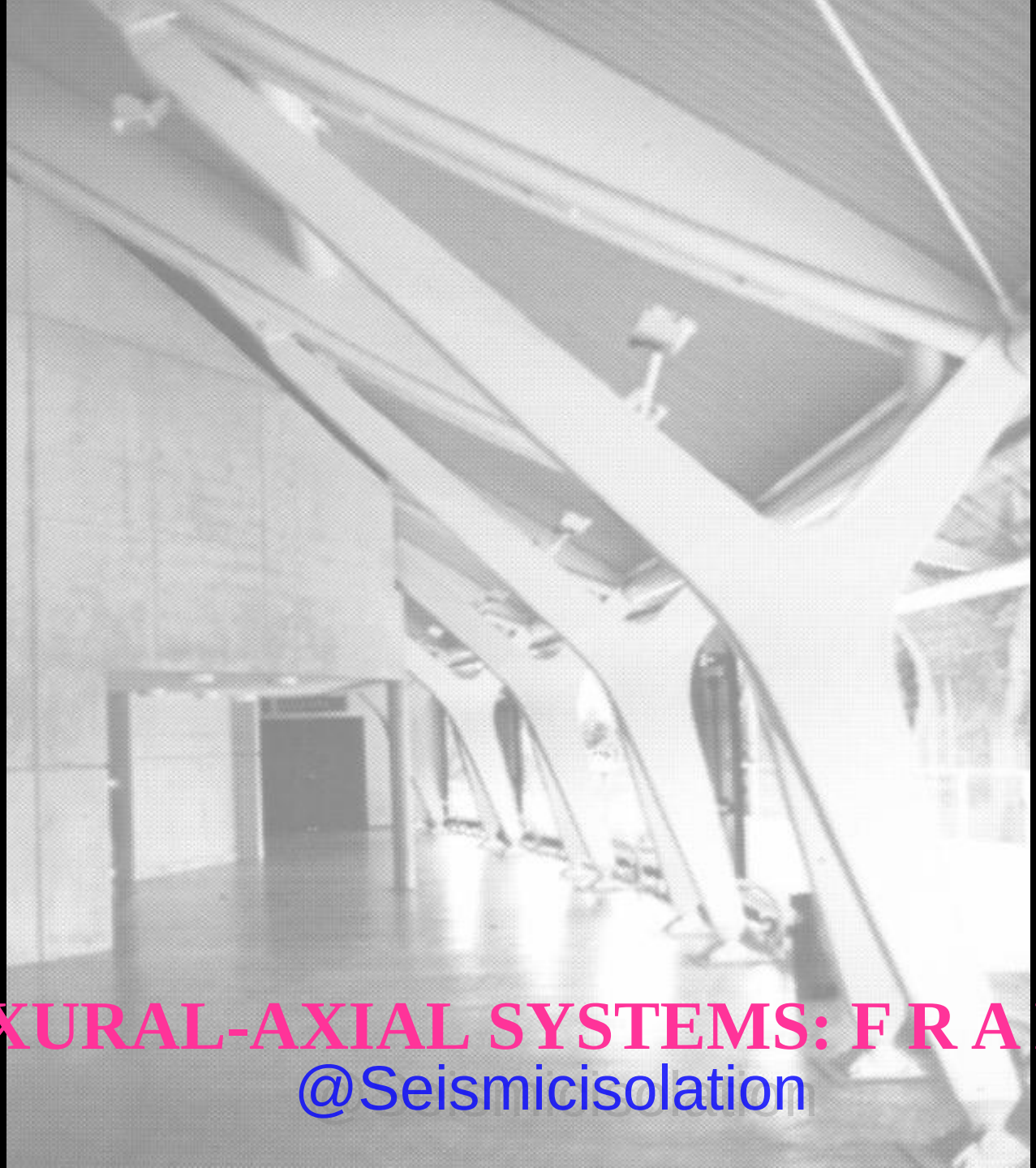

FLEXURAL-AXIAL SYSTEMS: F R A M E S

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Municipal Stadium, Florence, 1932, Pier Luigi Nervi

@Seismicisolation

Glass House, New Canaan, Conn., 1949, Philip Johnson

@Seismicisolation


@Seismicisolation


@Seismicisolation

Republic Newspaper Plant, Columbus, Indiana, 1971, Myron Goldsmith/ SOM

@Seismicisolation

Reliance Controls factory
Swindon, 1967, Team 4, Hunt

@Seismicisolation

Cummins Engine Component Plant
Columbus, IN, 1965, Roche & Dinkeloo

@Seismicisolation

Lake Shore Drive Apts Chicago, Ludwig Mies van der Rohe, at Chicago, 1948 to 1951

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@Seismicisolation

Museum of Modern Art, Rio de Janeiro, Brazil, 1958, Alfonso Eduardo Reidy

Beijing, 2006

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Beijing, 2006
@Seismicisolation


@Seismicisolation

Richard J. Klarchek Information Commons, Loyola University Chicago, 2007, Solomon Cordwell Buenz, *Halvorson and Partners Striuct.*

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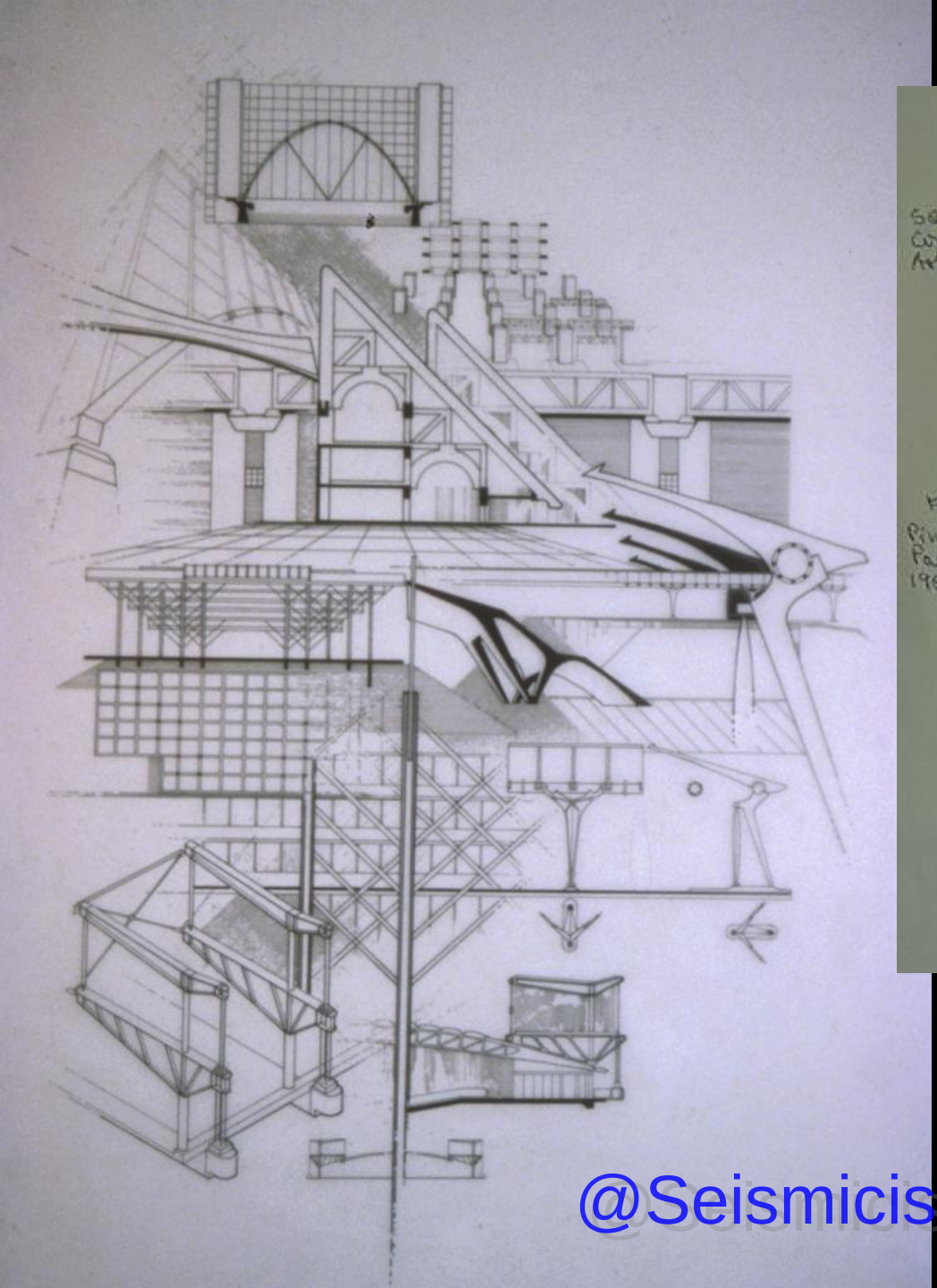
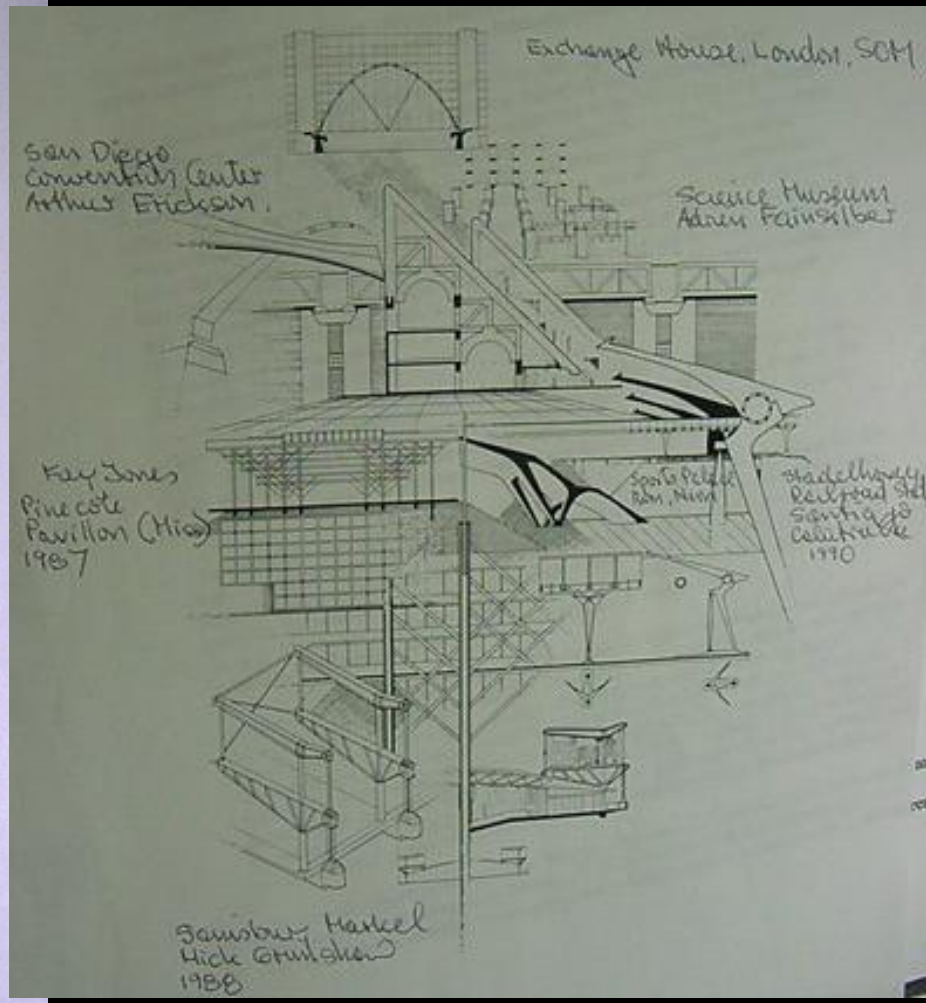
Richard J. Klarchek Information Commons, Loyola University Chicago, 2007. Solomon Cordwell Buenz, *Halvorson and Partners Striuct.*

@Seismicisolation

Richard J. Klarchek Information Commons, Loyola University Chicago, 2007, Solomon Cordwell Buenz, *Halvorson and Partners Striuct.*

@Seismicisolation





Frames, arches, trusses

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Structure Systems & Structure Behavior

INTRODUCTION TO STRUCTURAL CONCEPTS

SKELETON STRUCTURES

- Axial Systems
- Beams
- Frames
- Arches
- Cable-supported Structures

SURFACE STRUCTURES

- Membranes: beams, walls
- Plates: slabs
- Hard shells
- Soft shells: tensile membranes
- Hybrid tensile surface systems: tensegrity

SPACE FRAMES

LATERAL STABILITY OF STRUCTURES

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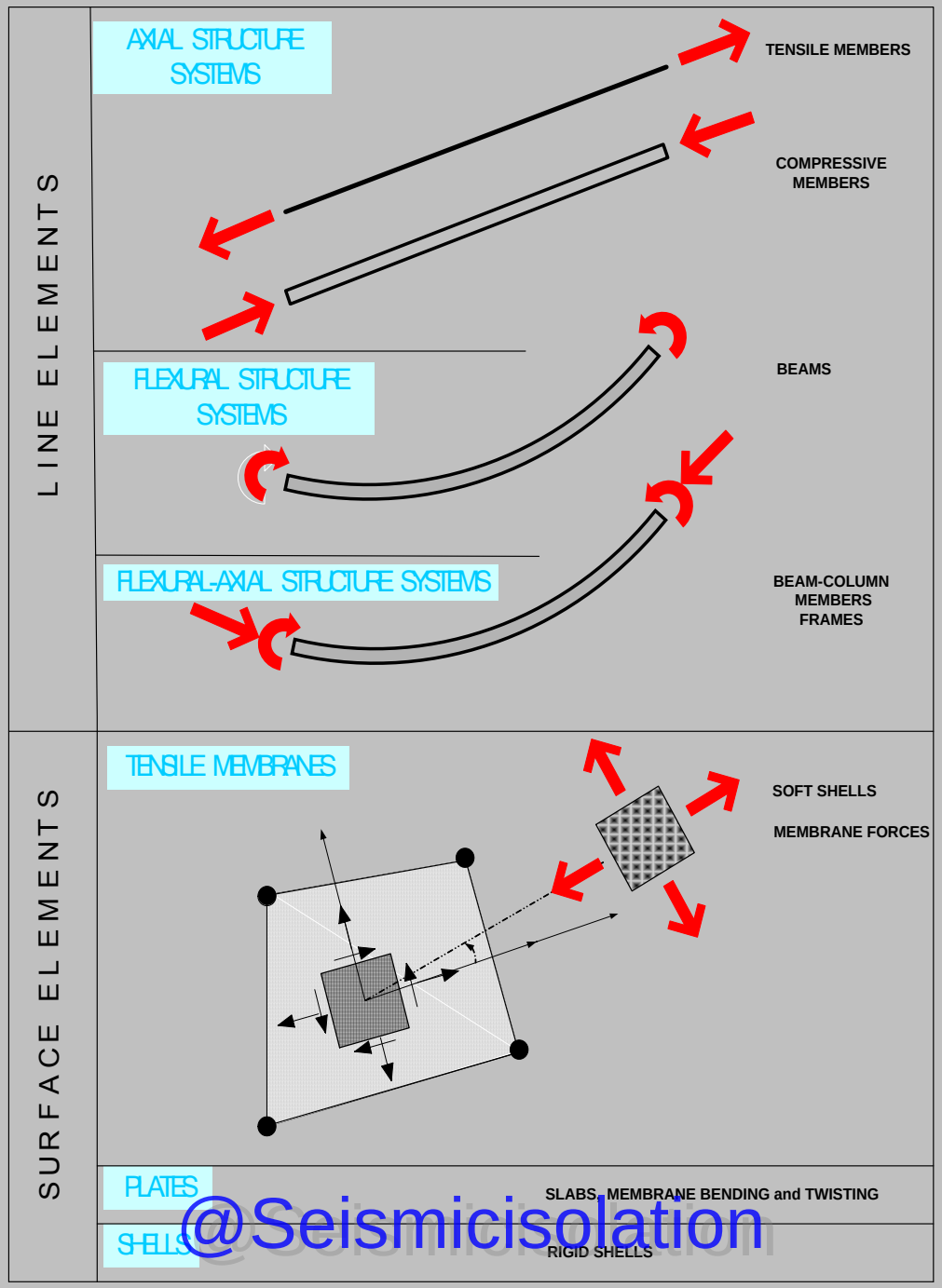

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FRAMES are **flexural-axial systems** in contrast to **hinged trusses**, which are axial systems, and **beams**, which are flexural systems. Flexural-axial systems are identified by **beam-column behavior** that includes the effects of biaxial bending, torsion, axial deformation, and biaxial shear deformations.

Here, **two-dimensional skeleton structures composed of linear elements** are briefly investigated. The most common group of planar structure systems includes

post-beam structures,
bent and folded beams,
rectangular portal frames,
cantilever frames,
braced frames,
pitched frames,
arches,
and so on.

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These structures may form

short-span or **long-span,**
single-story or **multi-story,**
single-bay or **multi-bay systems.**

They range from low-rise to

single, open, large volume buildings
cellular massive buildings
skyscrapers.

Primary emphasis here is on the investigation of simple, but common single-story enclosure systems to develop a feeling for the behavior of structures under gravity and lateral loads. Investigated are the

- response and effect of the frame profile on **uniform gravity action** and on **lateral loading**.
- the magnitude of the internal member forces is determined so that the computer results can be checked.

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- Uniform Loading on Inclined Members
- Simple Folded and Bent Beams
- Single-bay Frames
  - Three-Hinged Frames
  - Indeterminate Frames
  - Cantilever Frames
  - Braced frames
  - Pitched Frames
- Arches
  - The Geometry of the Arch
  - Construction of a Circular Arch with SAP
  - The Response of Roof Arches to Loading
  - Composite Systems and Form-Resistant Arches
  - Arches with Tensile Webs
- Multi-bay Frames
  - Multi-bay, Single-Story Frames
  - Multi -Story Frames
  - Vierendeel Trusses

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The loading on a simply supported inclined beam is investigated in with a pin support at the base and a roller support at the top, which however may have different orientations.

The typical gravity loading of an inclined member consists of the dead load w_D acting along the structure, and the live load w_L, which is usually given by codes on the horizontal projection of the structure (a). To determine the maximum moment, it is convenient to transfer the dead load to the horizontal projection of the beam (b), since **the maximum moment of a simply supported inclined beam is equal to that for an equivalent beam on the horizontal projection** carrying the same loading as the inclined beam In other words, the moment is independent of beam slope and support conditions.

The shear depends on the beam inclination but not on the orientation of the top support. It is equal to the shear of the beam on the horizontal projection multiplied by $\cos\theta$. The parallel load components cause axial forces along the beam and are equal to the load on the horizontal projection multiplied by $\sin\theta$. The axial force flow depends on the beam inclination and on the reaction condition of the top support.

The uniform lateral loading case is analogous to the uniform gravity loading case; just visualize the span L and height h to be exchanged. For example, the maximum moment due to the wind pressure q on the vertical projection of the beam is,

The fact that the moment is independent of the geometry of the bent or folded beam for vertical support conditions, is demonstrated in the drawing.

Various folded beam systems are investigated in the following drawing ranging from a simple inclined beam (B), a stair (E.), to other roof frame shapes.

Notice SAP automatically transfers the loads from the projection to an equivalent load along the member!

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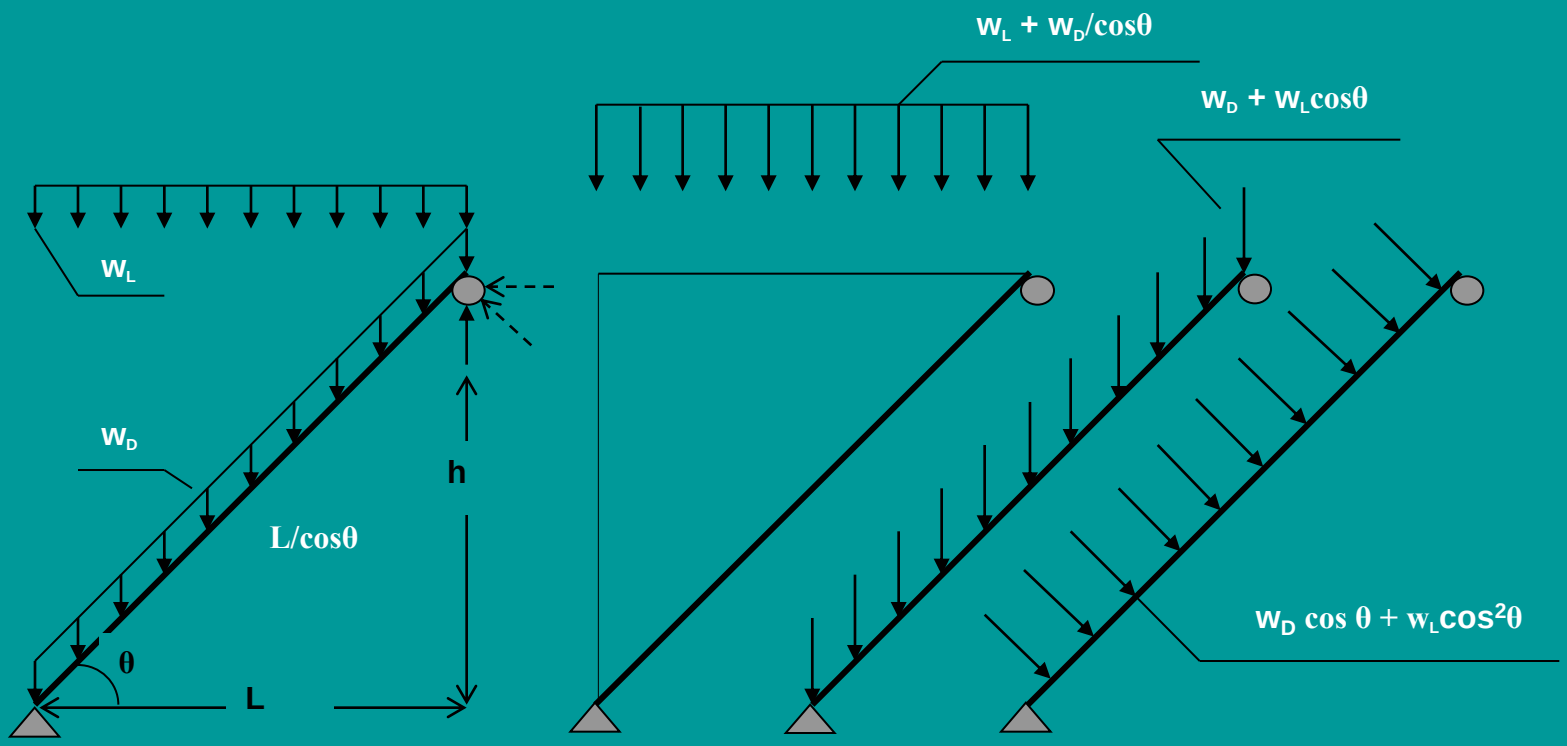

The parallel load component causes axial force action in the member: $(w_D + w_L\cos\theta)\sin\theta$

and from the perpendicular load component the shear is determined: $(w_D + w_L\cos\theta)\cos\theta$

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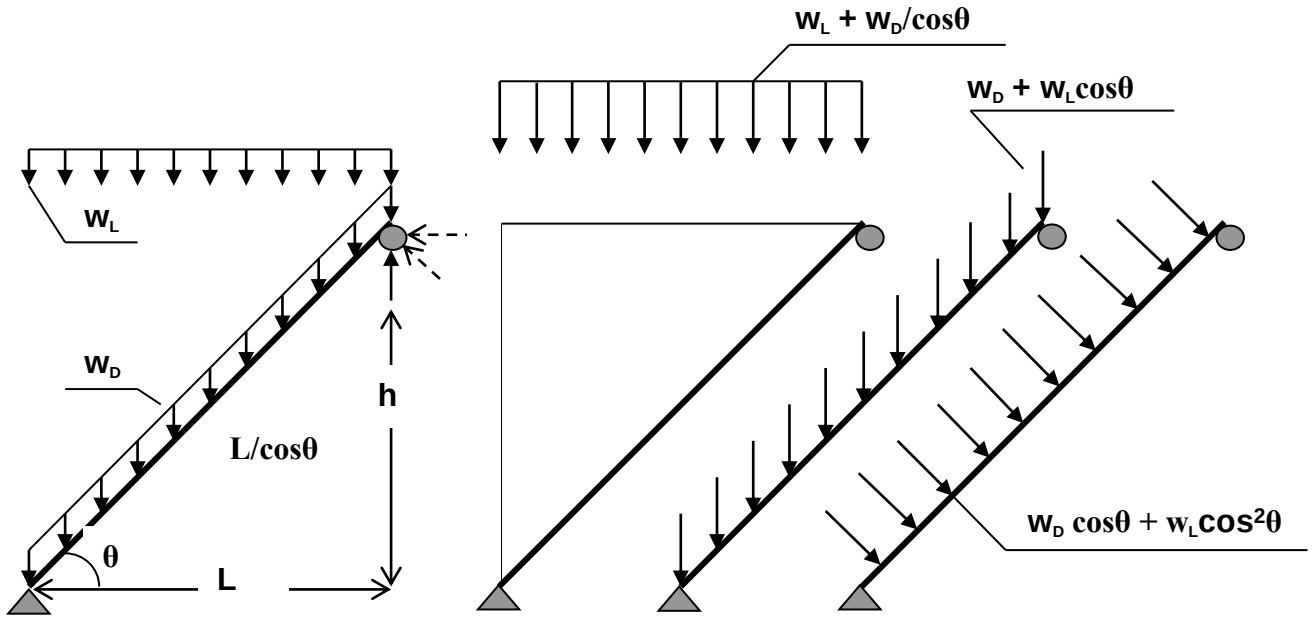

The parallel load component causes axial force action in the member: $(w_D + w_L\cos\theta)\sin\theta$
and from the perpendicular load component the shear is determined: $(w_D + w_L\cos\theta)\cos\theta$

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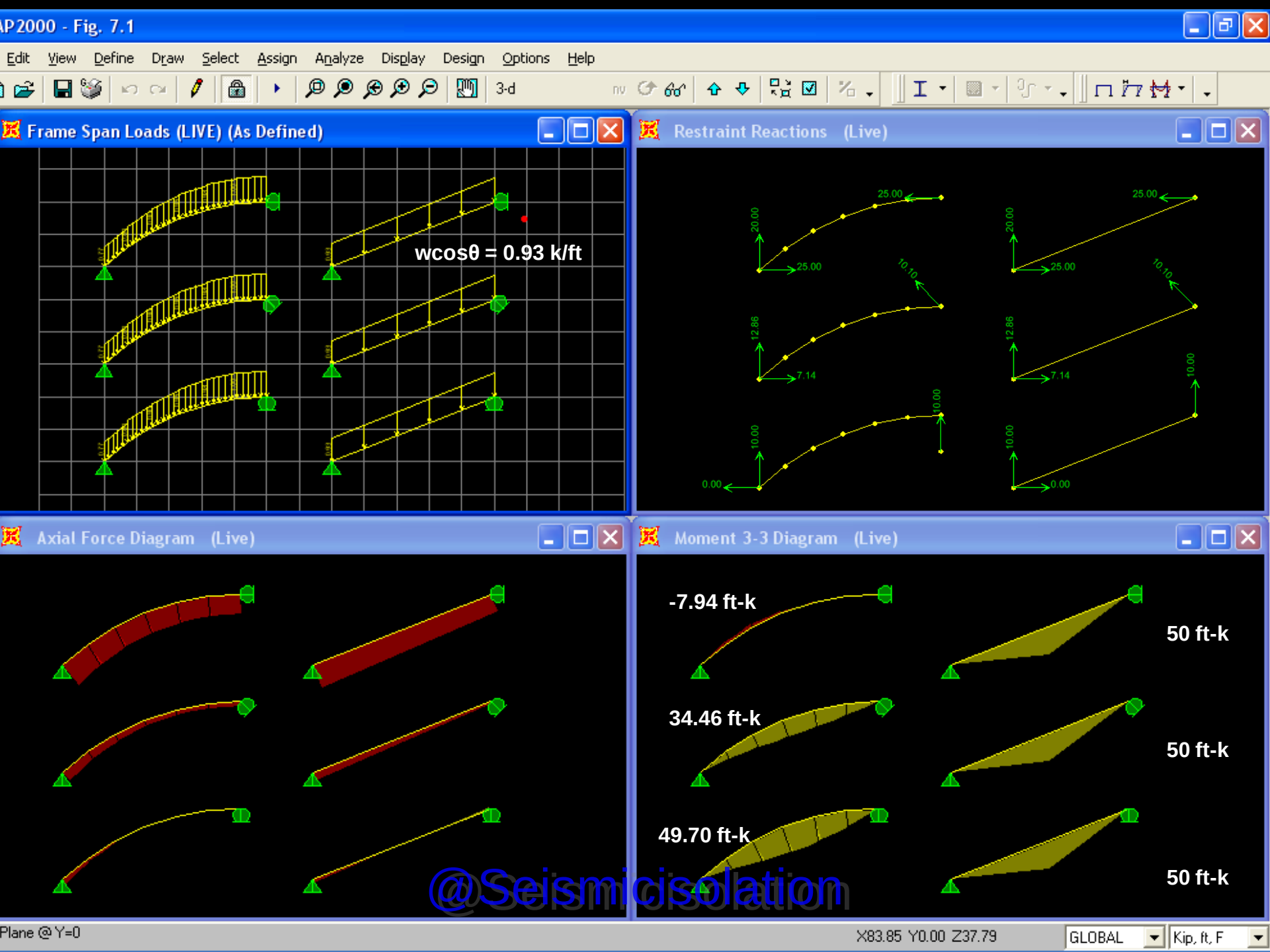
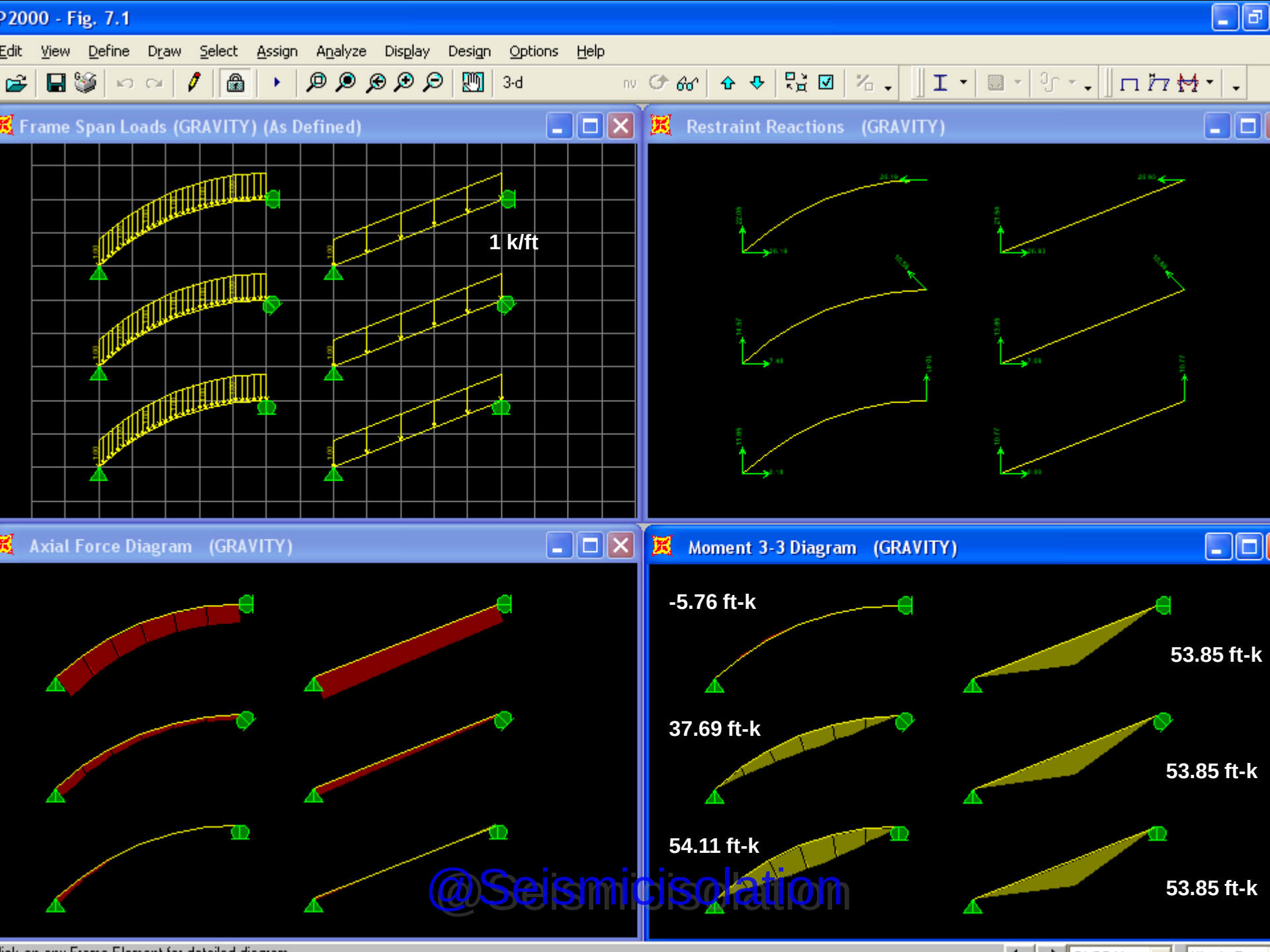
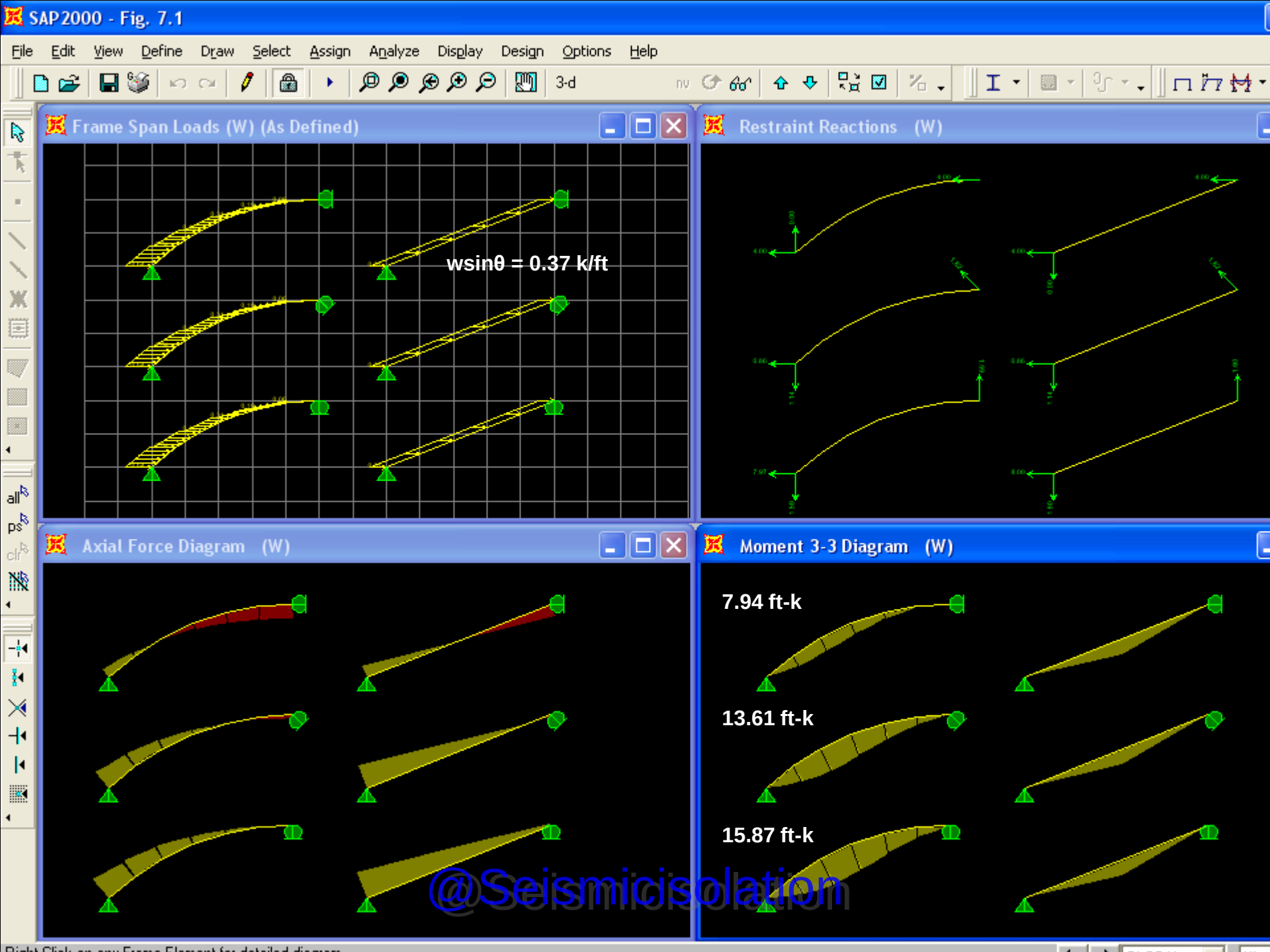
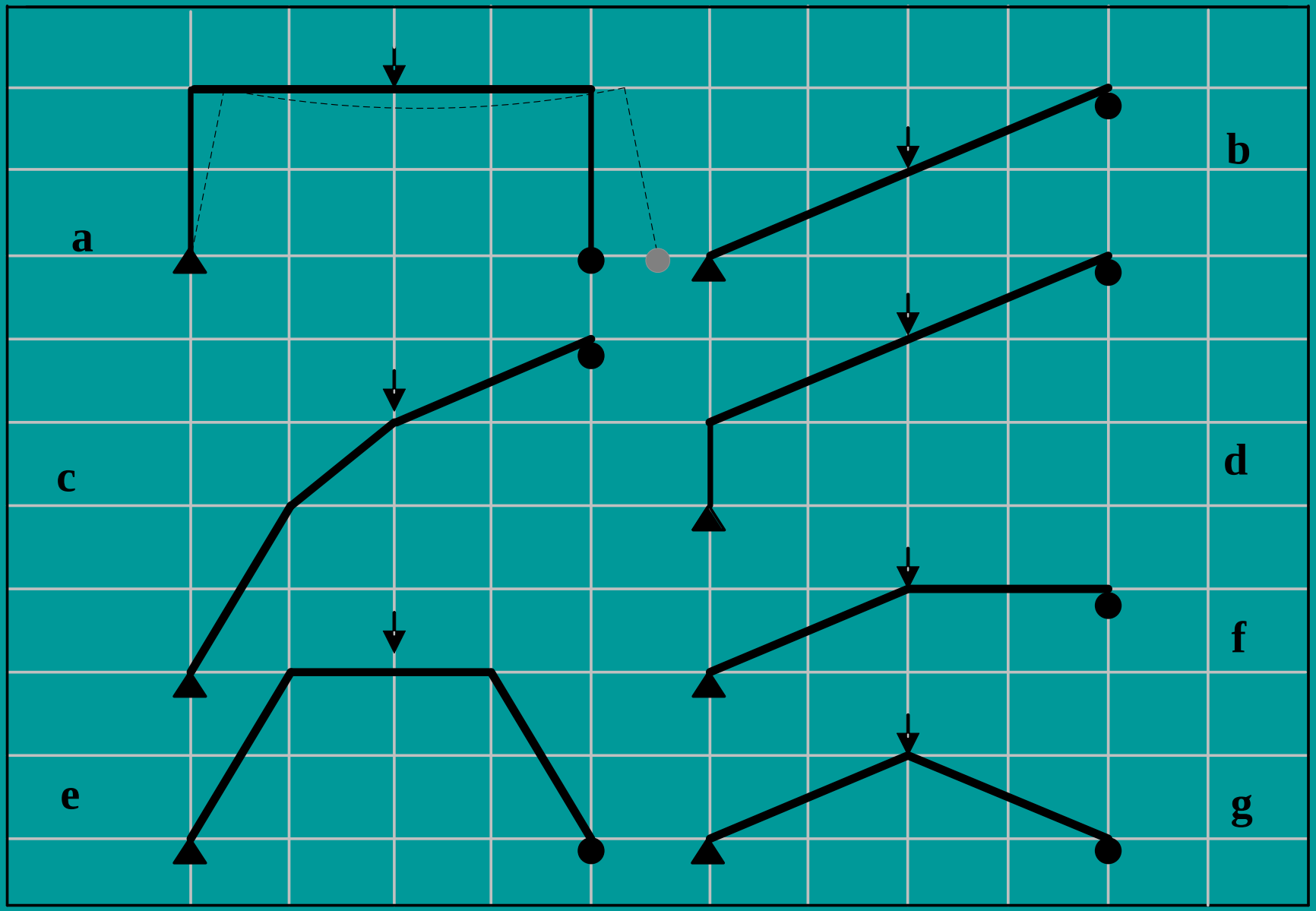
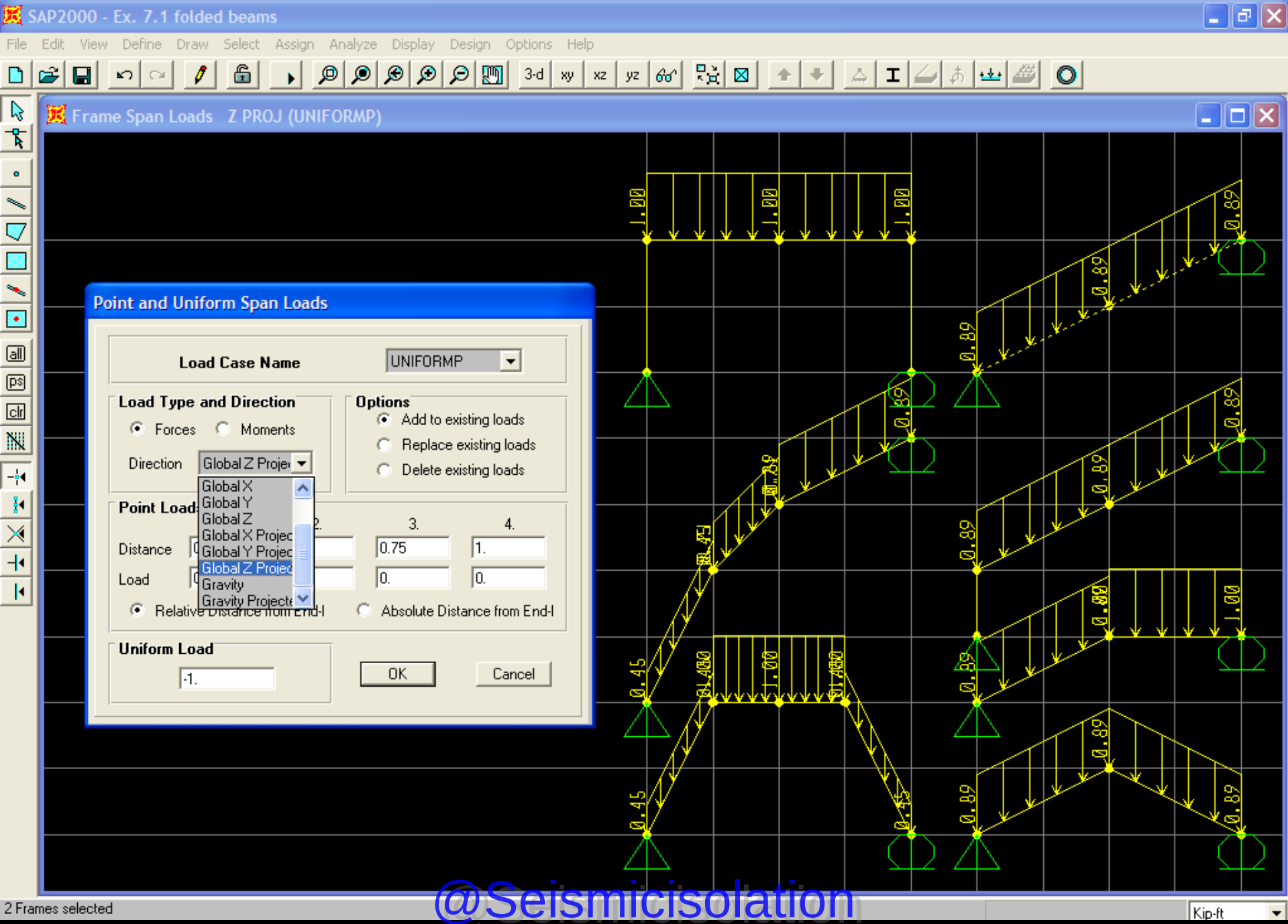

AP2000 - Fig. 7.1
Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d
Frame Span Loads (LIVE) (As Defined)
wcosθ = 0.93 k/ft
Restraint Reactions (Live)
25.00
20.00
25.00
10.10
12.86
7.14
10.00
0.00
Axial Force Diagram (Live)
Moment 3-3 Diagram (Live)
-7.94 ft-k
50 ft-k
34.46 ft-k
50 ft-k
49.70 ft-k
50 ft-k
@Seismicisolation
Plane @ Y=0
X83.85 Y0.00 Z37.79
GLOBAL
Kip, ft, F


P2000 - Fig. 7.1
Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d
Frame Span Loads (GRAVITY) (As Defined)
1 k/ft
Restraint Reactions (GRAVITY)
Axial Force Diagram (GRAVITY)
Moment 3-3 Diagram (GRAVITY)
-5.76 ft-k
53.85 ft-k
37.69 ft-k
53.85 ft-k
54.11 ft-k
53.85 ft-k
@Seismicisolation

