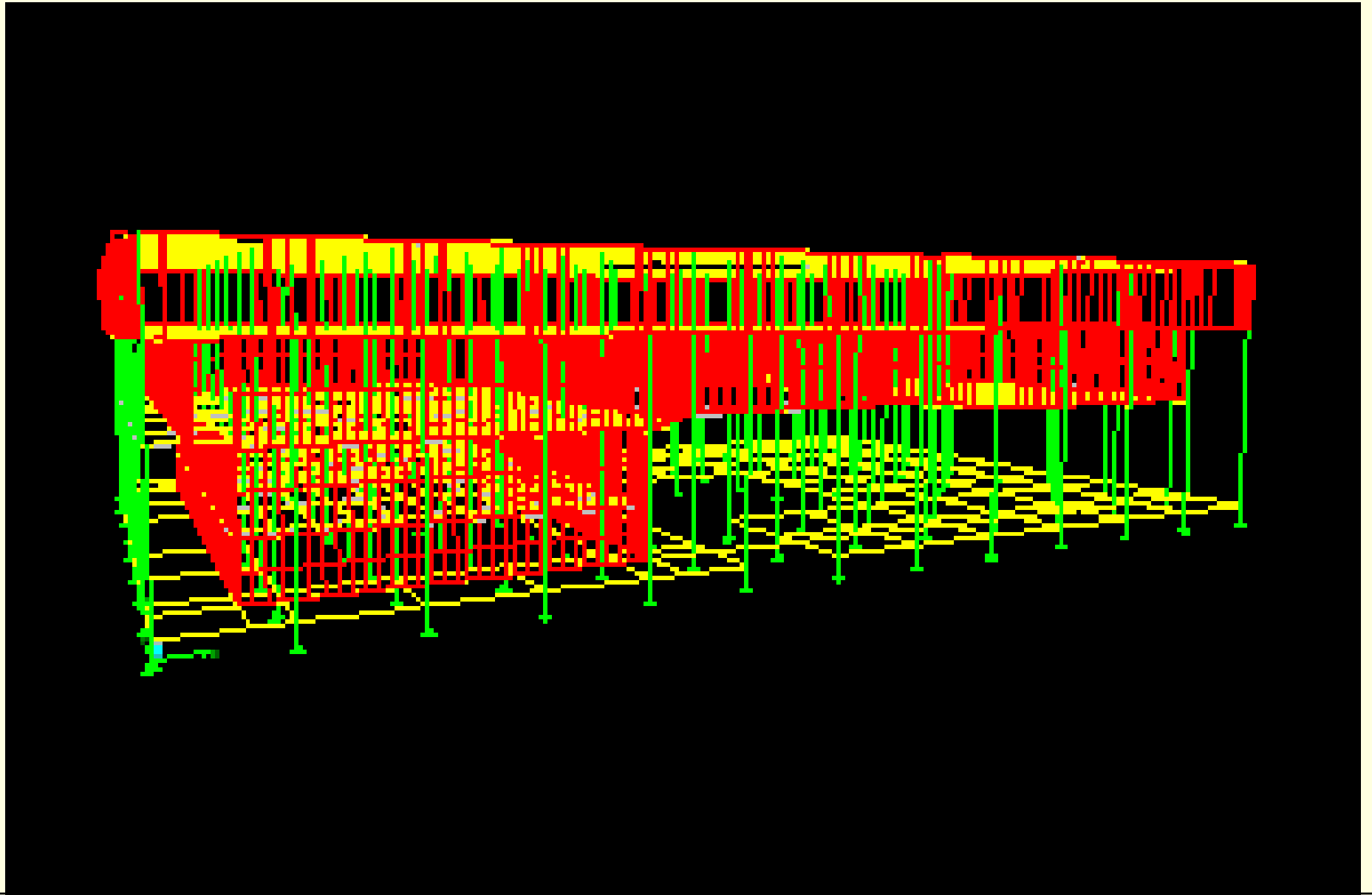


Model with Masonry walls without Openings

- Prominent Mode-Translation along North-South with time Period of 0.7100 s

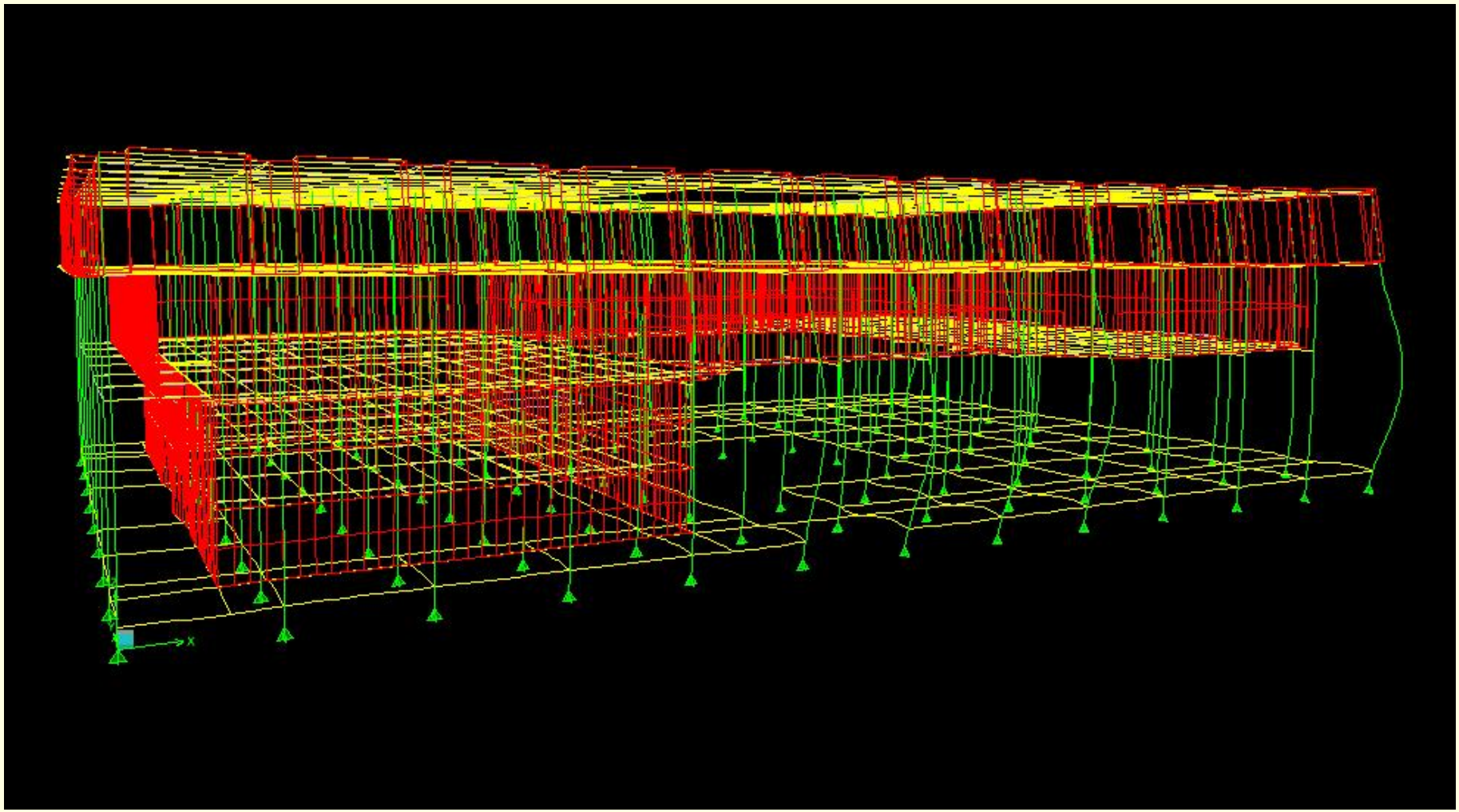