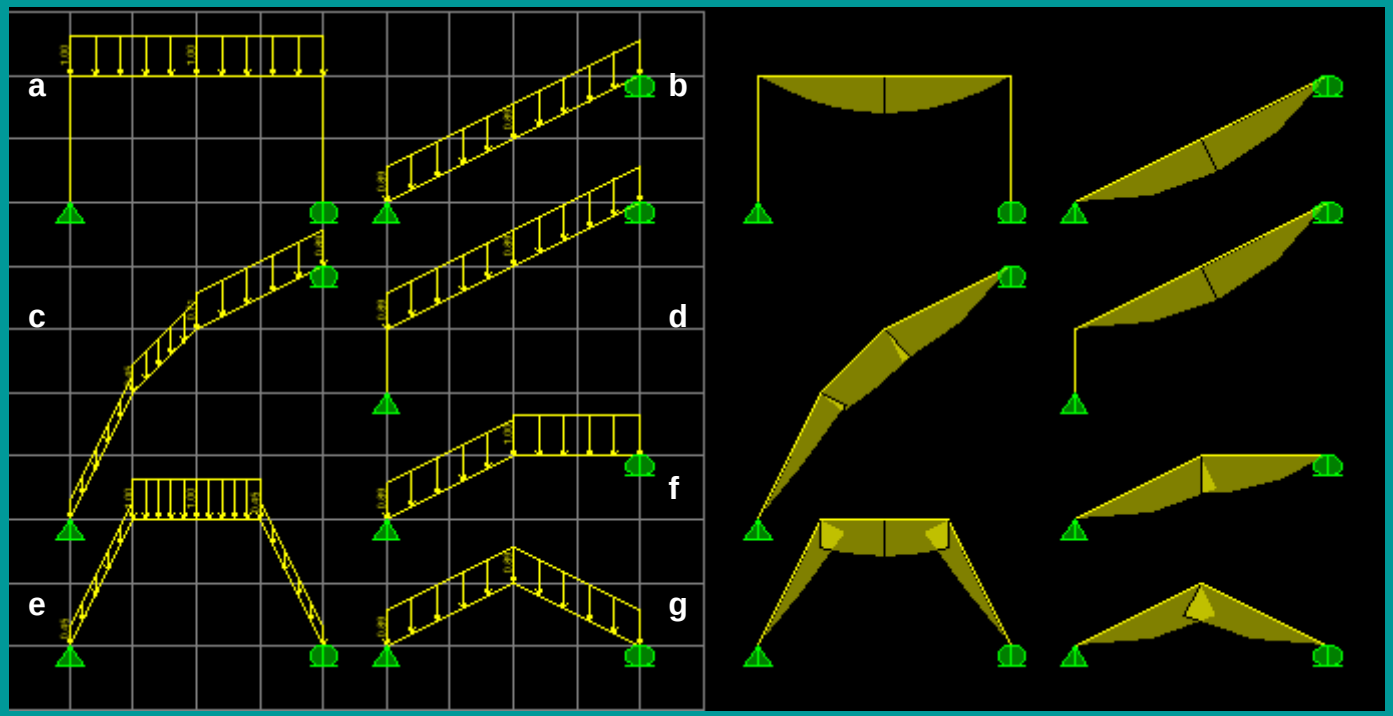

SAP2000 - Fig. 7.1
File Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d
Frame Span Loads (W) (As Defined)
wsinθ = 0.37 k/ft
Restraint Reactions (W)
Axial Force Diagram (W)
Moment 3-3 Diagram (W)
7.94 ft-k
13.61 ft-k
15.87 ft-k
@Seismicisolation



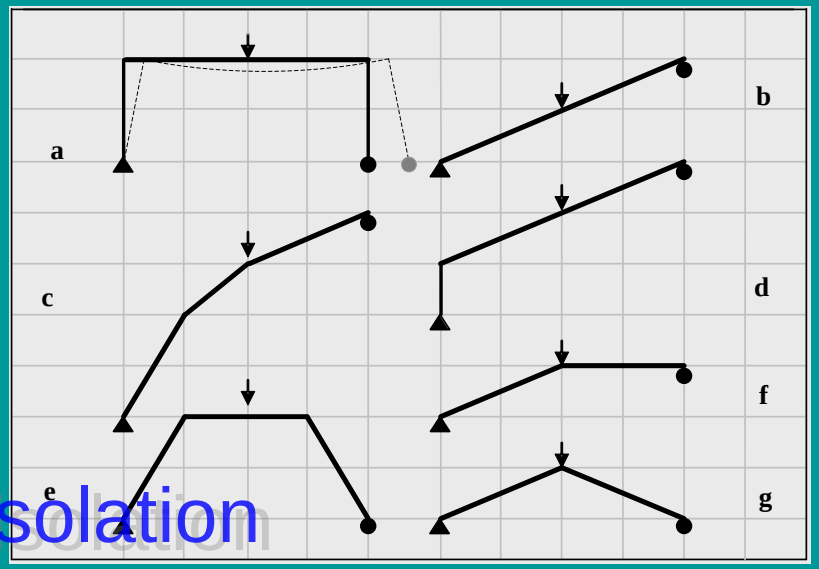
@Seismicisolation



@Seismicisolation



$$M_{max} = wL^2/8$$



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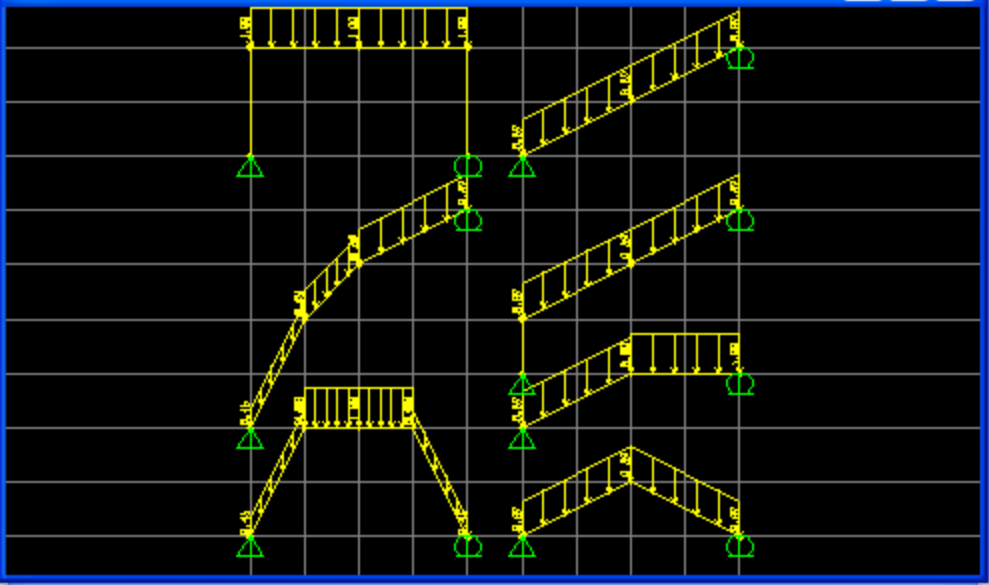
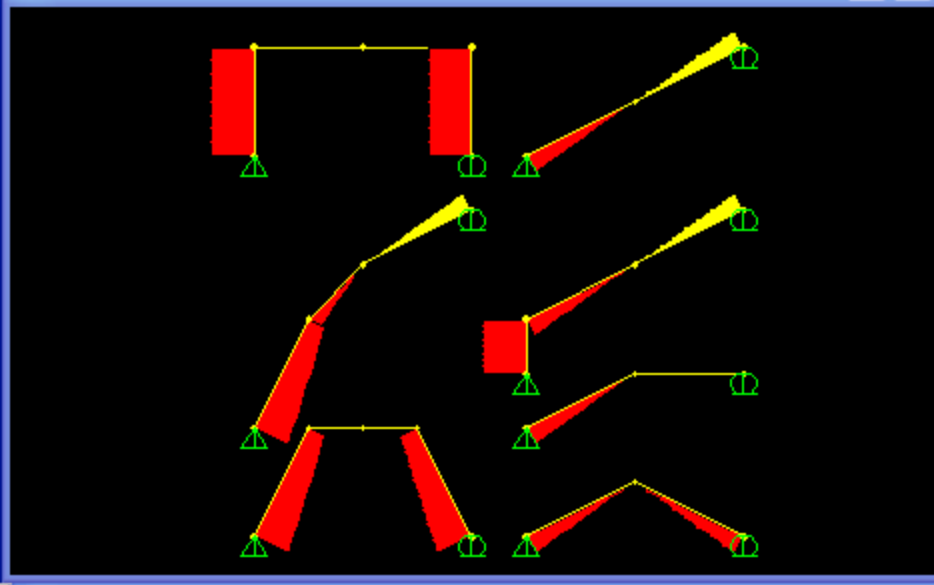
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

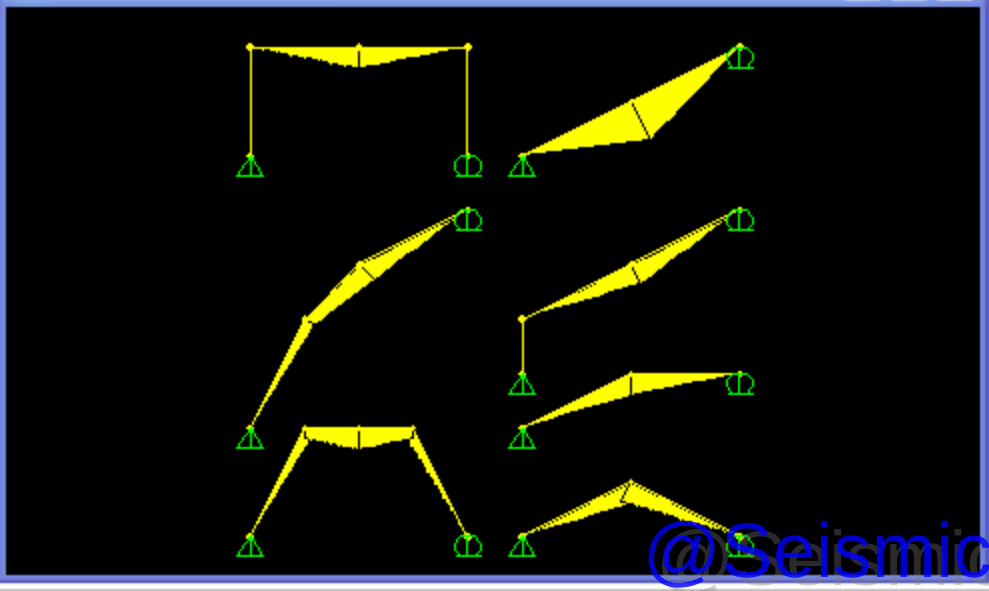
Frame Span Loads (UNIFORMP)



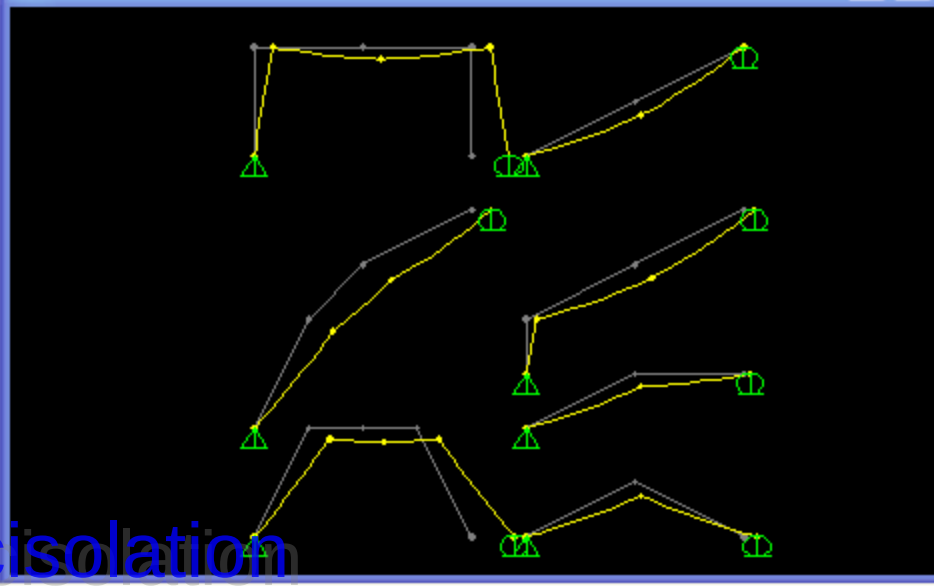
Axial Force Diagram (UNIFORMP)



Moment 3-3 Diagram (SINGLEP)



Deformed Shape (UNIFORMP)



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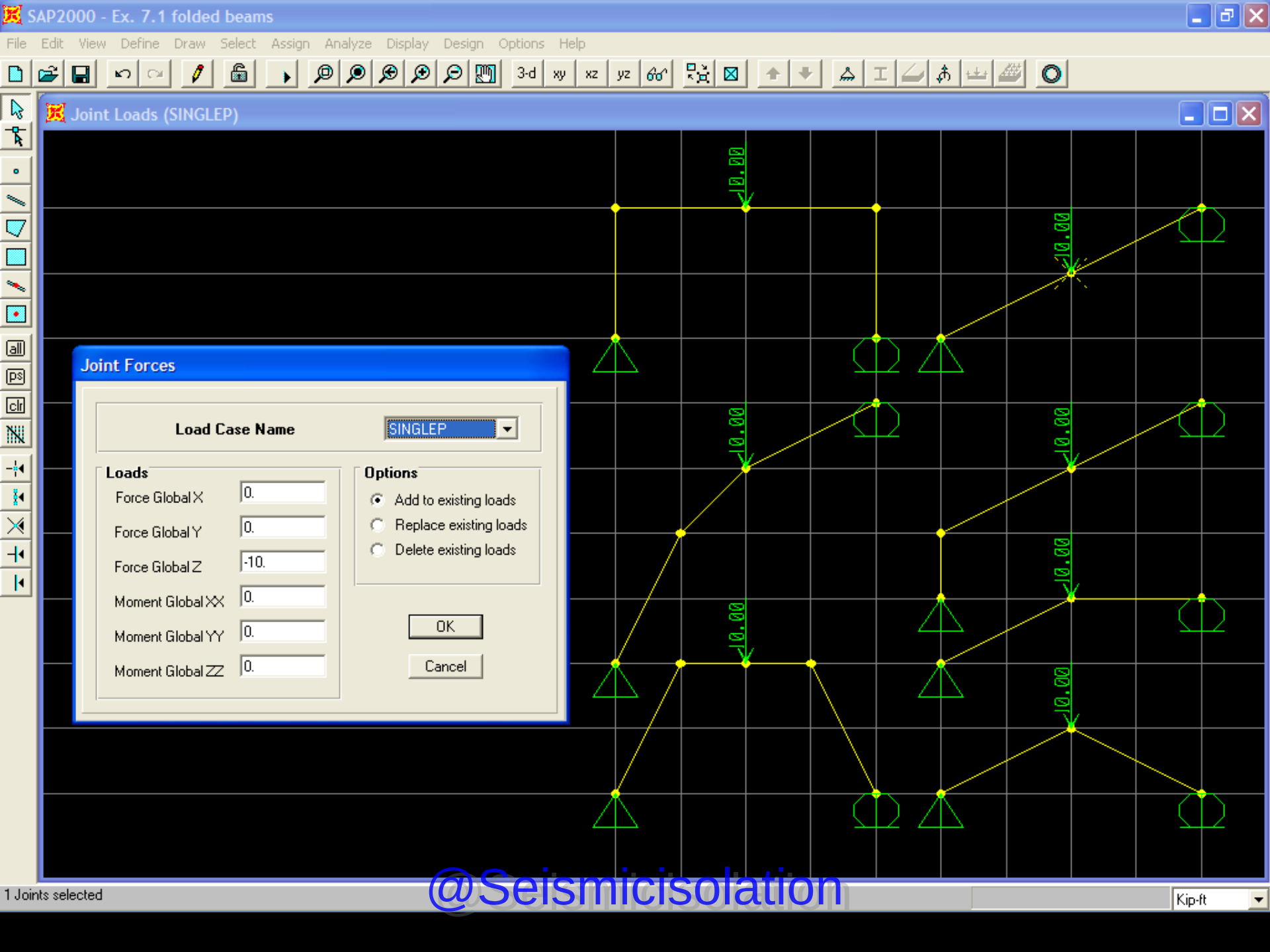
Plane @ Y=0

X-25.36 Y0.00 Z58.60

Kip-ft


SAP2000 - Ex. 7.1 folded beams
File Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d xy xz yz
Joint Loads (SINGLEP)
Joint Forces
Load Case Name
SINGLEP
Loads
Force Global X
0.
Force Global Y
0.
Force Global Z
-10.
Moment Global XX
0.
Moment Global YY
0.
Moment Global ZZ
0.
Options
Add to existing loads
Replace existing loads
Delete existing loads
OK
Cancel
10.00
1 Joints selected
Kip-ft
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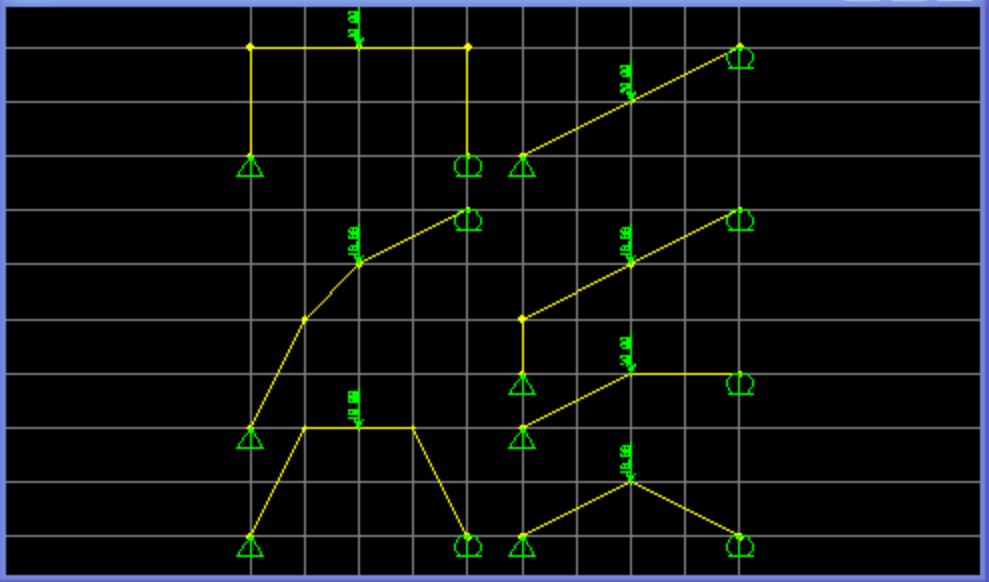
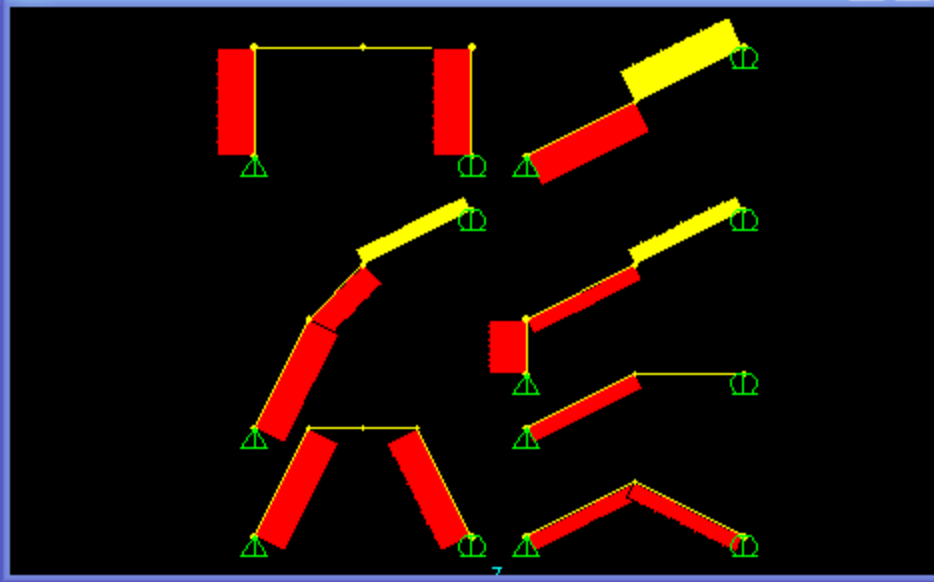
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

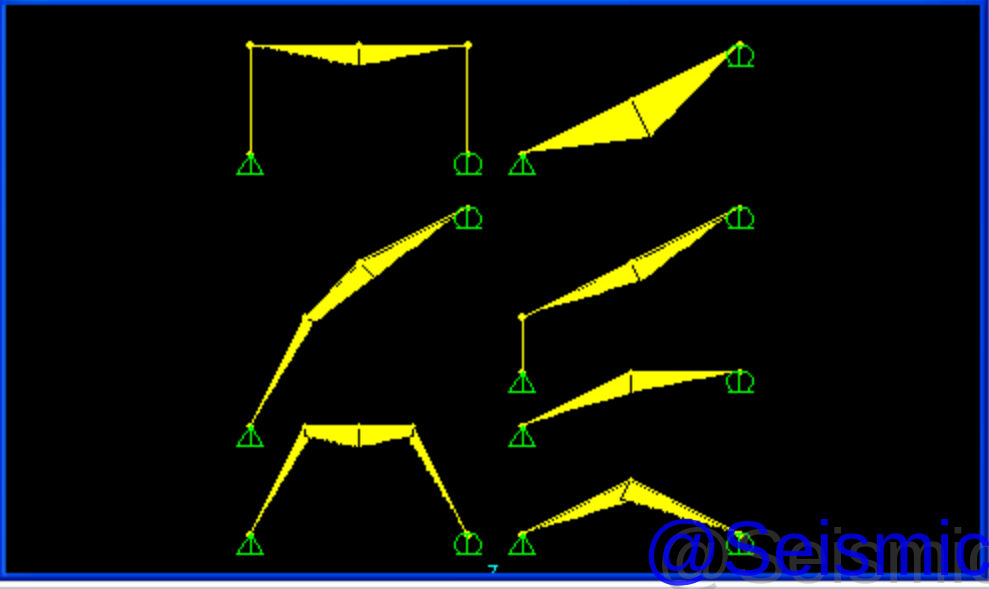
Joint Loads (SINGLEP)



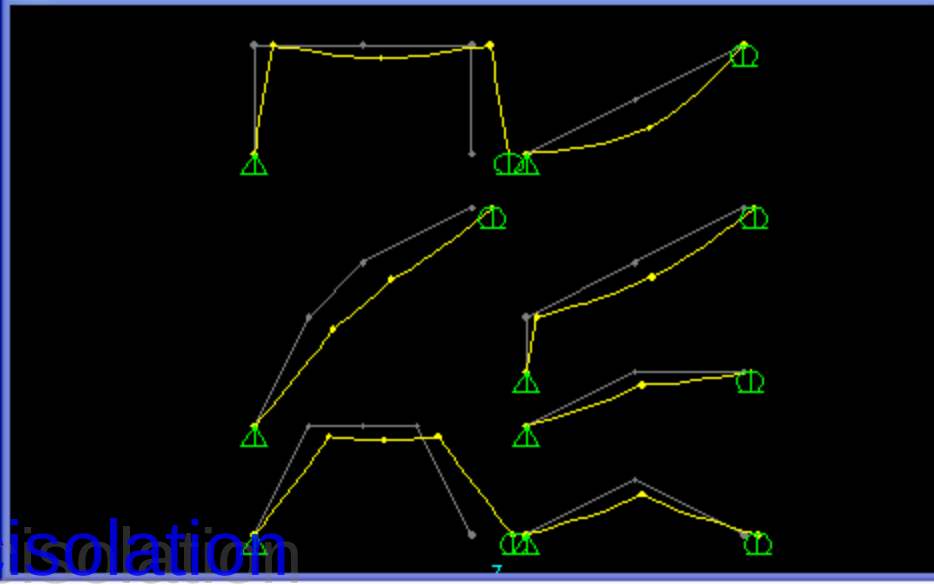
Axial Force Diagram (SINGLEP)



Moment 3-3 Diagram (SINGLEP)



Deformed Shape (SINGLEP)



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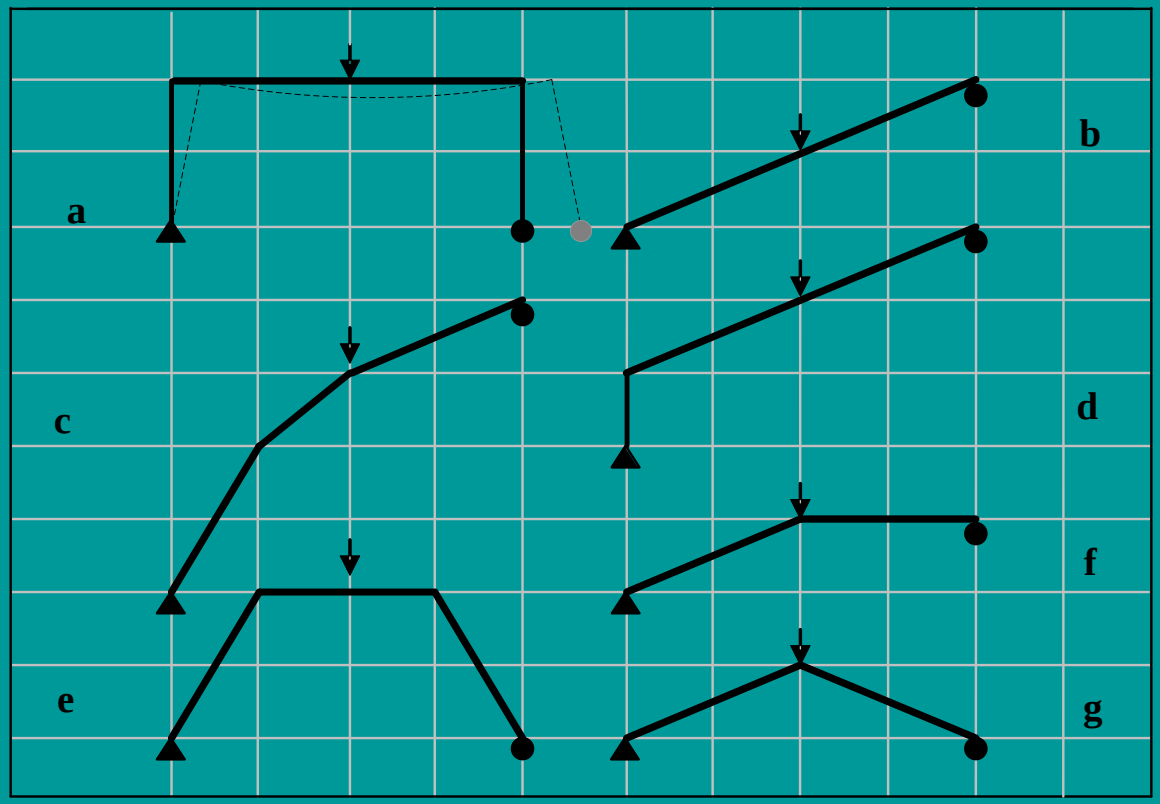
Click on any Frame Element for detailed diagram

Kip-ft

Folded Beam Structures



The magnitude of the maximum moment for simple folded or bent beams under uniform vertical loads does not change when the load is applied **on the horizontal projection** of the beams. Naturally, the magnitude of the axial forces will change.

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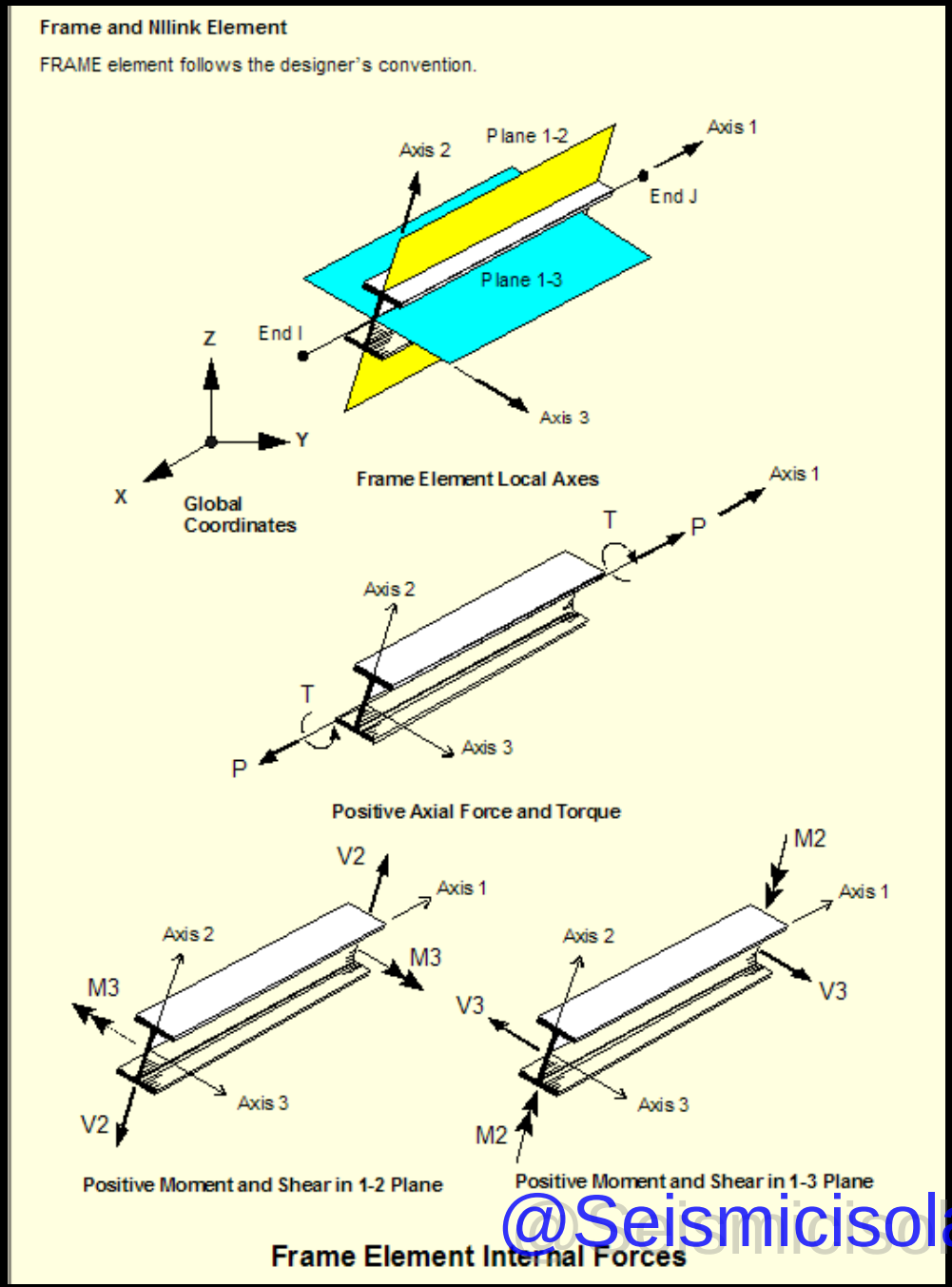

MEMBER ORIENTATION

Is defined by local coordinate system

Each part of the structure (e.g. joint, element) has its own **LOCAL** coordinate system **1-2-3**.

The joint local coordinate system is normally the same as the global X-Y-Z coordinate system.

For the elements, one of the element local axes is determined by the geometry of the individual element; the orientation of the remaining two axes is defined by specifying a single angle of rotation.

For frame elements, for example, the local axis **1** is always the longitudinal axis of the element with the positive direction from I to J. The default orientation of the local 1-2 plane in SAP is taken to be vertical (i.e. parallel to the Z-axis). The local 3-axis is always horizontal (i.e. lies in the X-Y plane).

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Siam Square, Bangkok

@Seismicisolation

Ningbo downtown, 2002,
Qingyun Ma

@Seismicisolation


Big Wood
@Seismicisolation

If the **roller** in the simple folded beams is replaced by a **pin support**, horizontal thrust or kickout forces are generated by the gravity loads at the base (since the boundary conditions do not allow outward displacement), which in turn cause bending of the columns and beam.

By providing two pin supports, the structure is once indeterminate and cannot be solved directly with the equations of equilibrium as is discussed further in the next section of this book. But when an **internal hinge** is introduced somewhere along the frame one more known condition is introduced because the moment must be zero at this point, so the frame can be solved by statics.

Quite common are **three-hinged frame systems** where the hinge is placed at mid-span of the beam as demonstrated in the following drawing for various one-story, single-bay frame shapes.

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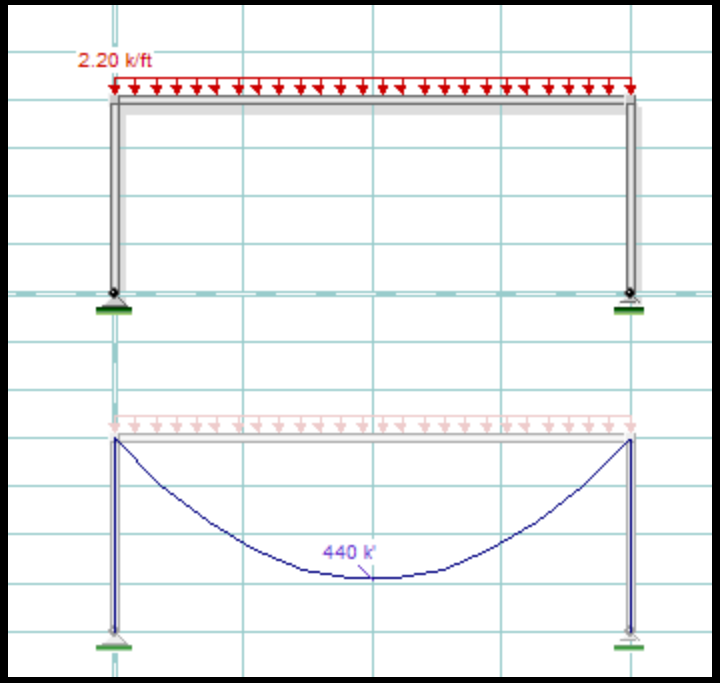

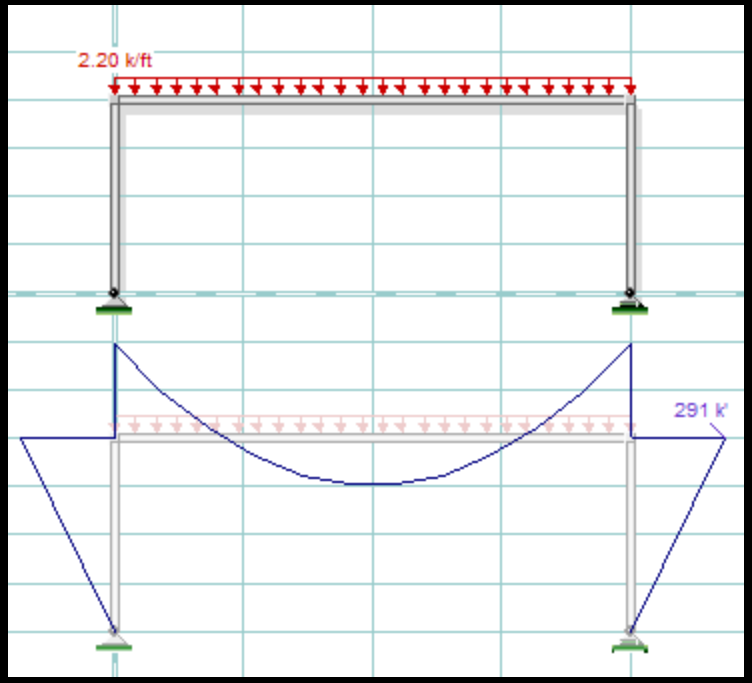

FOLDED BEAM vs. FRAME

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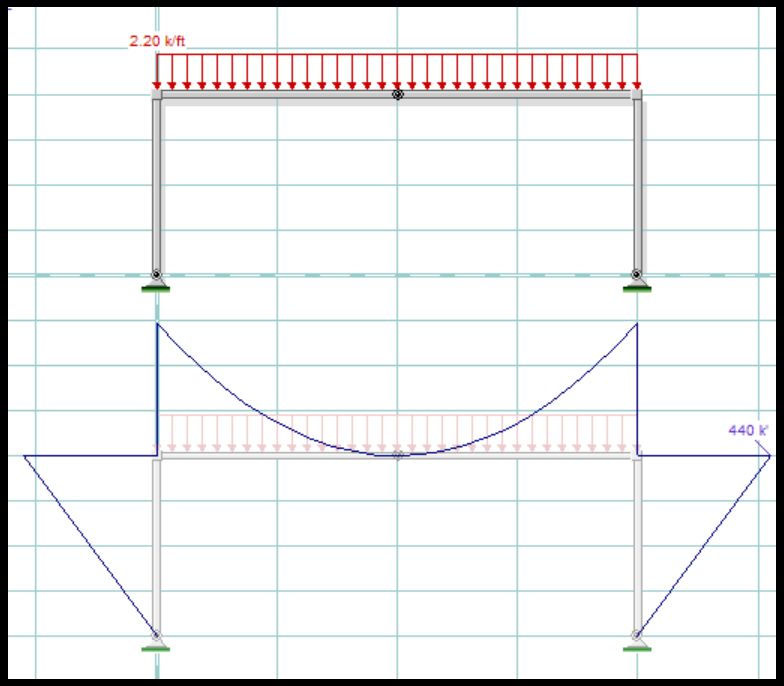

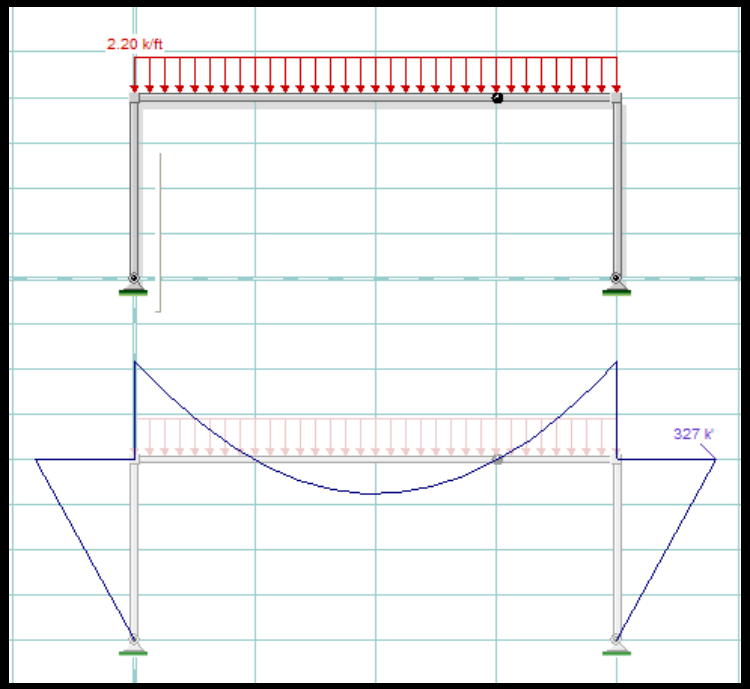

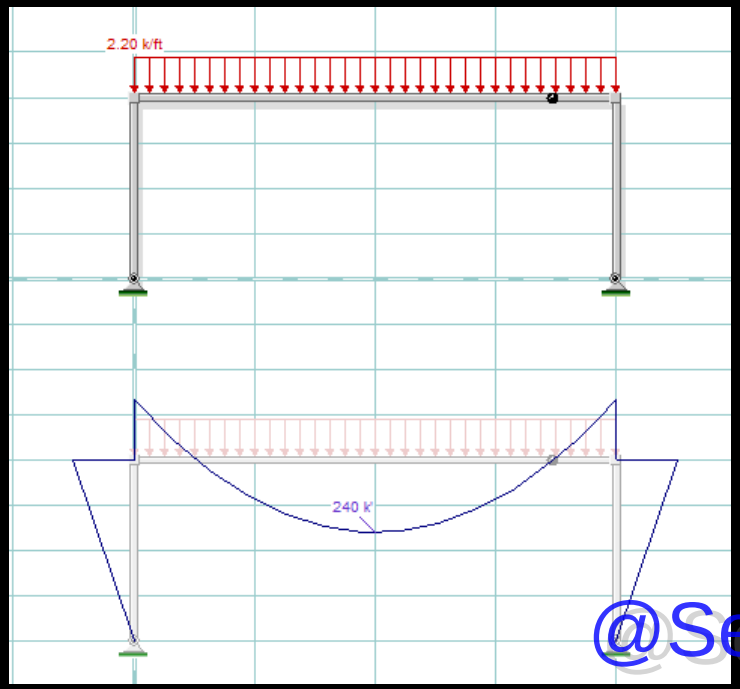

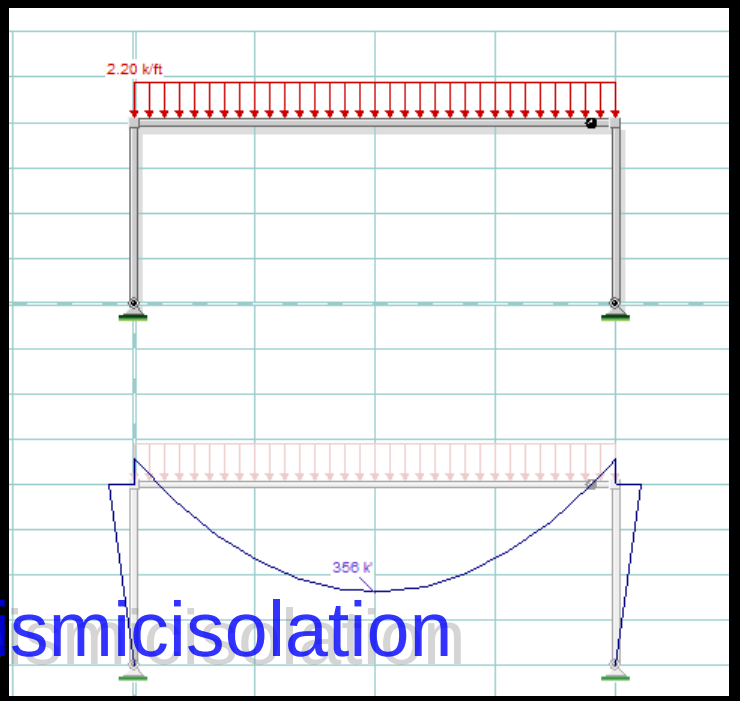

THE EFFECT OF HINGE LOCATION

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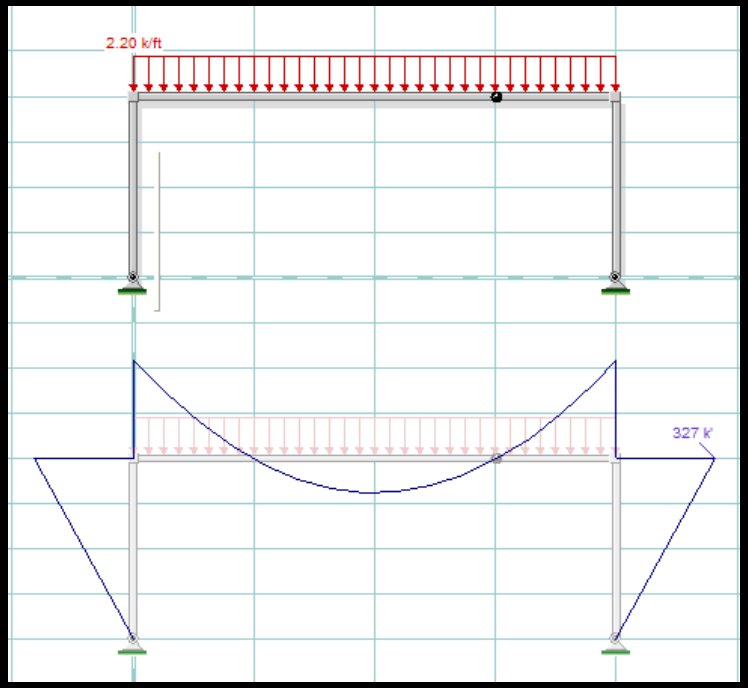