Model with Masonry walls without Openings

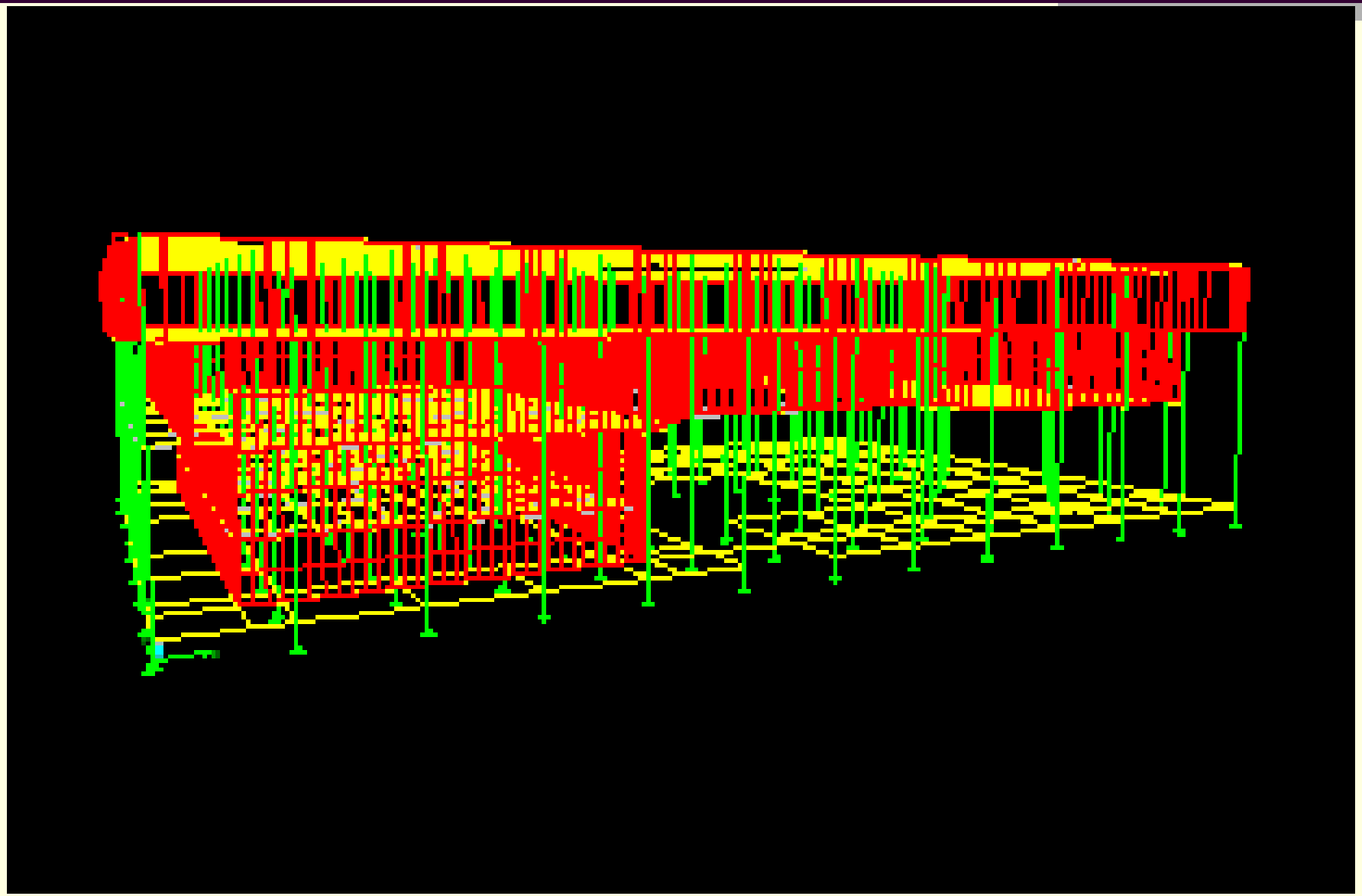


Model with Masonry walls without Openings

- Translation along East-West with Time Period of 0.1066 s