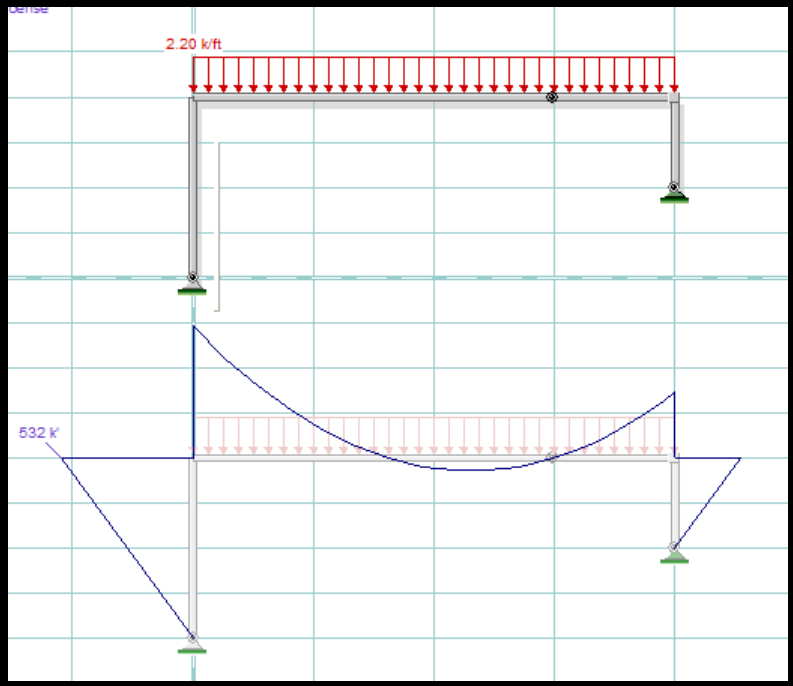

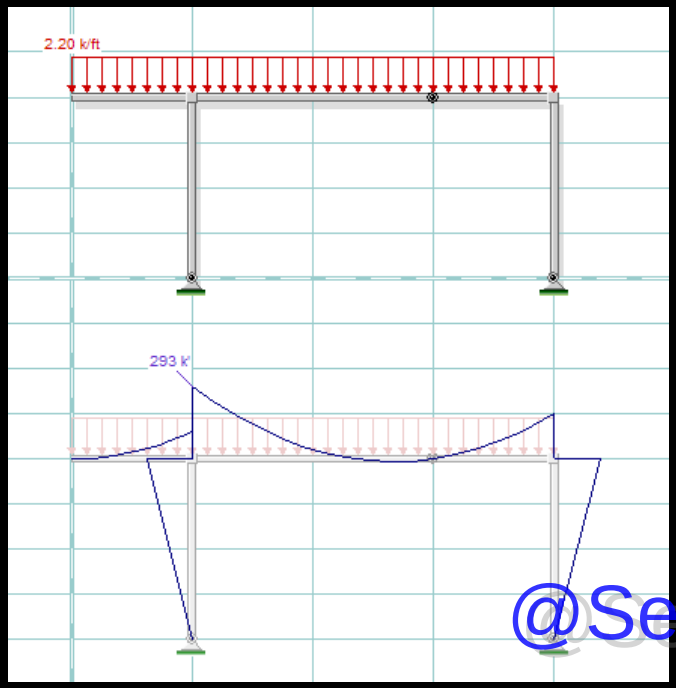

GEOMETRY - THE EFFECT OF CHANGE :
shorter column and cantilever

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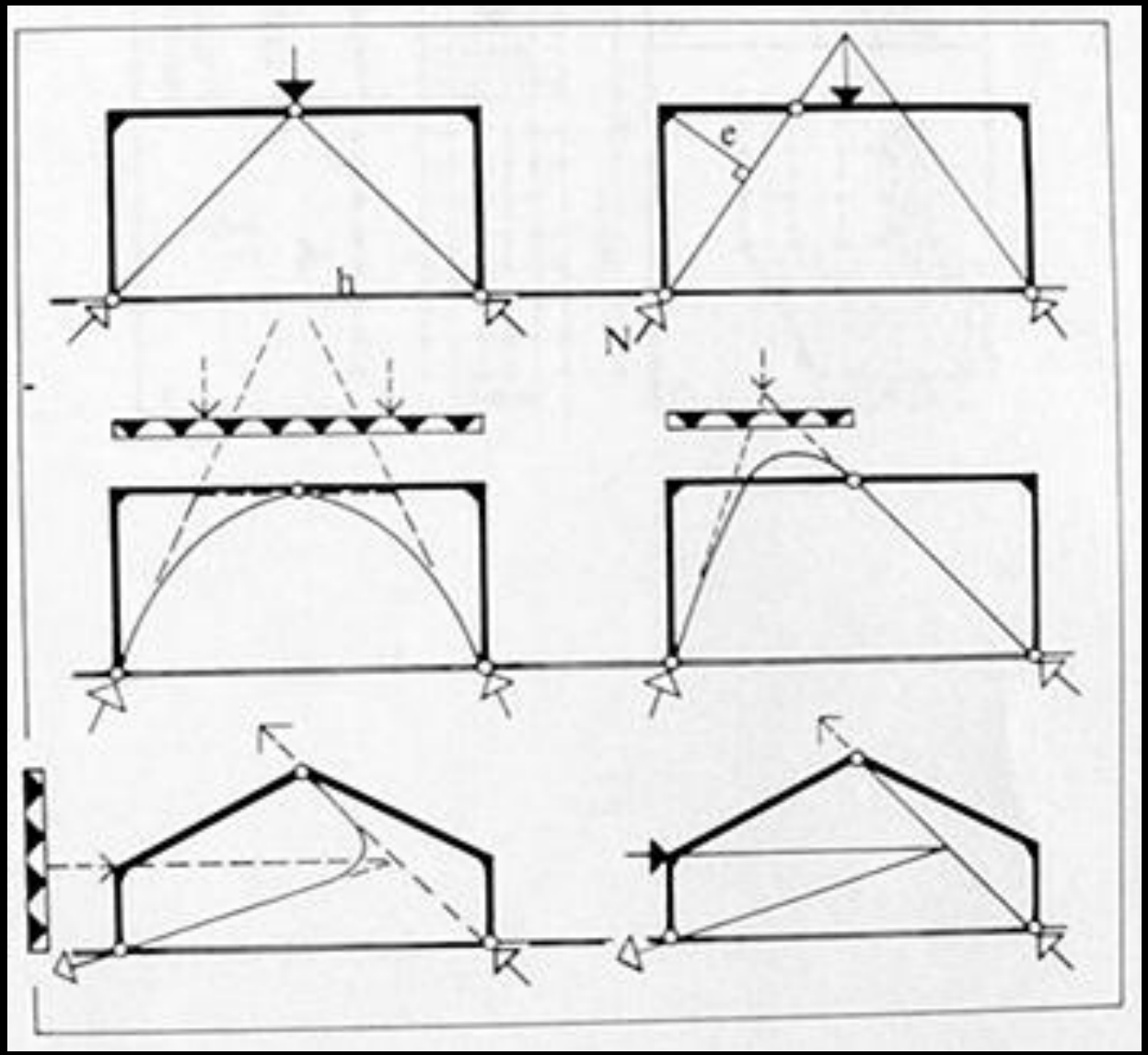

PRESSURE LINE RESPONSES TO VARIOUS LOAD ACTIONS:

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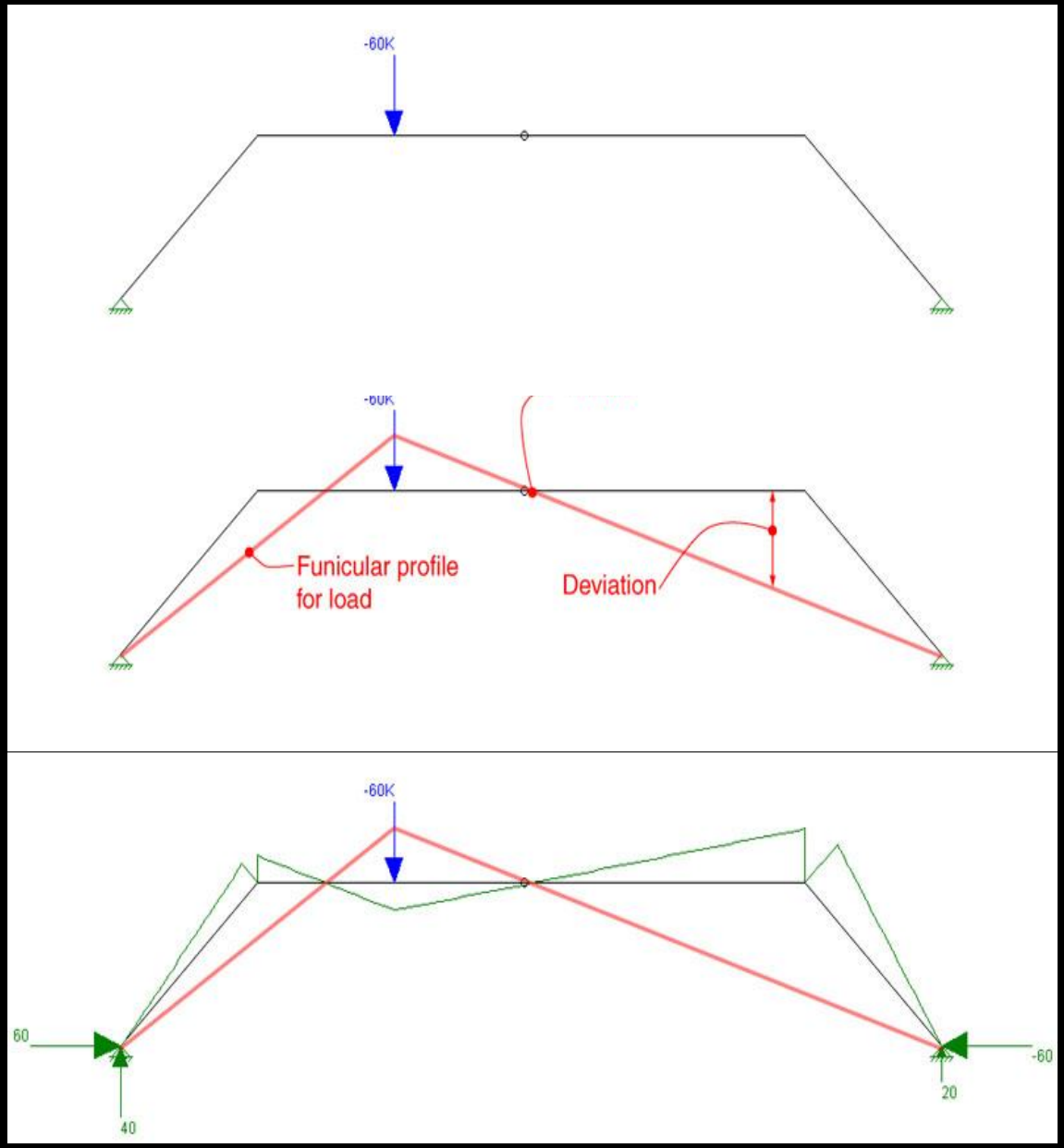
funicular shapes



PRESSURE LINE VS. FRAME SHAPE VS. M-diagram

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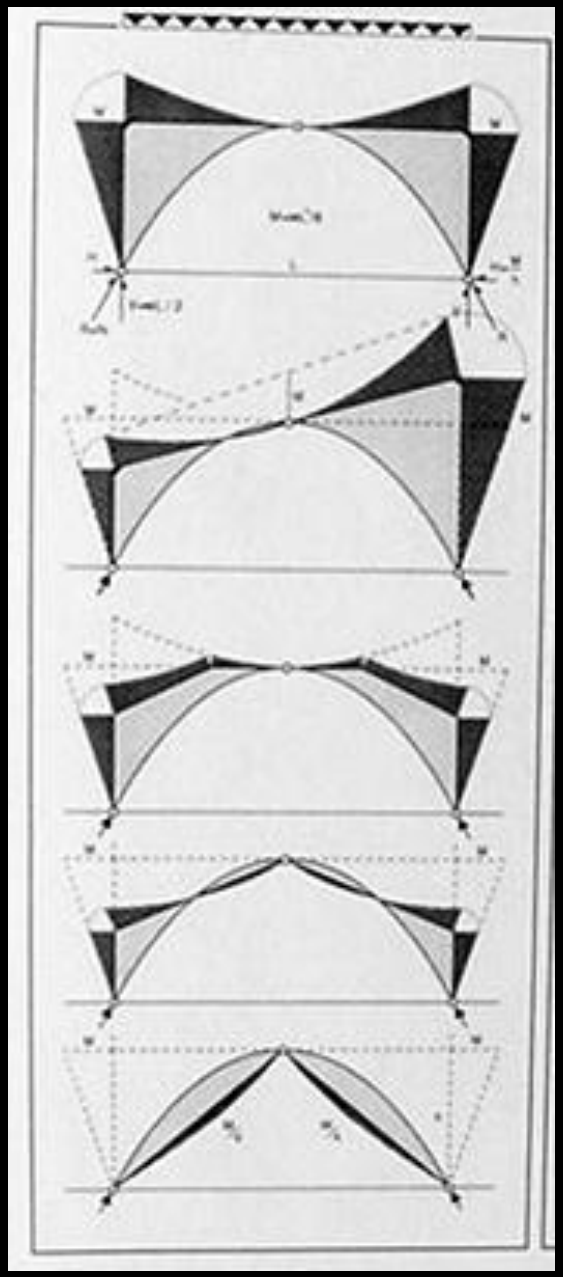

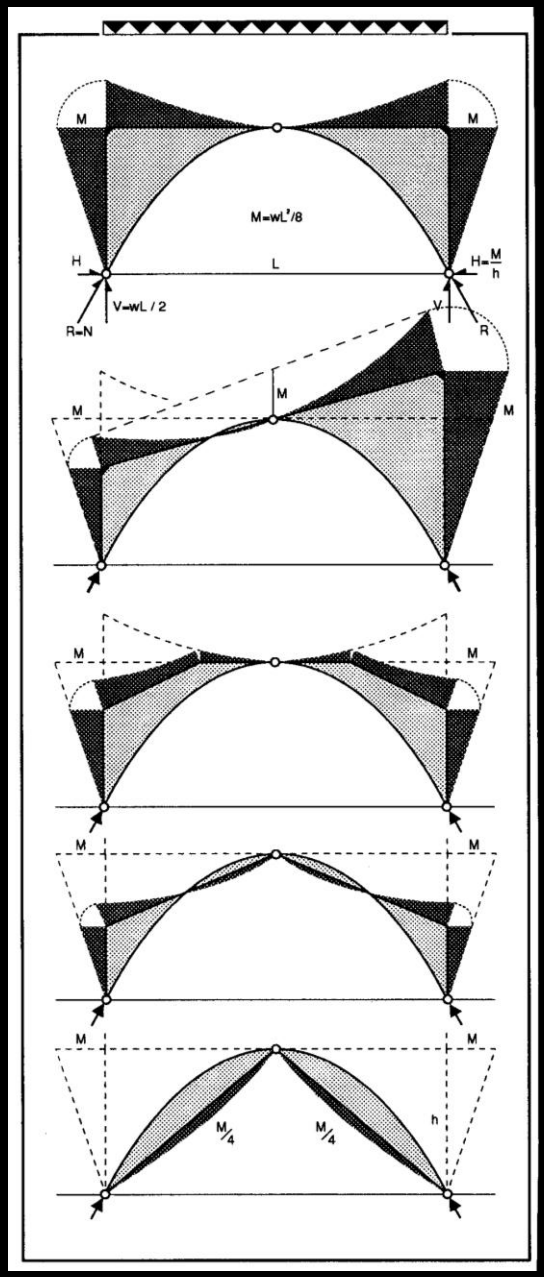

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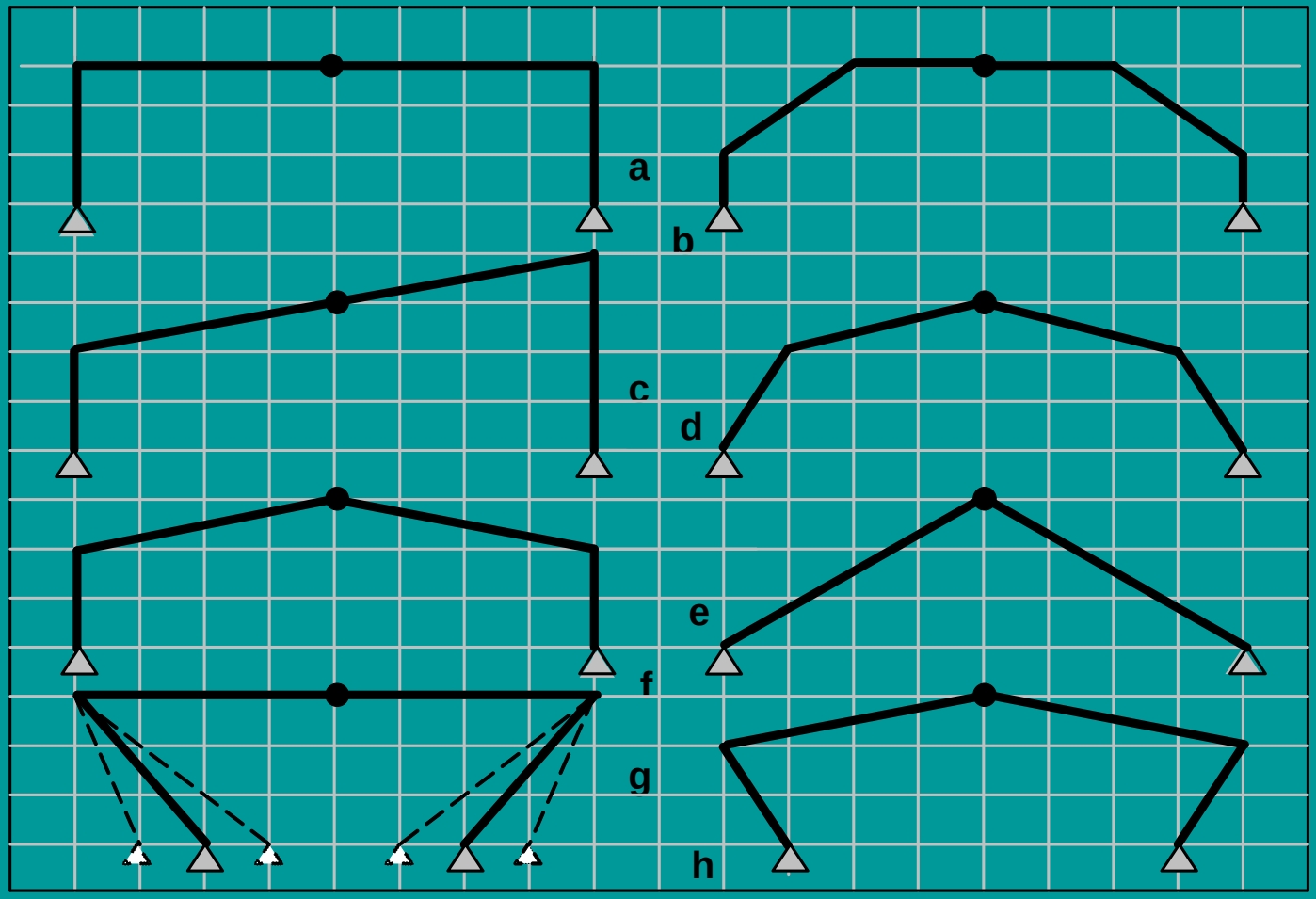
THE EFFECT OF PROFILE ON 3-HINGE FRAMES



Three-Hinged Frames

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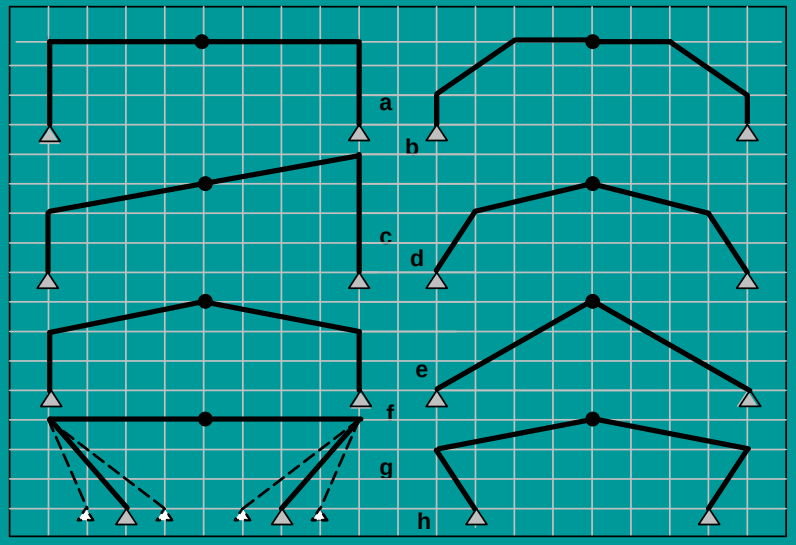

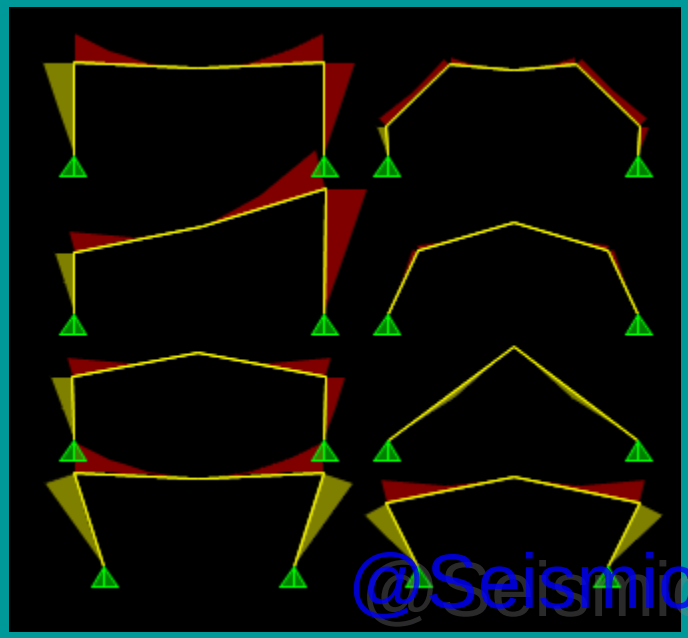

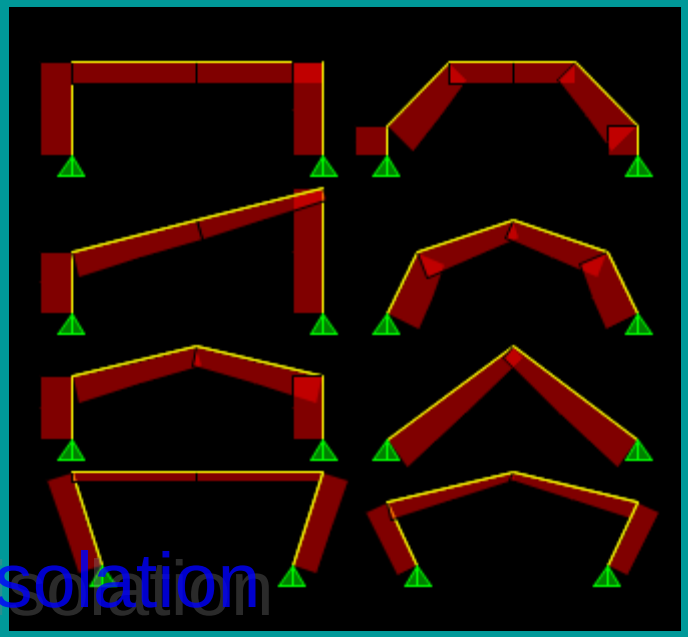

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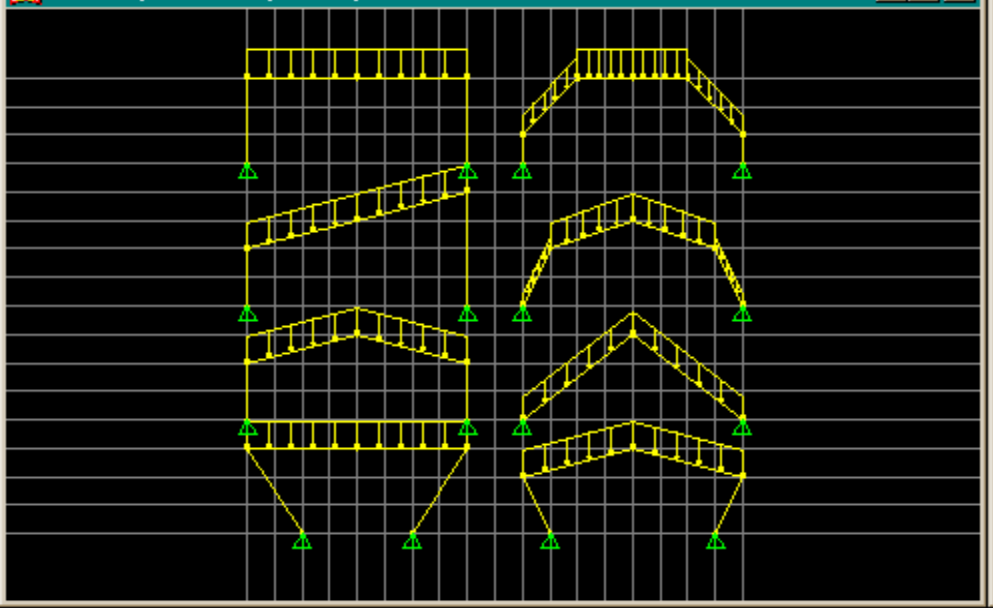
AP2000 - Ex. 6.2 three-hingeframes

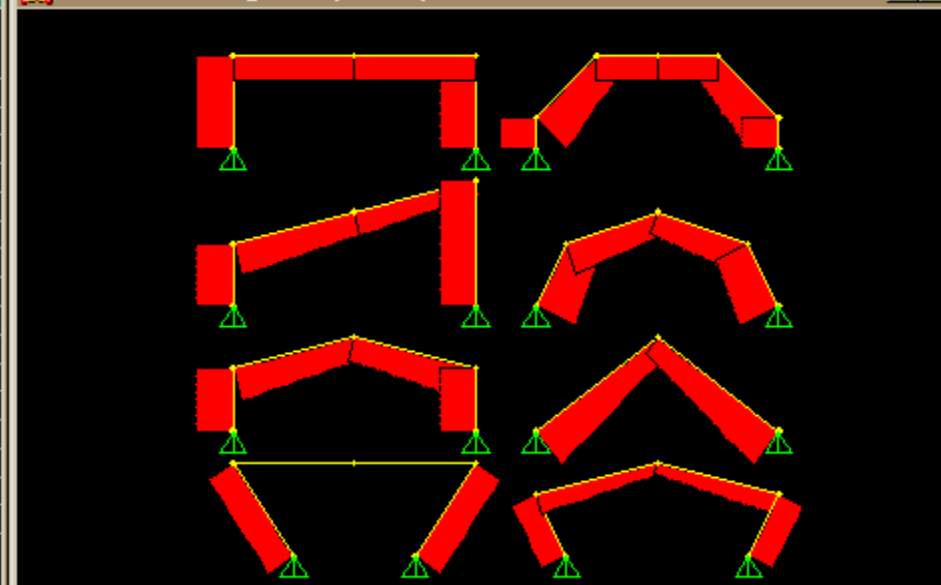
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

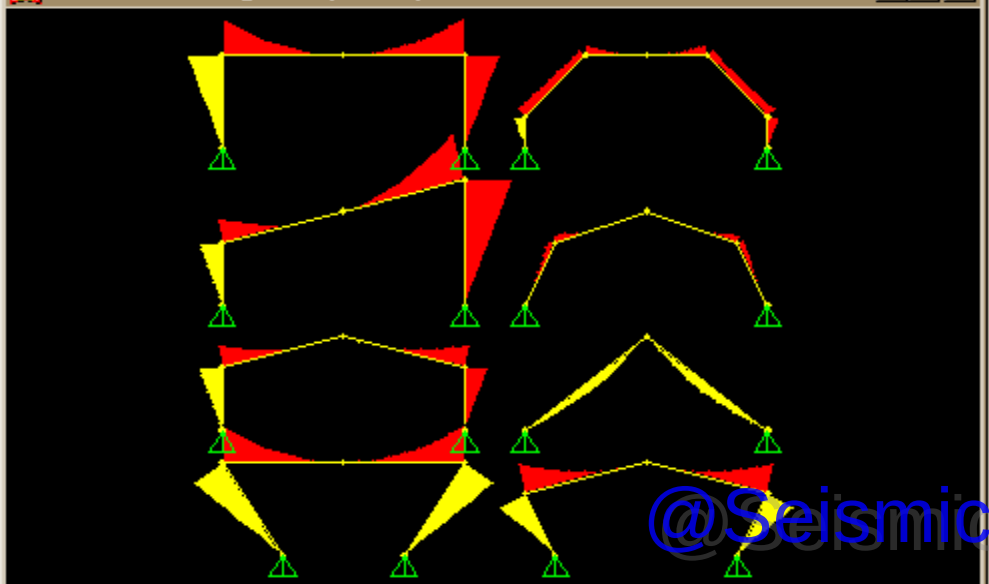
Frame Span Loads (LOAD1)



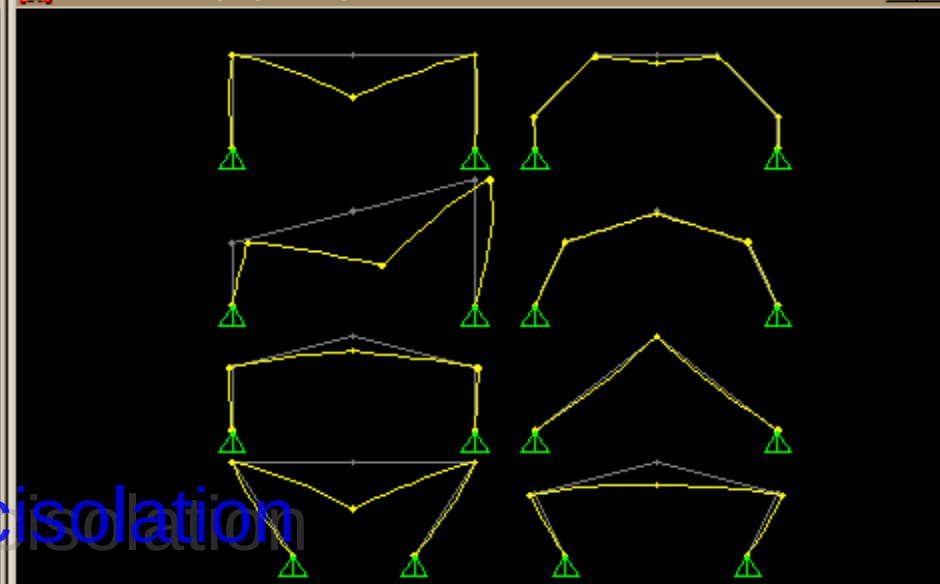
Axial Force Diagram (LOAD1)



Moment 3-3 Diagram (LOAD1)



Deformed Shape (LOAD1)



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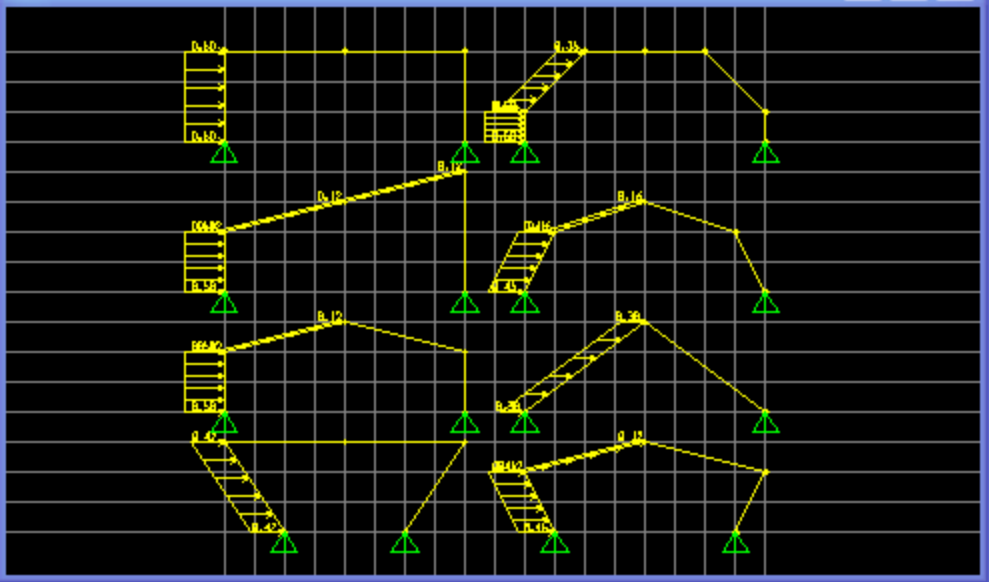
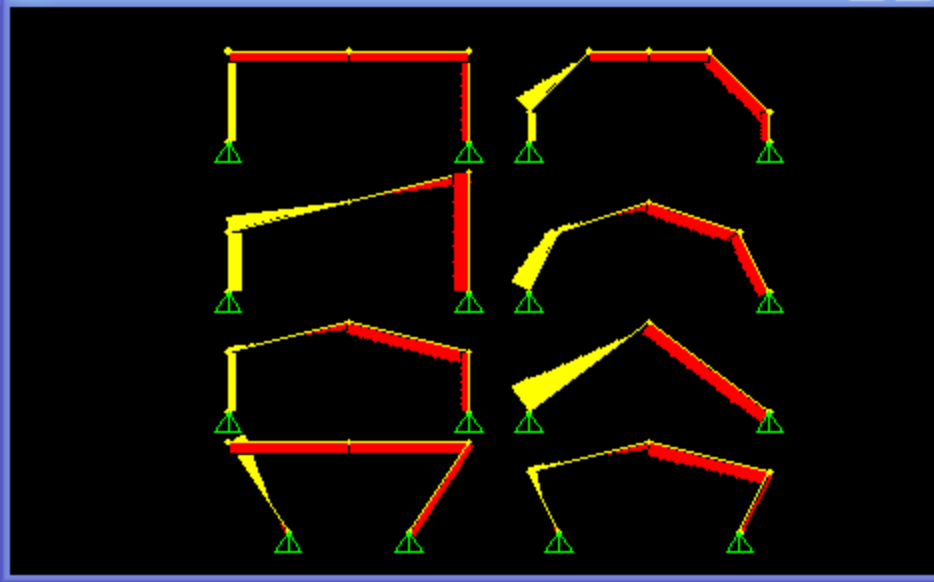
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz

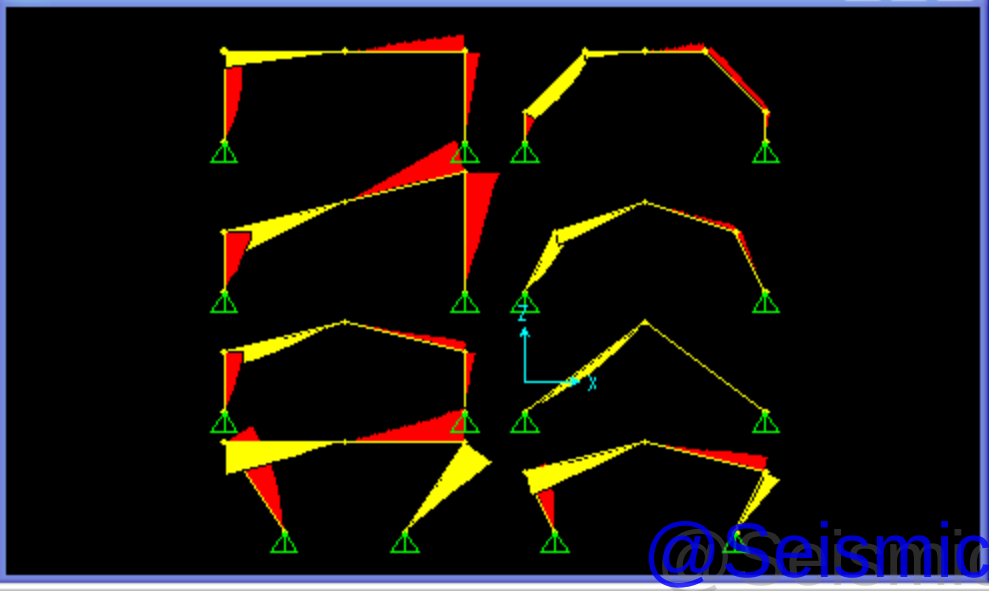
Frame Span Loads (WIND)



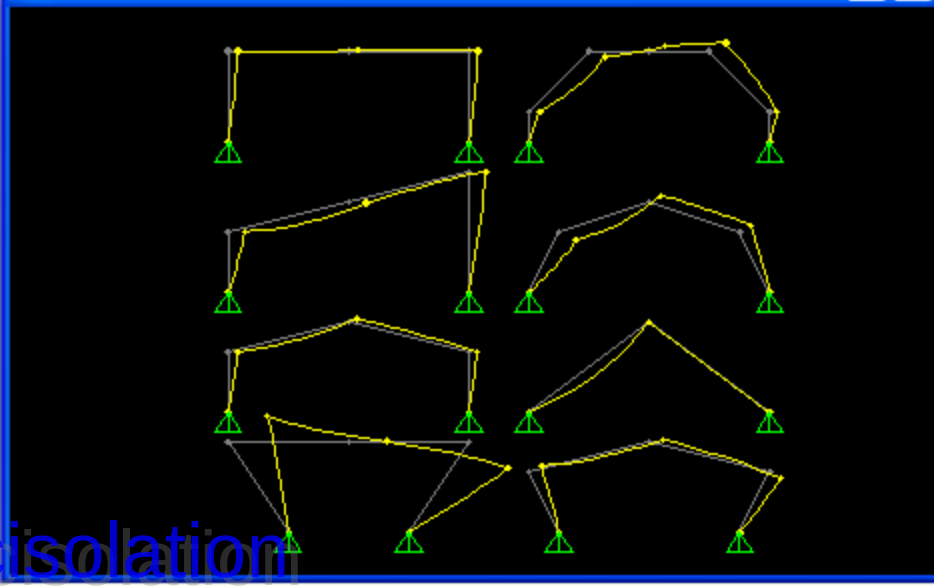
Axial Force Diagram (WIND)



Moment 3-3 Diagram (WIND)



Deformed Shape (WIND)



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Click on any joint for displacement values

Start Animation

Kip-ft

In general, a structure is **statically determinate** when the three equations of static equilibrium are sufficient for solving the unknown forces. When, however, the conditions of the structure are such that the three equations are not sufficient for determining the magnitude of the force flow, additional equations related to member properties, are required, and the structure is said to be **statically indeterminate**, **hyperstatic** or **redundant**. It is apparent that the structure must be in static equilibrium and **stable**, whether it is statically determinate or indeterminate.

The degree of indeterminacy may be found by making the structure statically determinate and stable by removing supports and/or cutting members. The number of force-resisting conditions taken away is equal to the degree of indeterminacy or redundancy, so named after the number of forces that are needed to ensure static equilibrium.

Redundancy is an important phenomenon be cause it allows the force flow to take an alternate path if the structure should be failing at a certain location, thus not necessarily resulting in a **progressive collapse** of the building as for determinate structures.

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Crown Hall, IIT, Chicago, 1956, Mies van der Rohe

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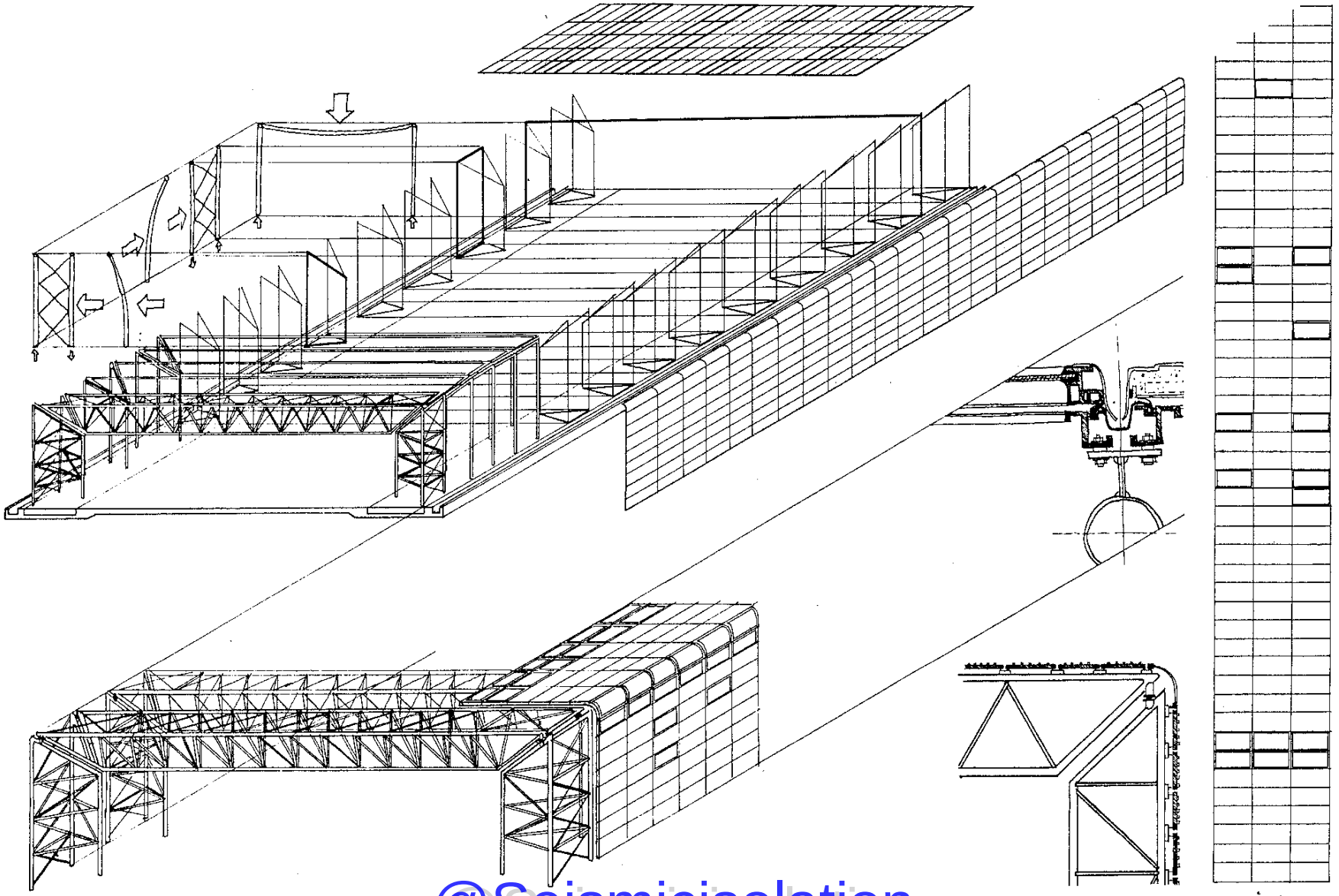
Sainsbury Centre, Norwich UK, 1977, Norman Foster

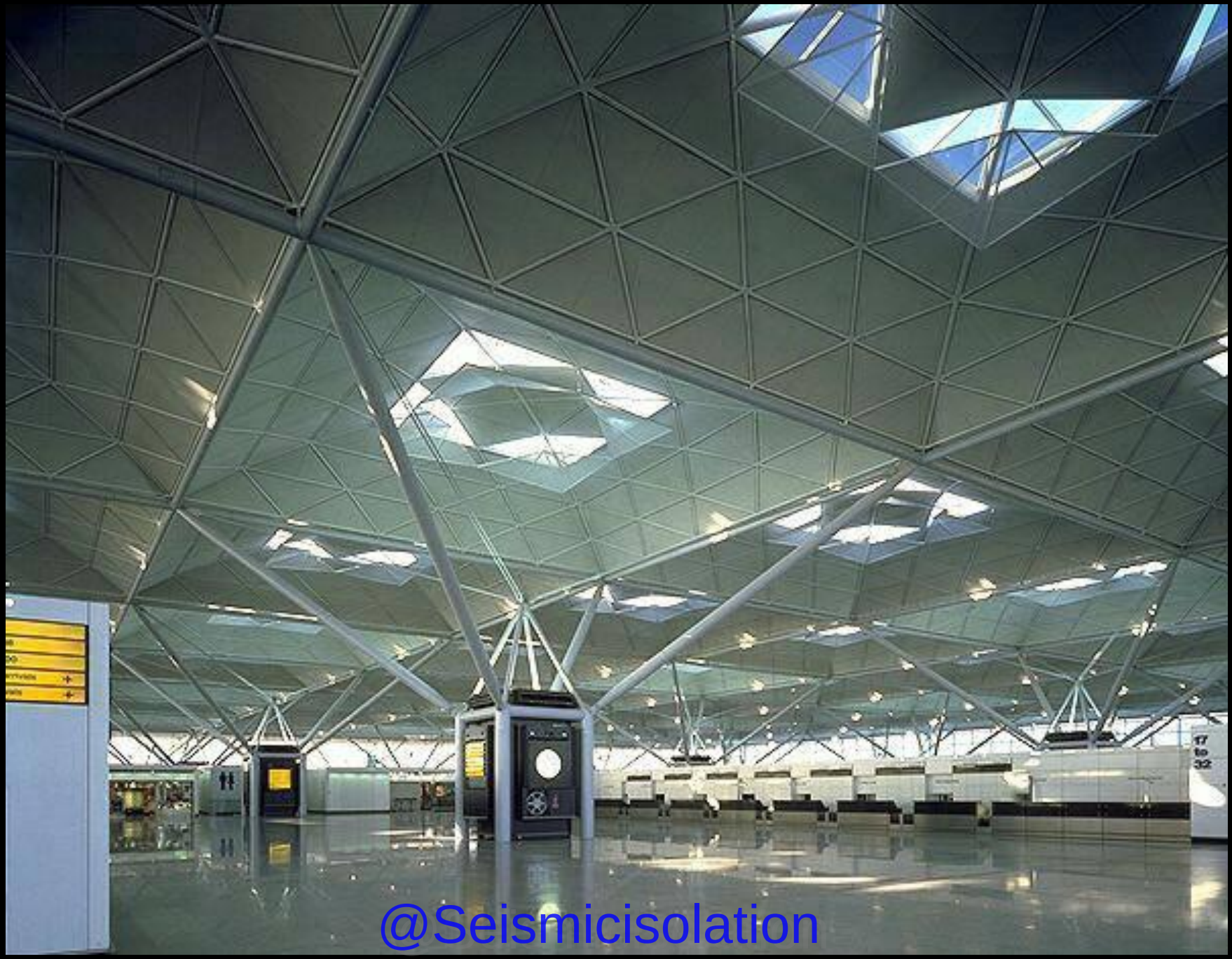
@Seismicisolation



@Seismicisolation

Stansted Airport, London, 1991. Norman Foster

@Seismicisolation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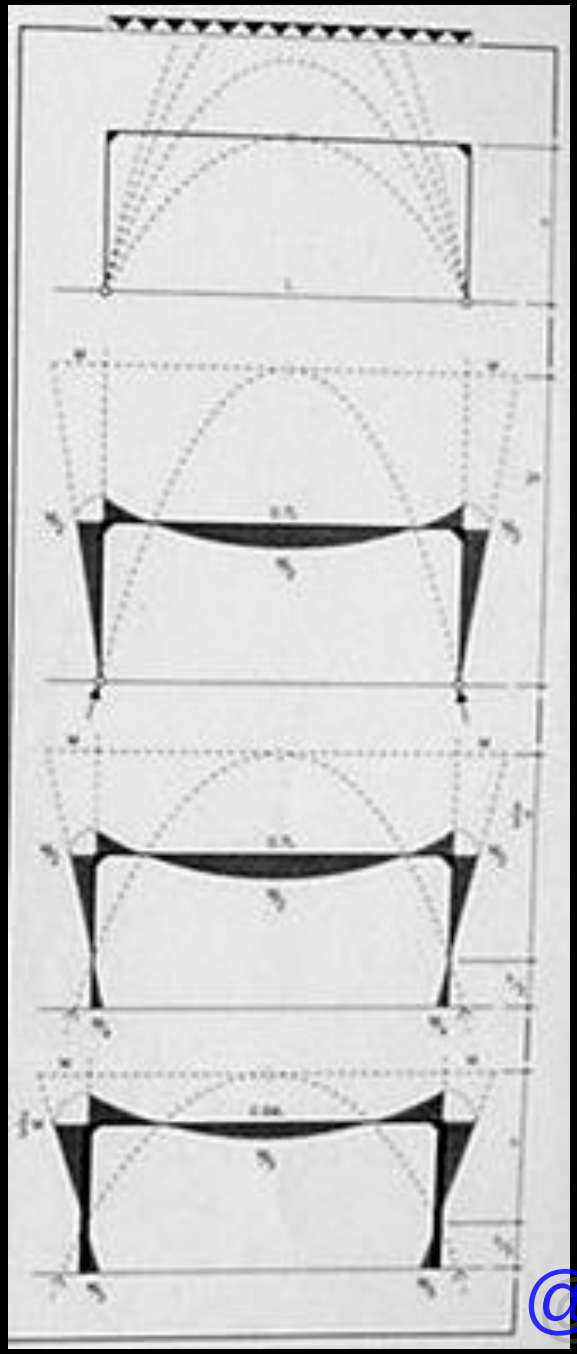

THE EFFECT OF BEAM AND COLUMN STIFFNESS FOR CONTINUOUS FRAMES

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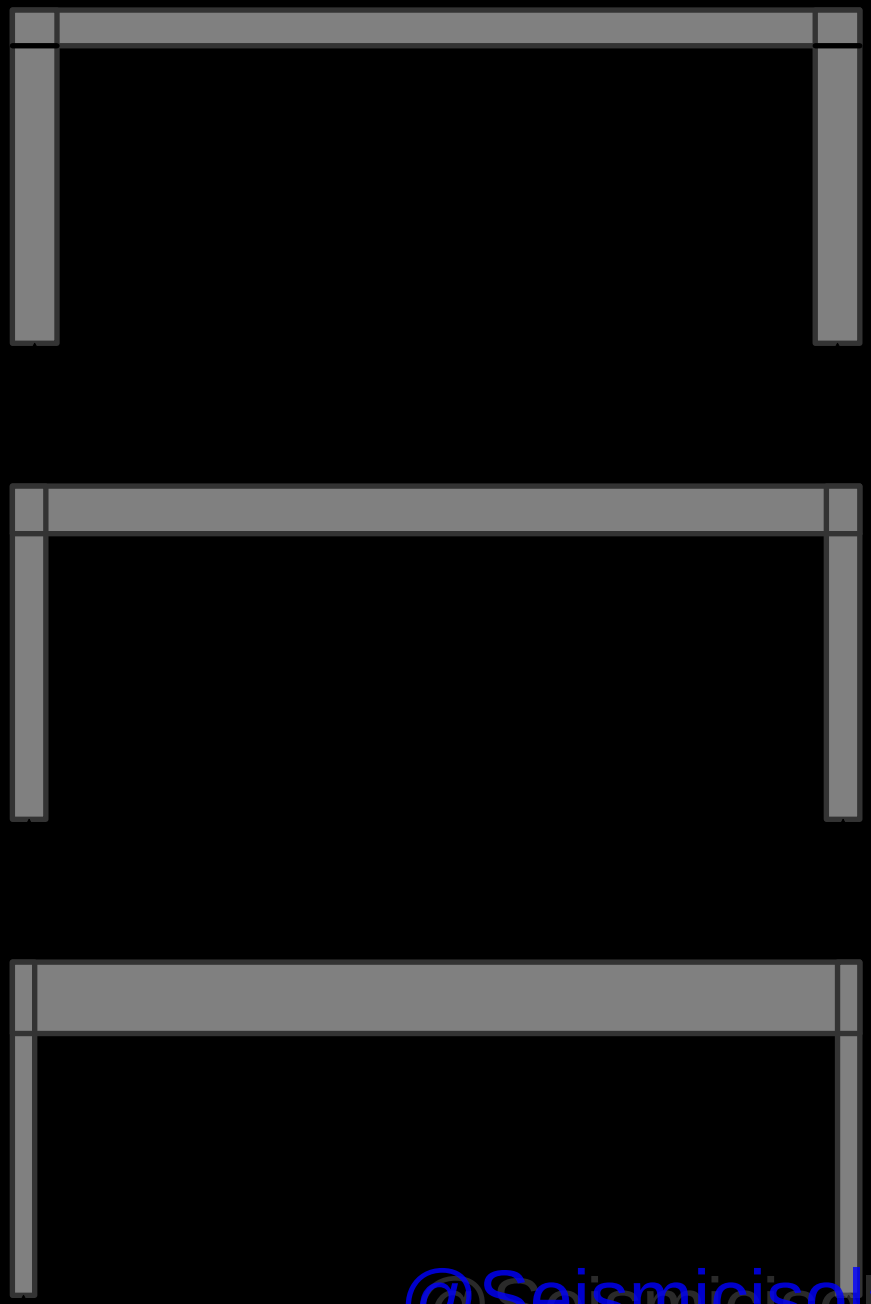

THE EFFECT OF CHANGE OF MEMBER STIFFNESS: conceptual drawing

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When the hinge in the three-hinged portal frame is taken out, then the two-hinged frame becomes once statically indeterminate; now the force flow cannot be found anymore simply by statics, the **bending stiffness *EI*** of the members must be considered. For example**,** the support moment M_s in the two-hinge frame **of one material** ($E_c = E_b$) is dependent on the stiffness of the beam (I_b/L_b) and column (I_c/L_c) that is the **stiffness factor *k***.

$$M_S = -[wL^2/12]/[3/(3+2k)]$$

where, $k = (I/L)_b/(I/L)_c = (I_b/L_b)L_c/I_c = n(L_c/L_b)$, where, $I_b = nI_c$

For some typical conditions, the support or column moment M_s is,

k = 1.0 (i.e. equal beam and column stiffness)*:* $M_s = - wL^2/20$
k = 0.5*:* $M_s = - wL^2/16$
k = 0.3 (same column and beam section, ***k =*** L_c/L_b**,** say ***1/3***)*:* $M_s \approx - wL^2/14$

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Fortunately, not the actual stiffness but the **relative stiffness** is used to determine the force flow along the members. Since the material does not generally vary, the stiffness factor for the two-hinged portal frame can be expressed simply in terms of nL_c/L_b.