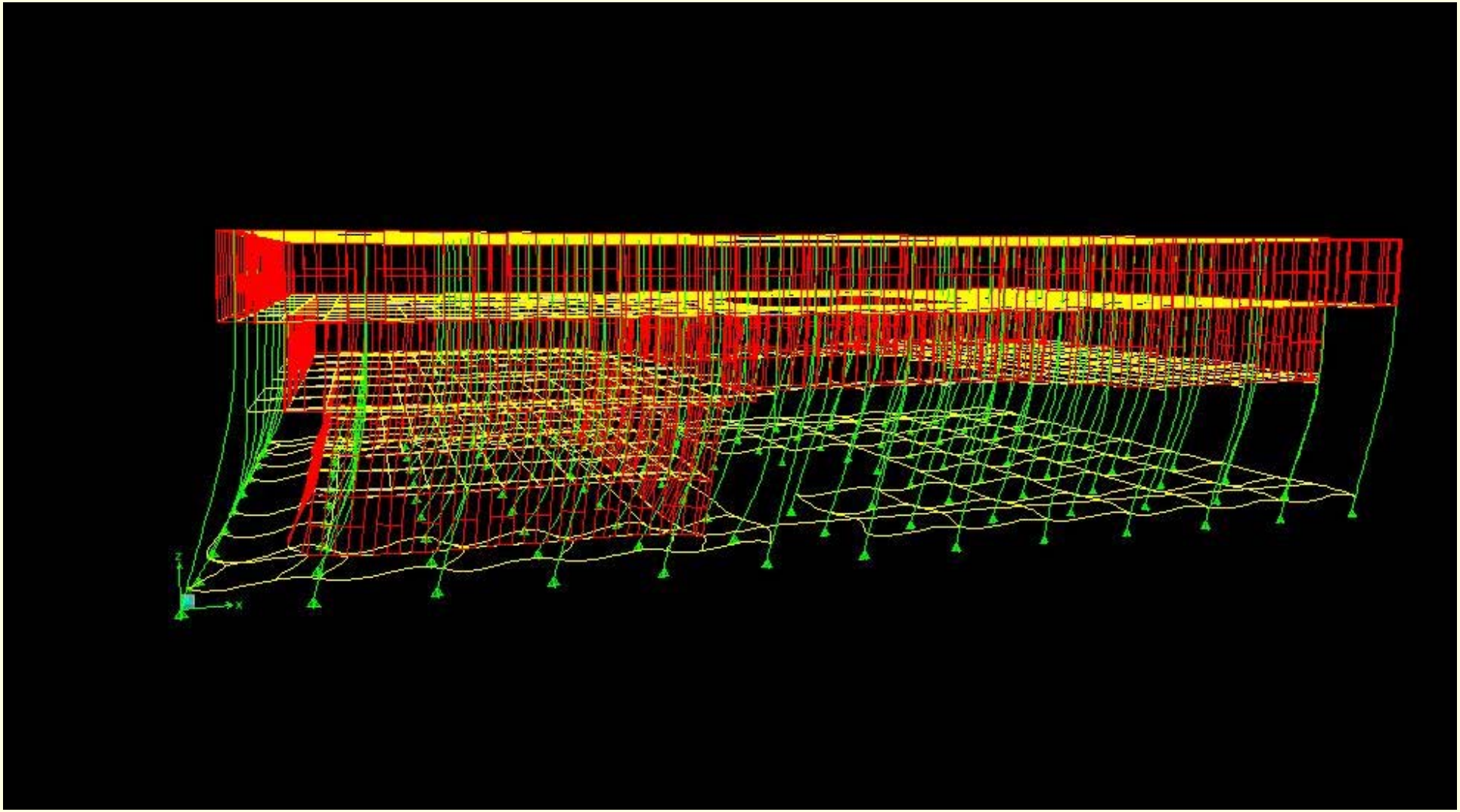


Model with Masonry walls without Openings

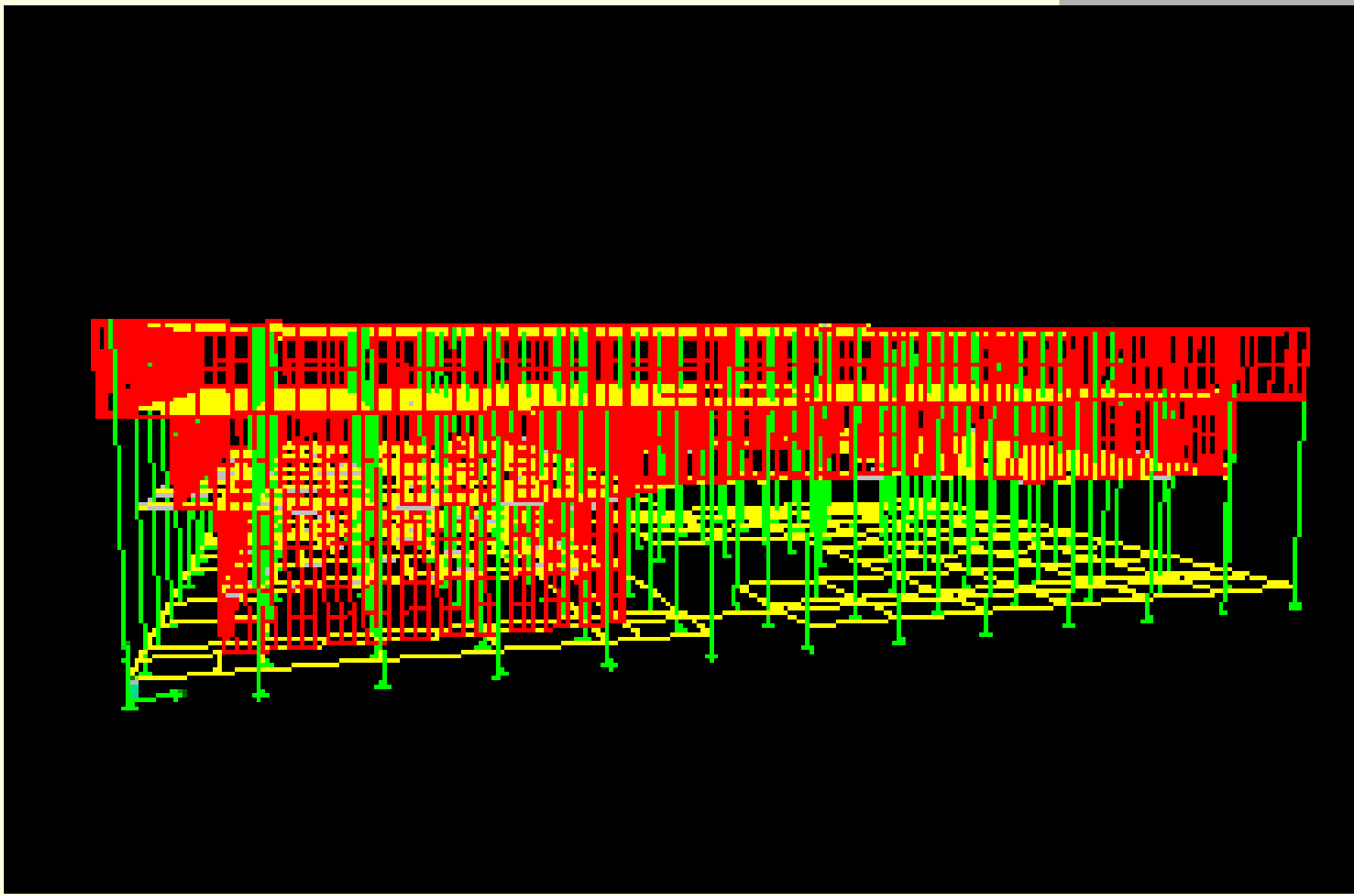


Model with Openings in the walls

- Prominent Mode- Translation along North-South with Time Period of 0.8122 s

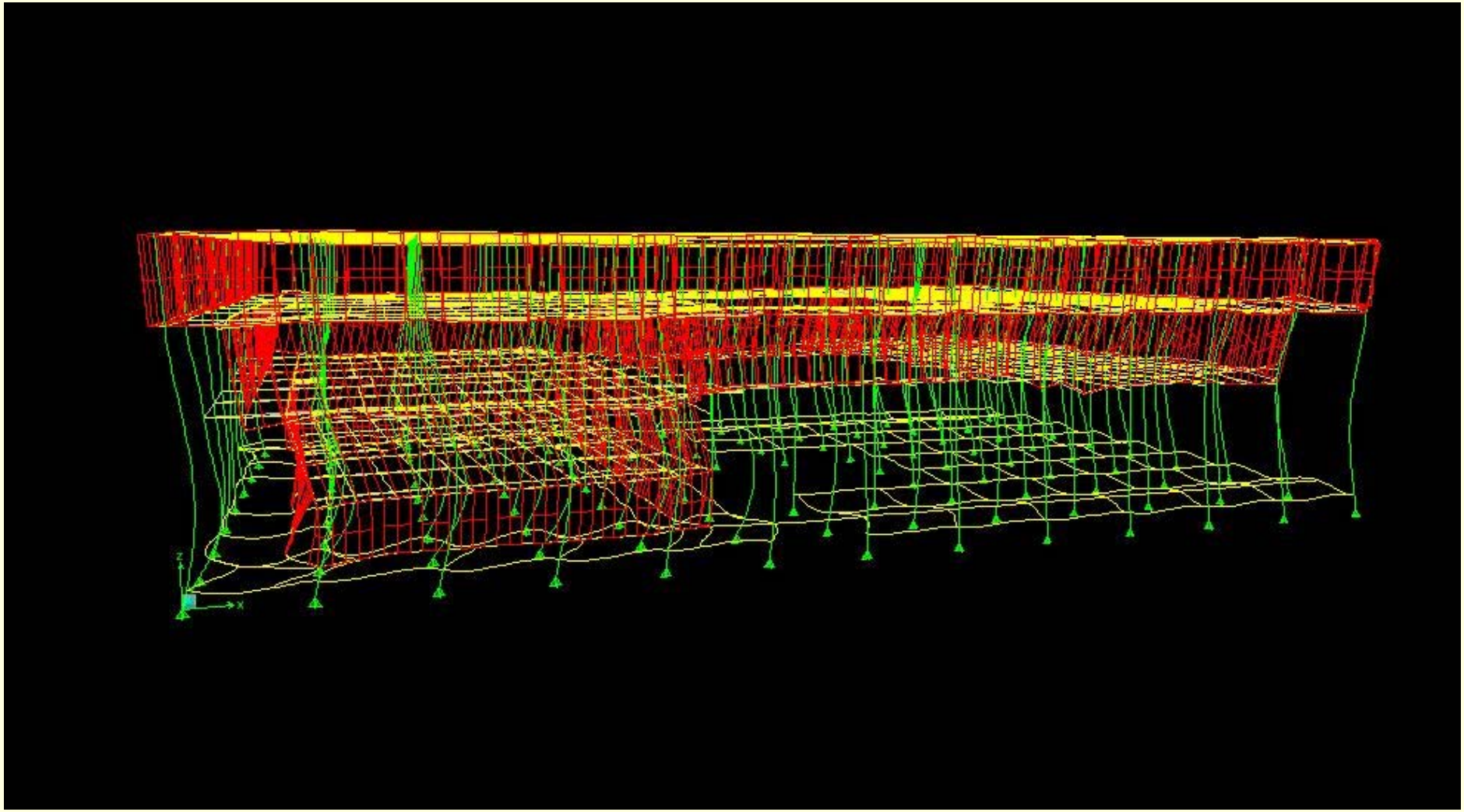


Model with Openings in the walls

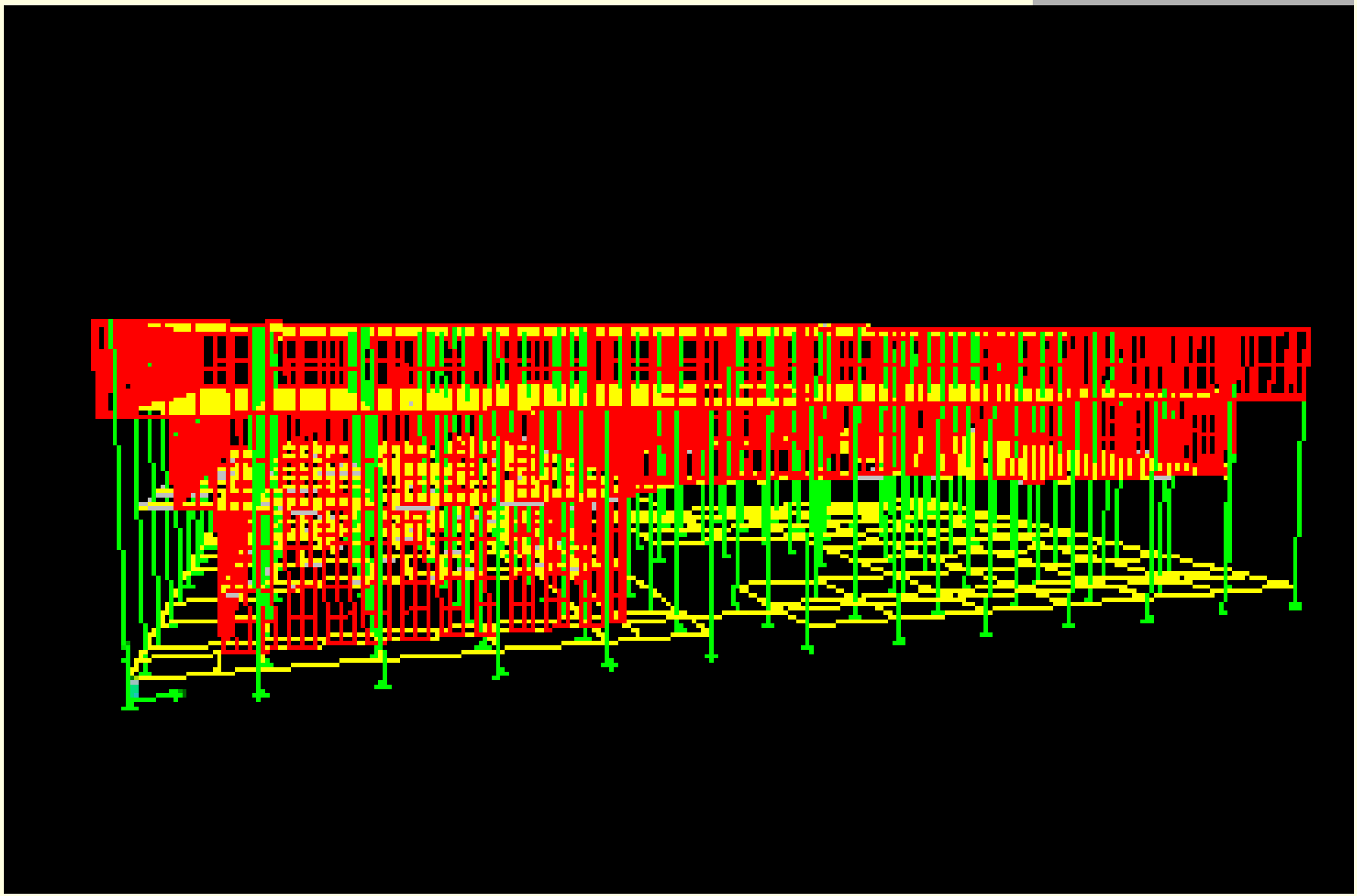