$k = (I/L)_b/(I/L)_c = (I_b/L_b)L_c/I_c = n(L_c/L_b)$ where, $I_b = nI_c$

In general, the magnitude of the frame moments in indeterminate frame structures depends on the relative stiffness of the adjacent beams ($\Sigma I_b/L_b$) and columns ($\Sigma I_c/L_c$). First, relative member sizes are assumed that is member sizes are expressed in terms of each other using the default sections in SAP and modifying the frame section to take the change of I into account by going to the ***Modification Factors***, and then filling in the appropriate factor (e.g. 2, 3) for the *Moment of inertia about 3 axis,* for example. Now the structure can be analyzed and can then be designed. Then, the structure has to be reanalyzed with the new member sections and be redesigned. Keep in mind that in the computer program design is an iterative process, where the analysis and design must be run multiple times to complete the design process.

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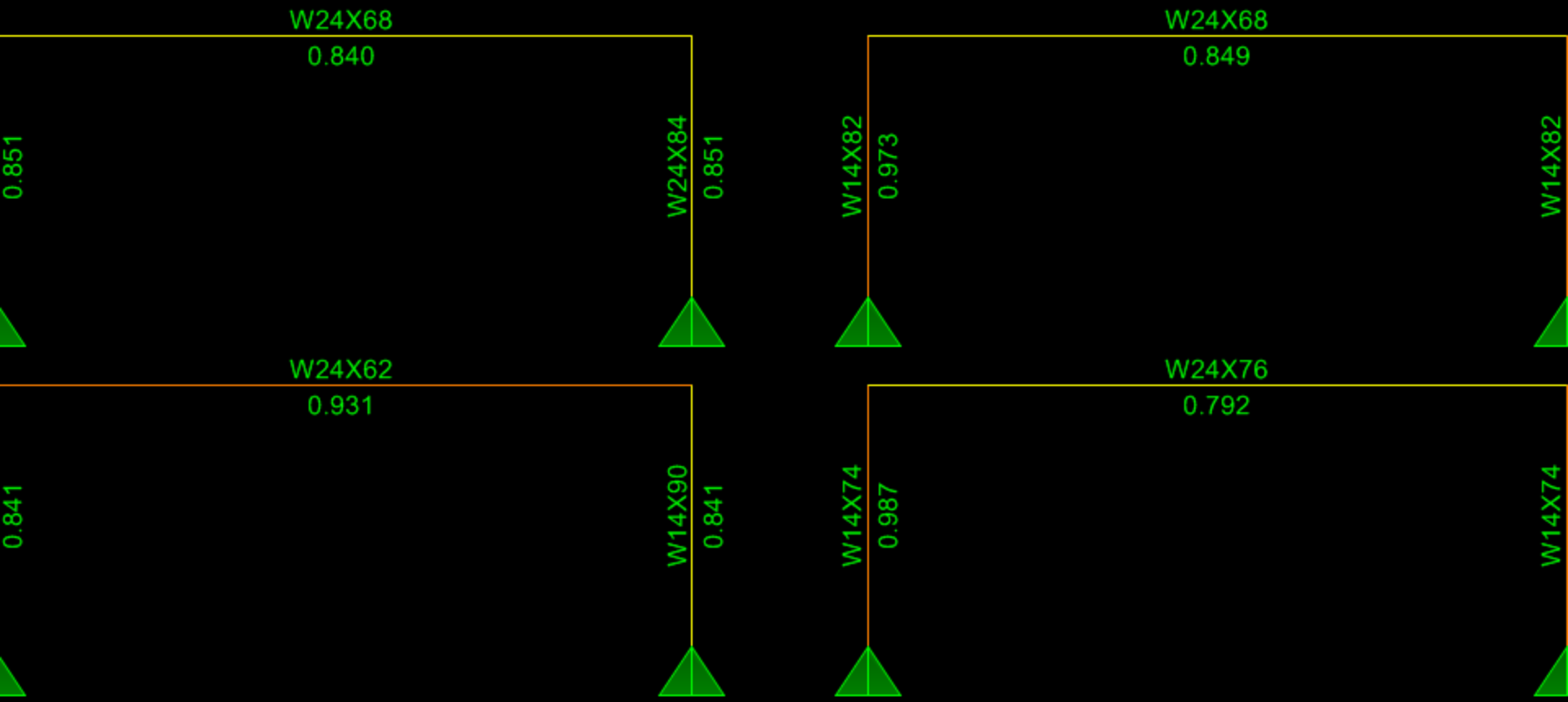
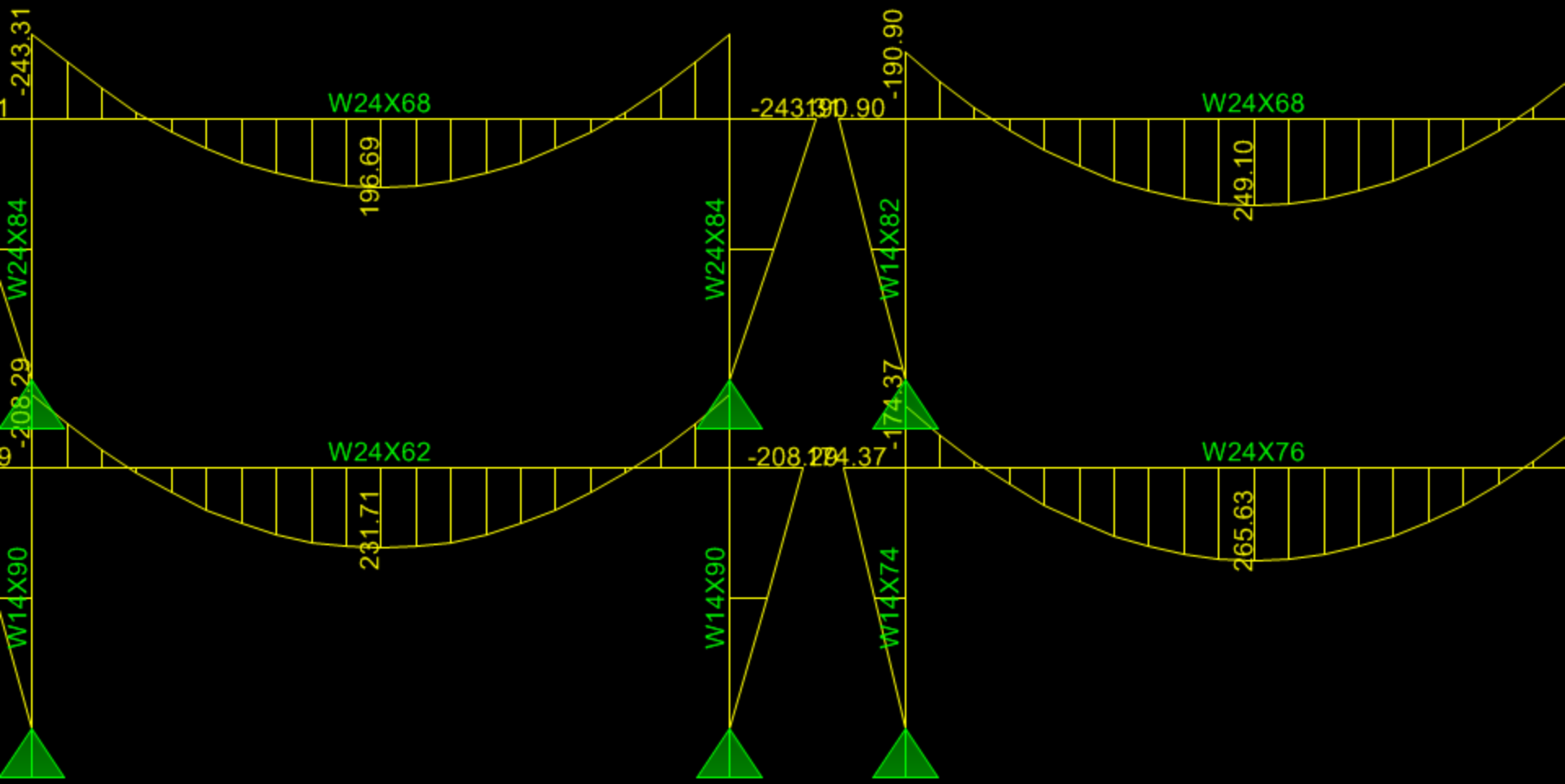


@Seismicisolation



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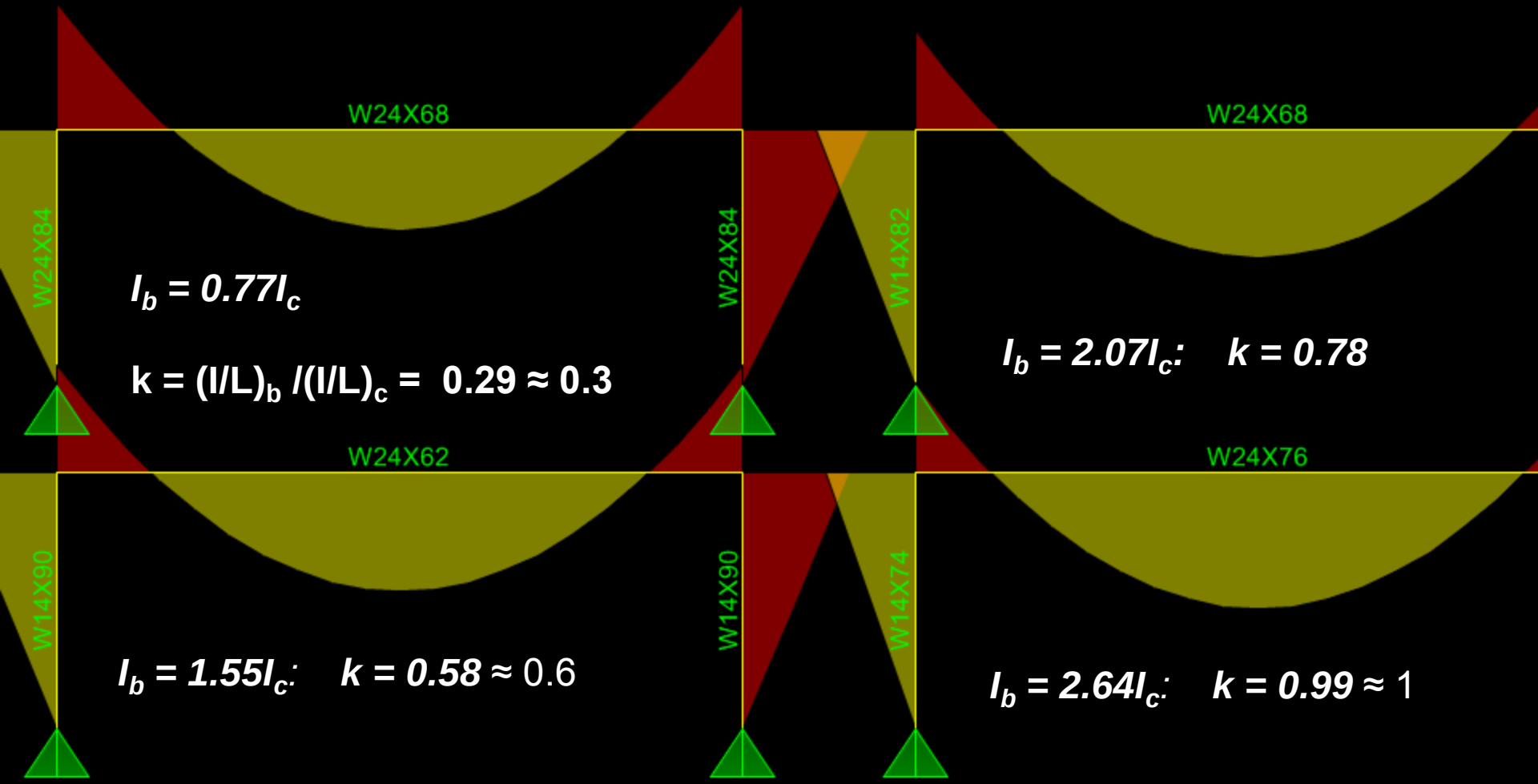

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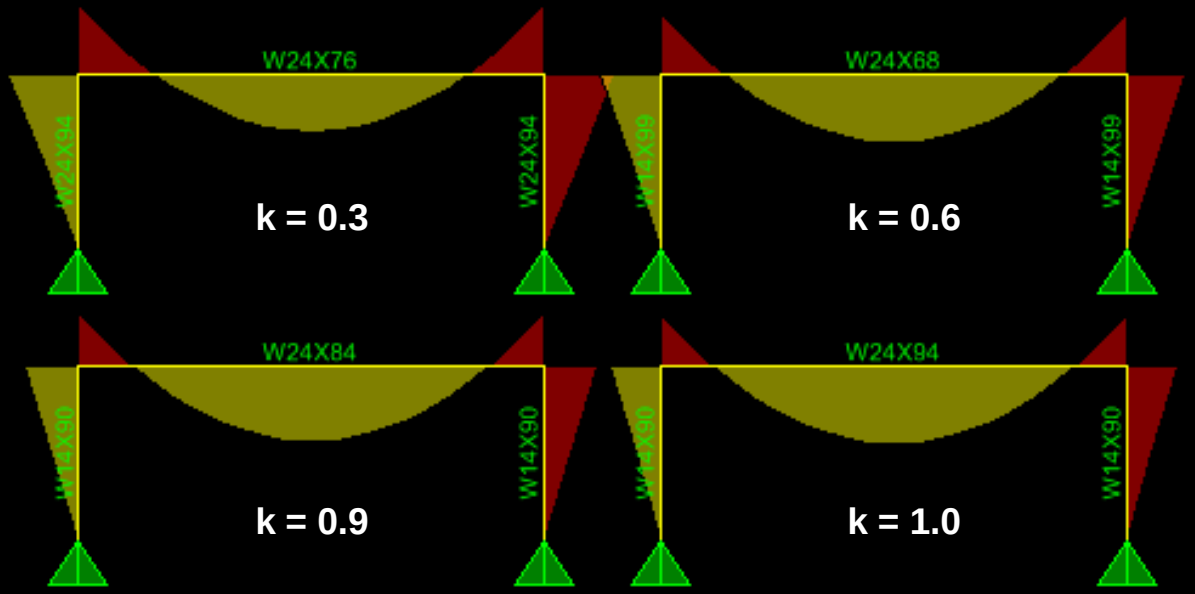

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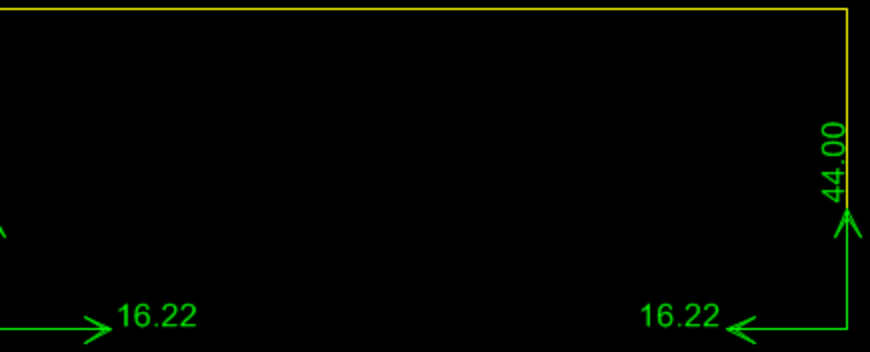

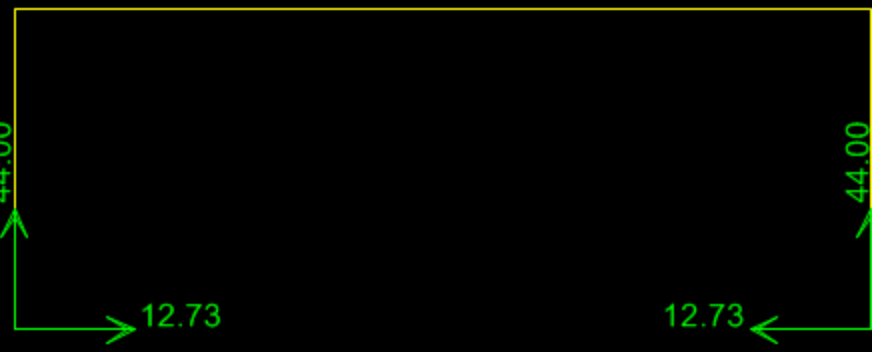

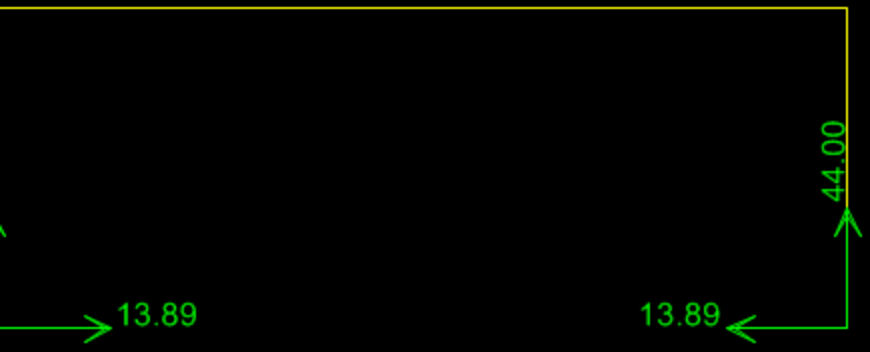

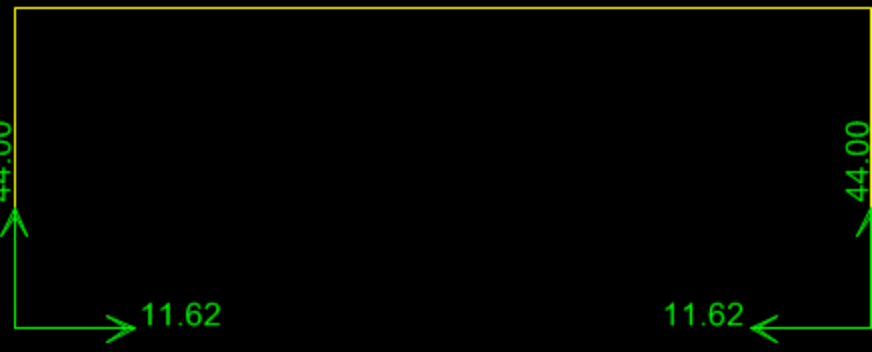

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A typical frame must support a roof area of one-half of a bay on each side; that is, the joists on each side of the frame transmit to the frame one-half of the gravity roof load.

$$w = w_D + w_L = 40(0.025 + 0.030) = 1.0 + 1.2 = 2.2 \text{ k/ft}$$

The curtain panels transmit the lateral wind load to the spandrel beams and roof *diaphragm*, which in turn apply a single load P_w to the frame at the beam-column intersection.

$$P_w = 40(15/2)0.017 = 5.1 \text{ k}$$

Here the total beam moment to be distributed to column is,

$$M = wL^2/8 = 2.2(40)2/8 = 440 \text{ ft-k}$$

Checking approximately the computer solutions for equal beam and column stiffness (***k = 1***), for

$$M_s = - wL^2/20 = 2.2(40)2/20 = 176 \text{ ft-k}$$ **(SAP gives 174.37 ft-k)**

or the maximum girder moment of $M_g = wL^2/8 - M_s = 440 - 176 = 264$ ft-k

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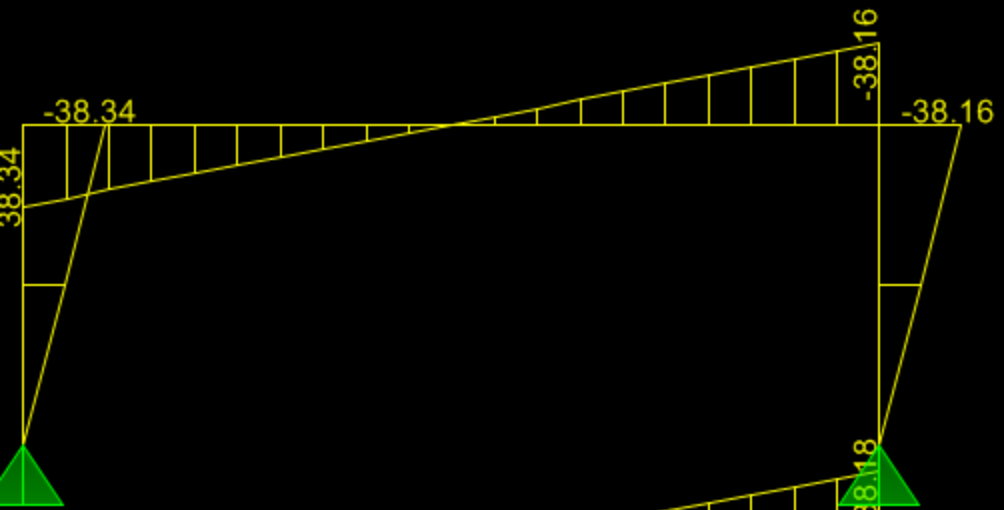

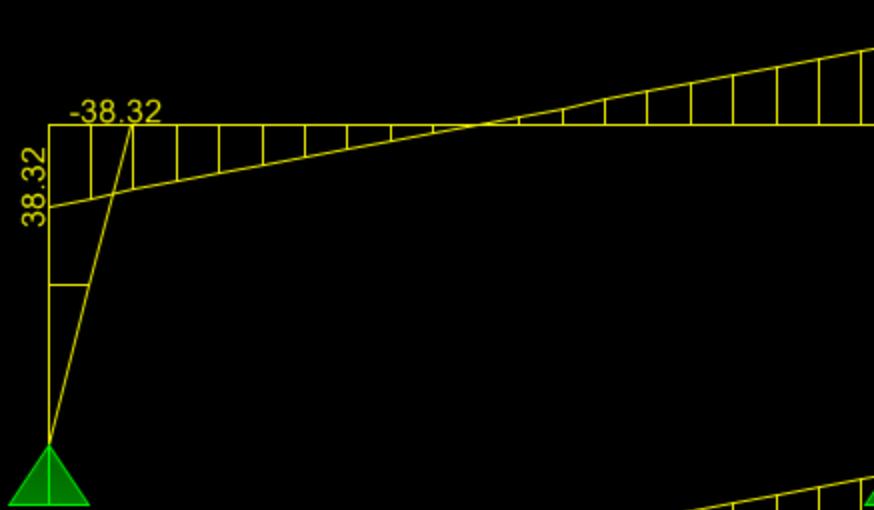

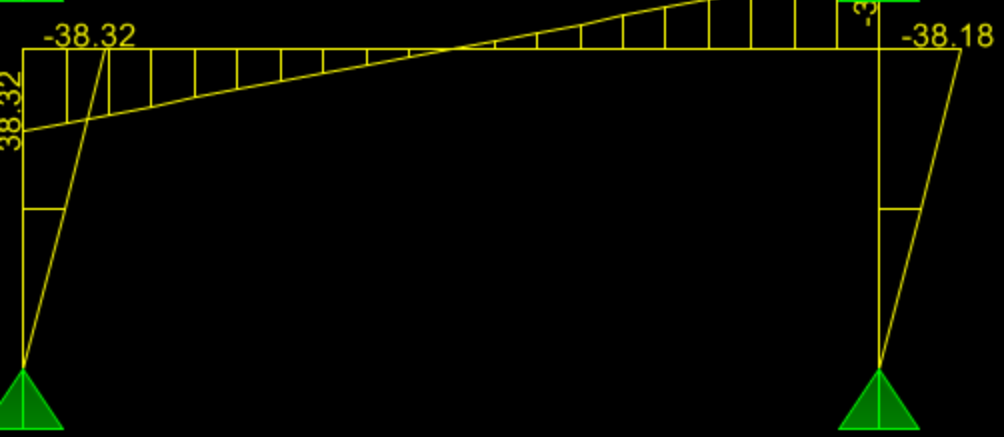

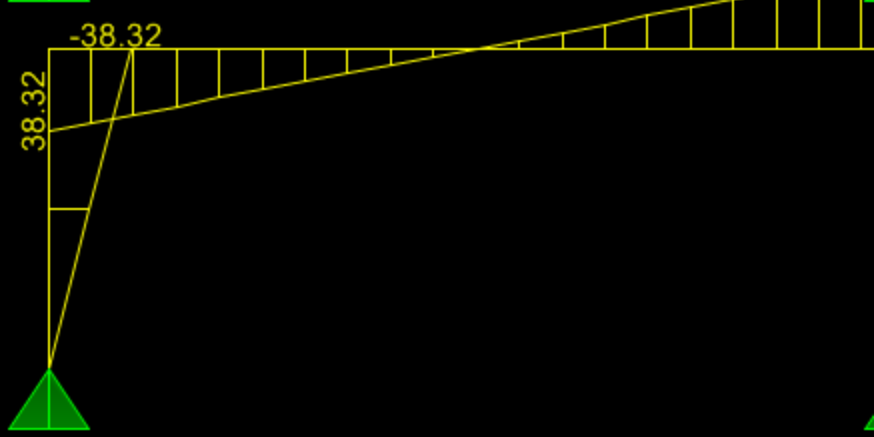

$R_h = P/2 = 5.1/2 = 2.55$ k

$M_{sw} = 2.55(15) = 38.25$ ft-k

Member stiffness does not influence lateral force distribution.

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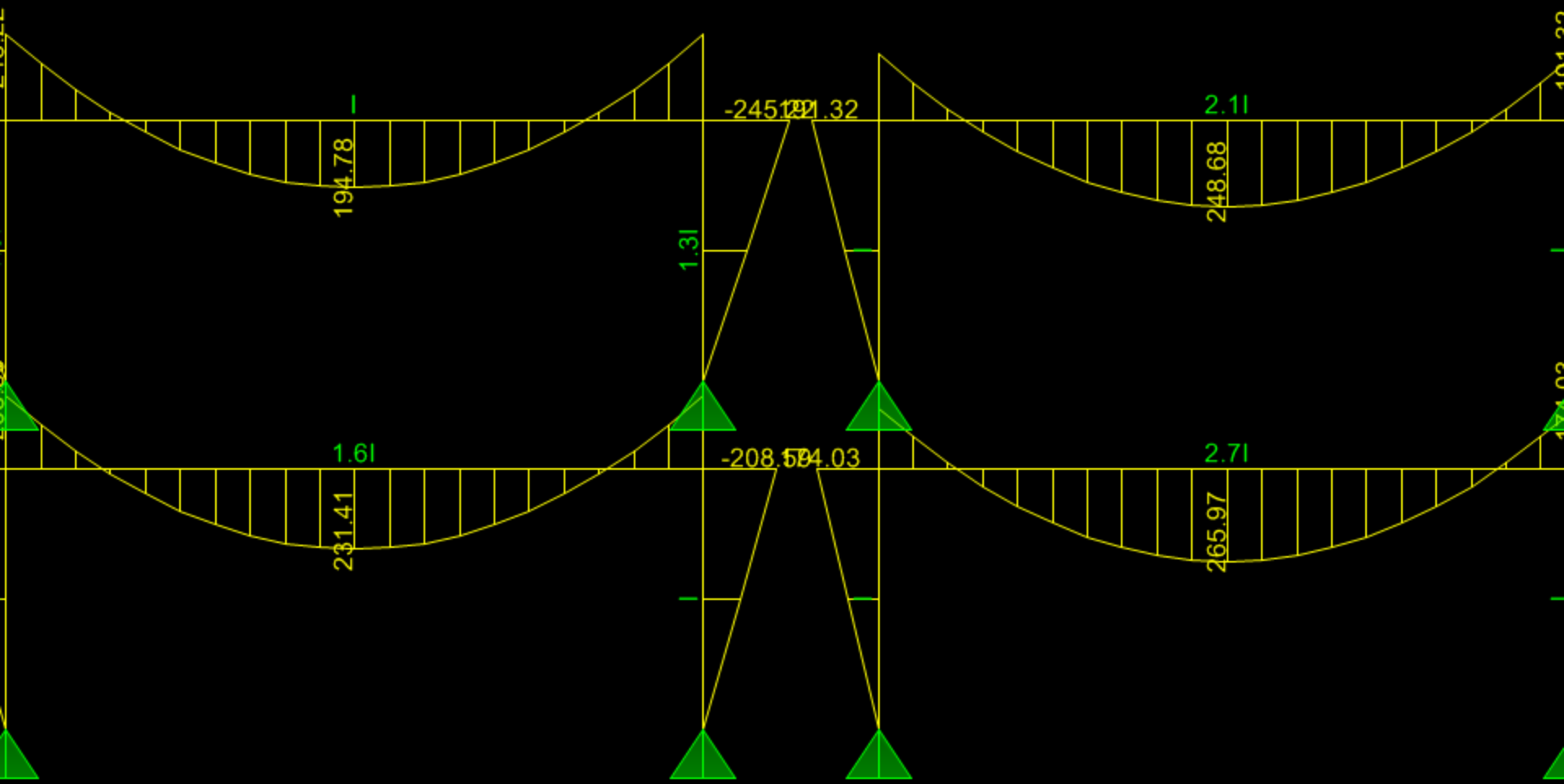
Using Modification Factors for Analysis



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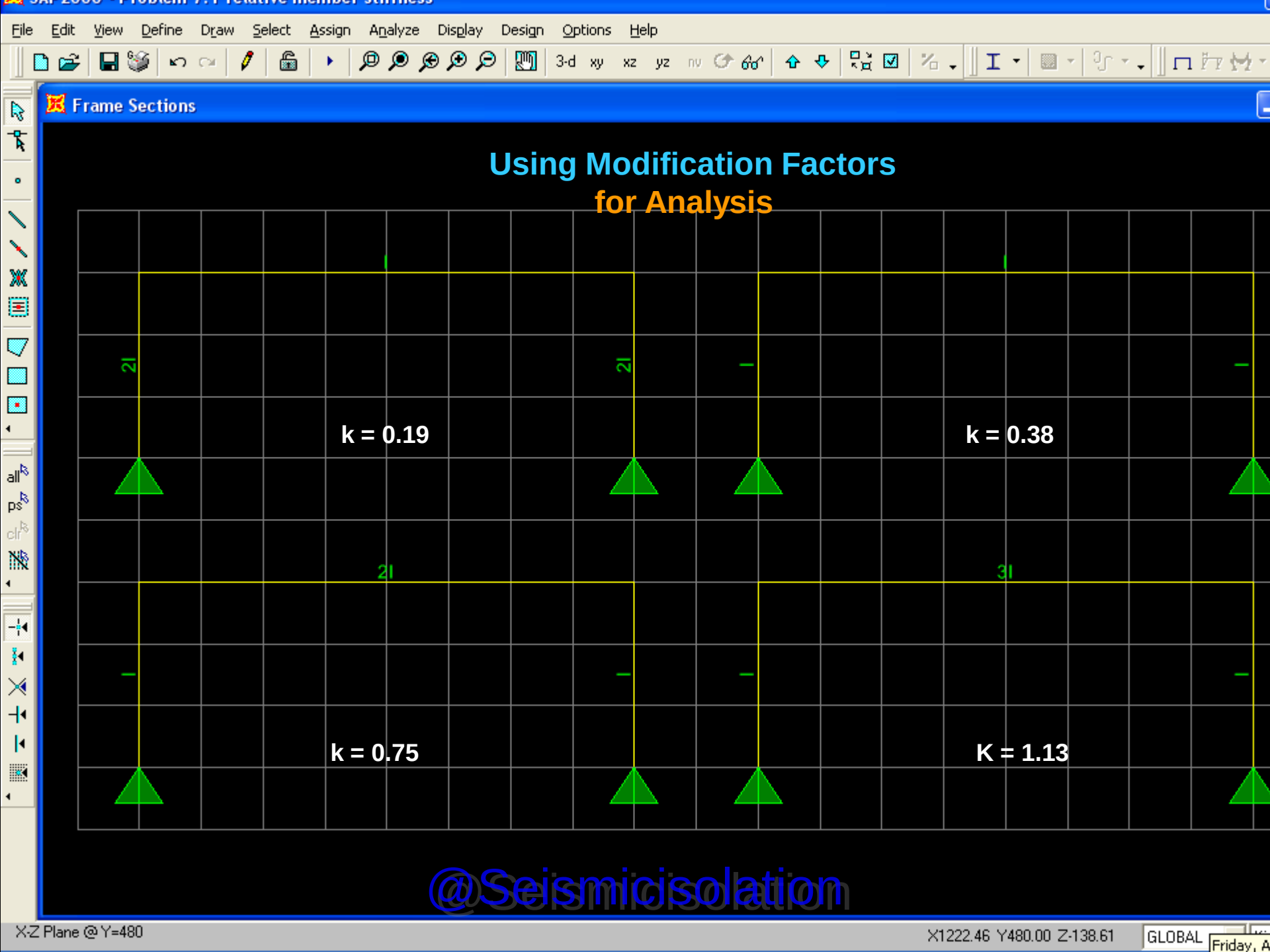
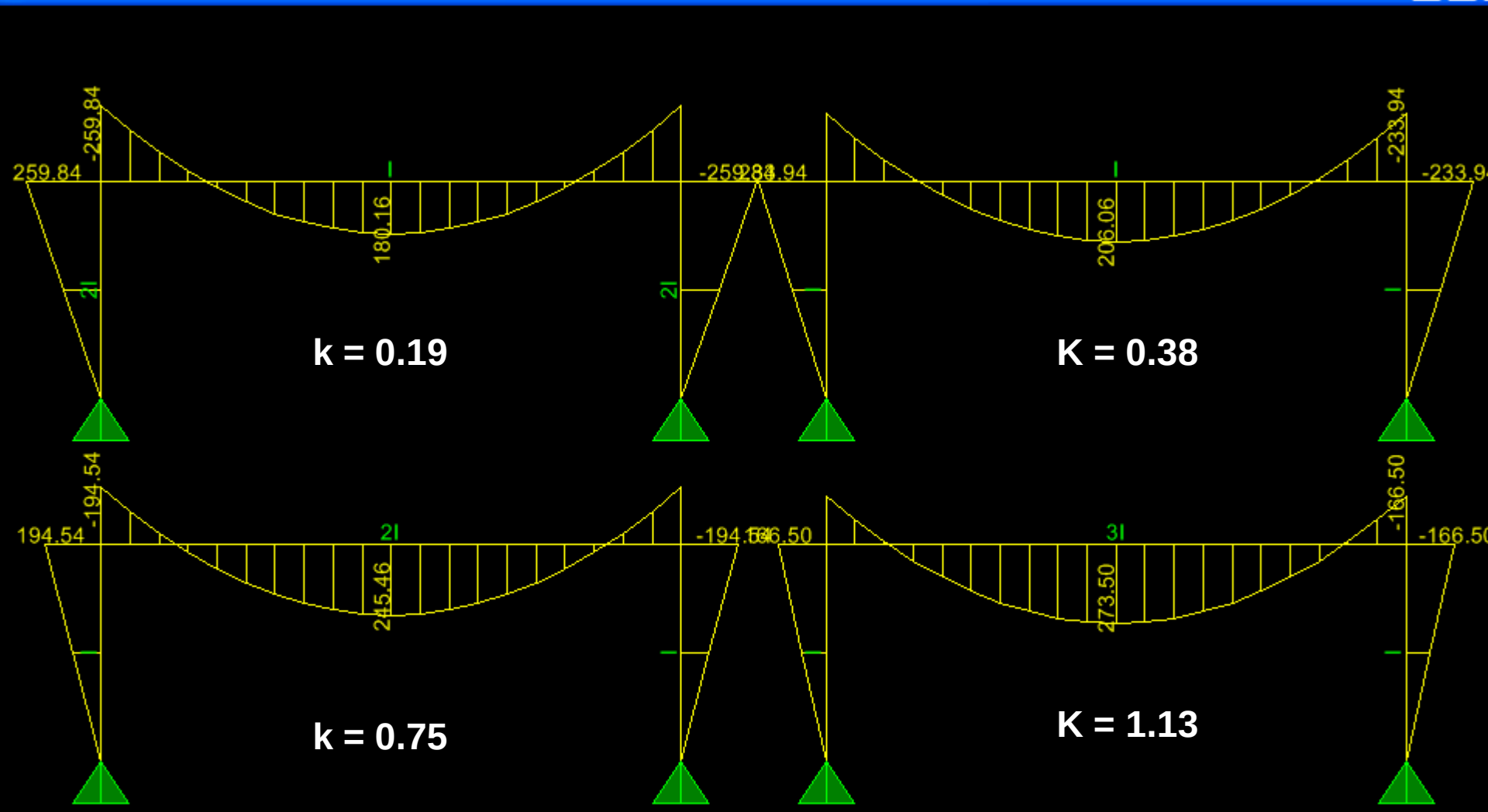

File Edit View Define Draw Select Assign Analyze Display Design Options Help
Frame Sections
Using Modification Factors
for Analysis
k = 0.19
k = 0.38
k = 0.75
K = 1.13
@Seismicisolation
X-Z Plane @ Y=480
X1222.46 Y480.00 Z-138.61
GLOBAL

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Moment 3-3 Diagram (COMB1)



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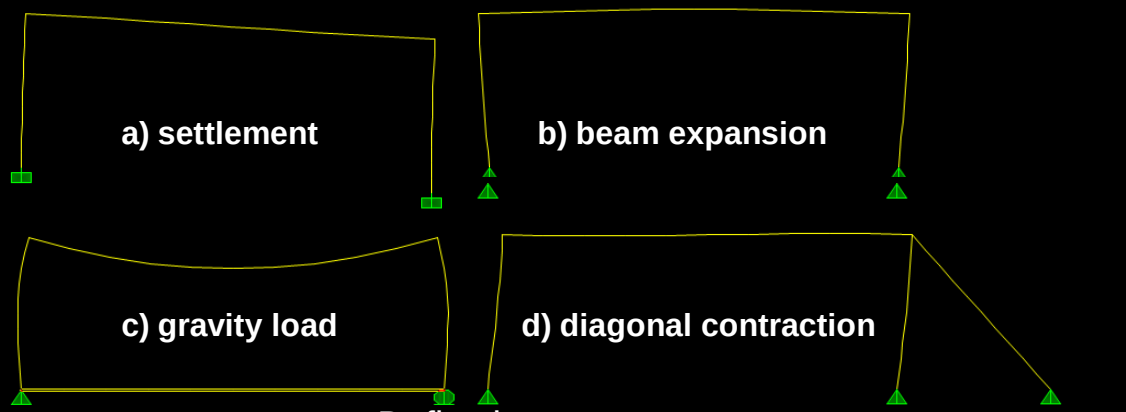
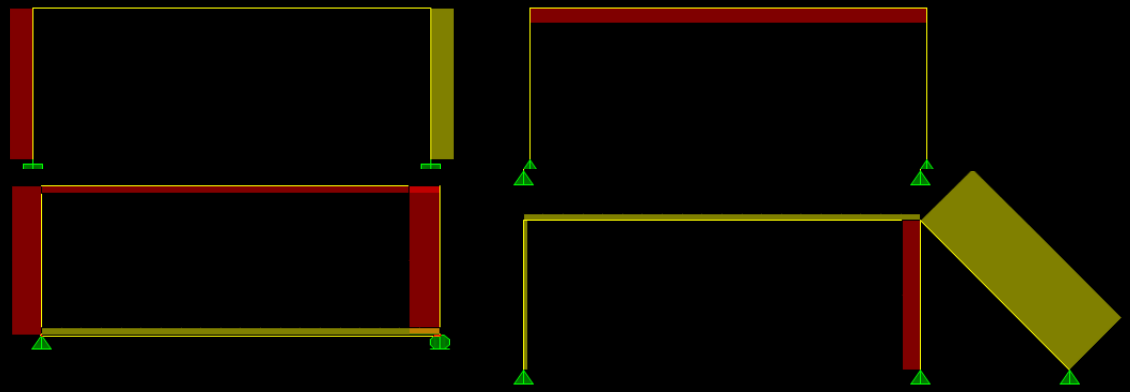
lick on any Frame Element for detailed diagram