Model with Openings in the walls

- Translation along East-West direction with time period of 0.1170 s

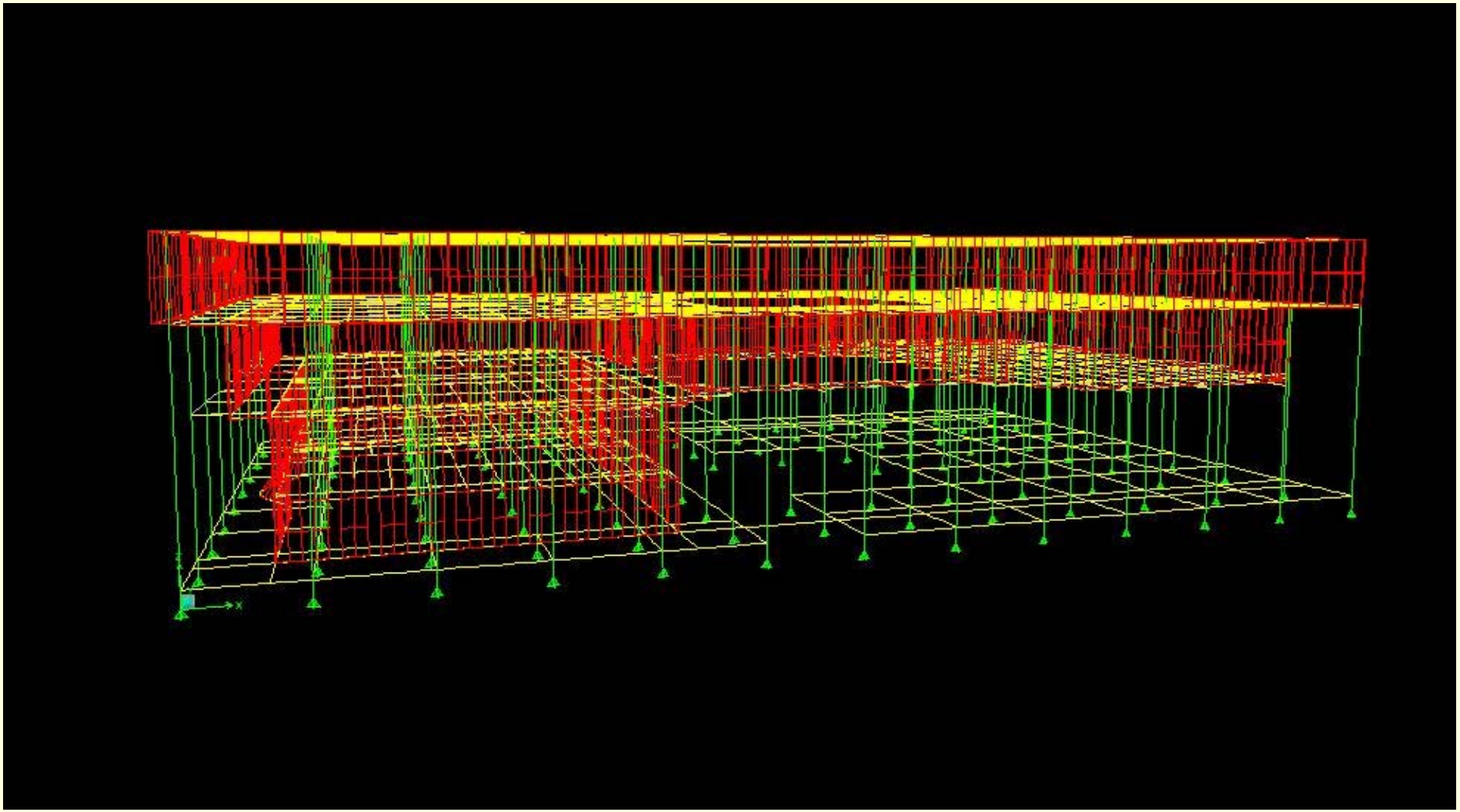


Model with Openings in the walls

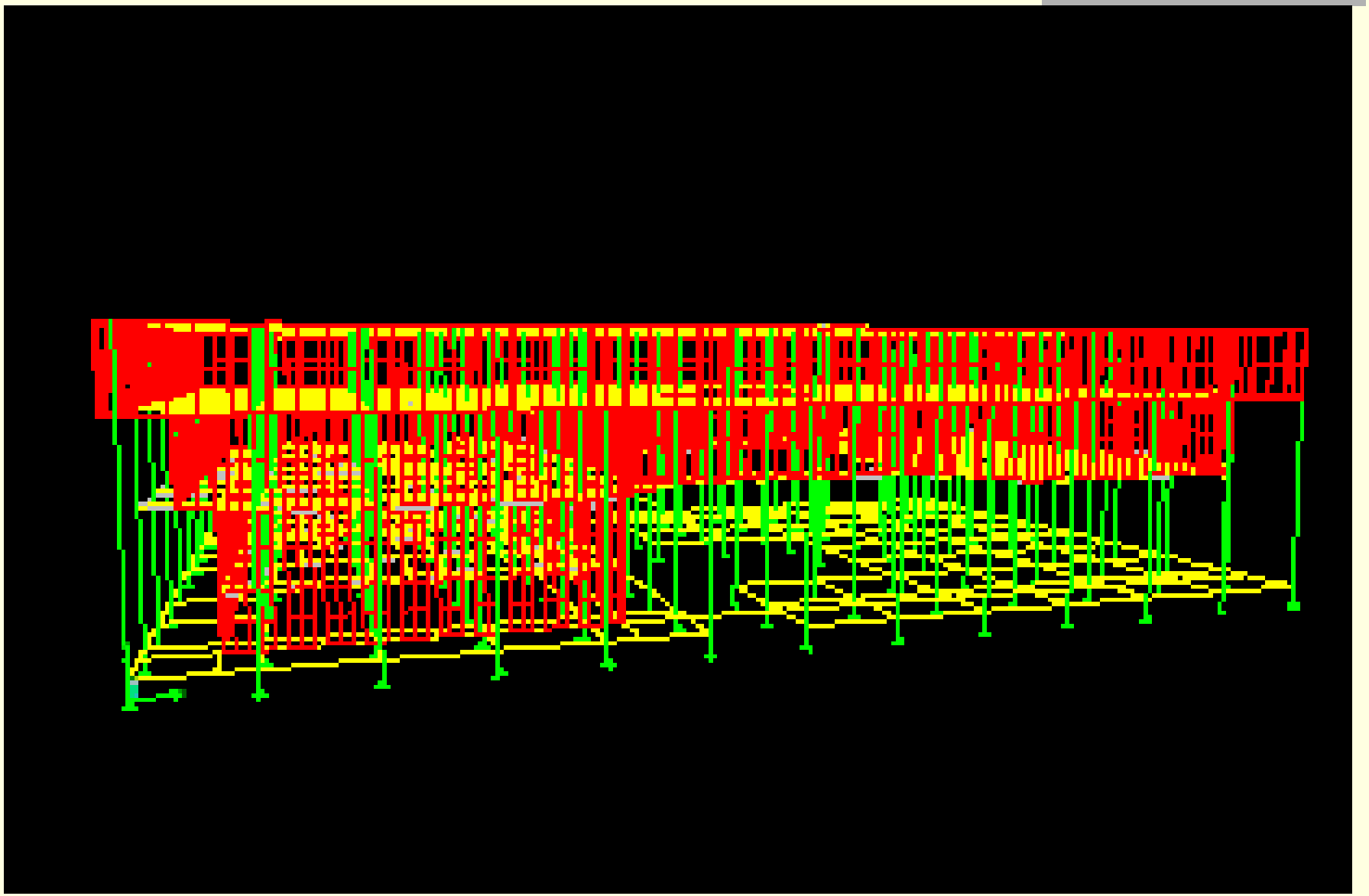


Model with Openings in the walls

- Torsional Mode with time Period of 0.0.1952 s



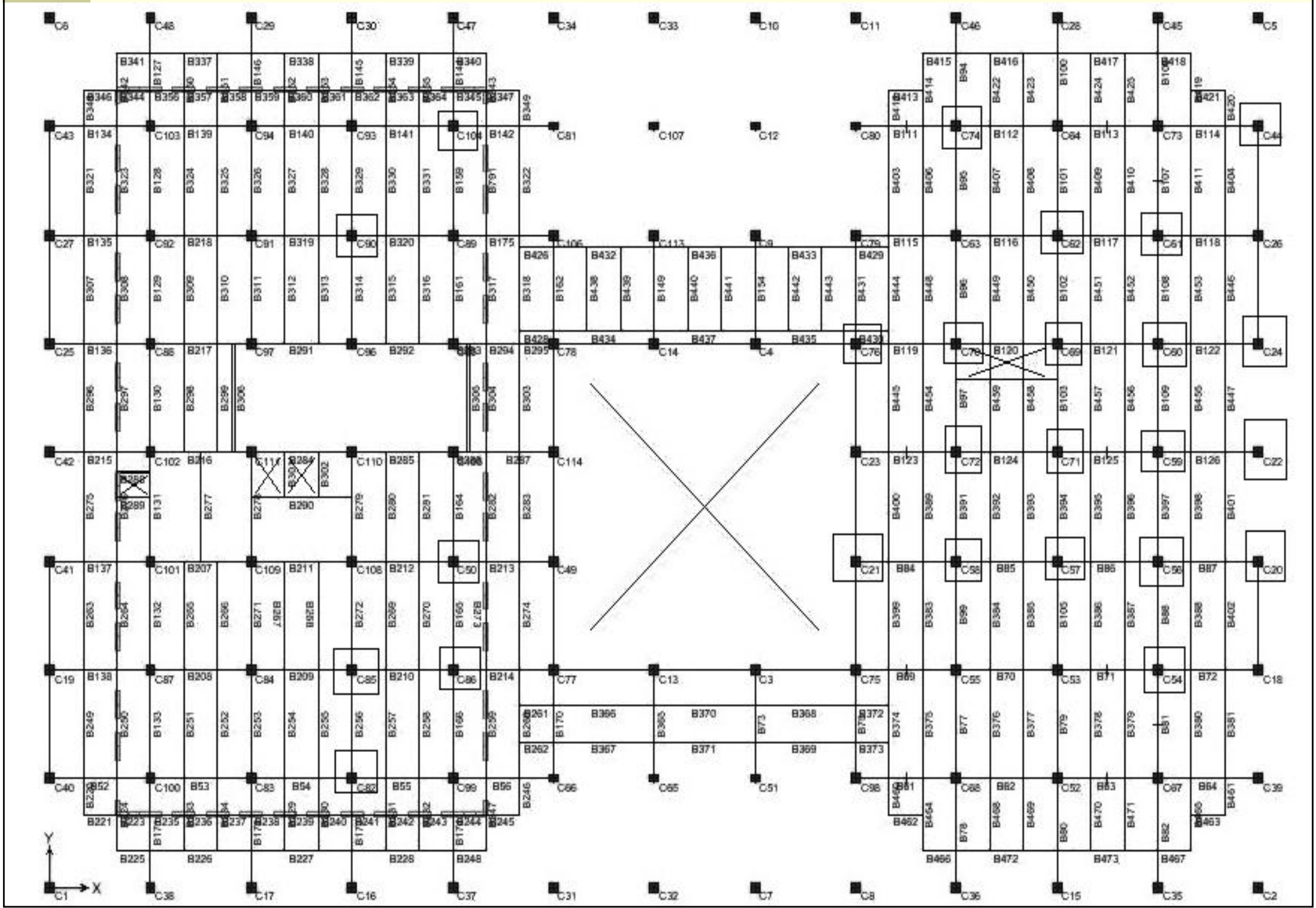
Model with Openings in the walls- Torsion