GLOBAL

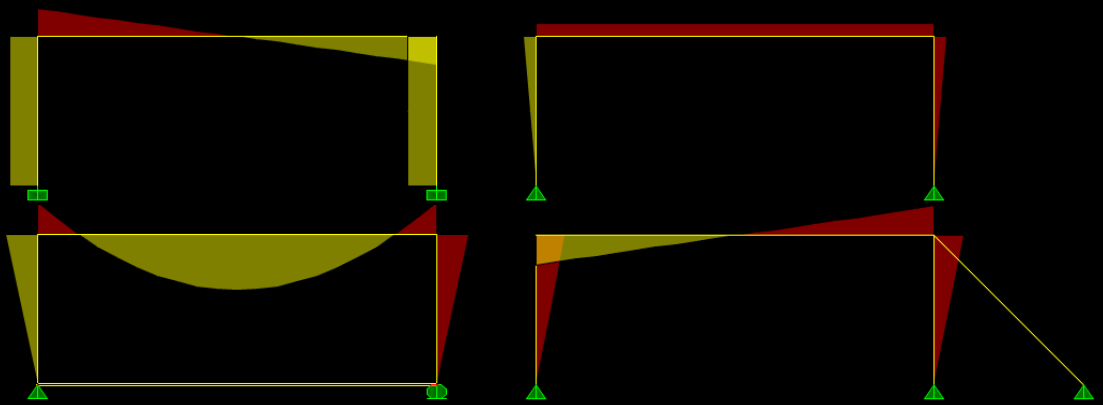
Kip, ft, F



Deflection



N-diagrams



M-diagrams

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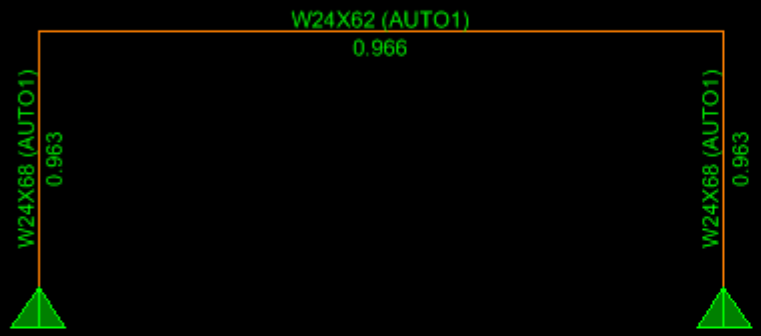
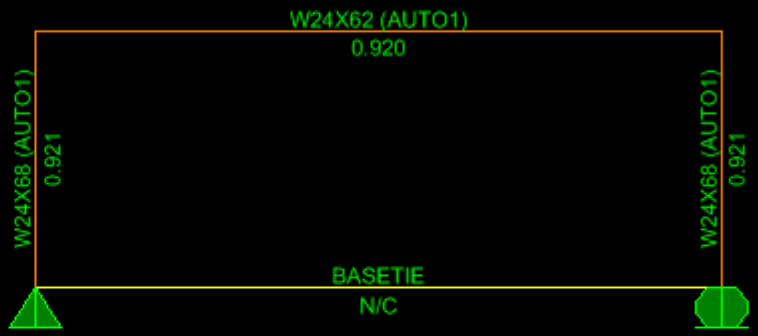
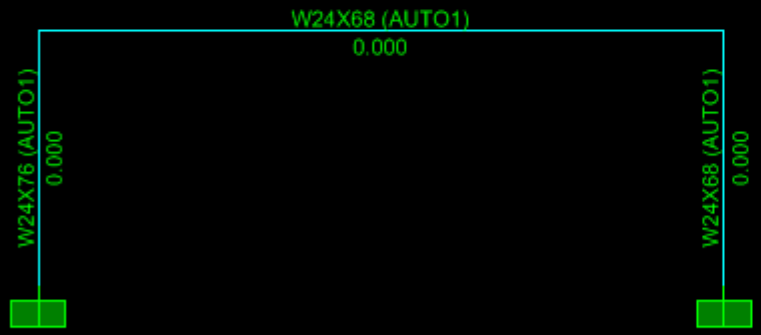
Edit View Define Draw Select Assign Analyze Display Design Options Help

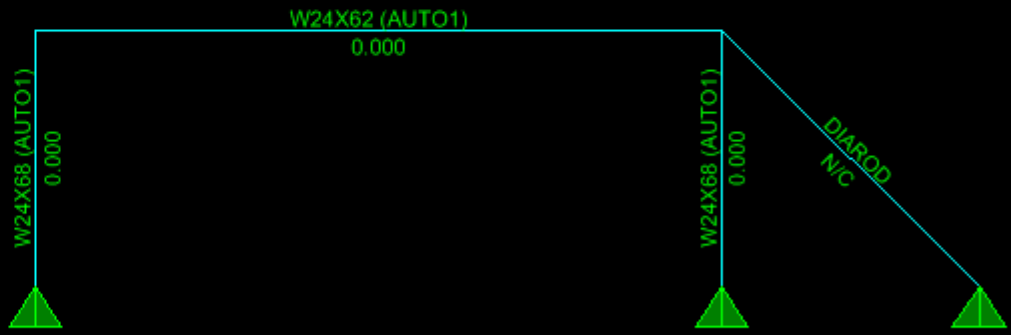
3-d

Steel P-M Interaction Ratios (AISC-ASD89)









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0. 1. 1. 1.

lane @ Y=40

X30.95 Y40.00 Z-11.74

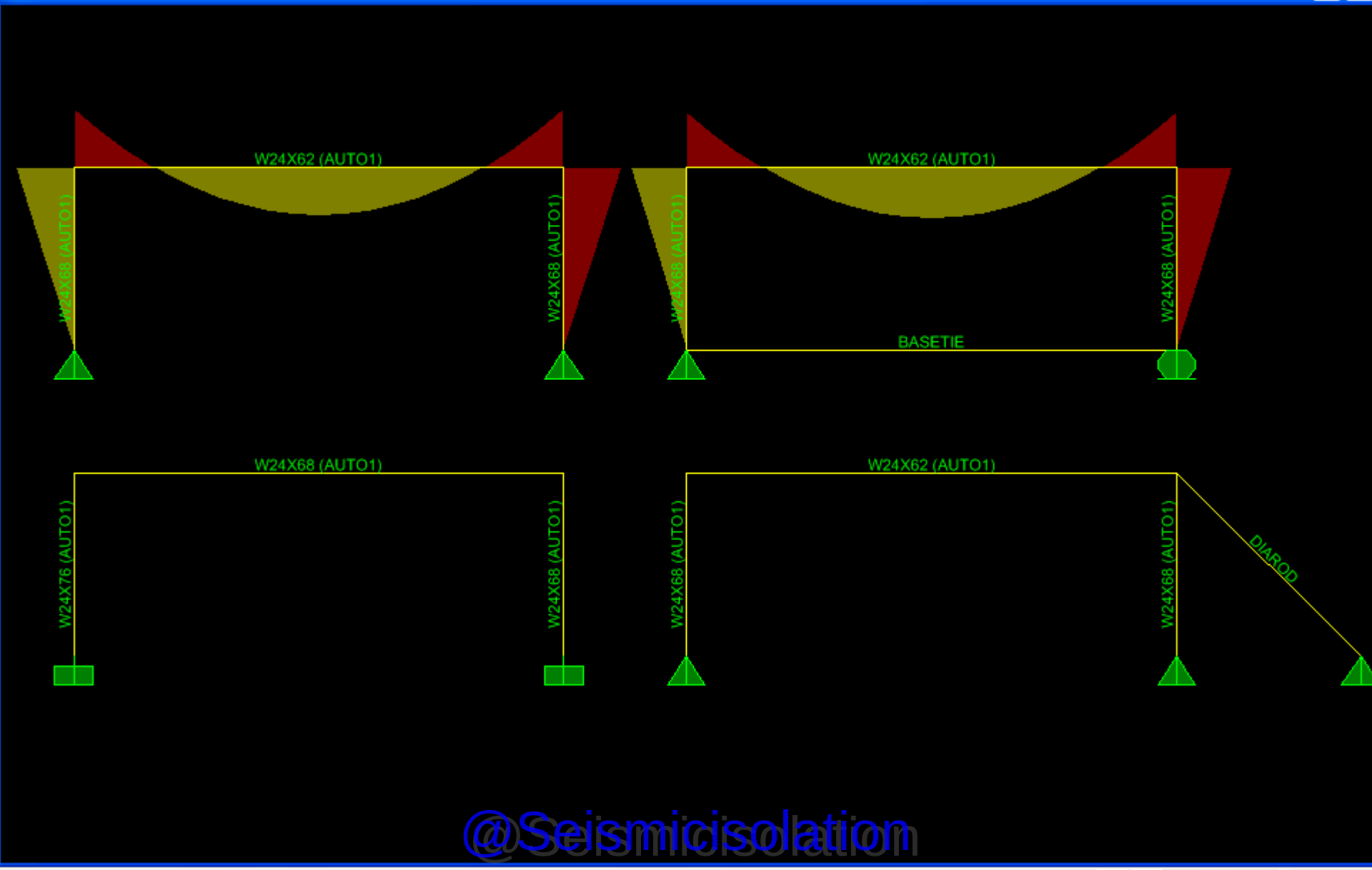
GLOBAL

Kip, ft, F

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Moment 3-3 Diagram (COMB1)



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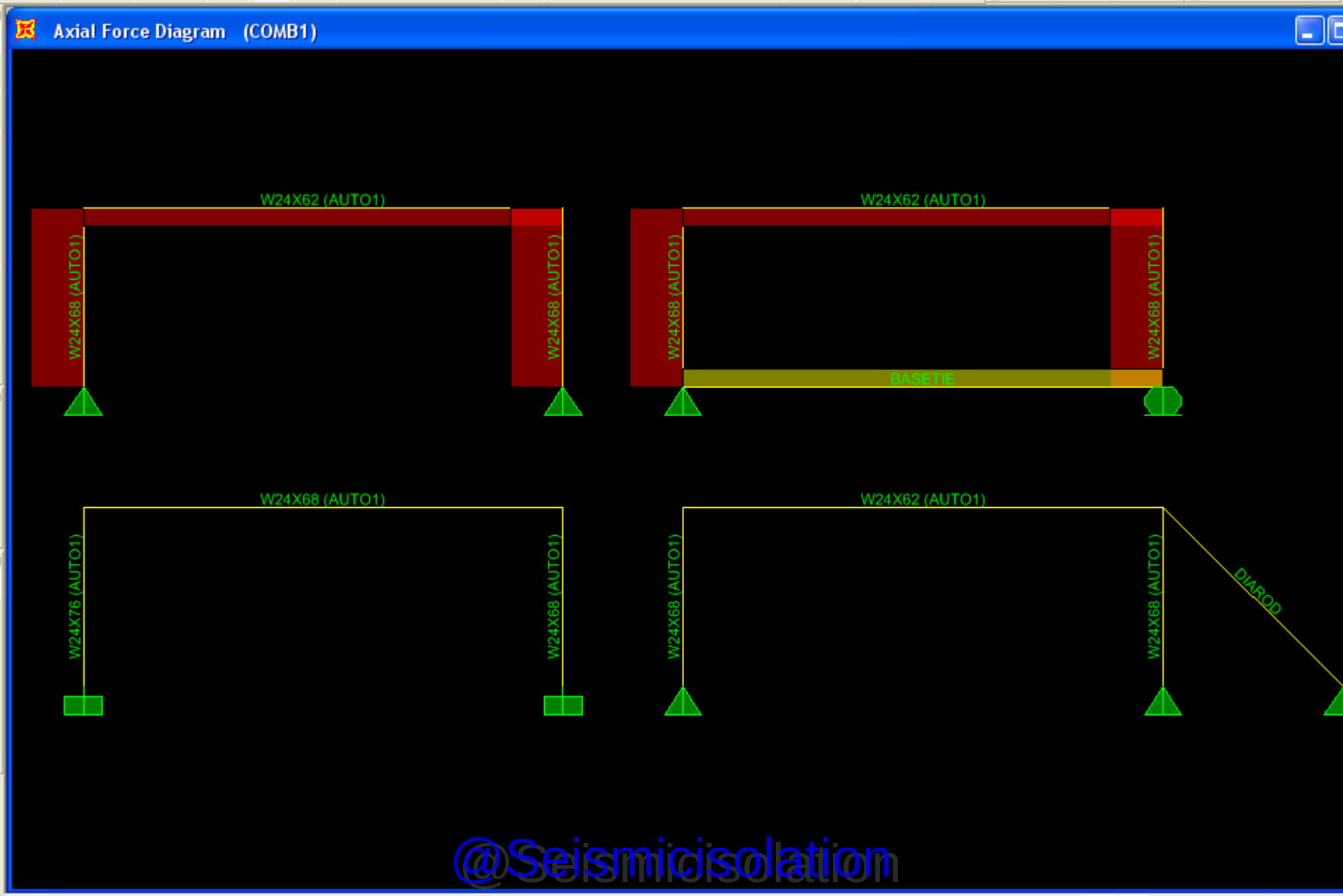
Click on any Frame Element for detailed diagram

Book GLOBAL Kip, ft, F



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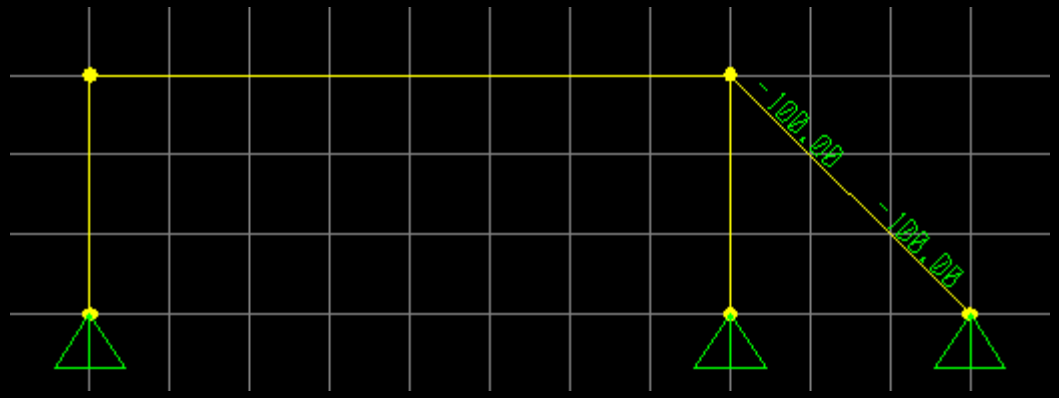
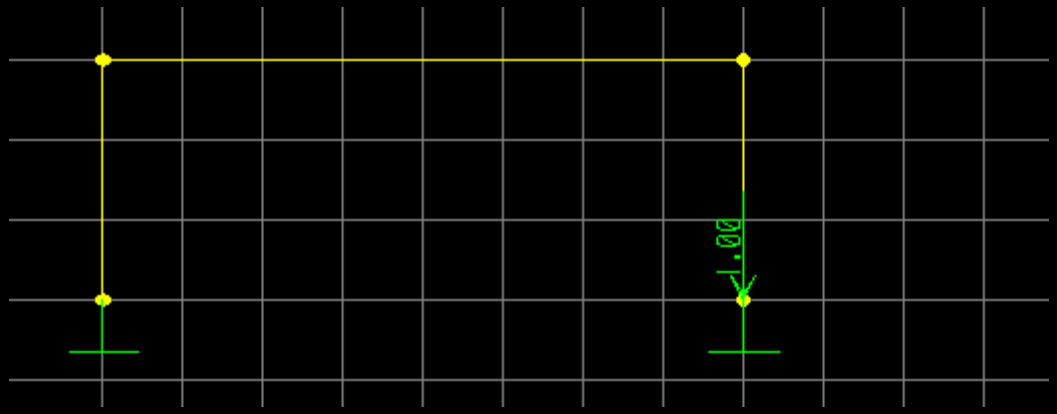




Frame Temperature Loading

Load Case Name: TEMP

Type
- (•) Temperature
- ( ) Temperature Gradient 2-2
- ( ) Temperature Gradient 3-3

Options
- (•) Add to existing loads
- ( ) Replace existing loads
- ( ) Delete existing loads

Temperature
- (•) By Element
  - Temperature: -100
- ( ) By Joint Pattern
  - Pattern:
  - Multiplier:

OK

Cancel

Ground Displacements

Load Case Name: SETTLE

Displacements

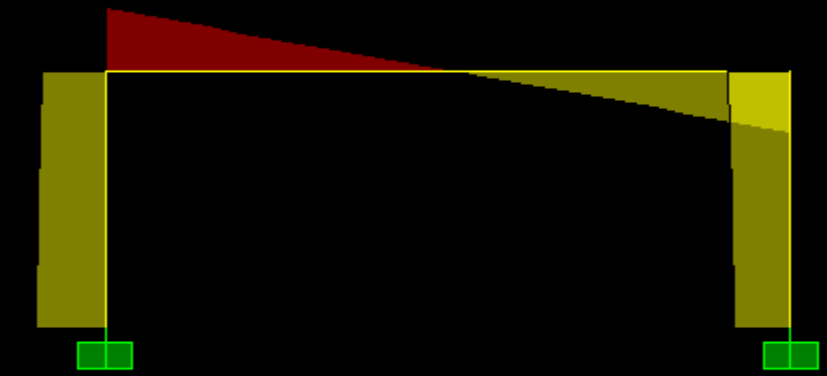
Translation X	0.
Translation Y	0.
Translation Z	-1
Rotation about XX	0.
Rotation about YY	0.
Rotation about ZZ	0.

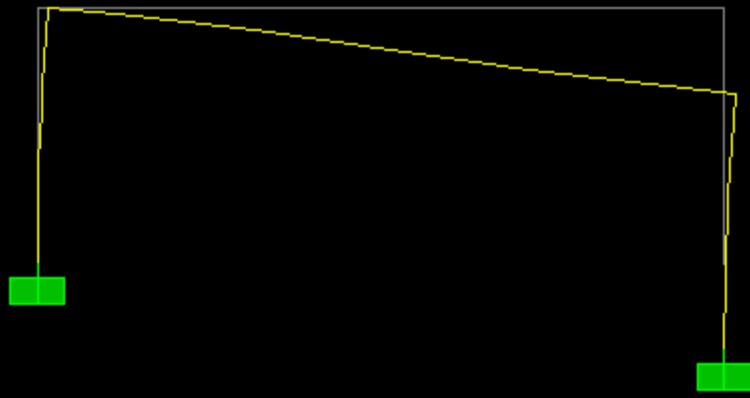
Options
- (•) Add to existing loads
- ( ) Replace existing loads
- ( ) Delete existing loads

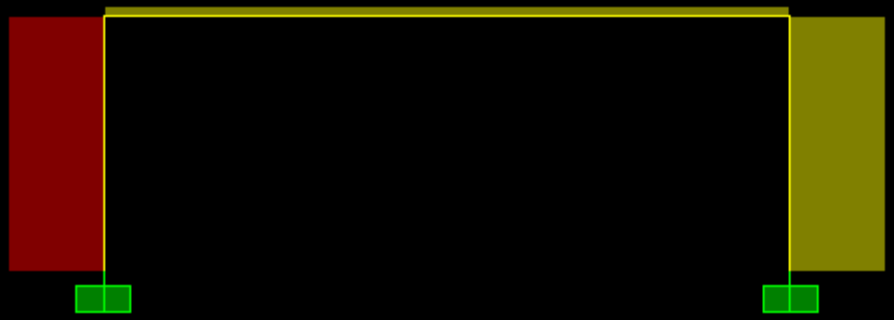
OK

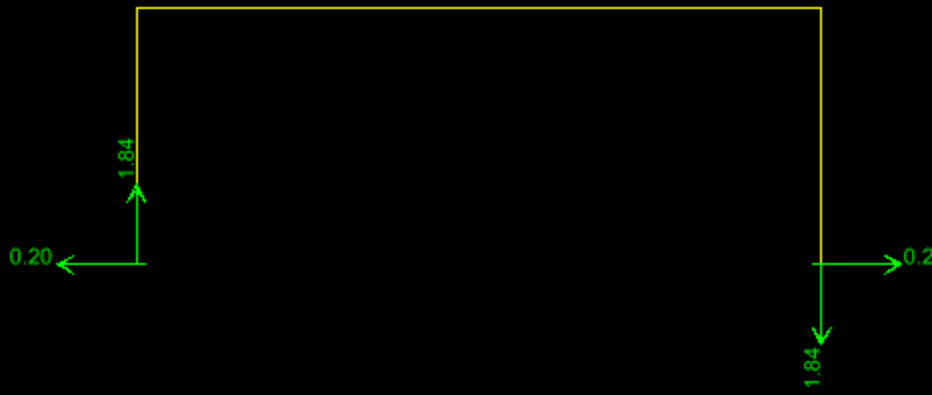
Cancel

@Seismicisolation



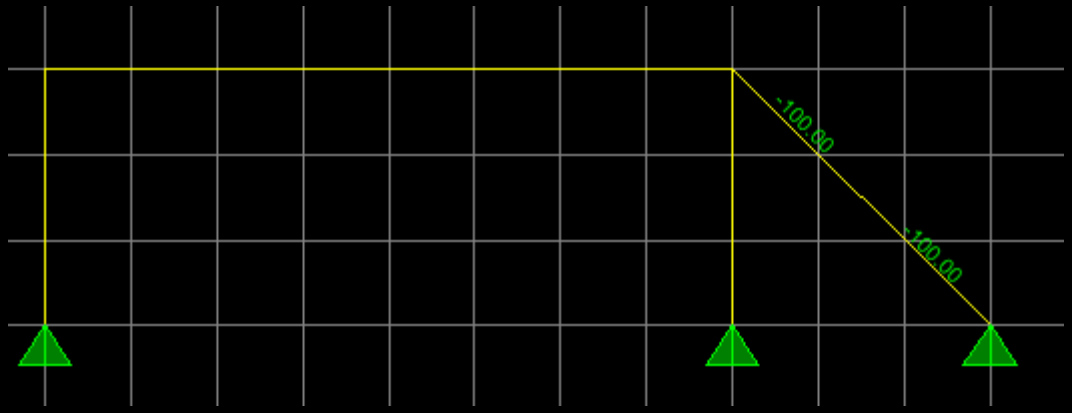




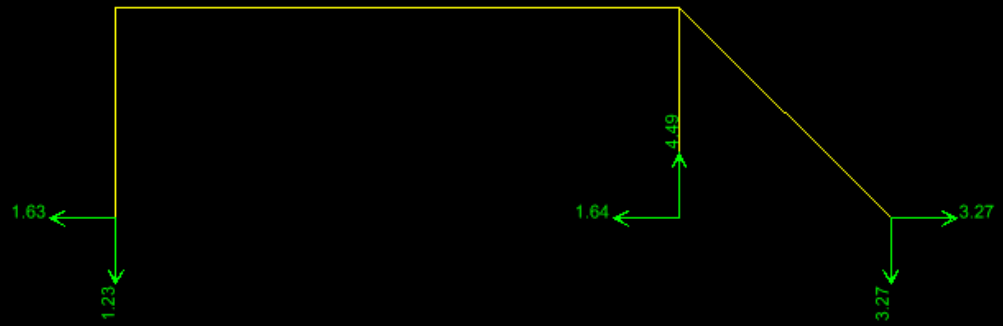


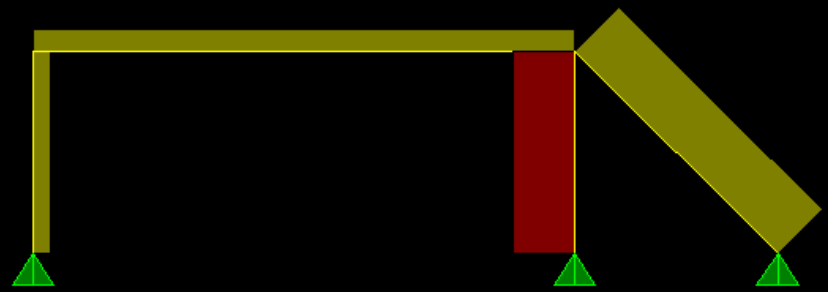
SUPPORT SETTLEMENT

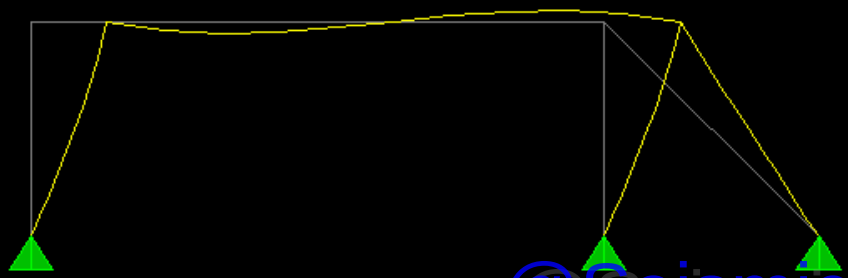
@Seismicisolation

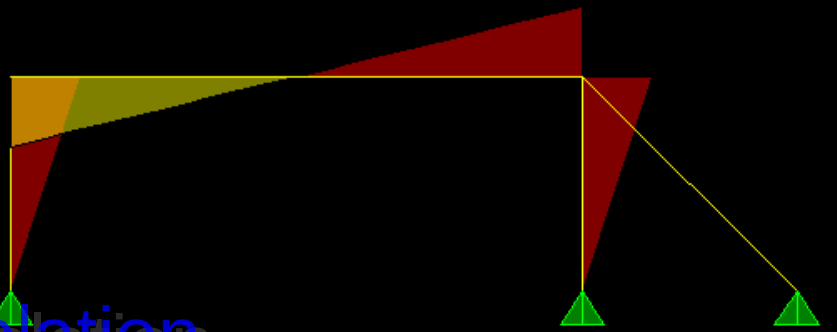


THERMAL LOADING









@Seismicisolation

Glass House, New Canaan, Conn., 1949, Philip Johnson

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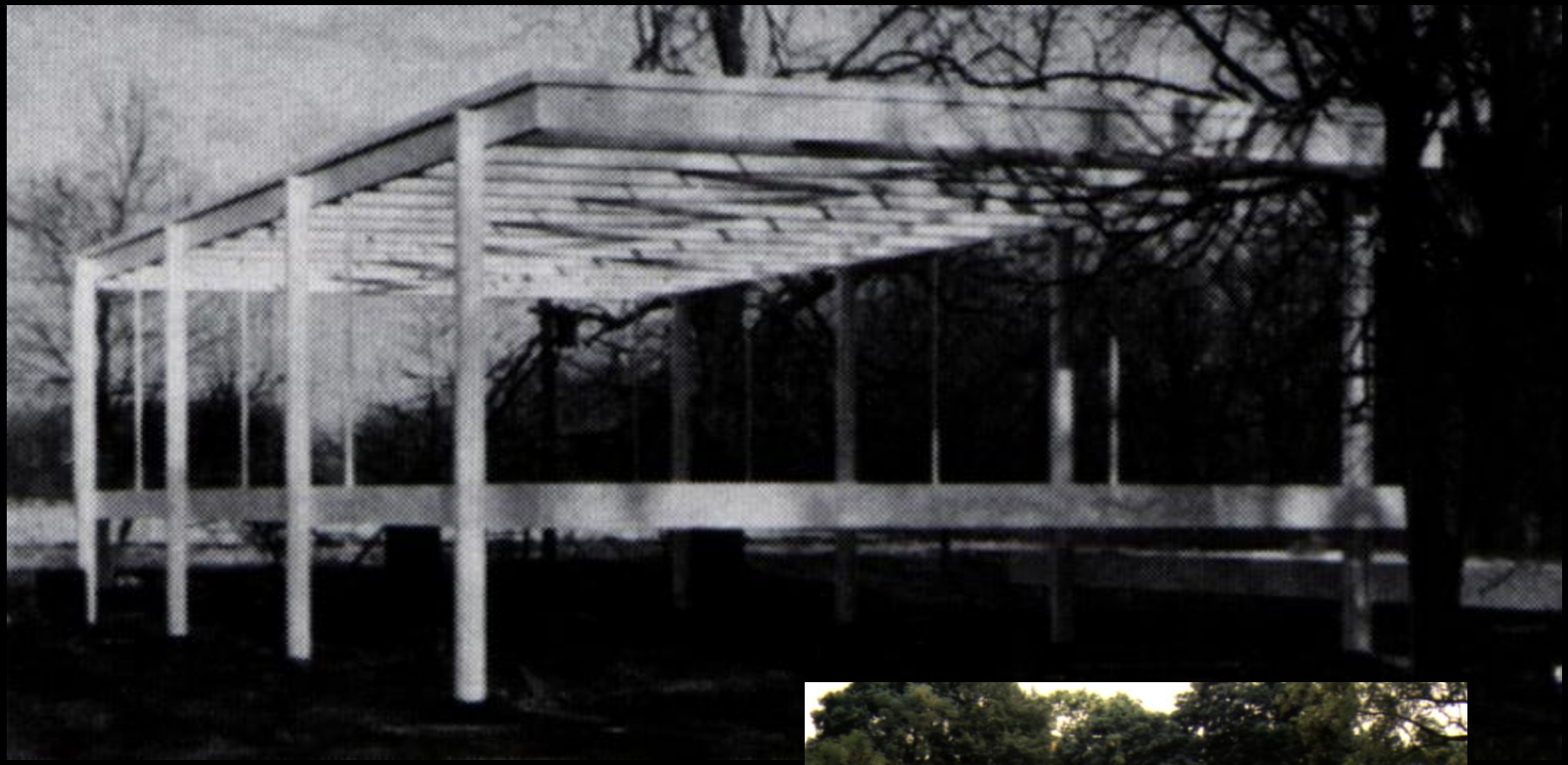
@Seismicisolation

Farnsworth House, Plano, Illinois, 1950, Mies van der Rohe

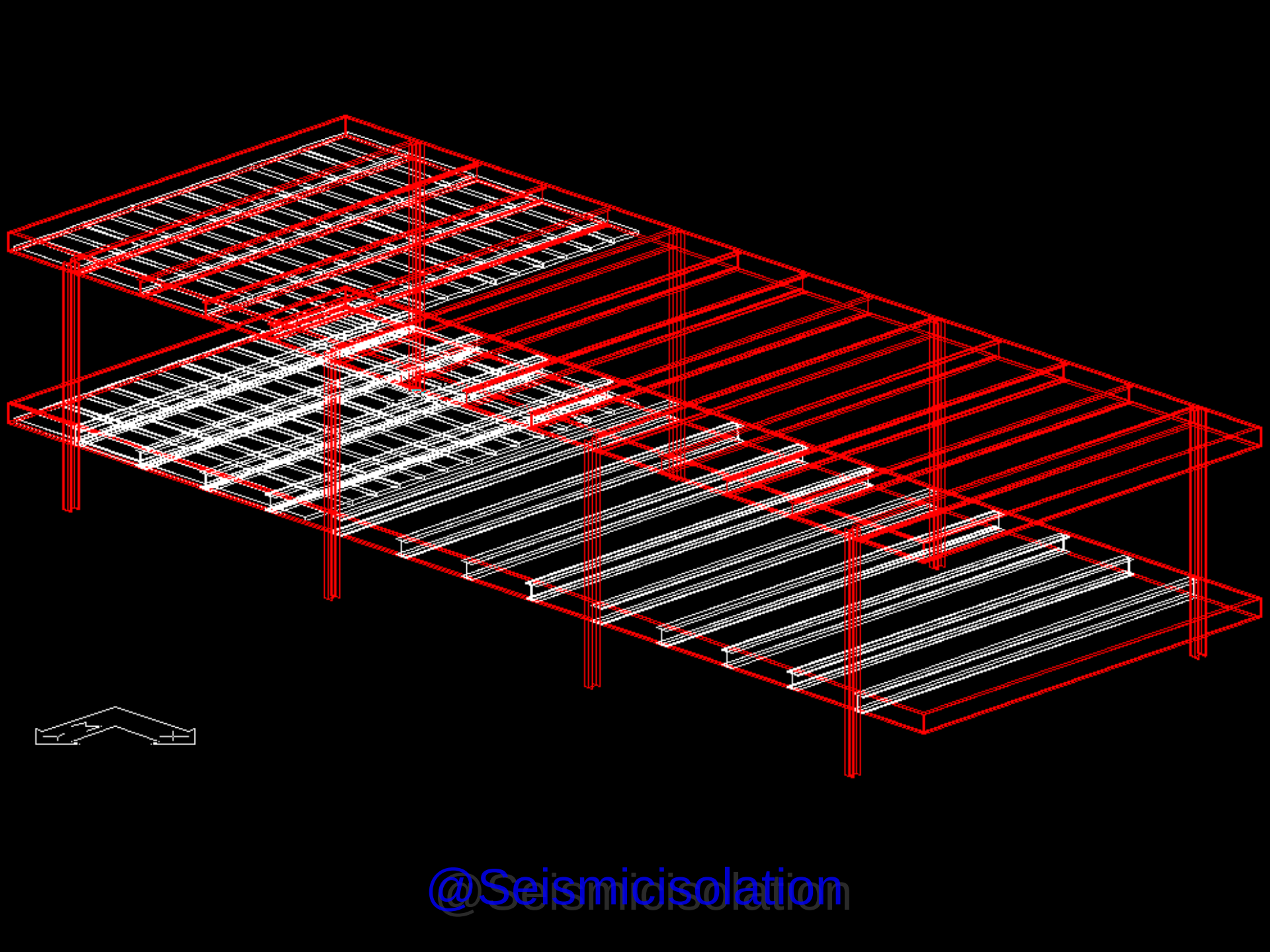
@Seismicisolation

@Seismicisolation

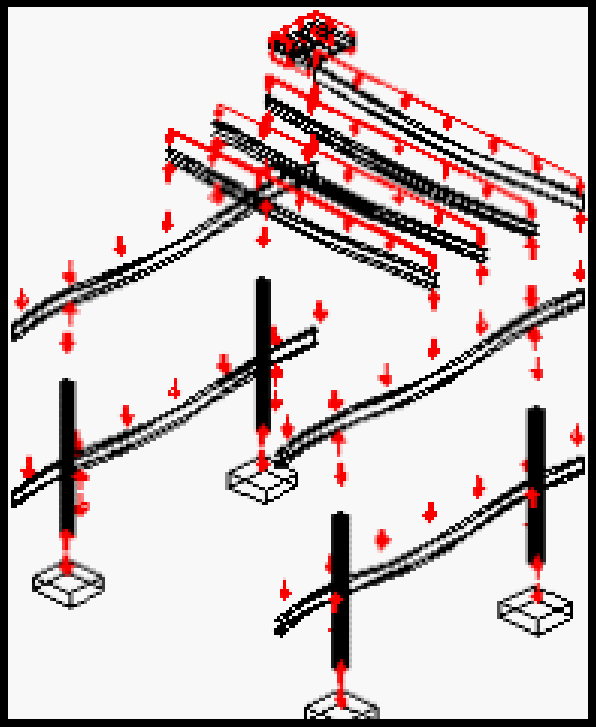
@Seismicisolation

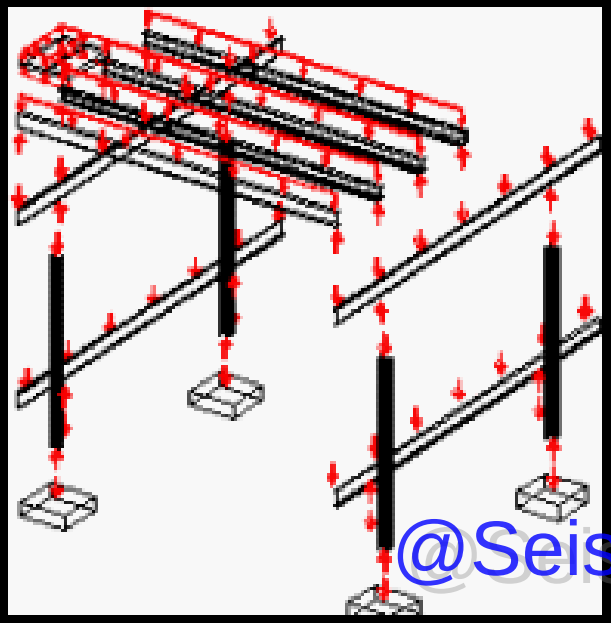


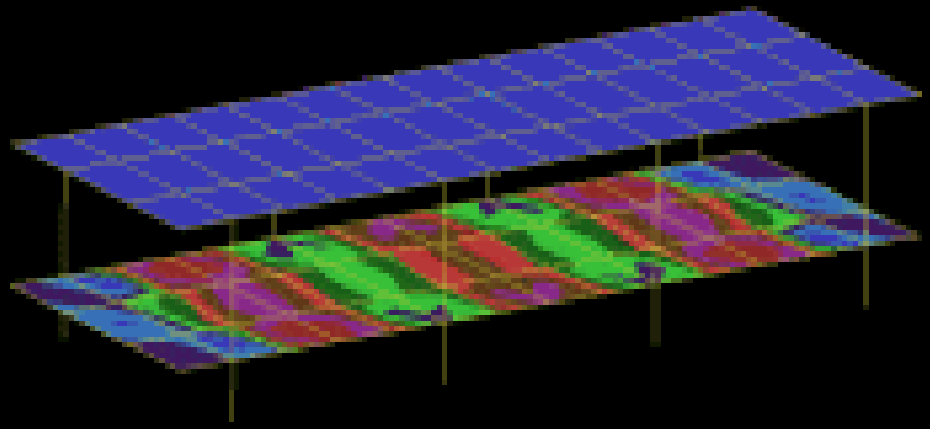
@Seismicisolation



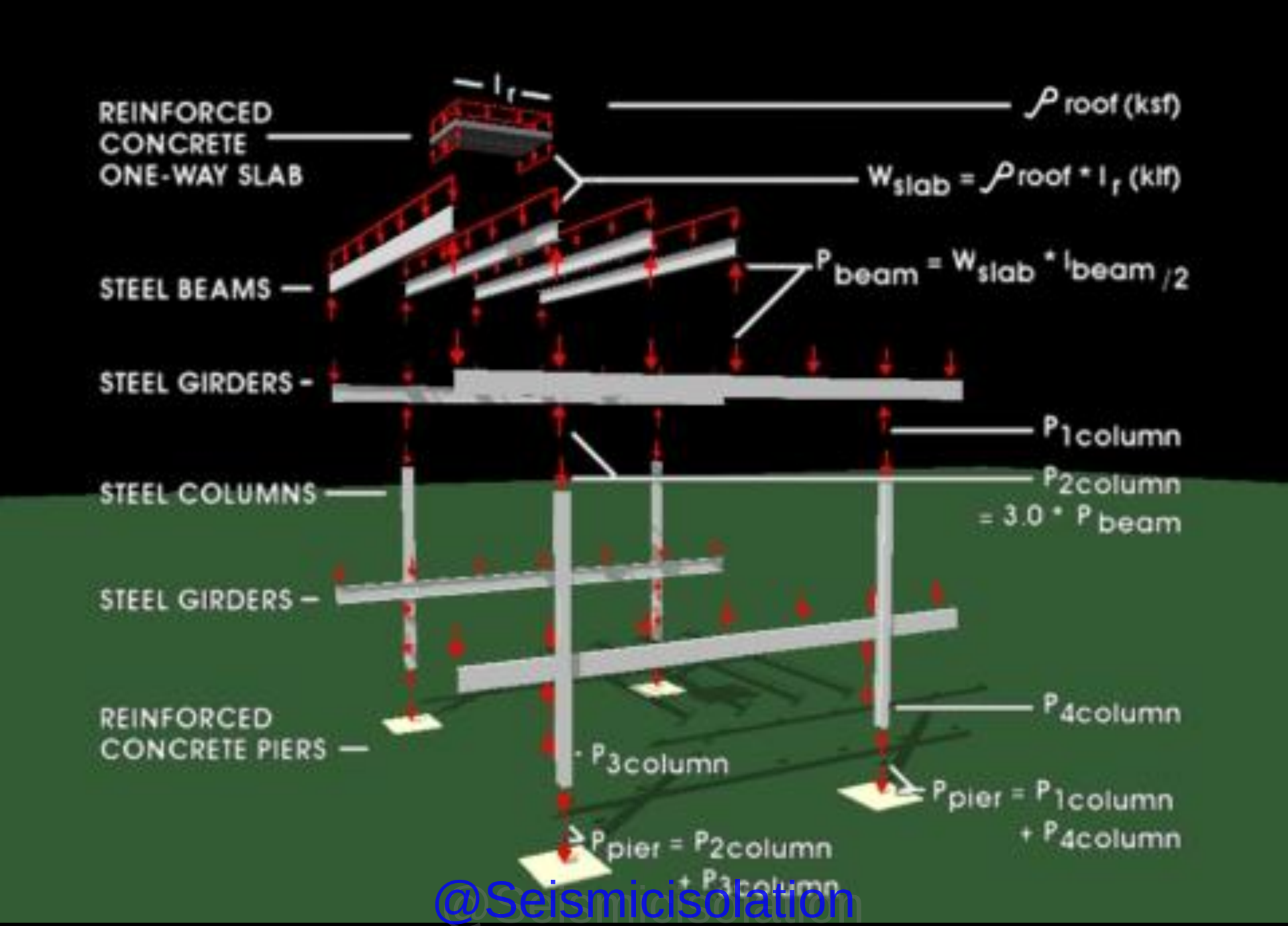
@Seismicisolation







@Seismicisolation



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Restaurant Bangkok

@Seismicisolation

Siam, Bangkok

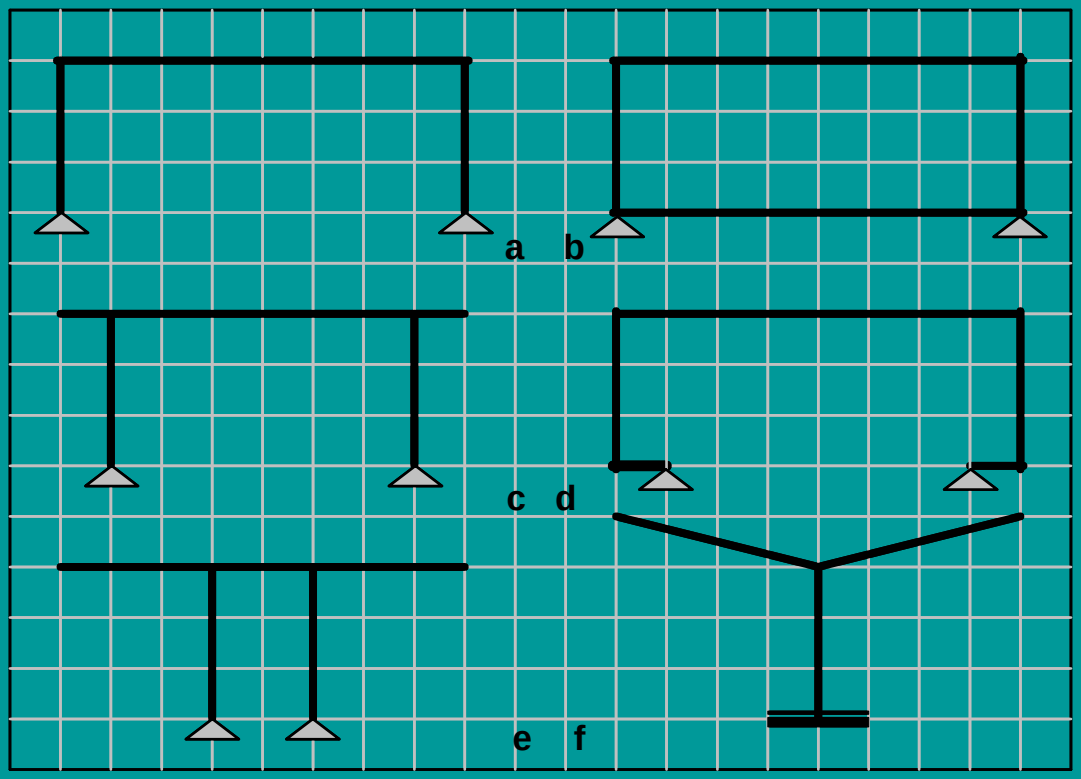

@Seismicisolation


@Seismicisolation


@Seismicisolation


@Seismicisolation

CANTILEVER FRAMES



With increase of span the single-span concept becomes less efficient because of the rapid increase in moment and deflection that is increase in dead weight. The magnitude of the bending stresses is very much reduced by the cantilever type of construction.

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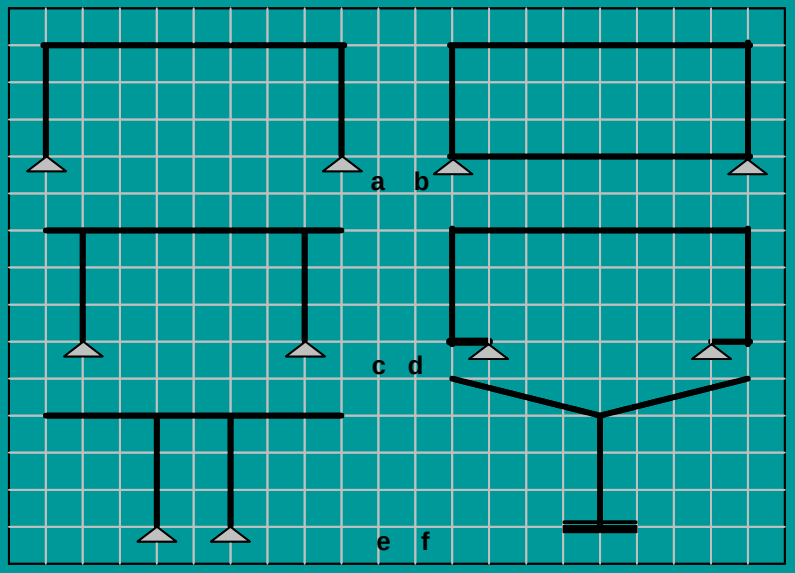
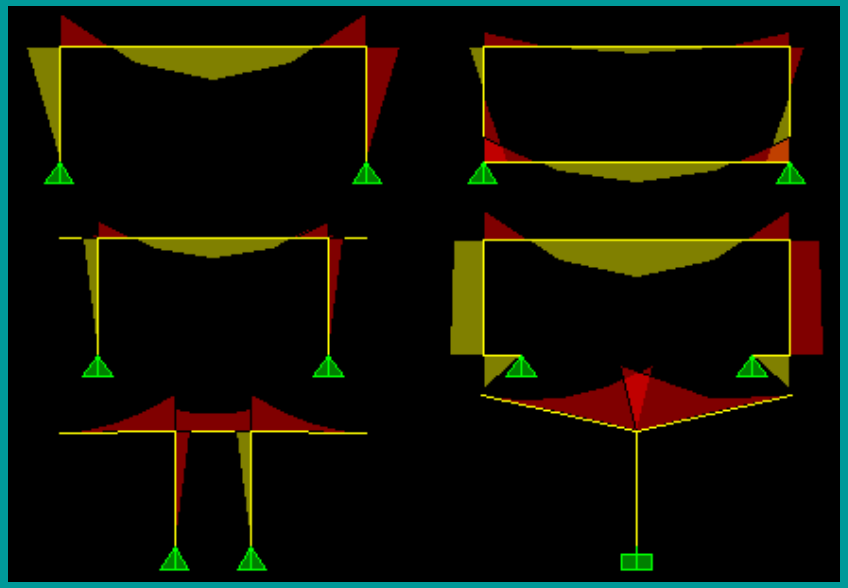


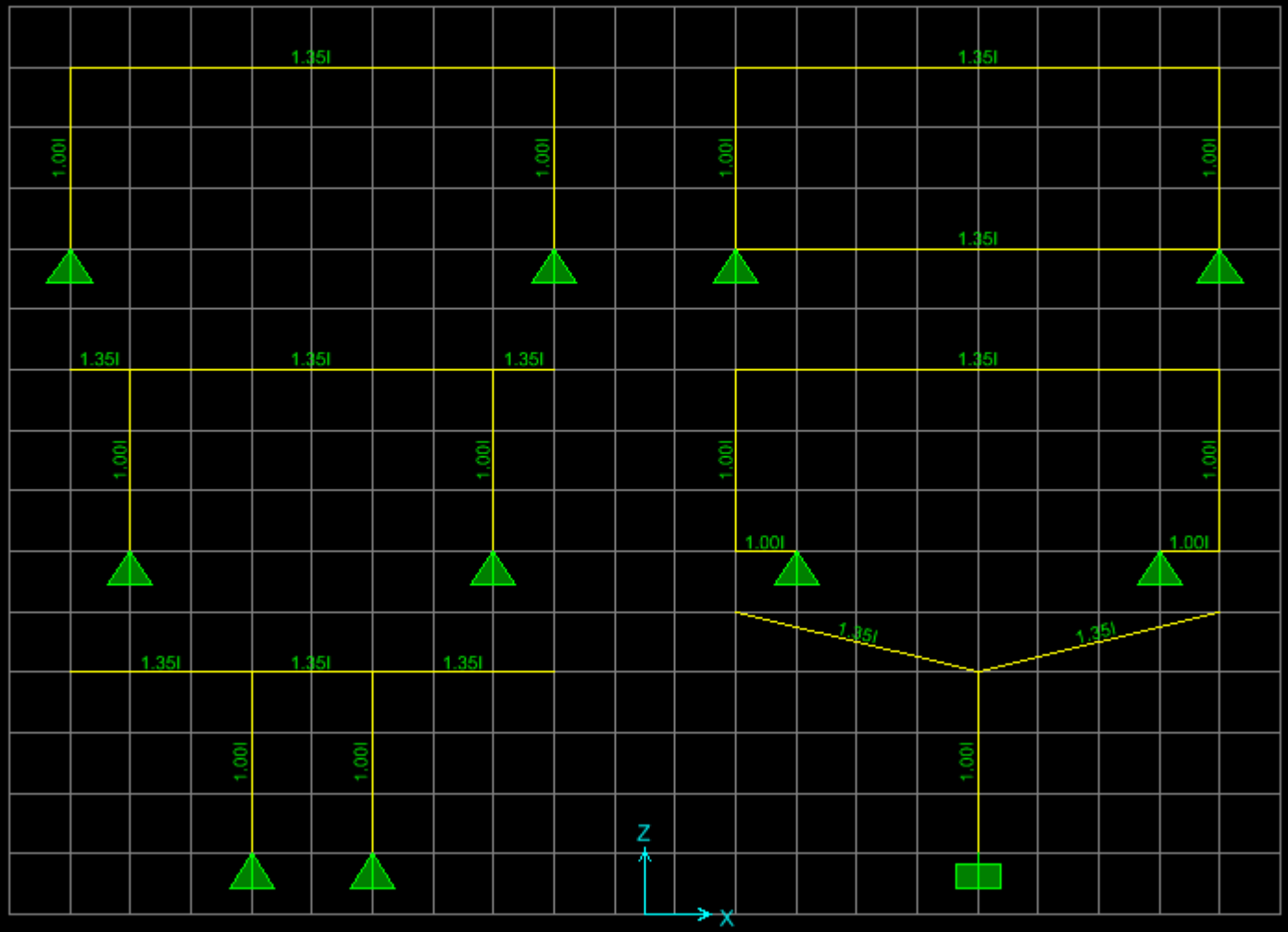


@Seismicisolation

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Frame Sections



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Z Plane @ Y=0

X-40.55 Y0.00 Z-8.09

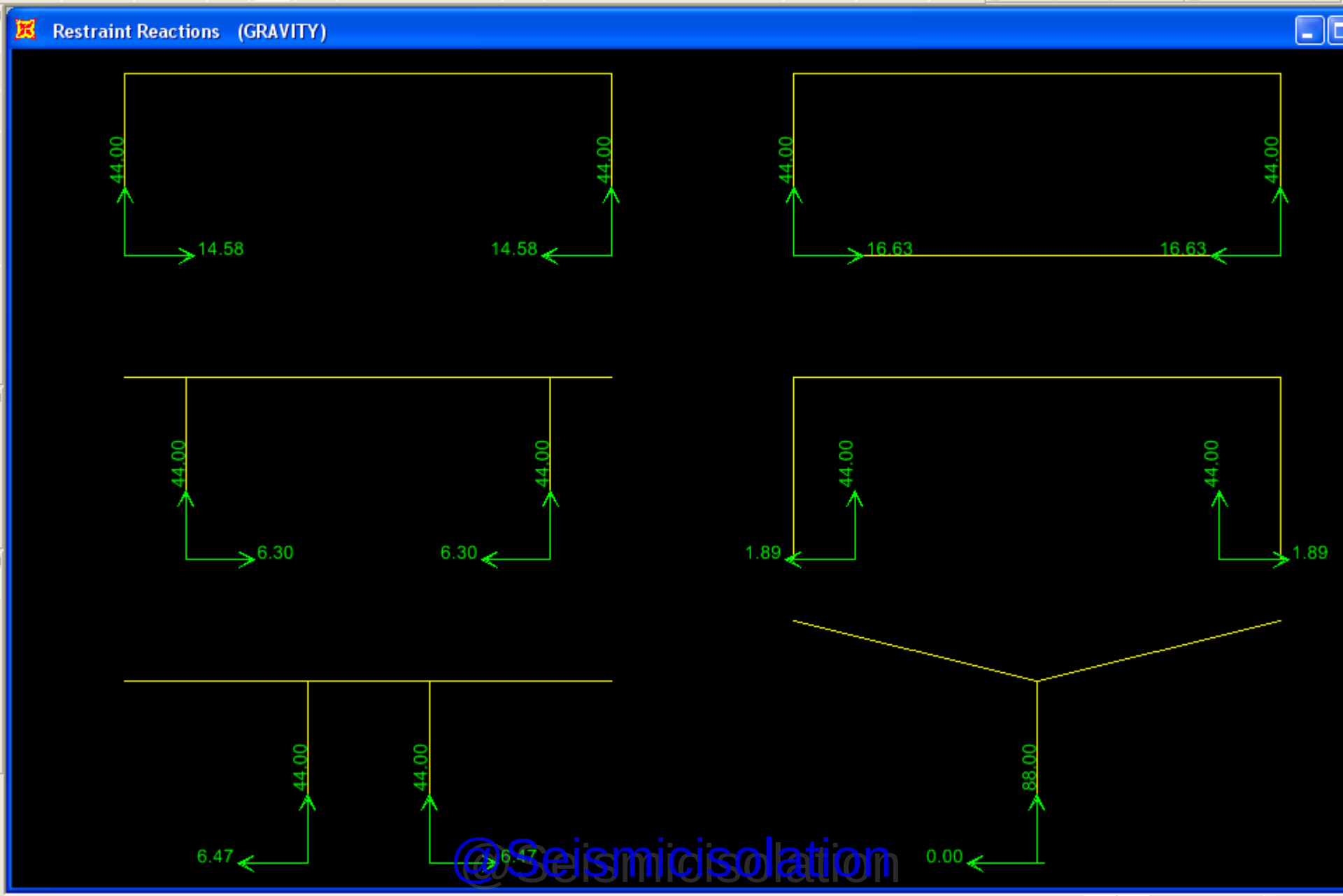
GLOBAL

Kip, ft,

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Restraint Reactions (GRAVITY)



@Seismicisolation

Click on any Joint for reaction values

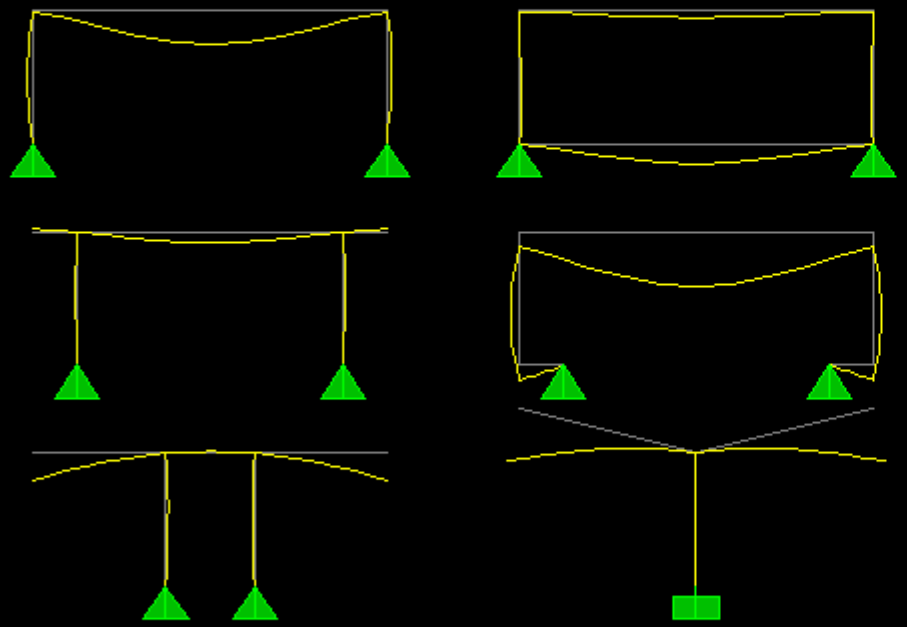
GLOBAL

Saturday, April 1

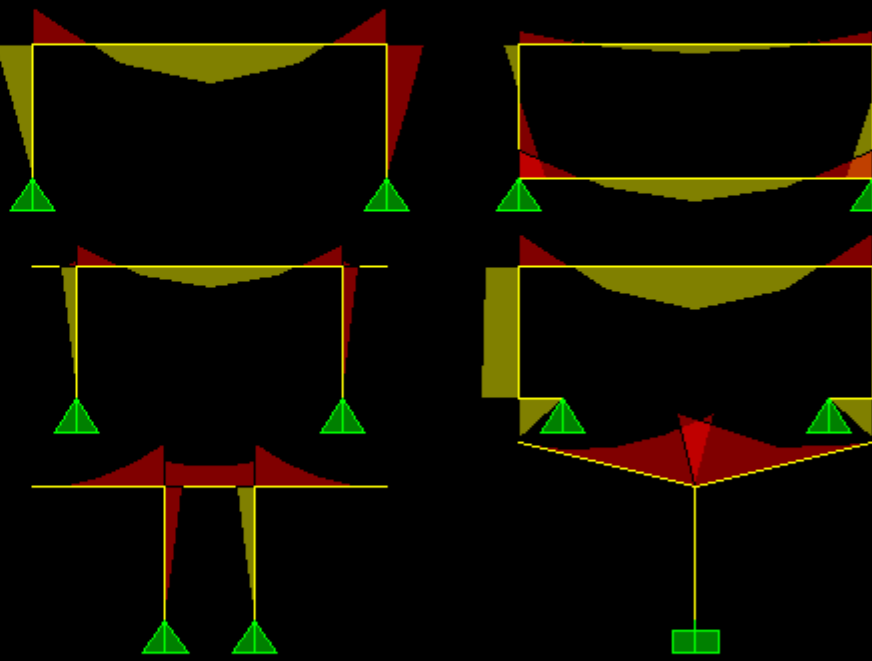
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Deformed Shape (GRAVITY)



Moment 3-3 Diagram (GRAVITY)



@Seismicisolation

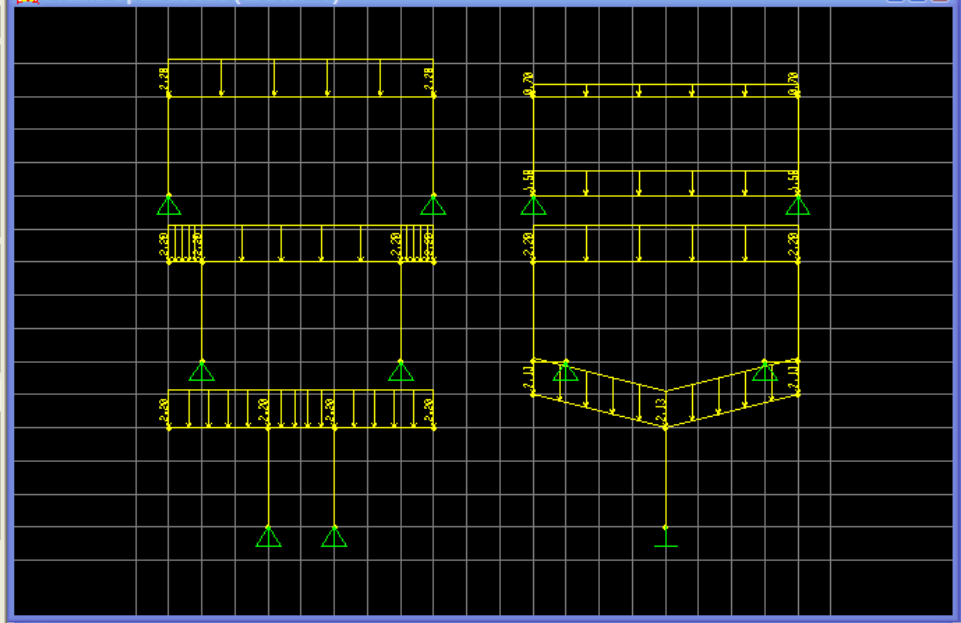
Click on any joint for displacement values

Start Animation GLOBAL Kip, ft, F

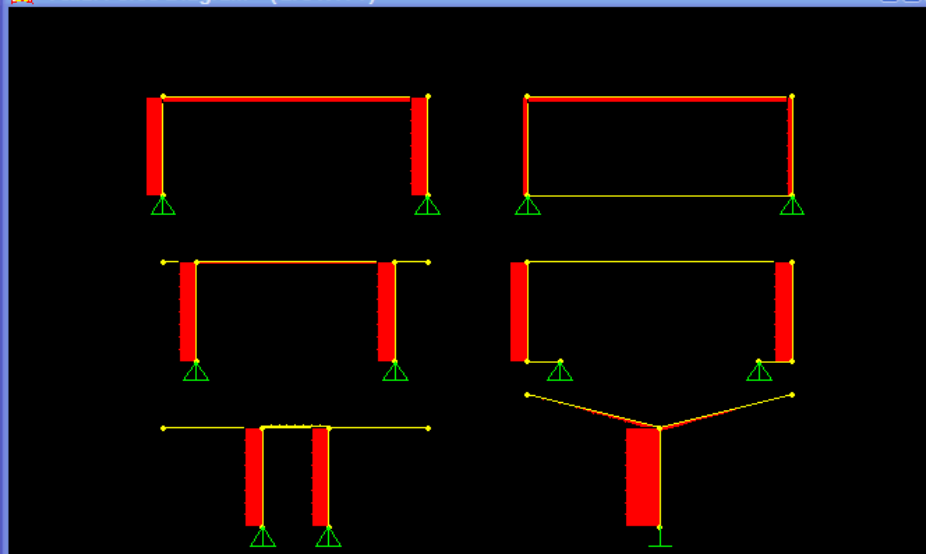
SAP2000 - Ex. 7.4 cantilever frames

File Edit View Define Draw Select Assign Analyze Display Design Options Help

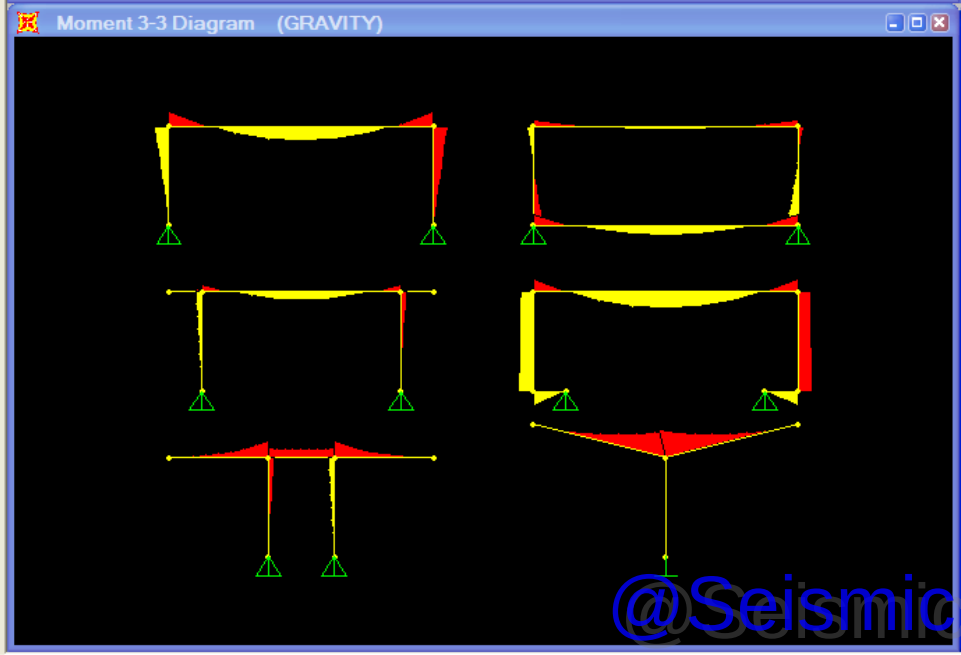
Frame Span Loads (GRAVITY)



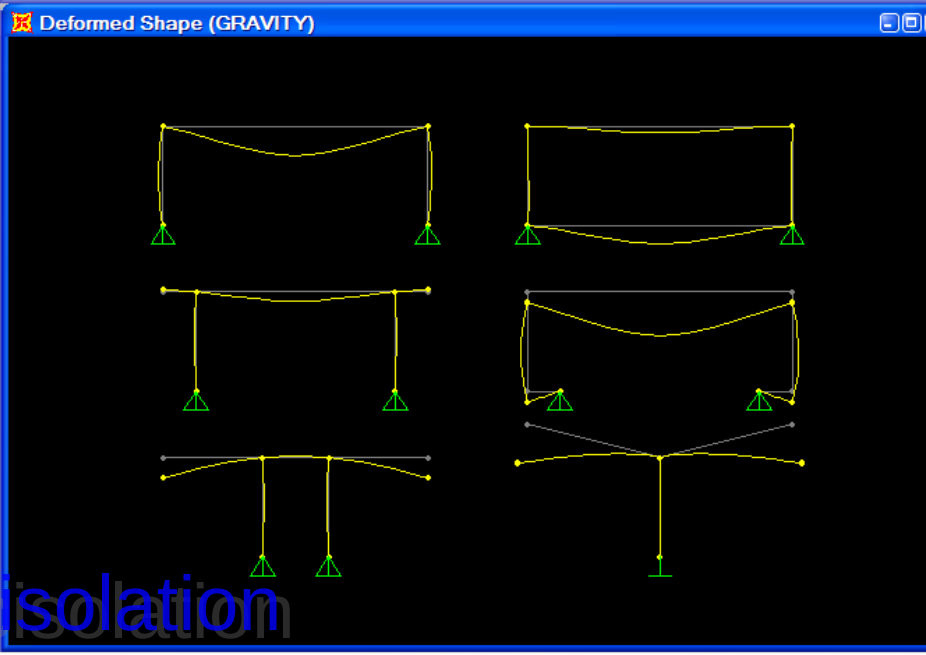
Axial Force Diagram (GRAVITY)



Moment 3-3 Diagram (GRAVITY)



Deformed Shape (GRAVITY)



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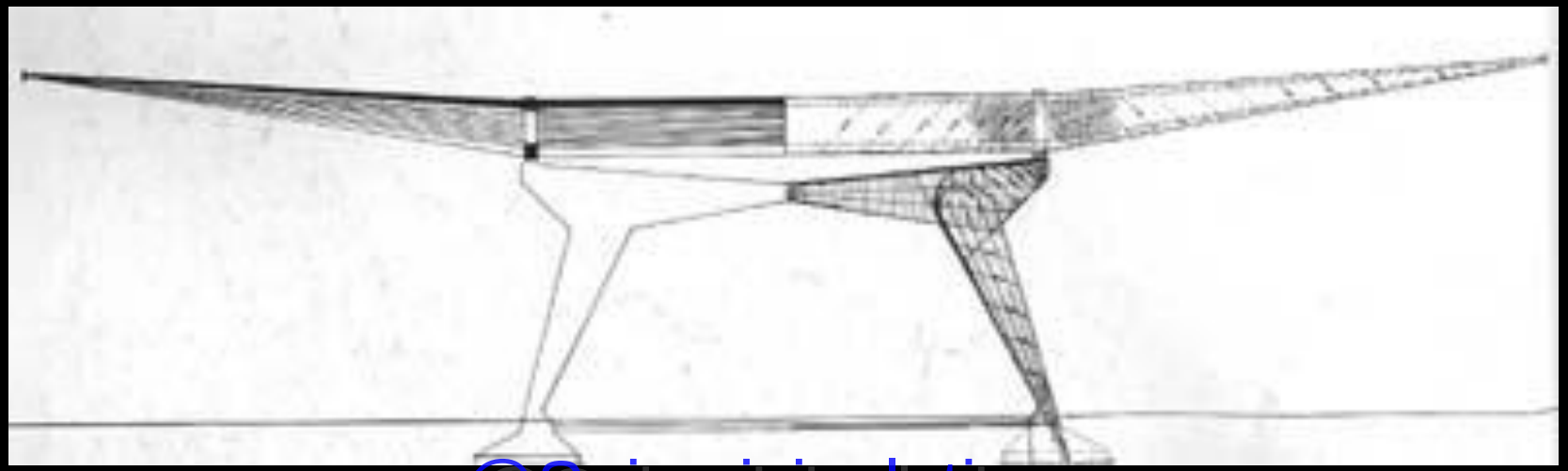
Right Click on any joint for displacement values

Start Animation

Kip-ft



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International Airport, Rome, Italy, 1957, Pier Luigi Nervi

San Diego Library, 1970, William L. Pereira

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Palau de les Arts, Valencia Opera House, 2005, Santiago Calatrava

Ciudad de las Artes.
Valencia, Spain, 2002,
Santiago Calatrava

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@Seismicisolation

Stadelhofen Station, Zurich, Switzerland, 1990, *Santiago Calatrava*

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@Seismicisolation

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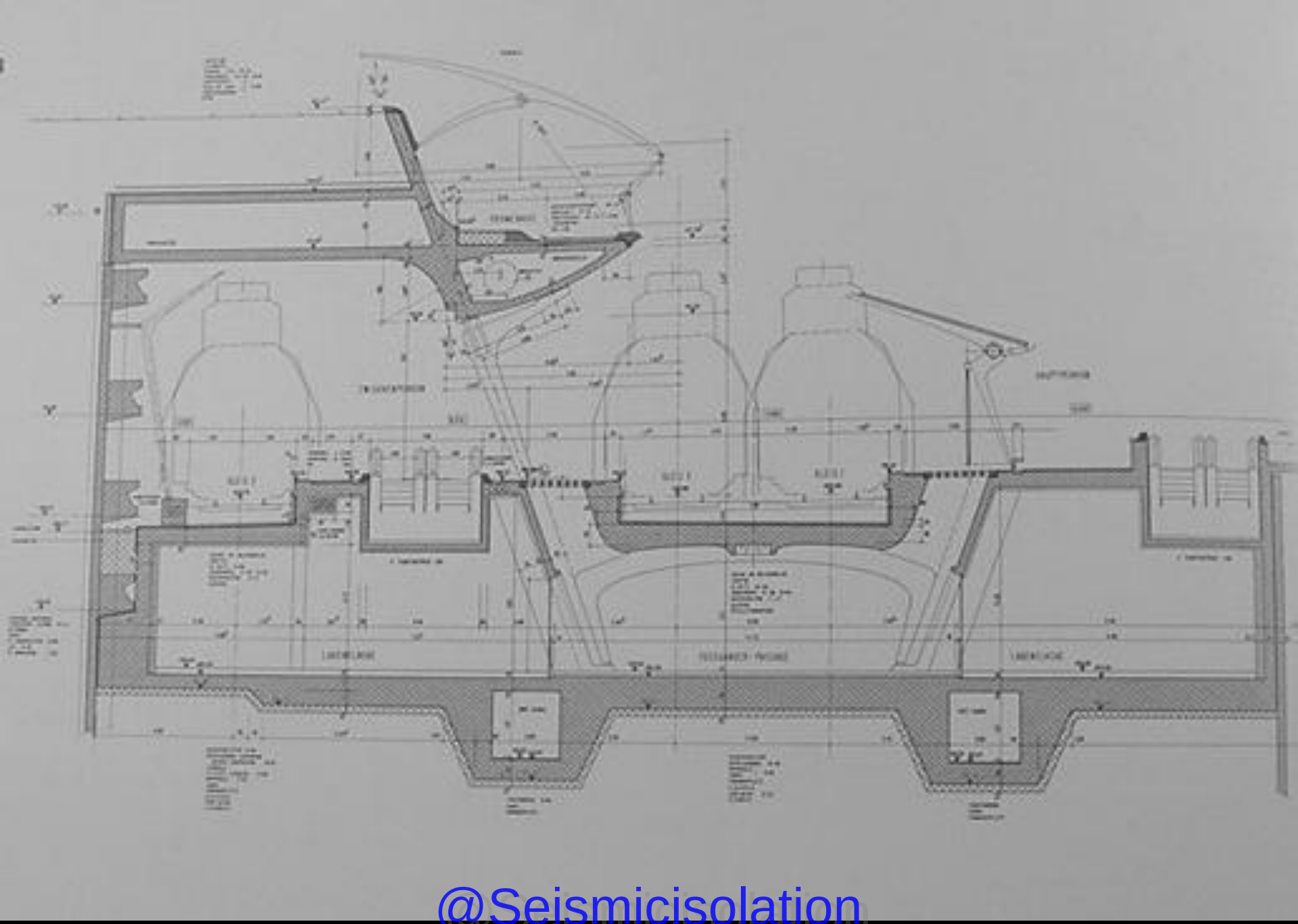
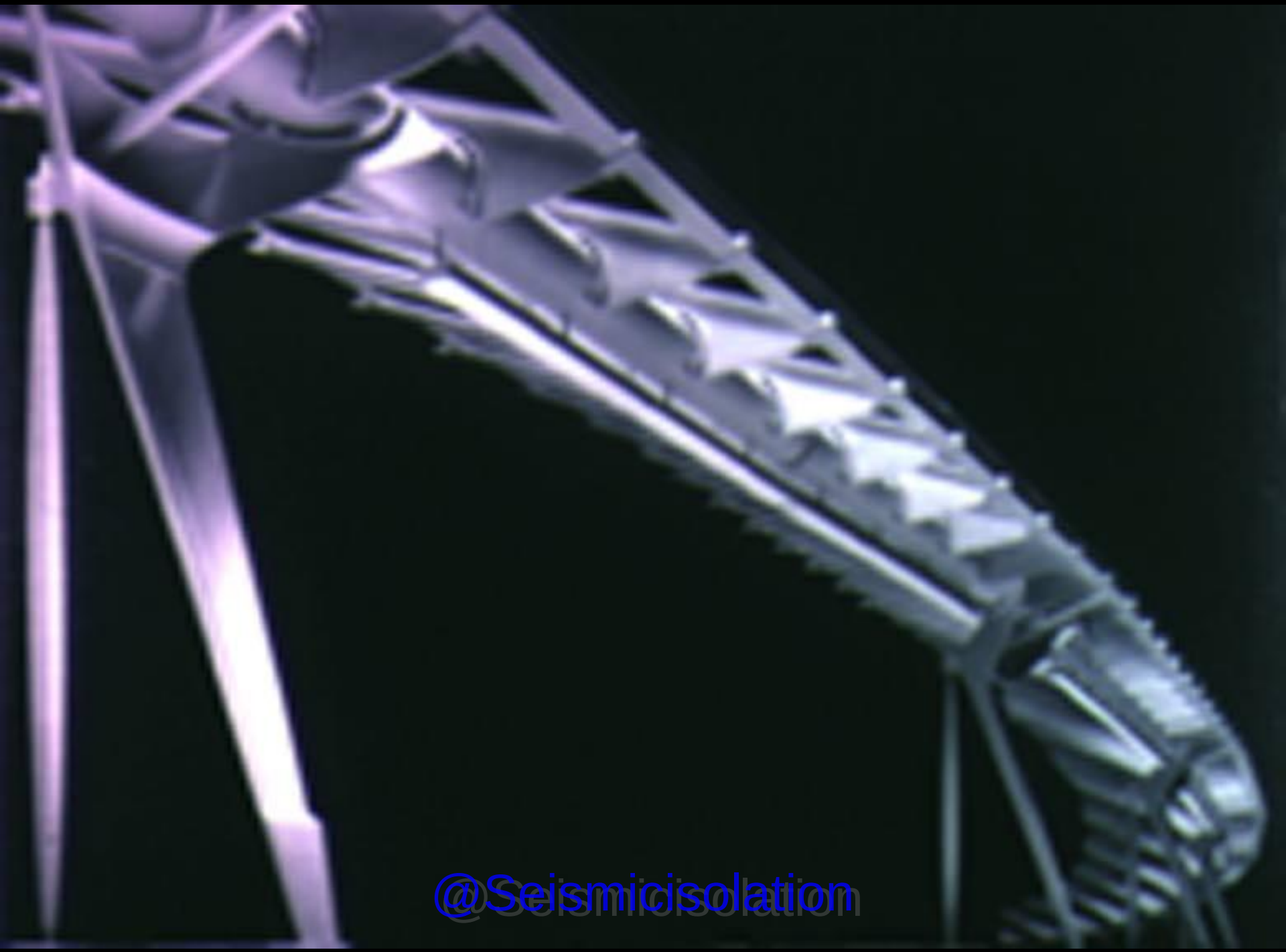


@Seismicisolation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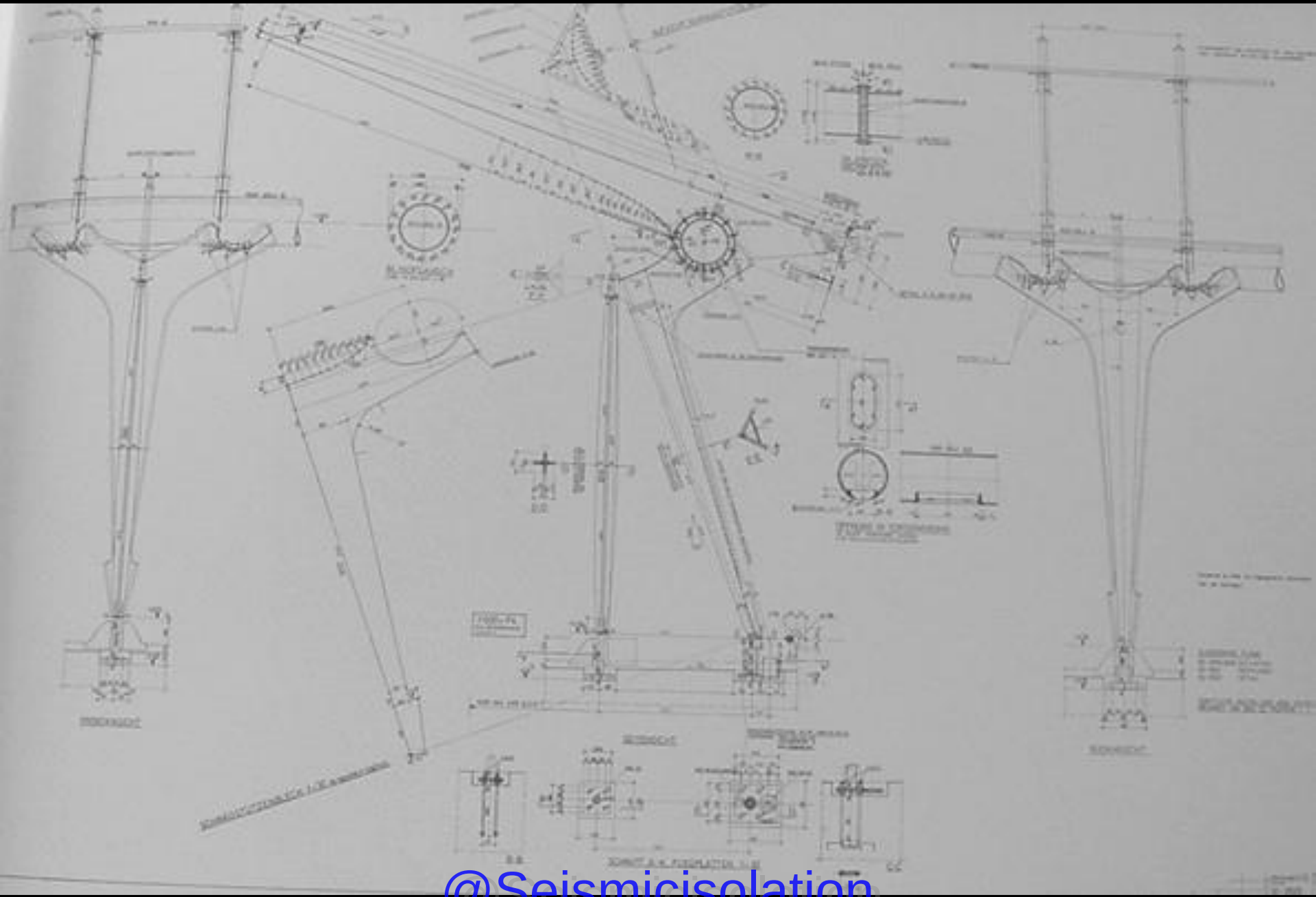

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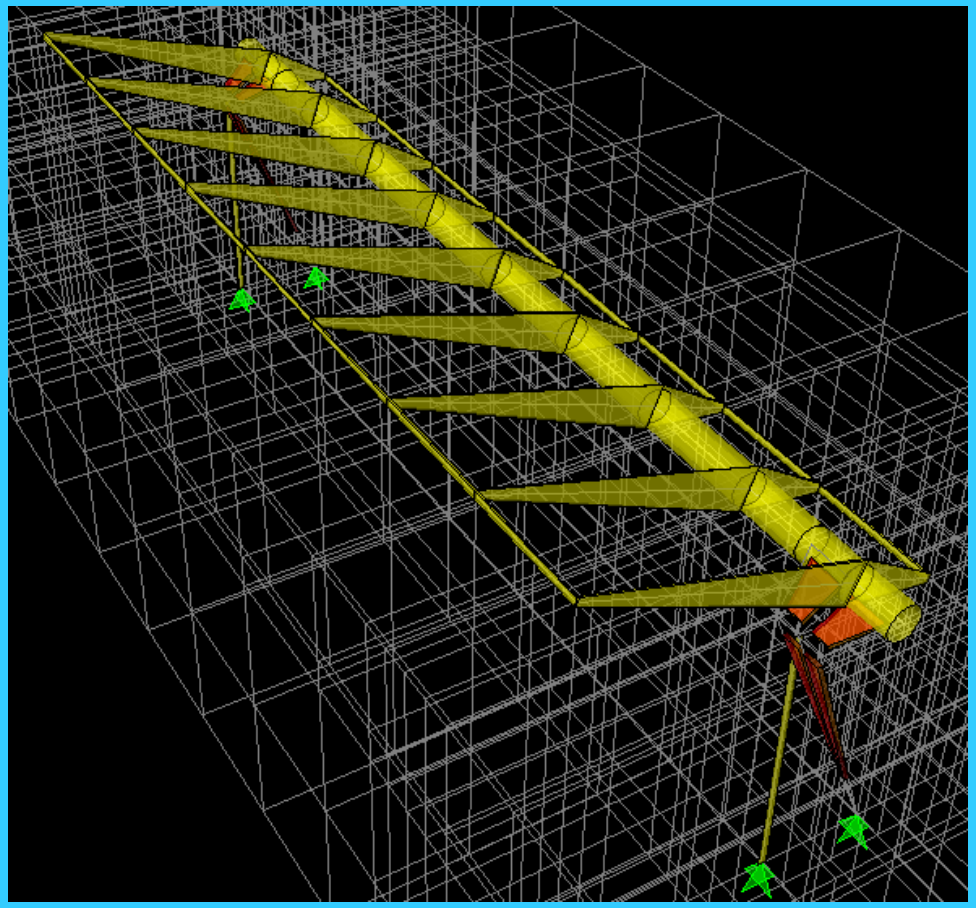