Extent of Deficiency of Critical Columns

Column	Storey	Pu (KN)	Mux (KNM)	Muy	Mux1	Muy1	Value of interaction curve
C90	STORY2	861.48	354.93	128.40	314.08	314.08	1.52
C82	STORY3	1227.48	426.02	219.36	314.08	314.08	2.11
C85	STORY2	879.03	357.48	132.46	296.63	296.63	1.64
C86	STORY2	1027.07	462.36	141.70	314.08	314.08	1.97
C104	STORY2	1197.62	454.27	220.12	296.63	296.63	2.40
C105	ROOF	874.10	446.44	27.24	296.63	296.63	1.65
C50	STORY2	940.96	453.65	78.16	296.63	296.63	1.84
C62	STORY2	555.53	321.86	50.50	261.73	261.73	1.42
C61	STORY2	580.27	355.92	52.56	261.73	261.73	1.56
C69	STORY2	510.54	321.52	25.49	251.26	251.26	1.38
C60	STORY2	563.56	356.45	26.15	261.73	261.73	1.46
C44	STORY2	479.20	342.30	77.92	261.73	261.73	1.61
C54	STORY2	952.71	356.60	58.34	279.18	279.18	1.49
C24	STORY2	487.00	338.19	35.73	244.29	244.29	1.53
C59	STORY2	562.29	340.11	4.23	296.63	296.63	1.16
C57	STORY2	559.10	322.18	26.58	296.63	296.63	1.18
C20	STORY2	487.76	339.39	36.86	314.08	314.08	1.20

Location of Critical Columns



Modal Storey Shear and Demand Capacity Ratios

Storey	Factored Shear (kN)	Estimated Storey Capacity (kN)	DCR
Roof	4501.75	21499.00	0.21
Storey2	8617.38	22558.00	0.38
Storey1	10383.29	25853.00	0.40
Ground	10986.26	26961.00	0.41
Plinth	11022.00	23113.00	0.48

Experimental Determination of Natural Periods…..

- Name : Ambient Vibration Survey
- Principle : Vibrations caused by the ambience
    - Measures The Vibration of Structure Due To
        - Operation of Machines, Fans, Elevators
        - Wind, Vehicular Motion and Tectonic Activity

Mode	Periods				Nature of Mode
	Bare Frame	Walls (Without Openings)	Walls (With Openings)	Experimental value	
1	1.1406	0.9563	1.0378	0.69	Torsional
2	0.9737	0.7100	0.8122	0.50	Translational (along X)
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6	0.2206	0.2456	0.1952		Torsional
7	0.1857	0.1170	0.1810		Torsional
8	0.1613	0.1160	0.1629		Torsional
9	0.1559	0.1066	0.1170	0.40	Translational Y
10	0.1286		0.1160		
11	0.1191		0.1120		
12	0.1183		0.1039		

Inferences from Analysis…

- Most of the columns in the stilt portion will fail incase of earthquakes
- The Demand-Capacity ratio for columns demonstrate this fact.
- Steps should be taken to retrofit this structure.

Retrofitting of Columns…

- Requirements of the Retrofitting

  - Compatibility with existing construction
  - Reliability
  - Redundancy
  - Impact on architectural, mechanical and electrical systems
  - Suitability for phasing of construction work
  - Costs
  - Detailed implementation requirements

Methods of Retrofitting…

- Section enlargement
- Addition of Columns
- Jacketing of columns
- Reinforcing with fiber wraps
- Bracing

Bracing…

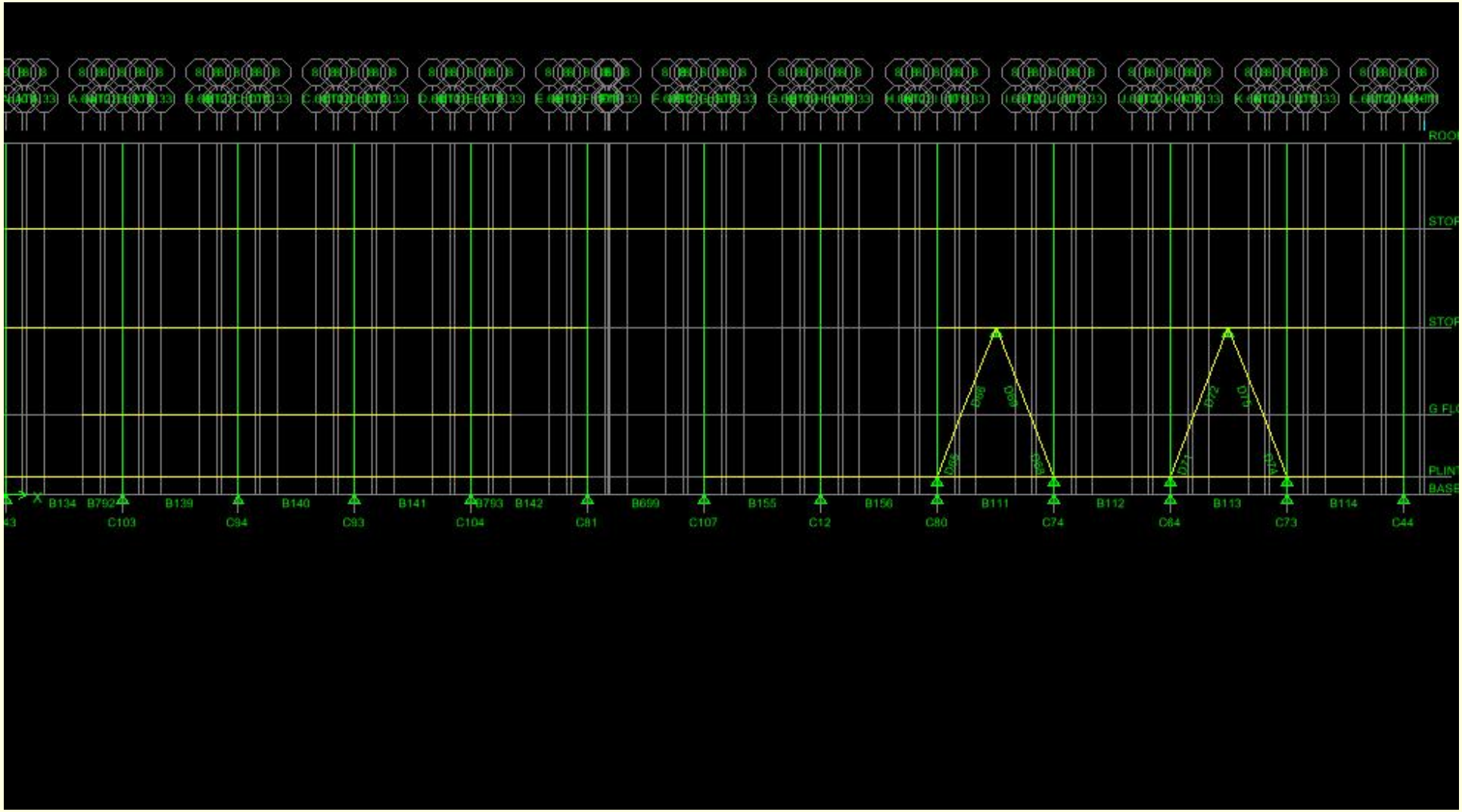
- Design of Braces based on the following points
  - Strength Criteria
    - Very low axial stress
    - Strength is not the governing criteria
  - Slenderness Ratio Criteria
    - Should be less < 350