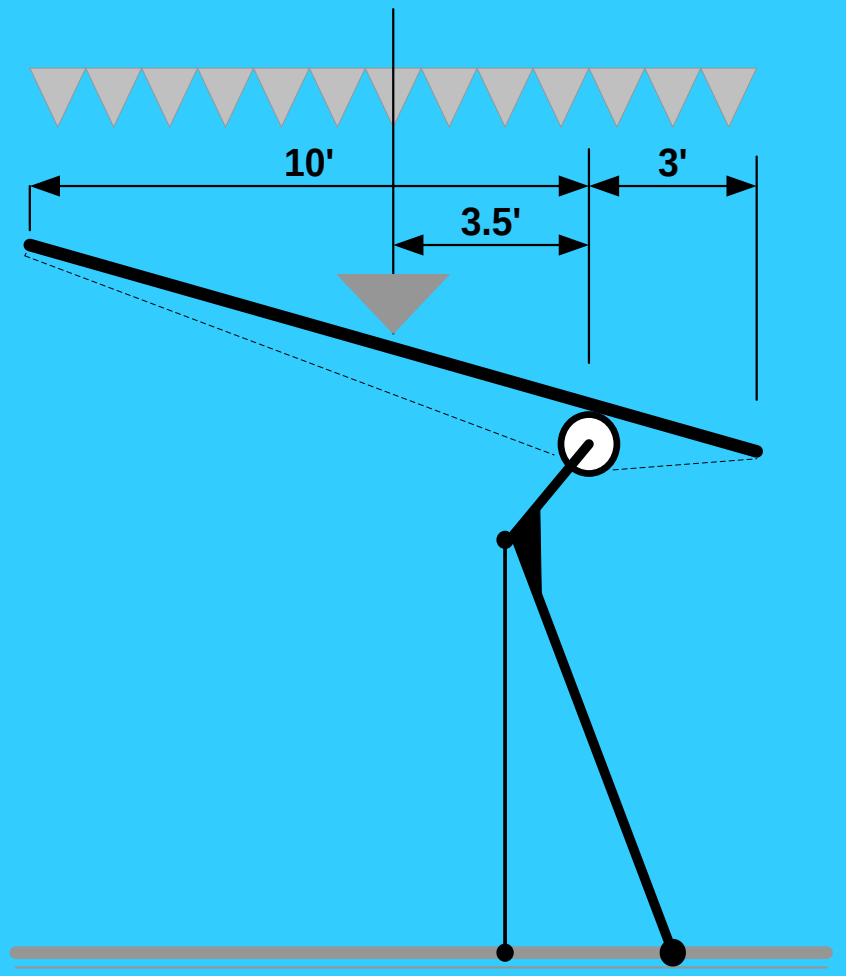

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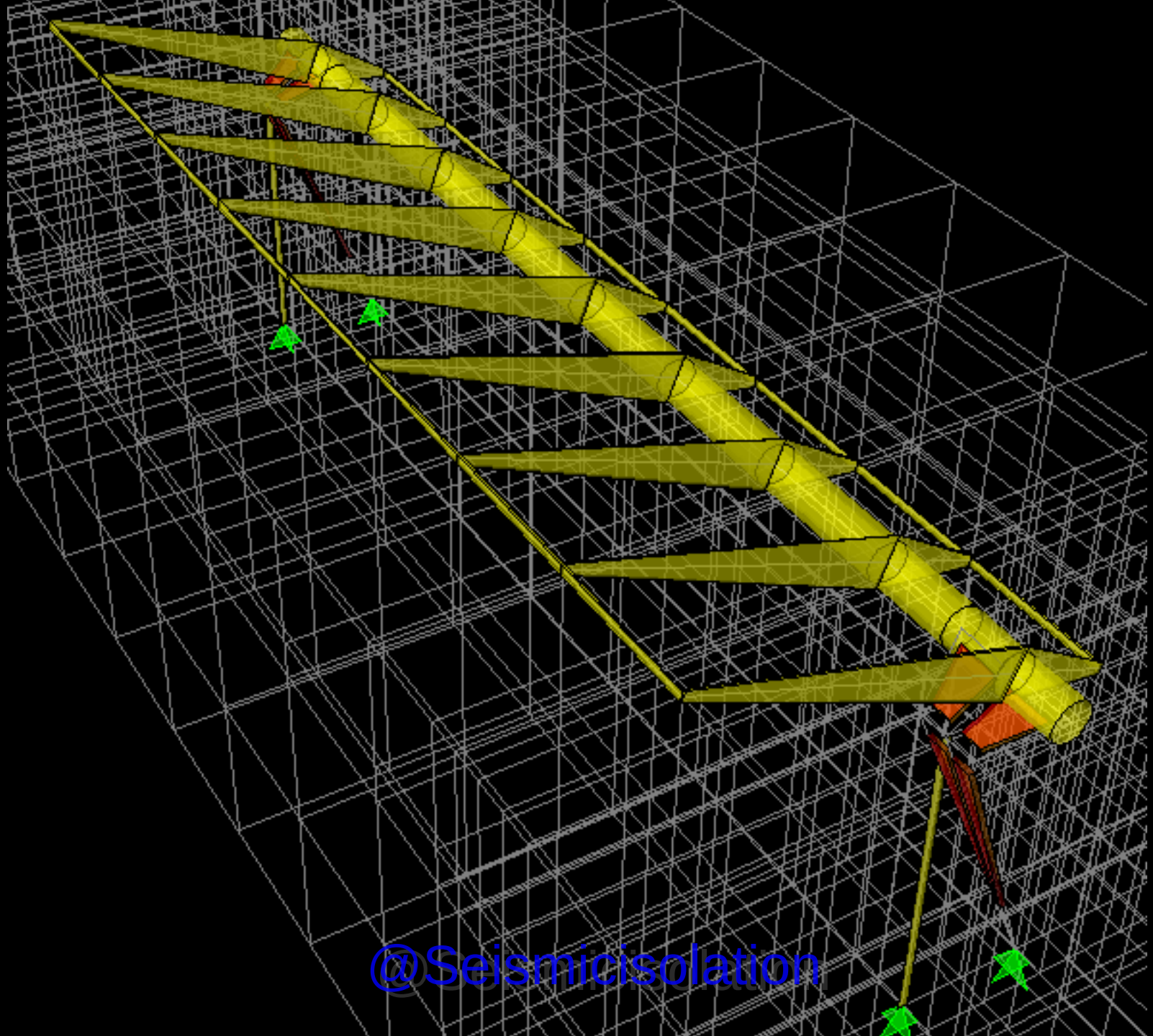
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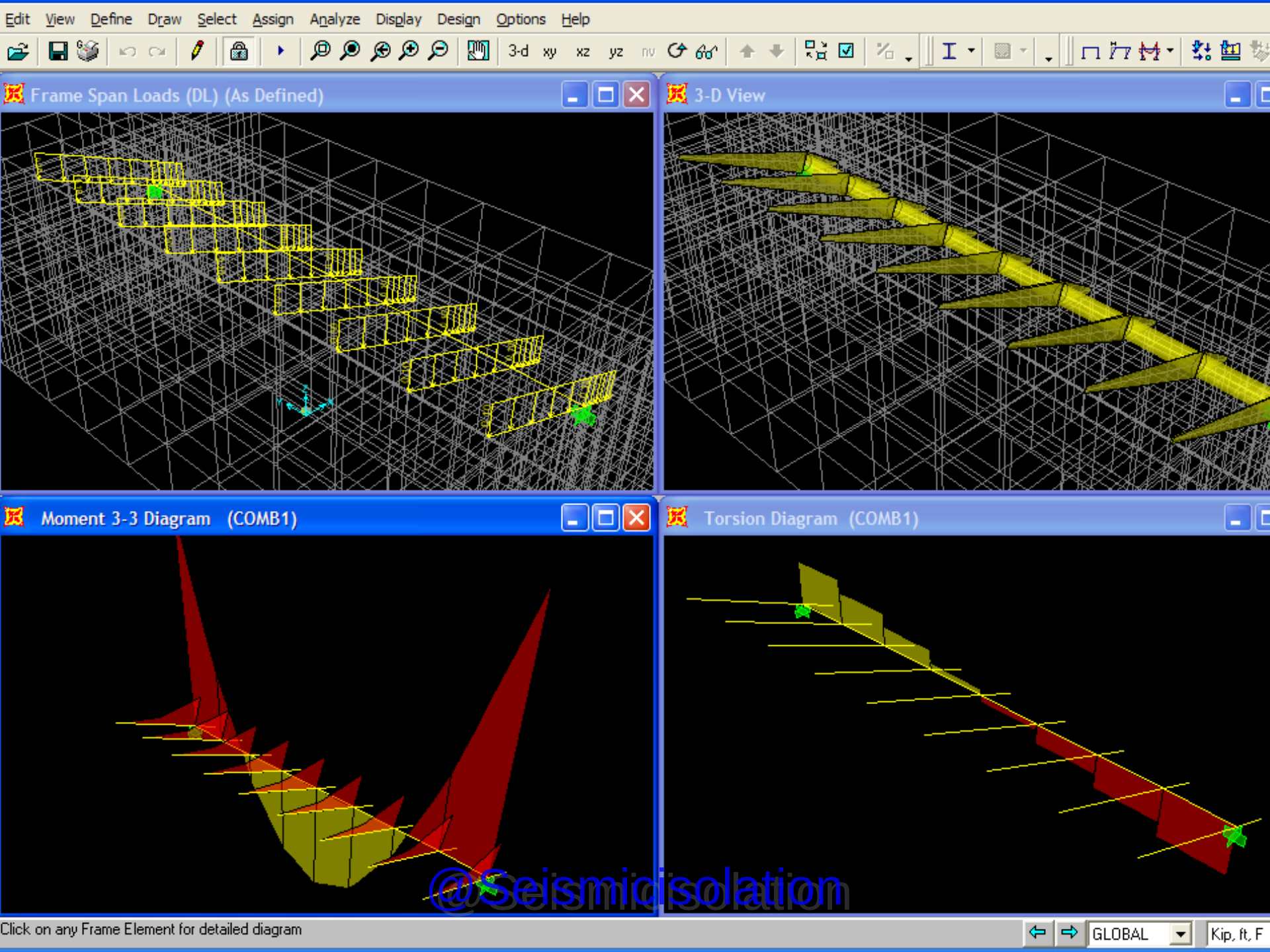
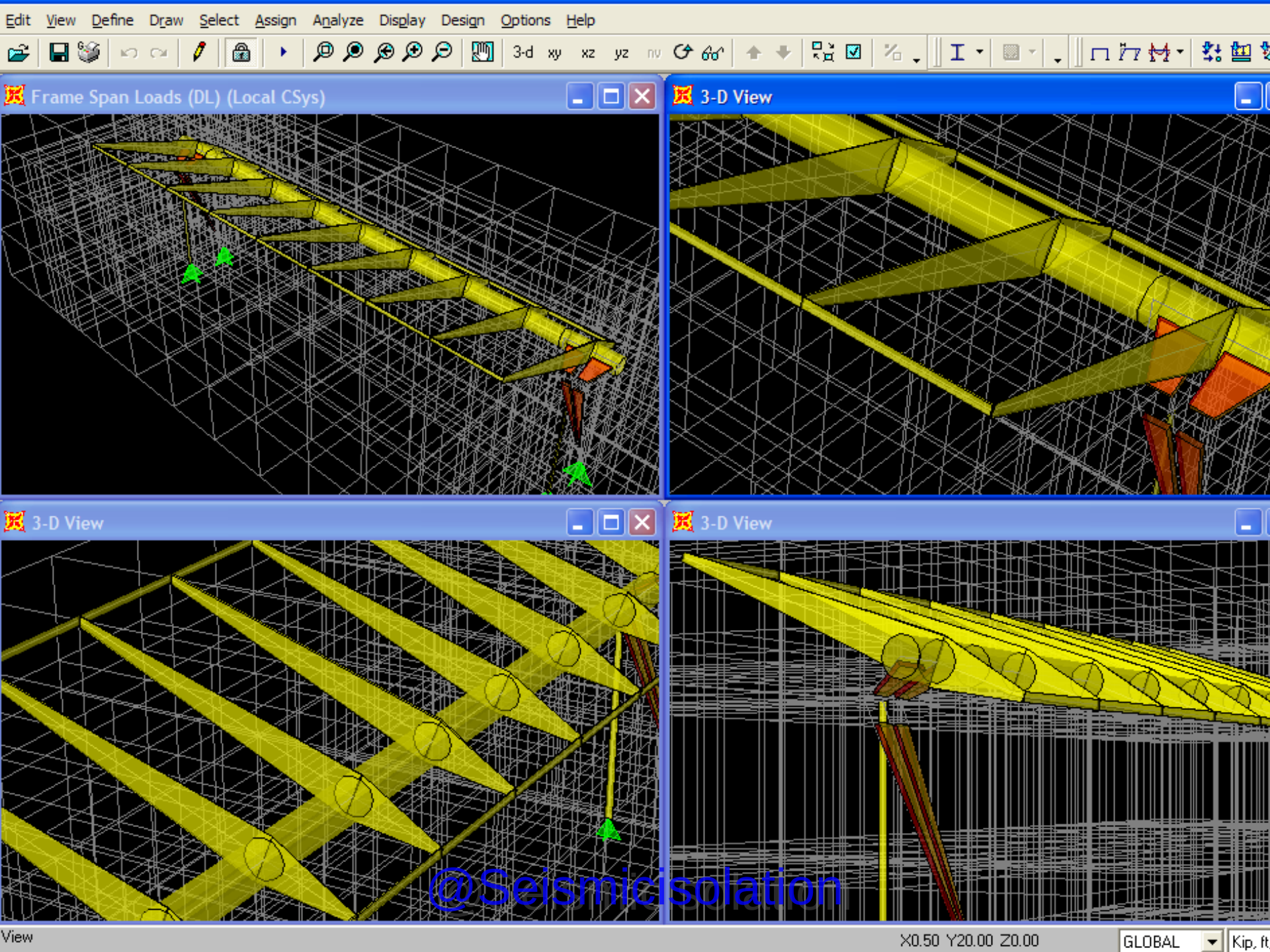
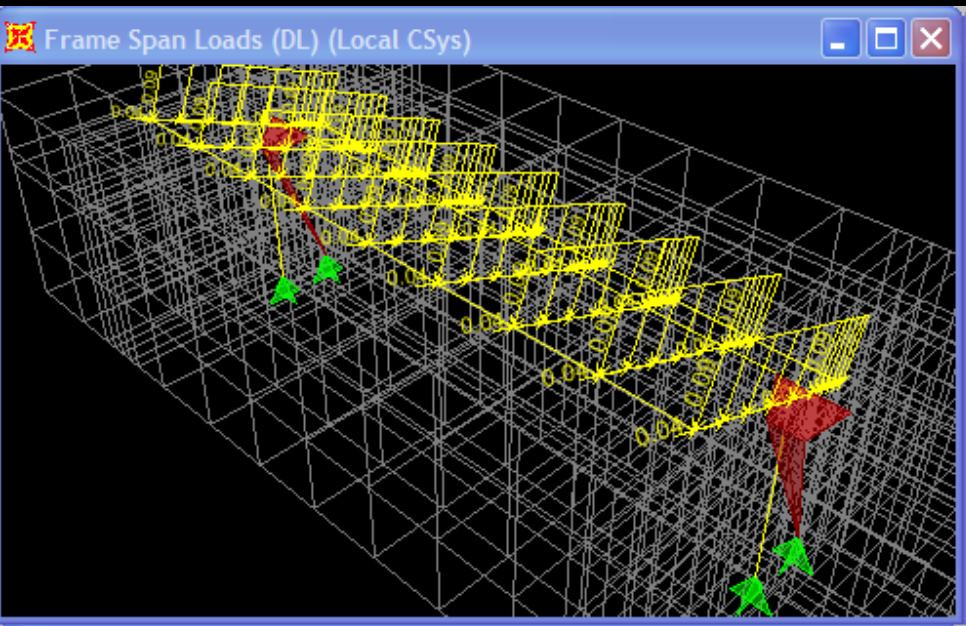
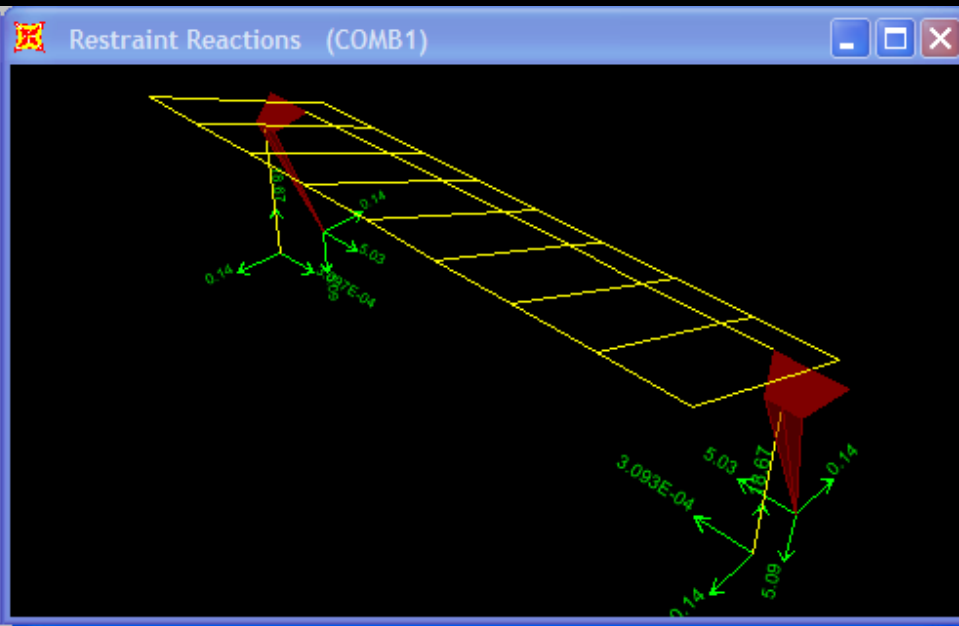
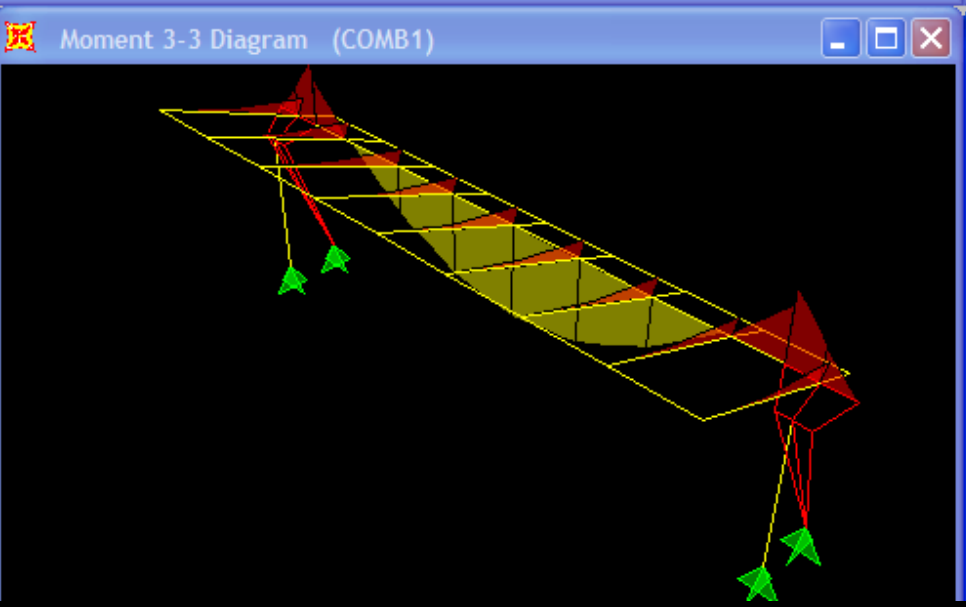
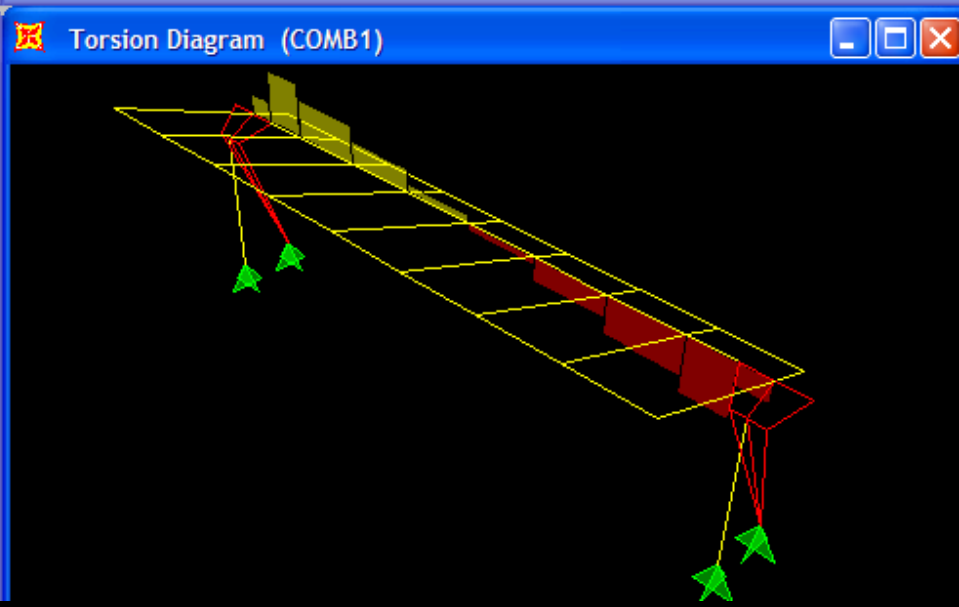

Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d xy xz yz nv
Frame Span Loads (DL) (As Defined)
3-D View
Moment 3-3 Diagram (COMB1)
Torsion Diagram (COMB1)
@Seismicisolation
Click on any Frame Element for detailed diagram
GLOBAL
Kip, ft, F


Edit View Define Draw Select Assign Analyze Display Design Options Help
3-d xy xz yz nv
Frame Span Loads (DL) (Local CSys)
3-D View
3-D View
3-D View
@Seismicisolation
View
X0.50 Y20.00 Z0.00
GLOBAL
Kip, ft









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BRACED FRAMES

Frames can be braced in a concentric or eccentric manner as indicated for portal bents. *Cases A*. and *B*. are concentrically braced, while *cases C.* and *D*. are eccentrically braced, and *cases E*. and *F.* have knee bracing. In the symmetrical post-beam structures (*A., C.,* and *E*.) the braces change from K-bracing, to eccentric bracing to knee bracing. In the asymmetrical frames (B. and D.) the change is similar from diagonal bracing to the beam-column intersection, to a single eccentric bracing, and then to knee bracing for the post-beam structure.

The knee braces as often found in wood construction, do not provide a rigid support to the beam; the support settlement is a function of the column stiffness. The knee-braced corners of frames can be visualized as rigid frame connections.

In earthquake regions the use of eccentric bracing should be considered. While the conventional concentrically braced frames are very stiff because the forces are transmitted directly in axial fashion, under severe cyclic loading the braces may buckle because of the lack of ductility and cause an unbalance of loading, which may result in failure. However, when the brace is connected eccentrically to the beam, rather than concentrically to the beam-column intersection, then the diagonal force is transmitted in shear and bending along the beam segment, forming a ductile link, where the plastic deformations prevent the brace from buckling.

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Eccentic, braced frame

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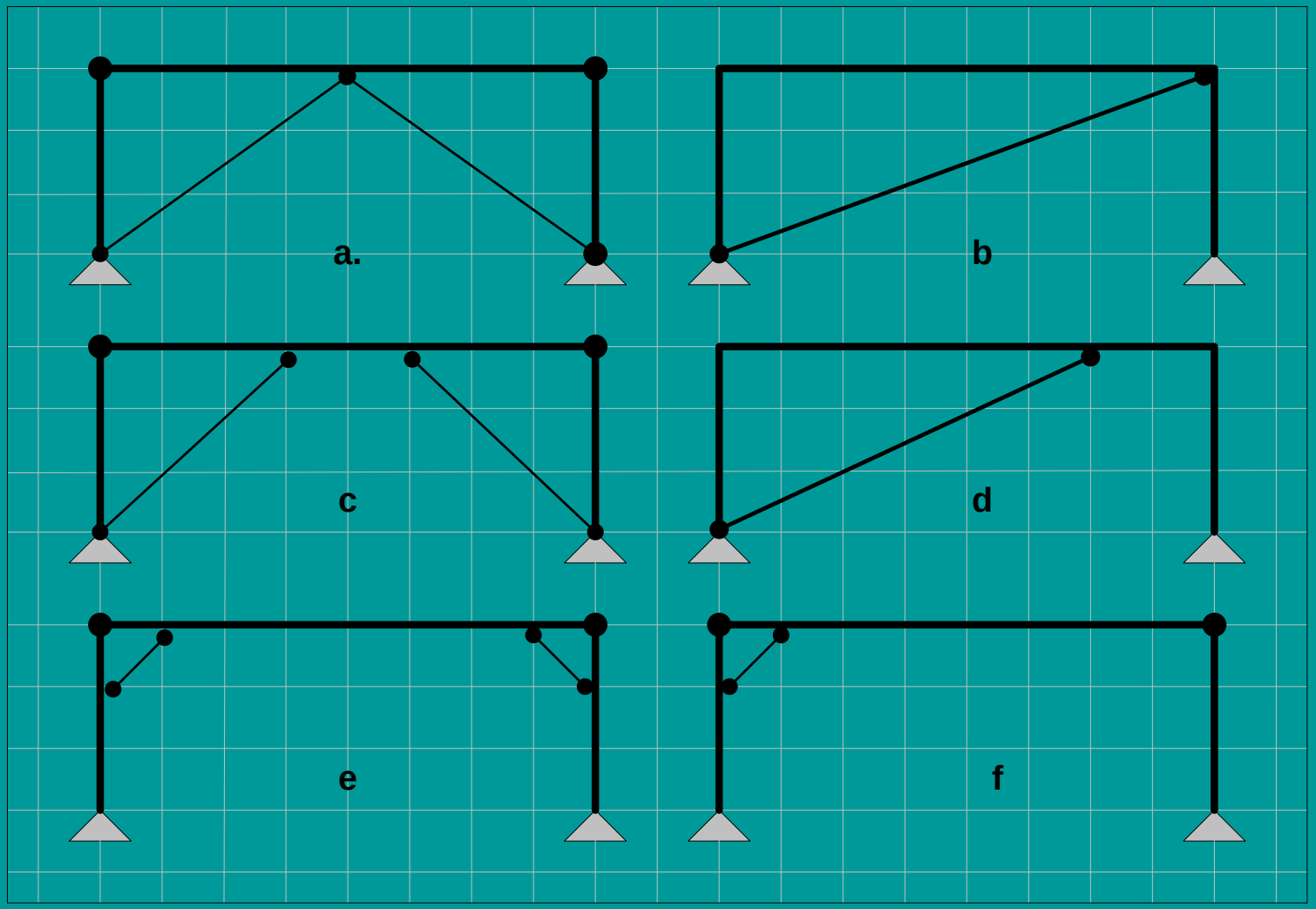

BRACED FRAMES

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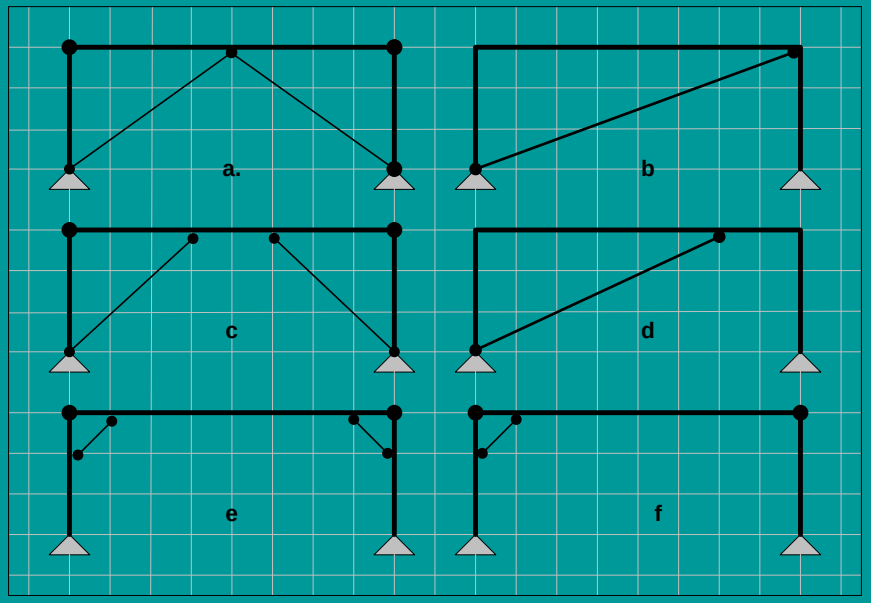

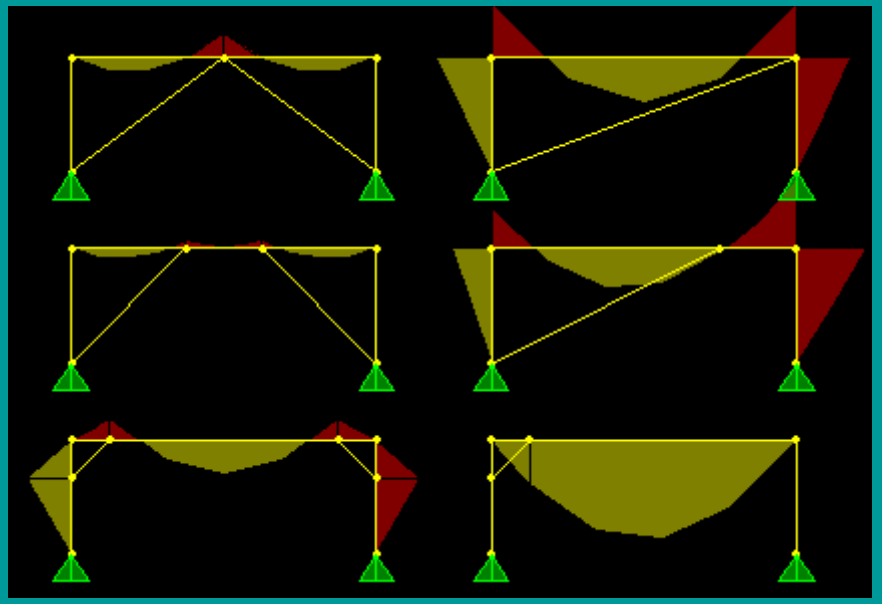

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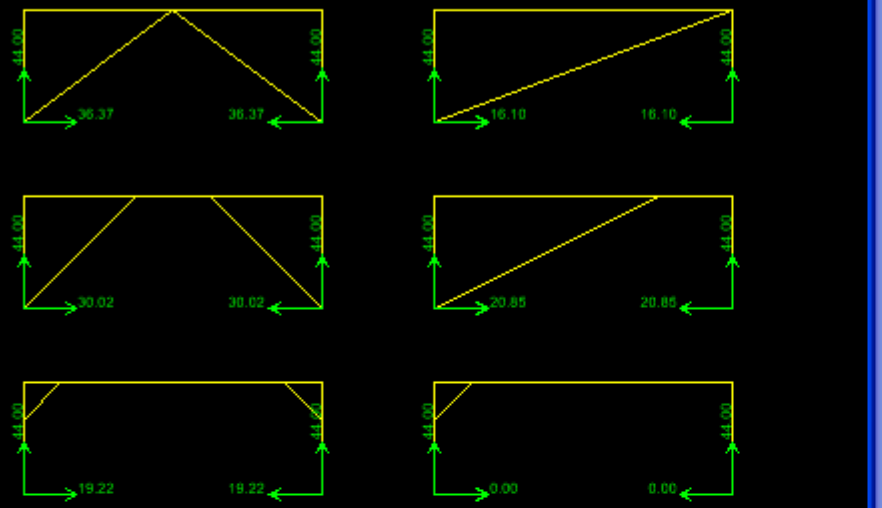
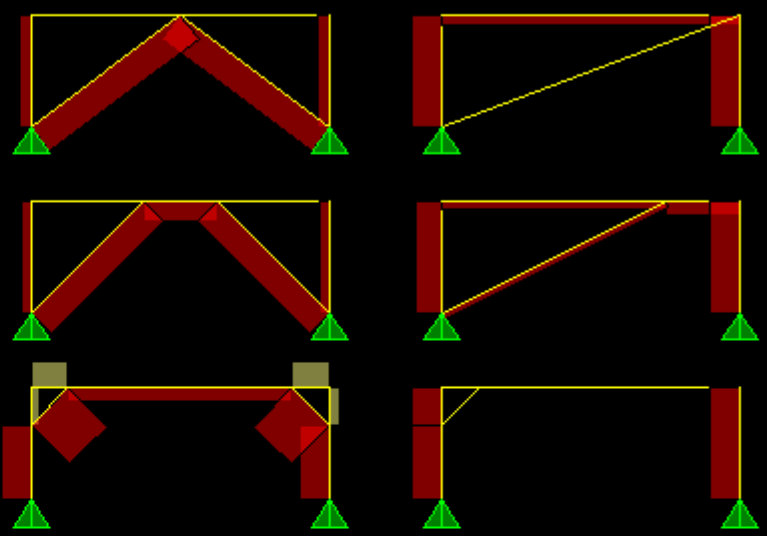
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xz

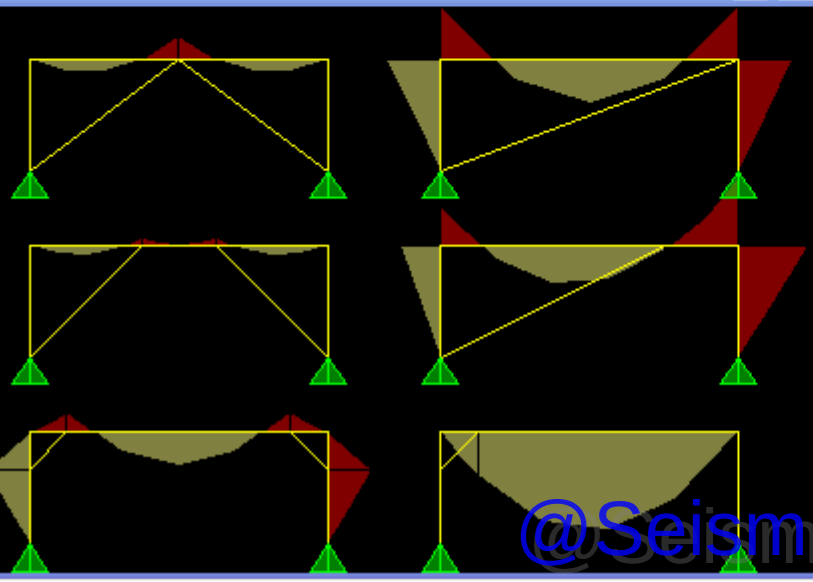
Restraint Reactions (COMB1)



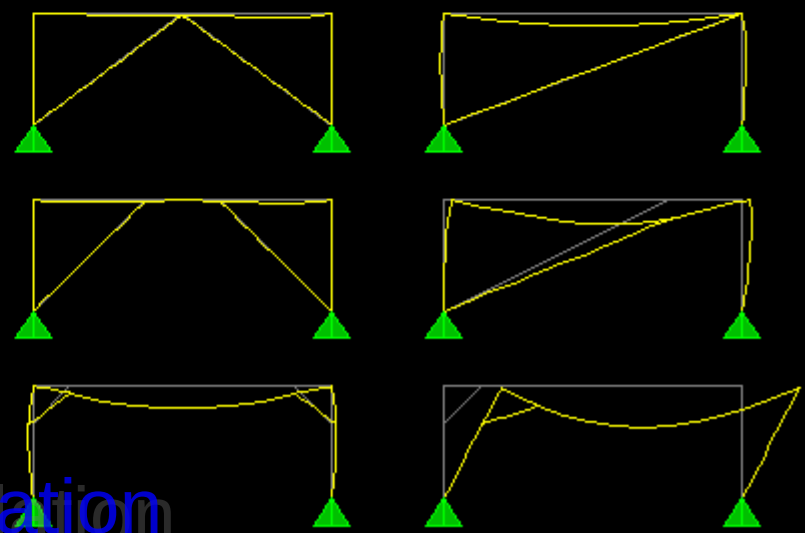
Axial Force Diagram (COMB1)



Moment 3-3 Diagram (COMB1)



Deformed Shape (COMB1)



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t Click on any Joint for reaction values

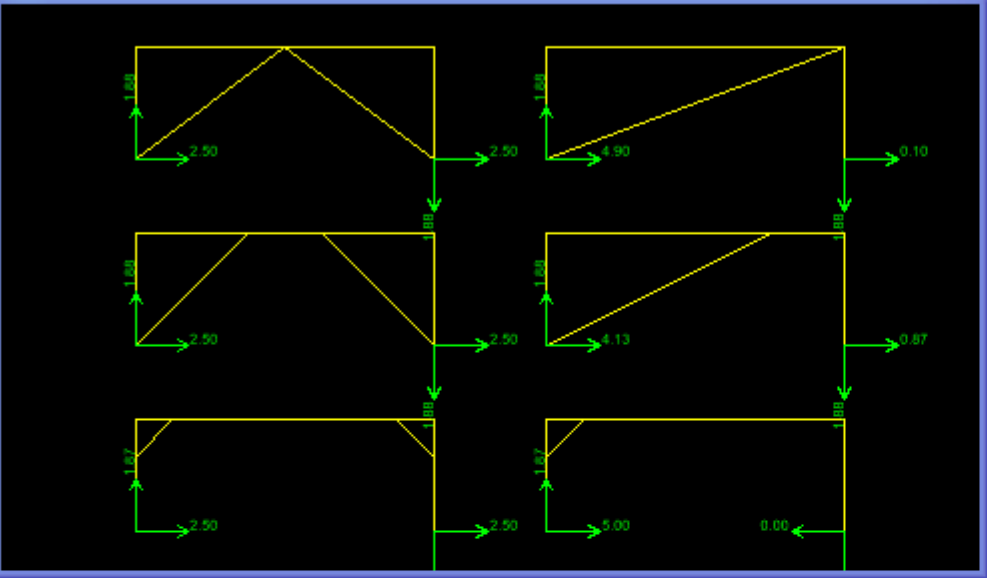
GLOBAL

Kip, ft, F

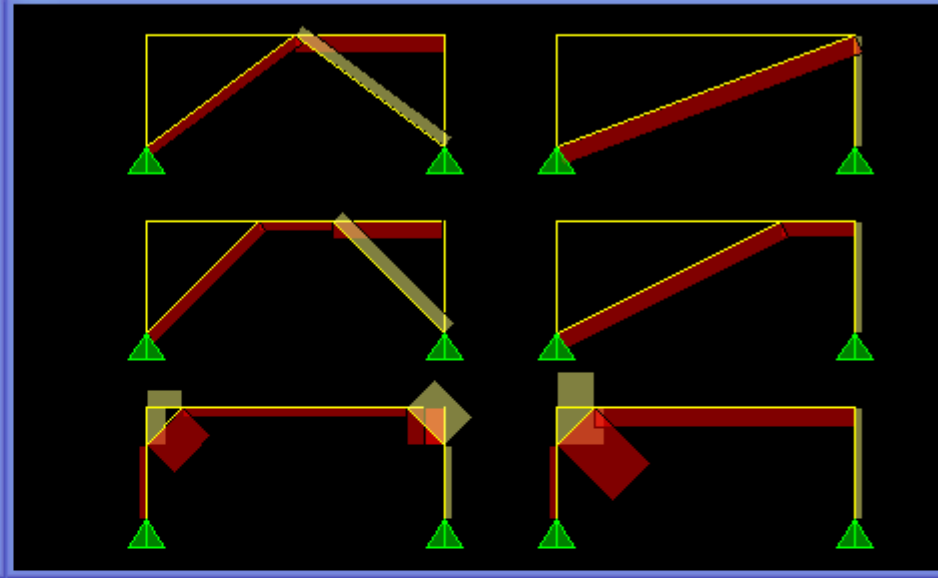
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xz

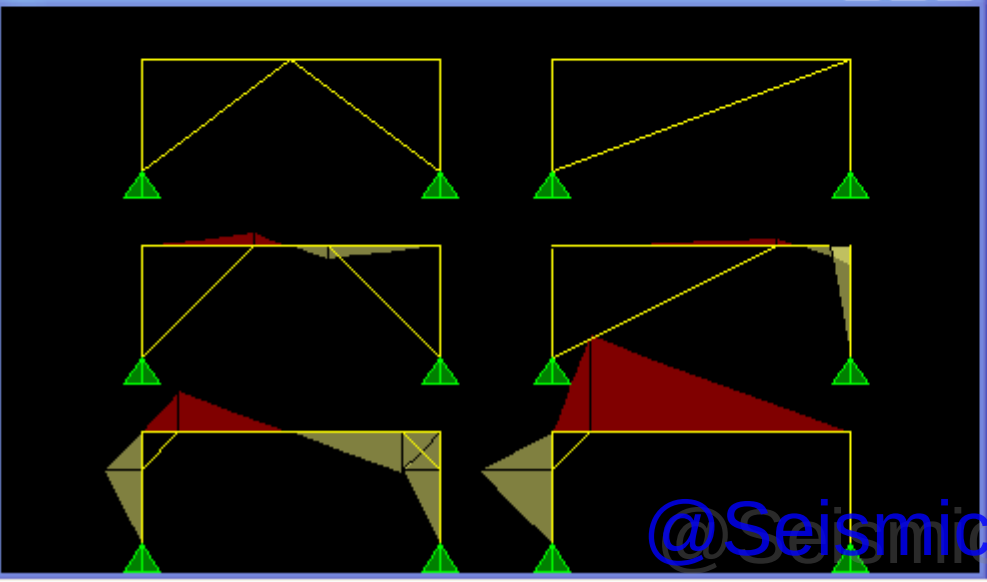
Restraint Reactions (W)



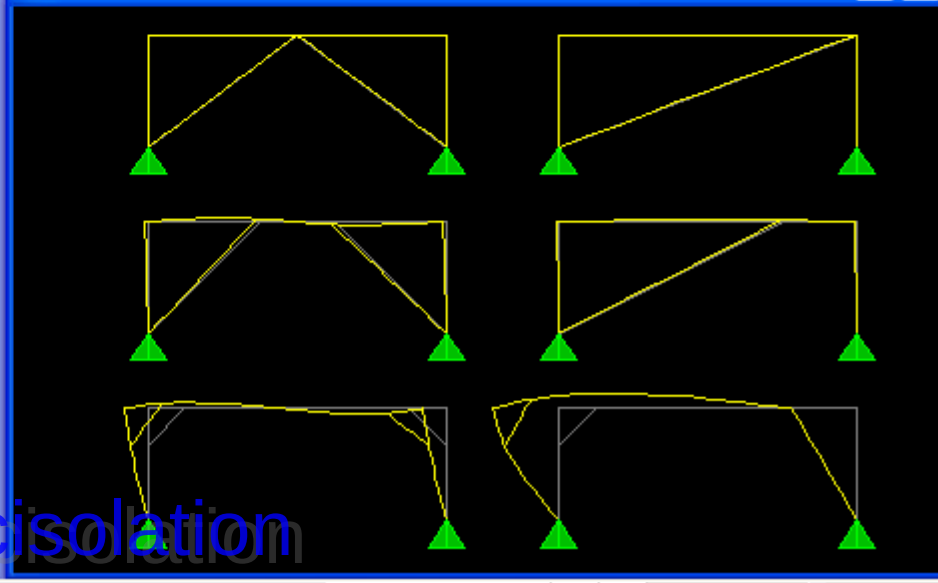
Axial Force Diagram (W)



Moment 3-3 Diagram (W)



Deformed Shape (W)



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Click on any joint for displacement values

Start Animation GLOBAL Kip, ft, F

Pitched Frames

The pitched frame concept ranges from residential roof construction to the folded frame for industrial buildings. Several typical examples are shown in Fig. 7.7.
Case (*A*.) is basic triangular truss unit; when the tie is taken out and the roller support is replaced by a pin support, then the structure forms a three-hinge A-frame. In wood construction the inclined beams are called rafters. A statically indeterminate collar frame is shown in case (*C*.), where the simple A-frame is internally braced by a collar strut to reduce the bending in the beams, w. For the strut to be truly effective, floor decking or horizontal bracing should connect the various collar ties together to form a horizontal deep beam, which must be supported by shear walls or vertical trussing. For this method of construction, the collar strut provides a rigid support to the beams; otherwise, a flexible support would only be available under unsymmetrical load action, requiring much larger member sizes.
Case (*B*.) represents a post-beam structure as is typical for residential construction. In contrast to A-frame construction, where the beams support each other at the crown to form a continuous frame, in the post-beam structure the inclined beams or joists (if they are closely spaced) function independently as inclined simple bending members, supported on ridge beams. For the post-beam structure there are no ties at the base support required because there is no thrust under gravity action. In case (D.) intermediate beam supports are introduced to reduce bending and deflection.
Case (*E*.) is a three-hinge gable frame whereas in case (*F*.) a tie rod is added to frame knees to reduce the thrust and thus reduce bending in the frame.
The critical moment for the gable frame is at the knee, the field moments along the inclined frame beam are rather small when compared with the support moments so they do not play an important role during the preliminary design process.

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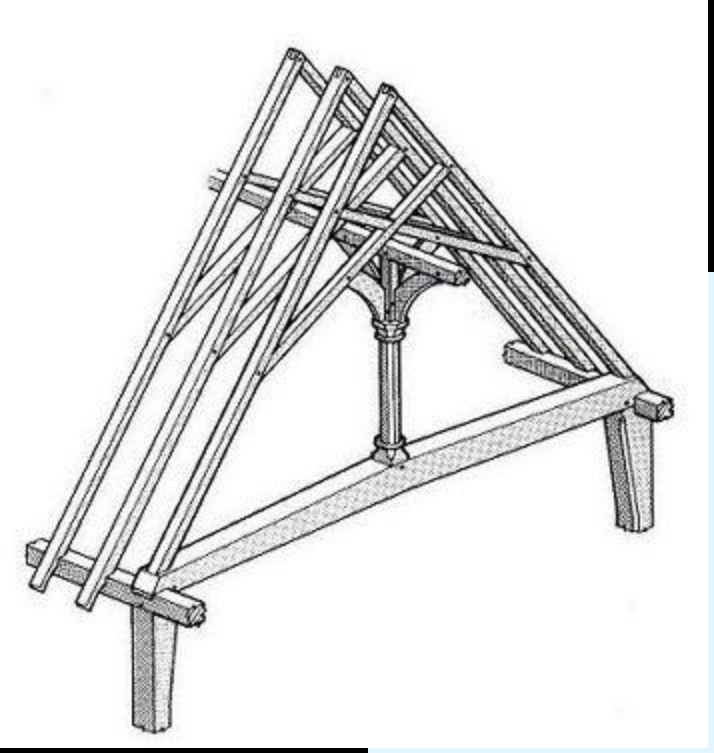
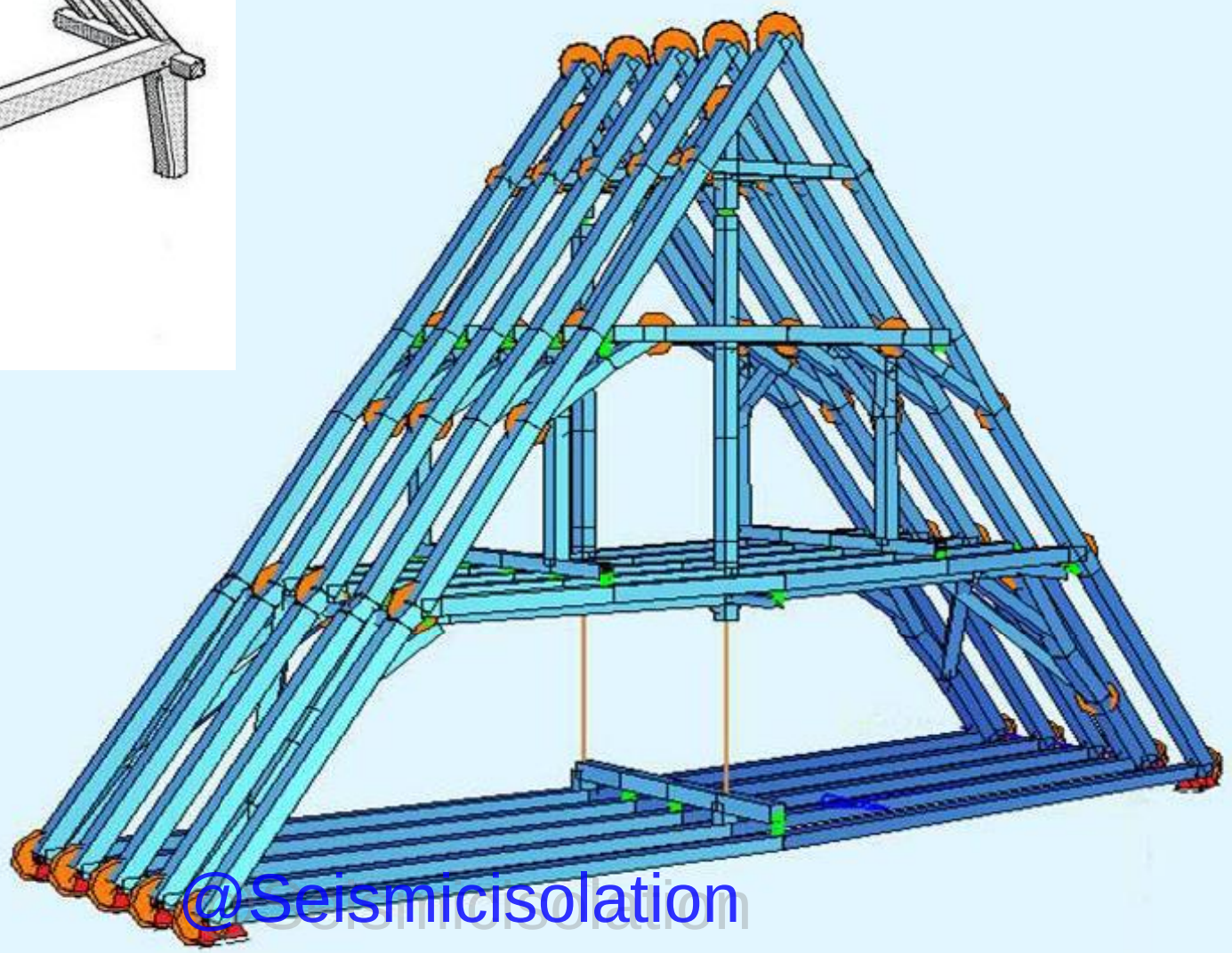
medieval roof structures





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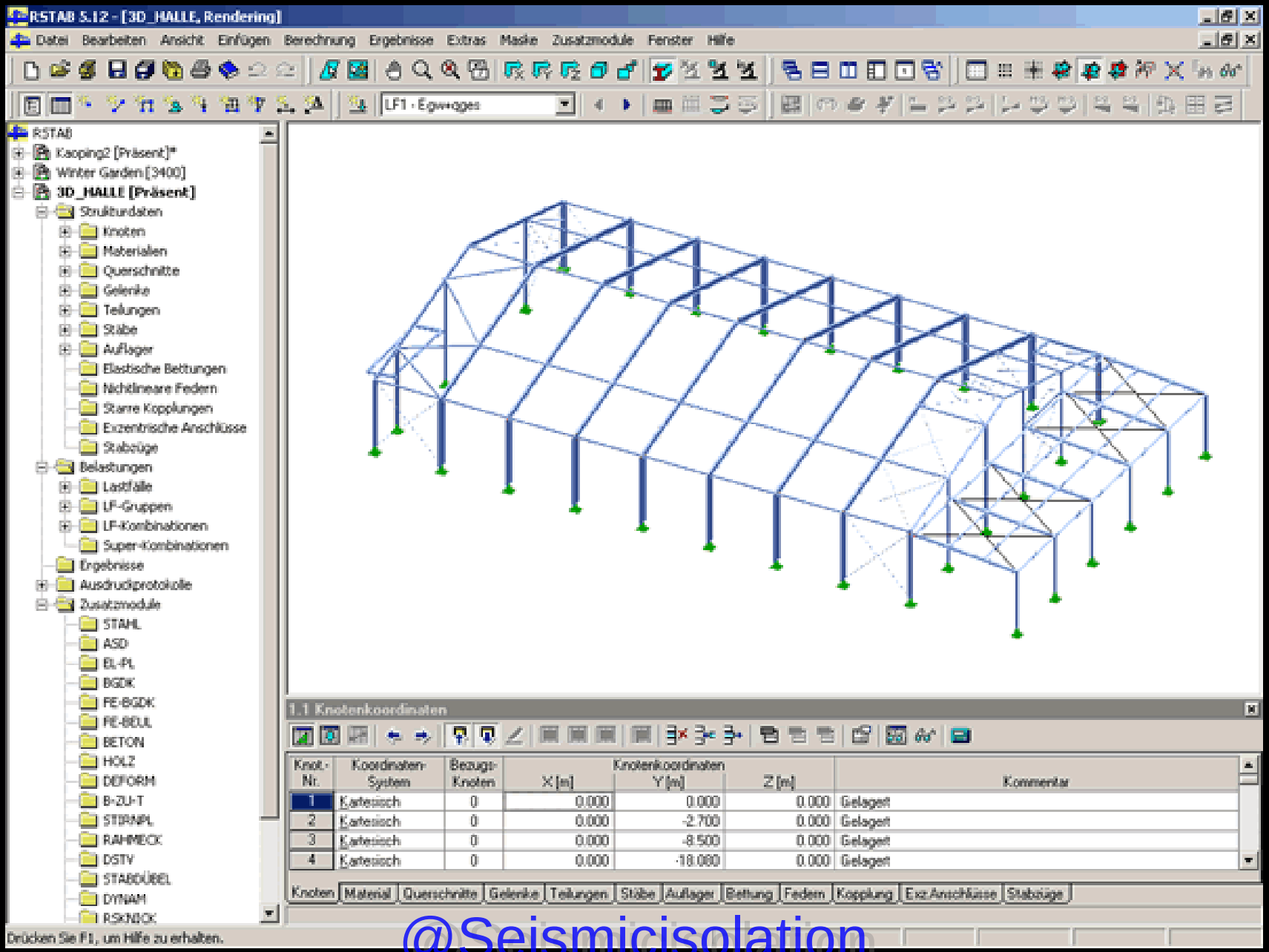
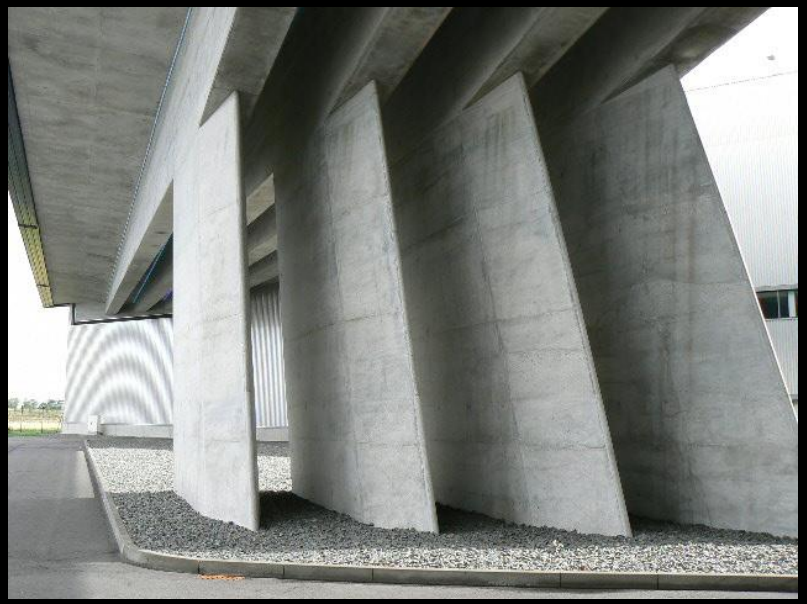