Determining the brace Sections…

Iteration Number	Section Assumed	Axial Stress (MPa)	Slenderness Ratio	
			λx	λy
1	ISMB 150	0.65	116	431
2	ISMB 175	0.50	99.8	385
3	ISMB 200	0.40	86	334
4	ISMB 225	0.30	77	306

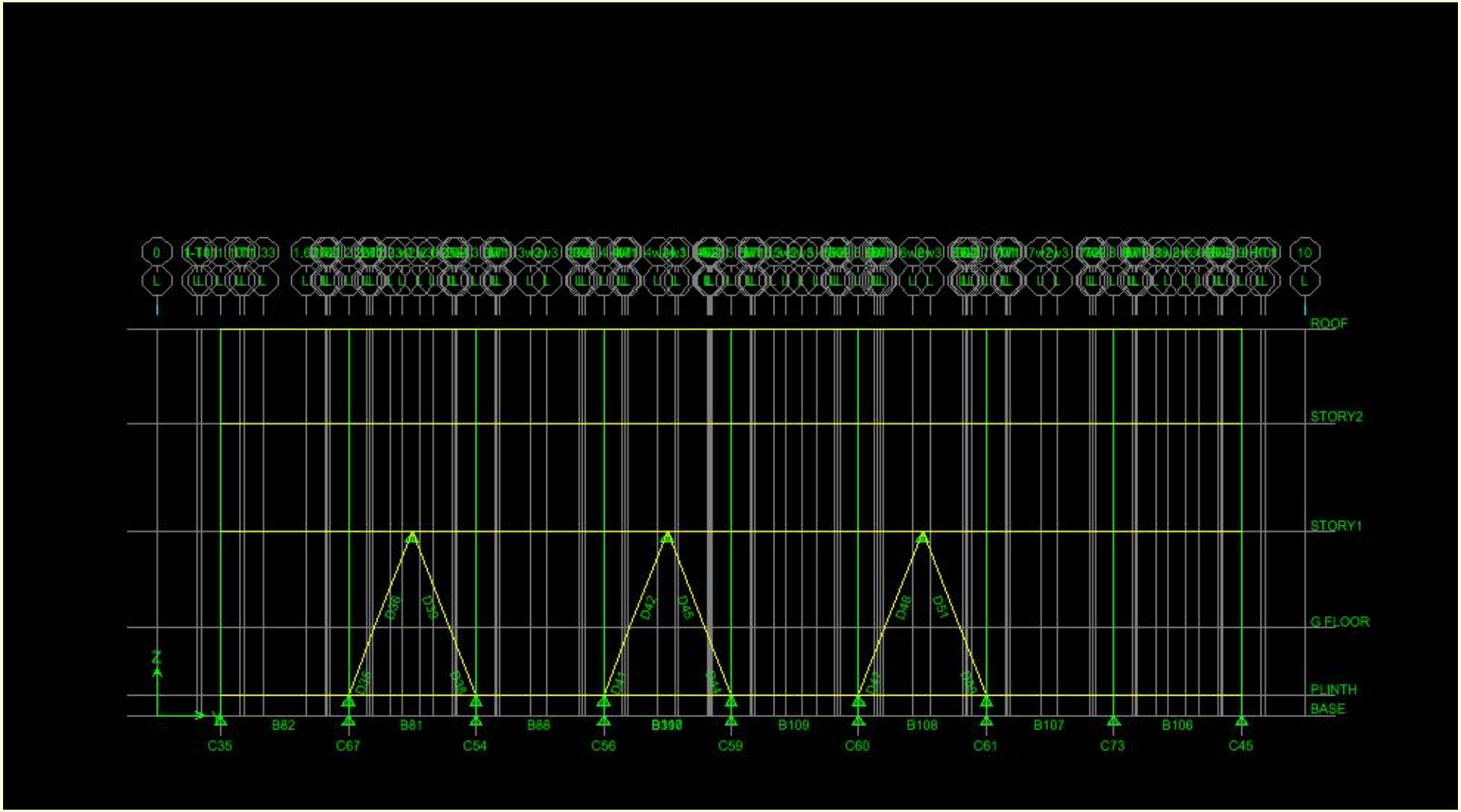
Location of Braces…

- Braces placed along the second row of columns- western side



Location of Braces…

- Braces placed along the second row of columns near pond



Effect of Braces…

Column	Storey	Value (Without Bracing)	Value (With Bracing)
C90	STORY2	1.52	0.40
C82	STORY3	2.11	0.37
C85	STORY2	1.64	0.36
C86	STORY2	1.97	0.38
C104	STORY2	2.40	0.37
C105	ROOF	1.65	0.37
C50	STORY2	1.84	0.27
C62	STORY2	1.42	0.41
C61	STORY2	1.56	0.52
C69	STORY2	1.38	0.31
C60	STORY2	1.46	0.47
C44	STORY2	1.61	0.54
C54	STORY2	1.49	0.55
C24	STORY2	1.53	0.47
C59	STORY2	1.16	0.47
C57	STORY2	1.18	0.43
C20	STORY2	1.20	0.47

Thank You