@Seismicisolation

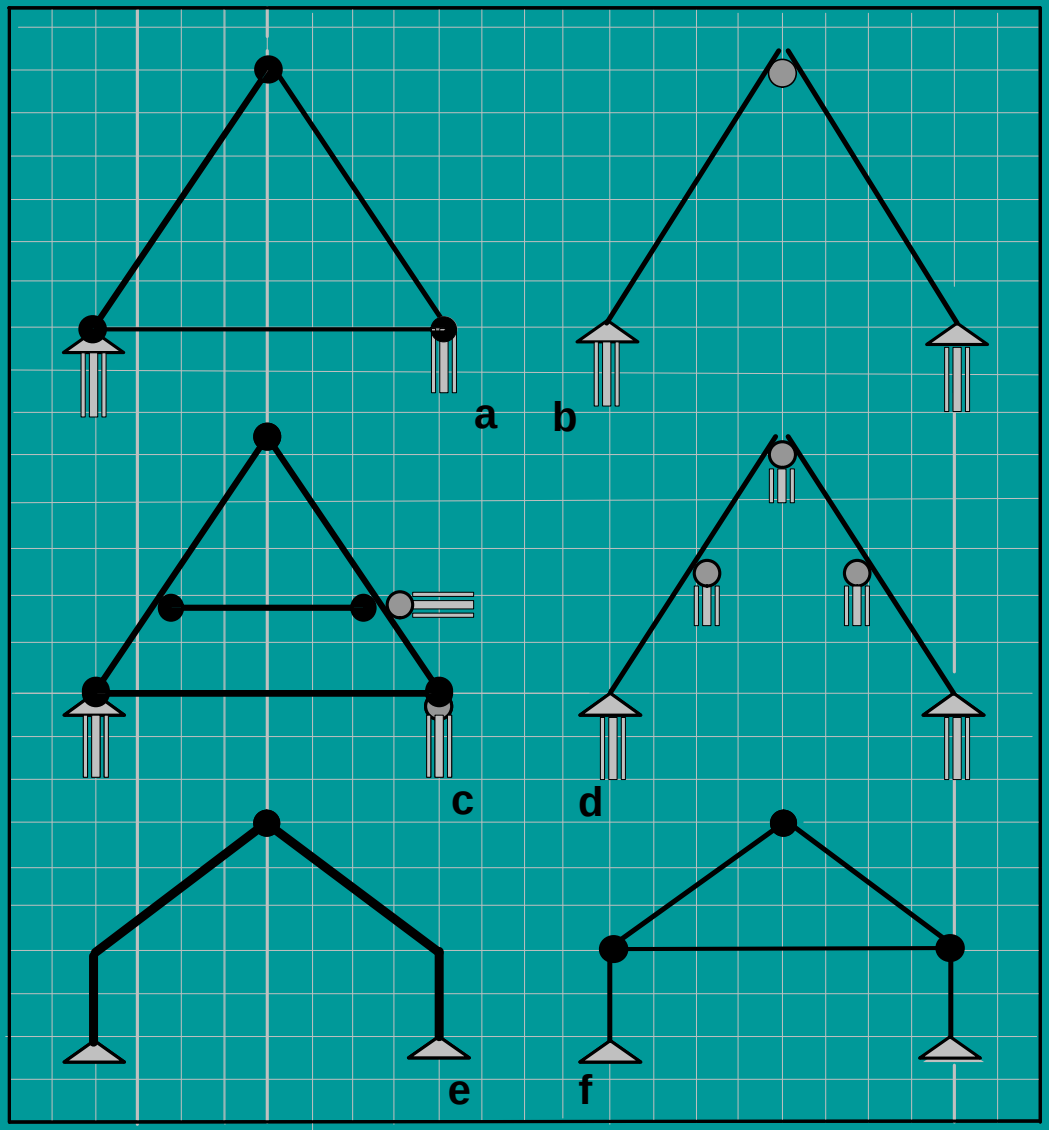


@Seismicisolation

BMW Plant Leipzig, Central Building, 2004, Zaha Hadid

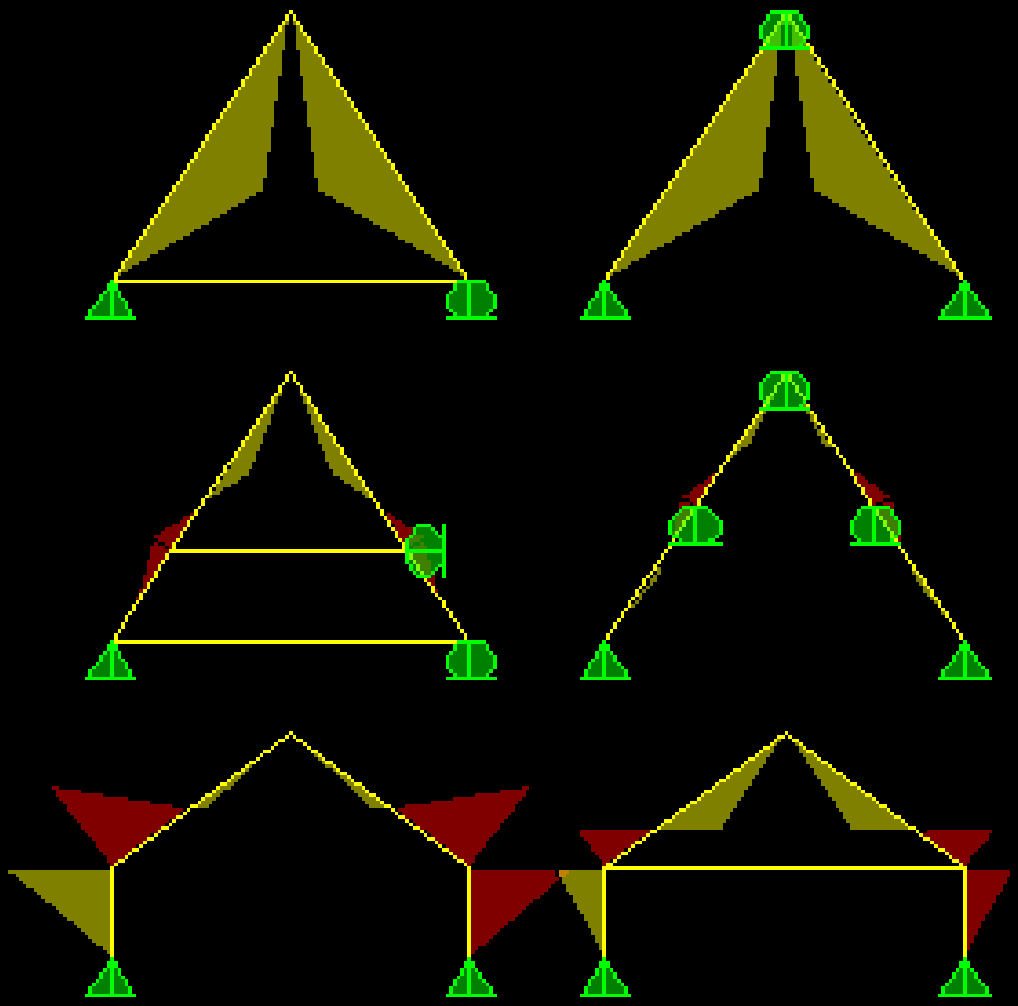
Airport Madrid, Spain, Richard Rogers, 2005


@Seismicisolation



PITCHED FRAMES

@Seismicisolation



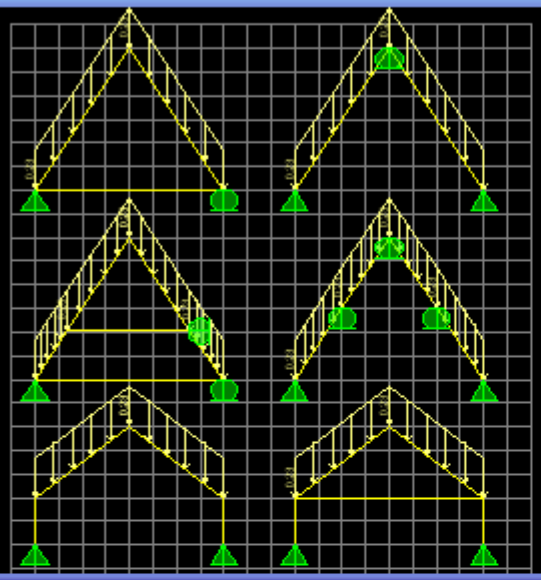
@Seismicisolation

P2000 - Ex. 7.6 gable frames_V8

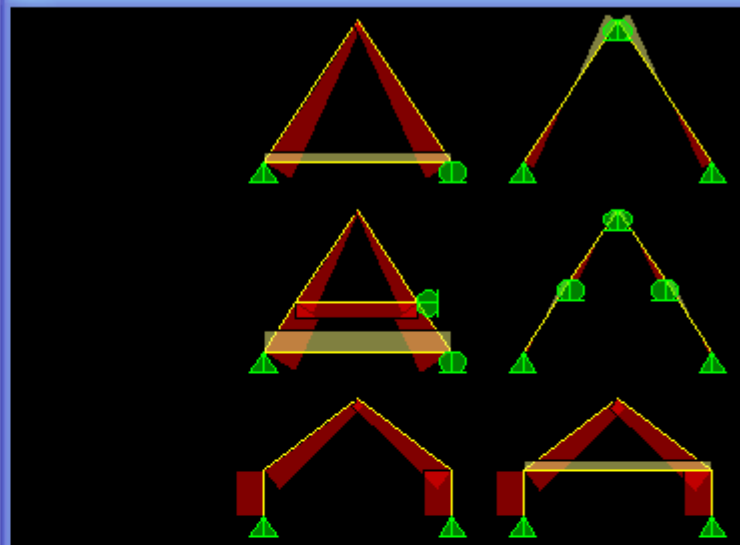
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

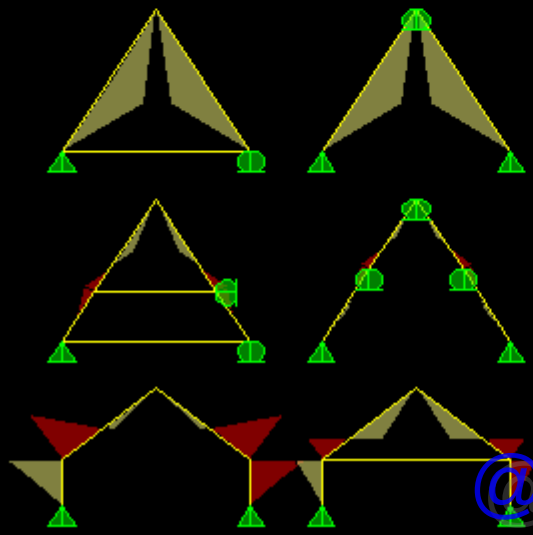
Frame Span Loads (DL) (As Defined)



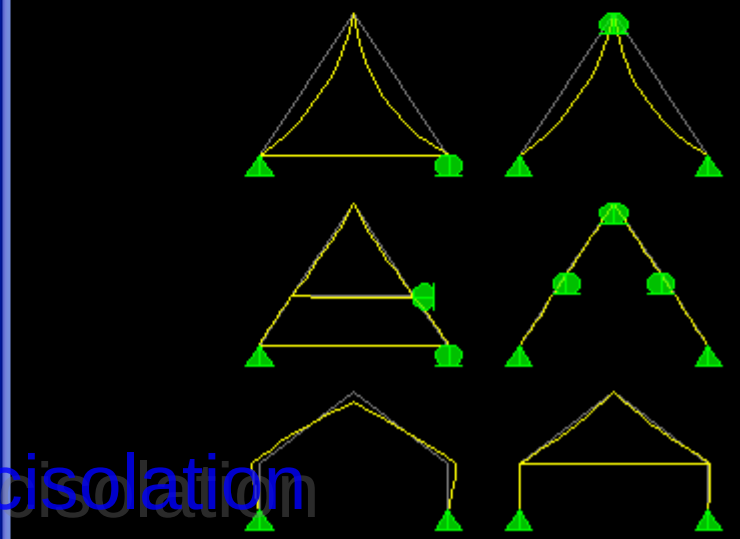
Axial Force Diagram (COMB1)



Moment 3-3 Diagram (COMB1)



Deformed Shape (COMB1)

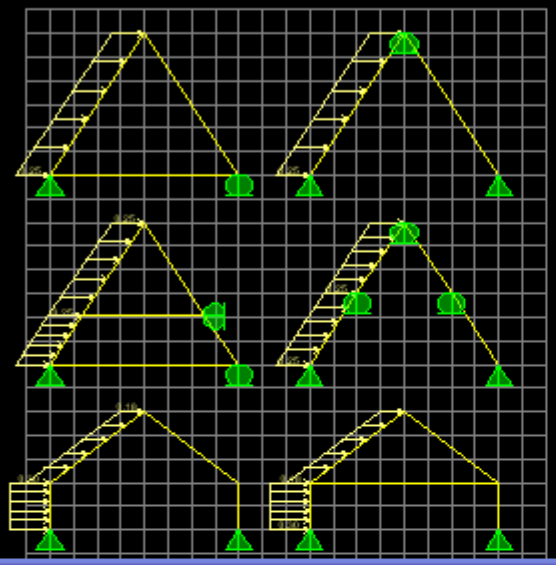


@Seismicisolation

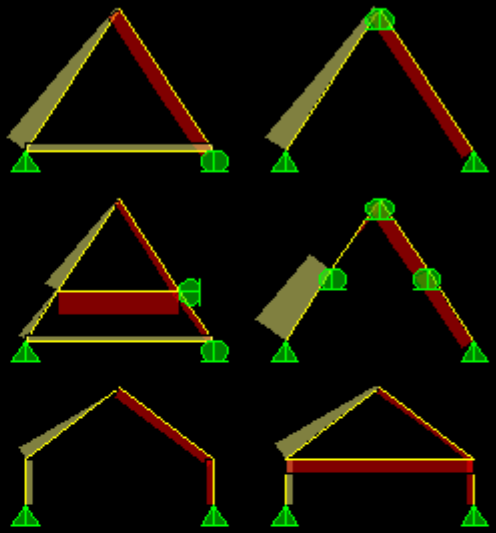
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

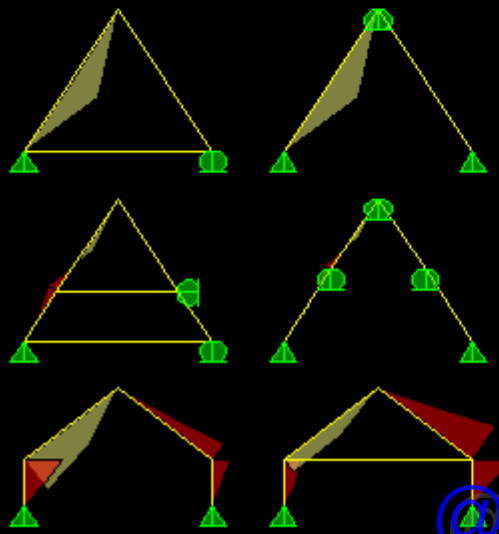
Frame Span Loads (W) (As Defined)



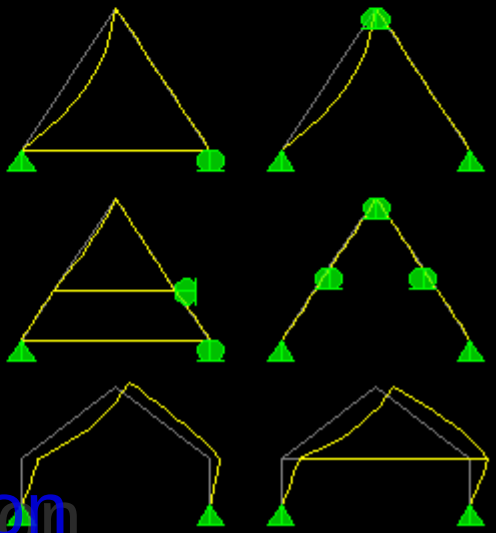
Axial Force Diagram (W)



Moment 3-3 Diagram (W)



Deformed Shape (W)



@Seismicisolation

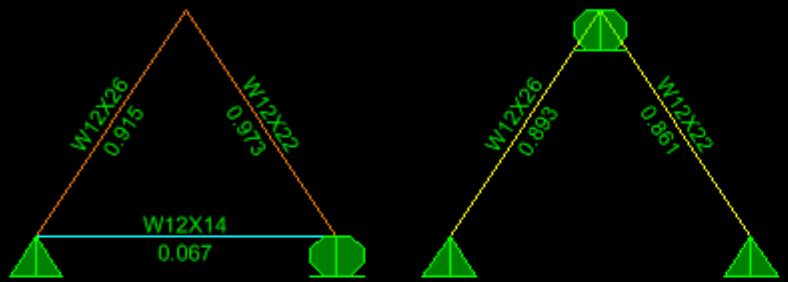
lick on any joint for displacement values

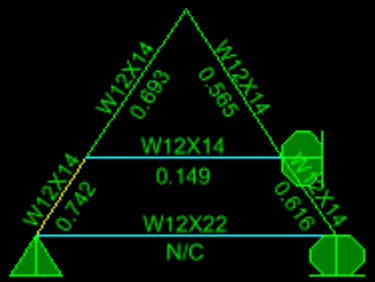
Start Animation GLOBAL Kip, ft, F

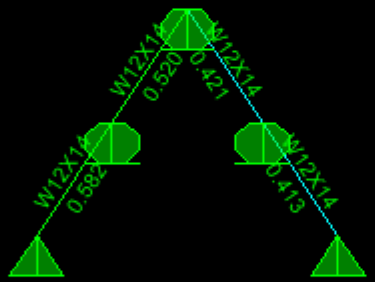
Edit View Define Draw Select Assign Analyze Display Design Options Help

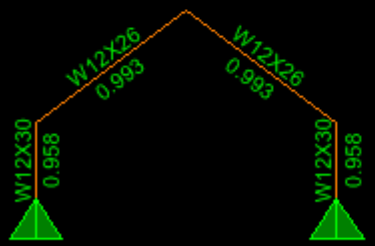
3-d

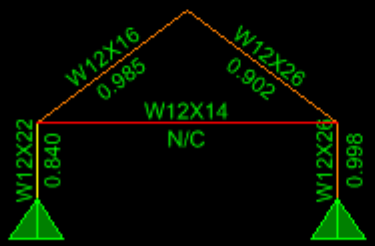
Steel P-M Interaction Ratios (AISC-ASD89)





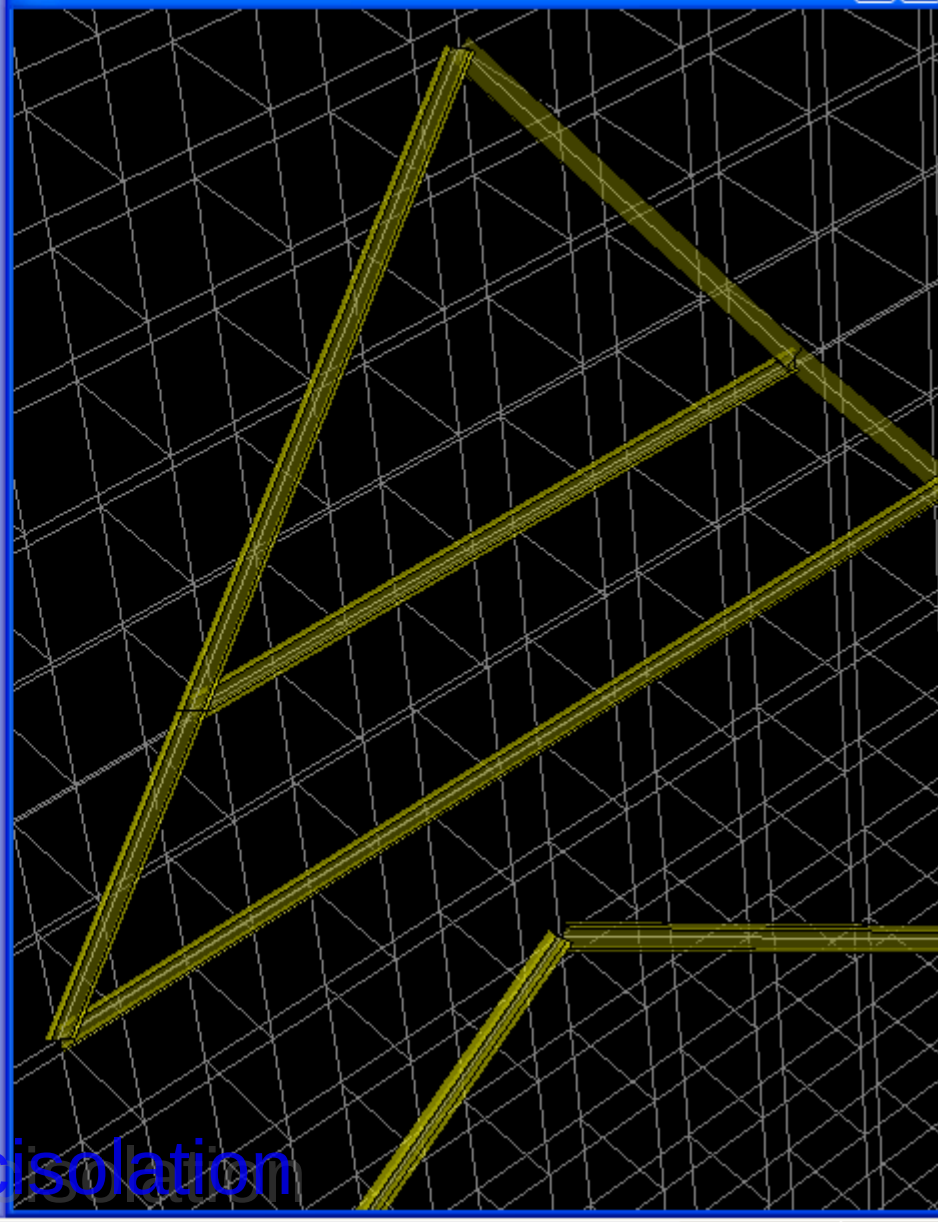






0.00 0.50 0.70 0.90 1.00

3-D View



@Seismicisolation

View

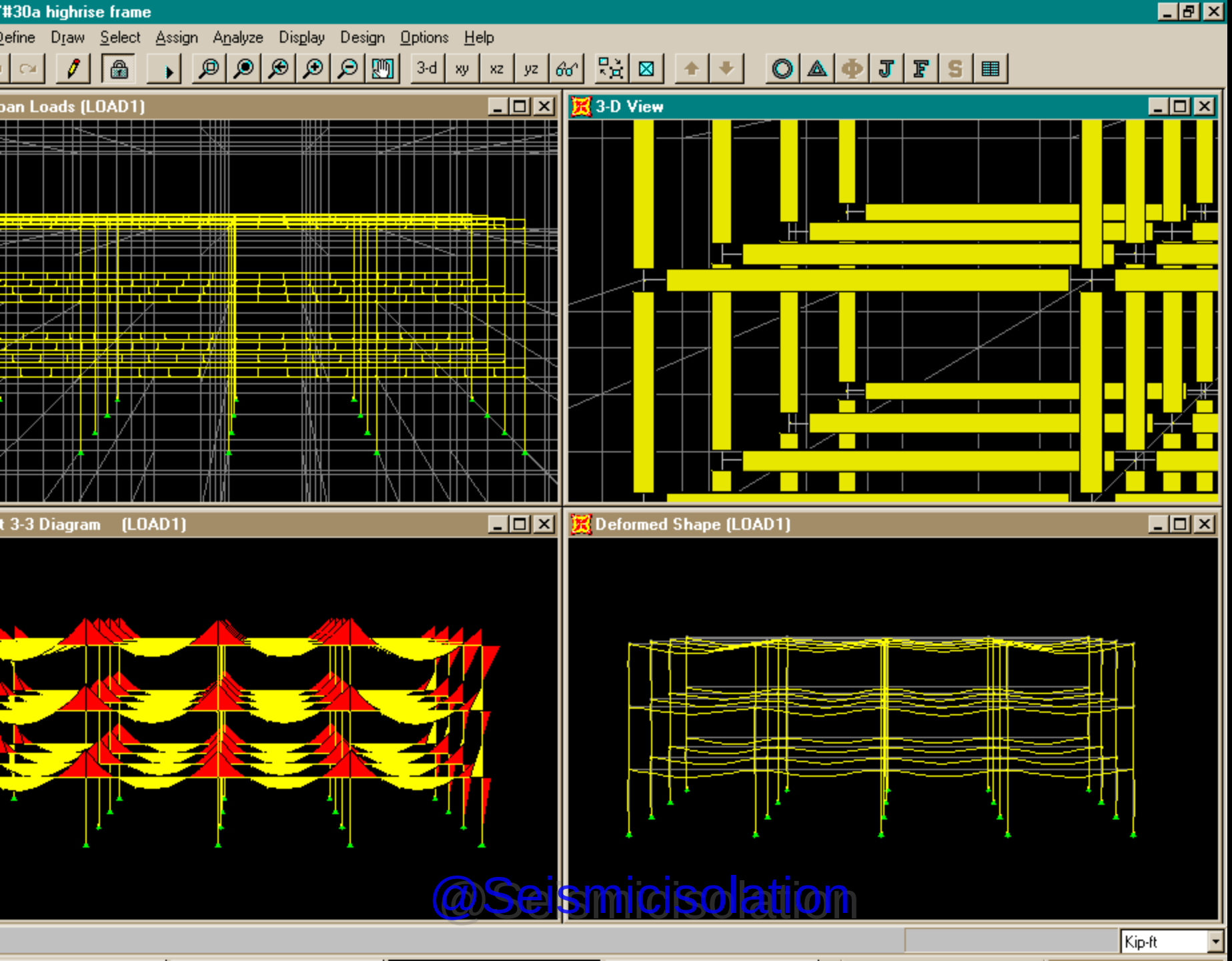
X0.00 Y0.00 Z0.00 GLOBAL Kip, in, F

Miyagi Stadium, Sendai City, Japan, 2000, Atelier Hitoshi Abe

@Seismicisolation


@Seismicisolation

Dalian, China


#30a highrise frame
Define Draw Select Assign Analyze Display Design Options Help
3-d xy xz yz
oan Loads (LOAD1)
3-D View
t 3-3 Diagram (LOAD1)
Deformed Shape (LOAD1)
Kip-ft
@Seismicisolation

SWISSBAU
1999

Xiangguo Si temple complex, Kaifeng

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Da Qingzhen Si (Great Mosque) originially built in 742 and then rebuilt in the Qing dynasty, Xi'an

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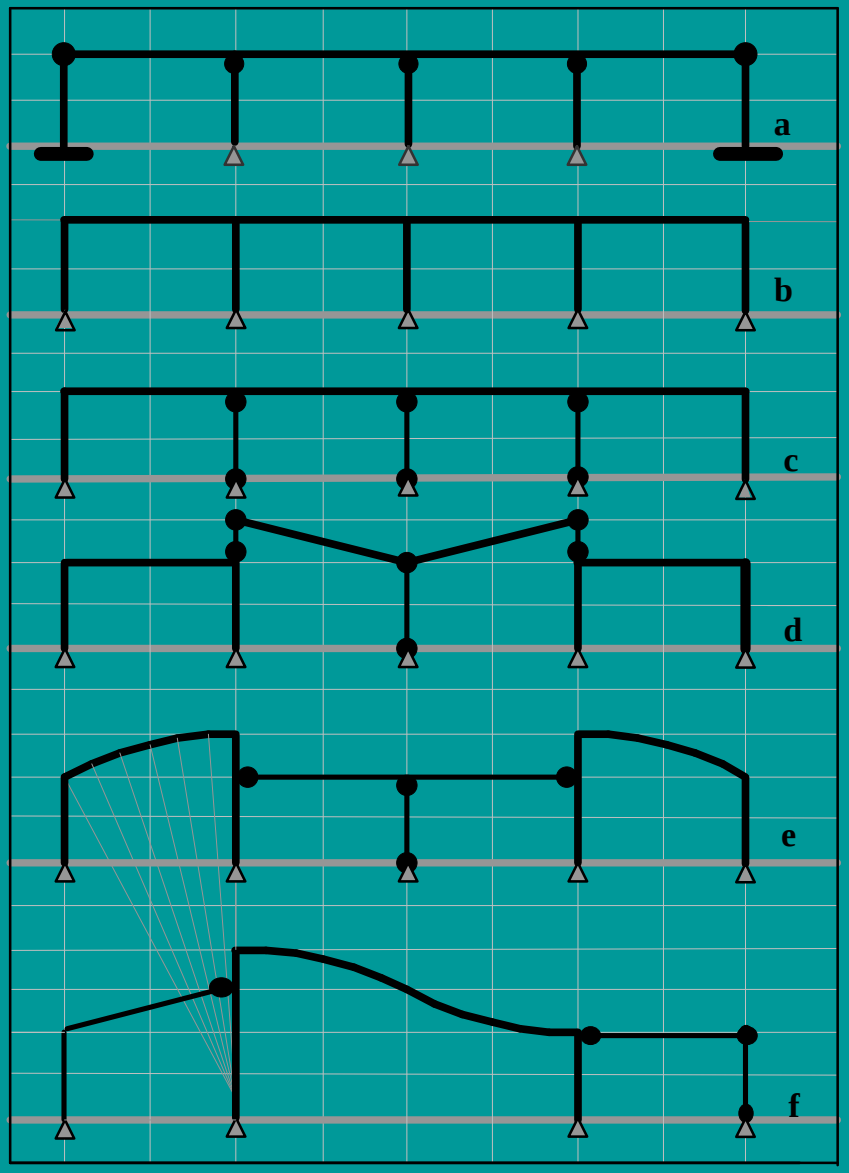
Factory 798 , art district, Beijing Northeast Dashanzi area, previously factory buildings buit by East German architects in the 1950's

@Seismicisolation


@Seismicisolation


@Seismicisolation



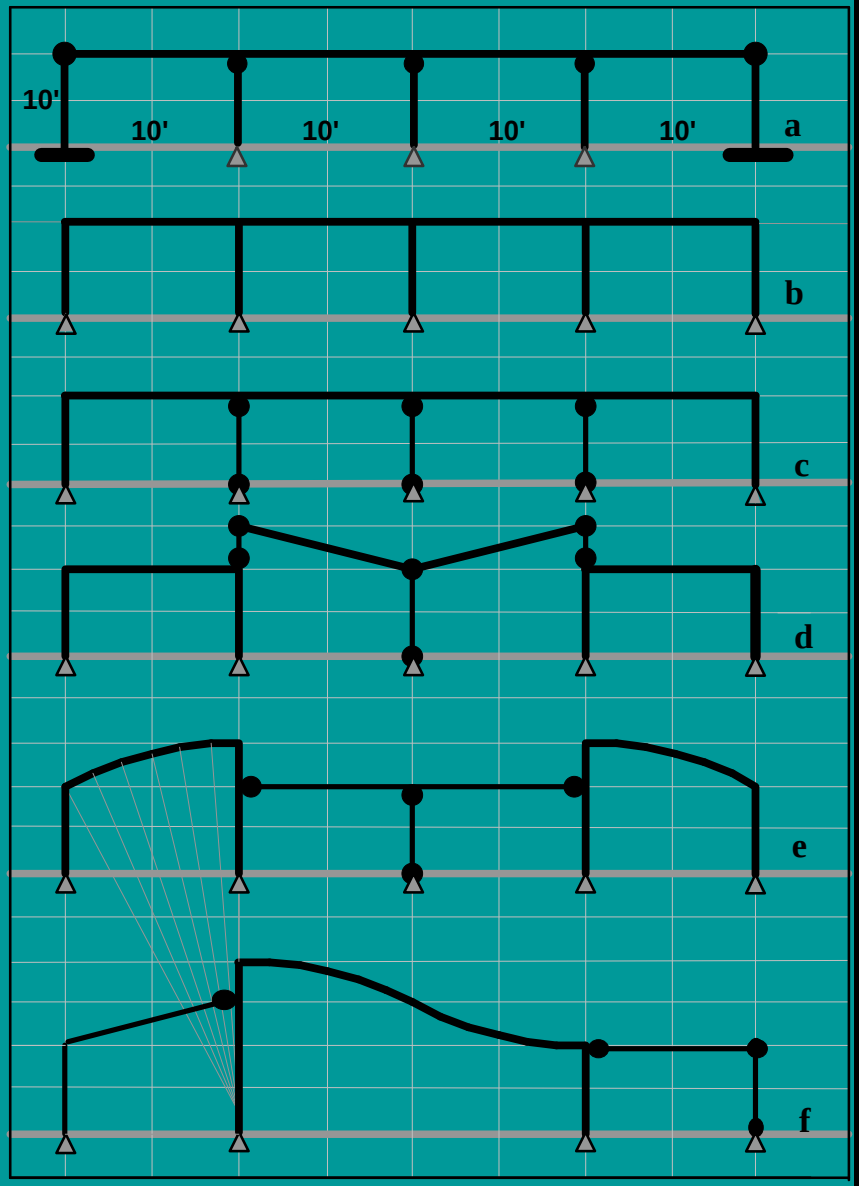
post-beam structure

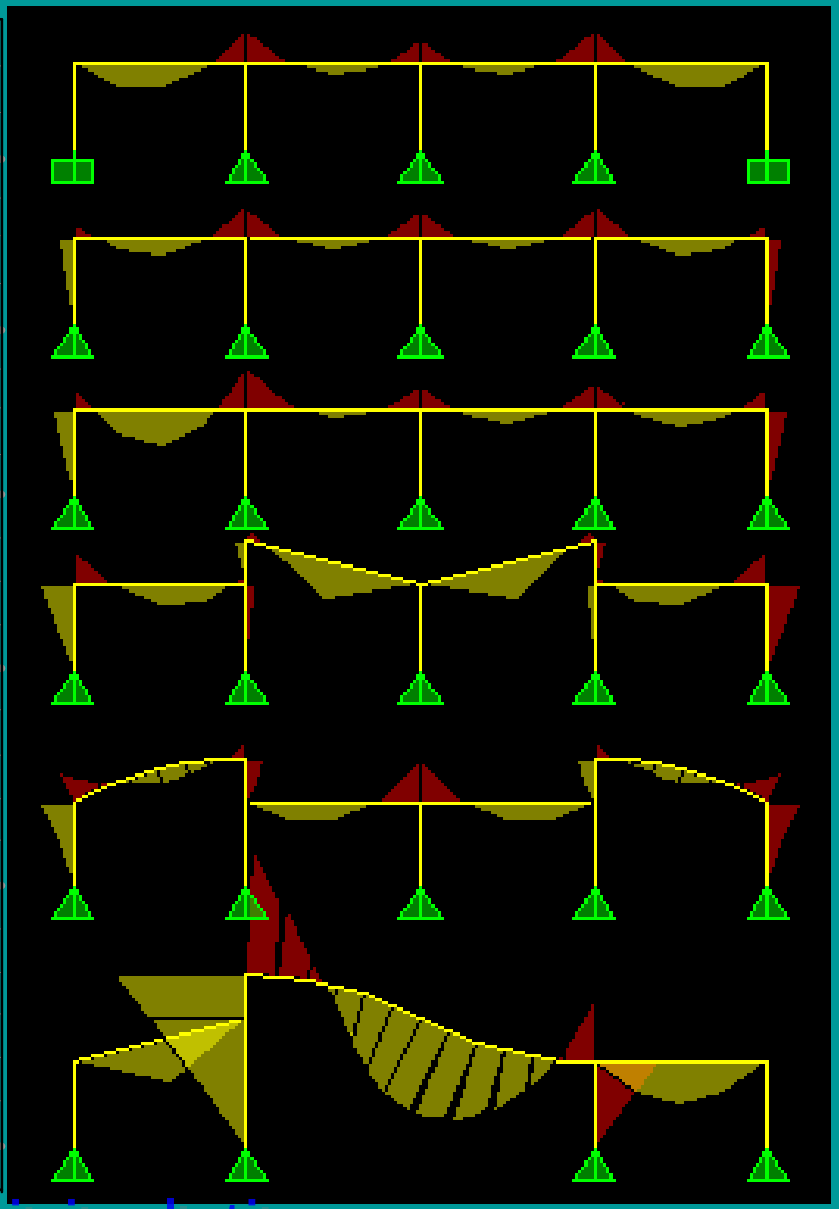
rigid frames

combinations of the above

Multi-Bay, Single-Story Frames

@Seismicisolation





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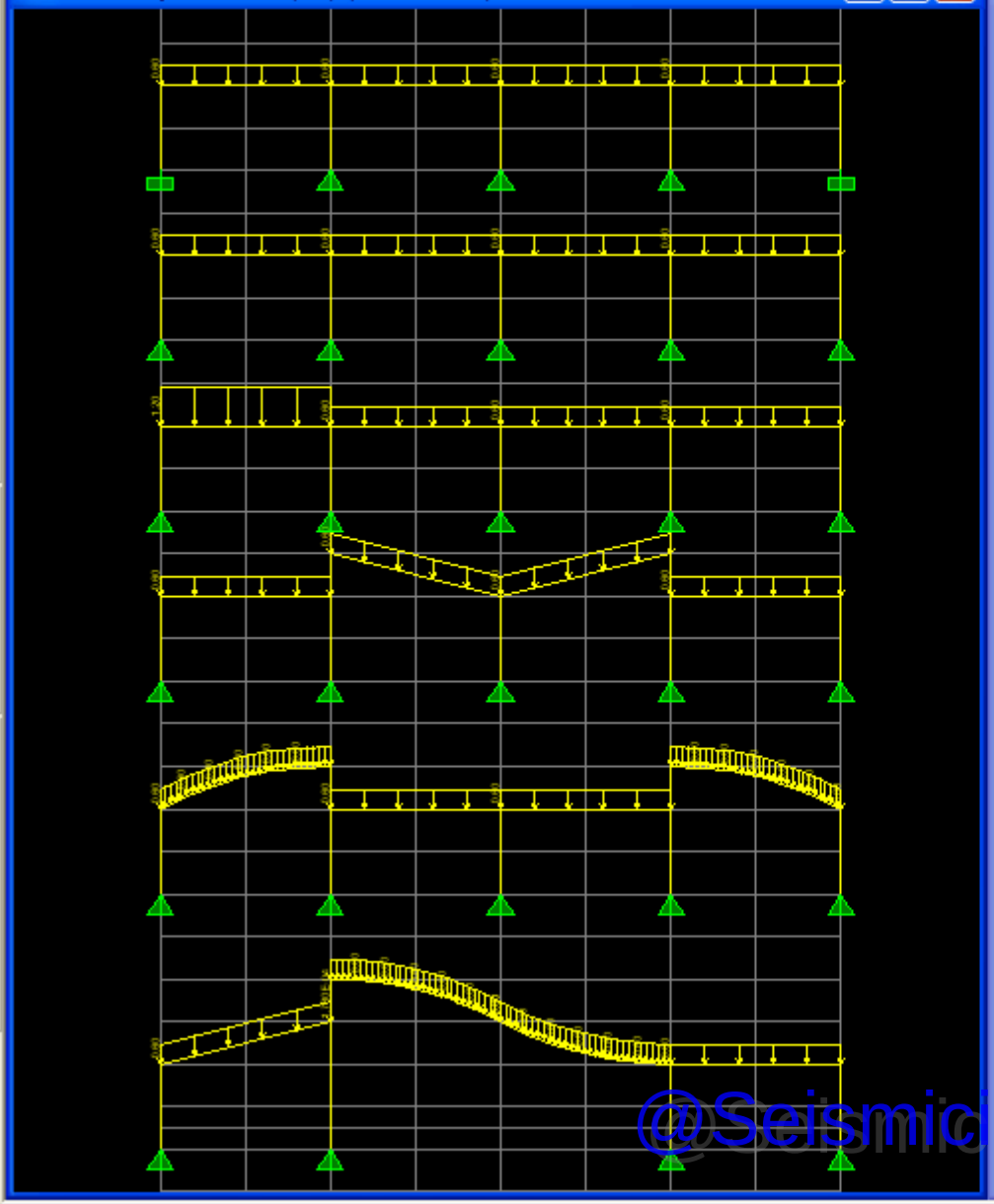
SAP2000 - Ex. 7.9 mutibay frames_V8

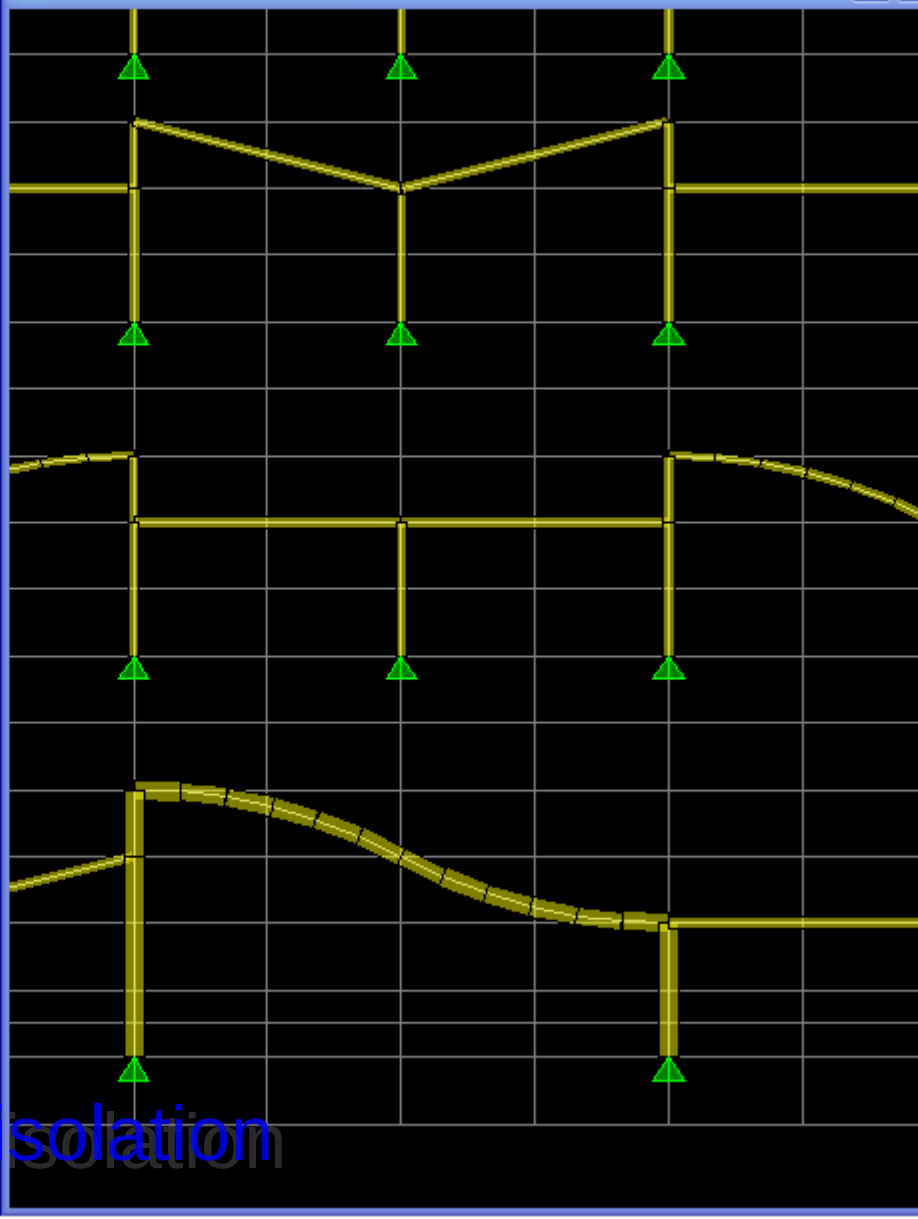
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Frame Span Loads (DL) (As Defined)



X-Z Plane @ Y=0



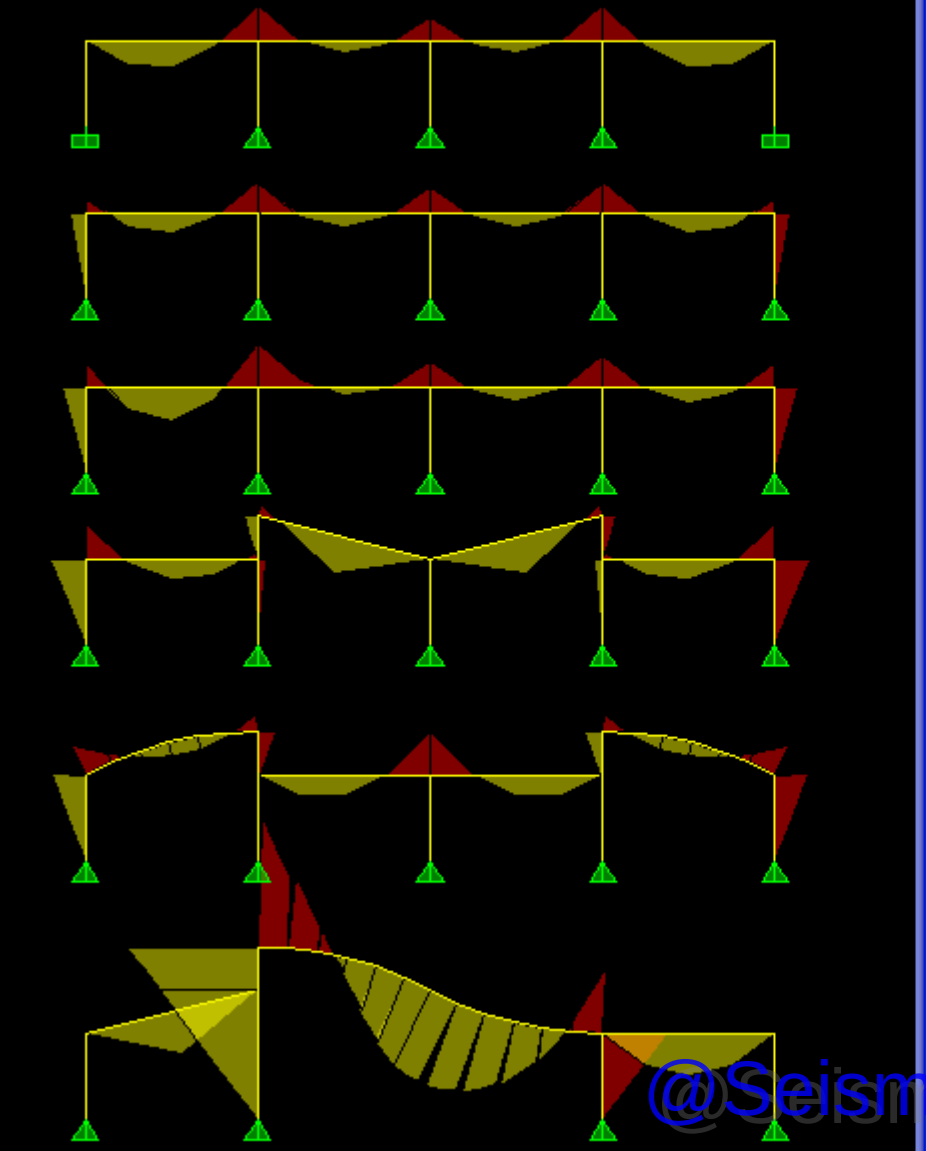
@Seismicisolation

00 - Ex. 7.9 mutibay frames_V8

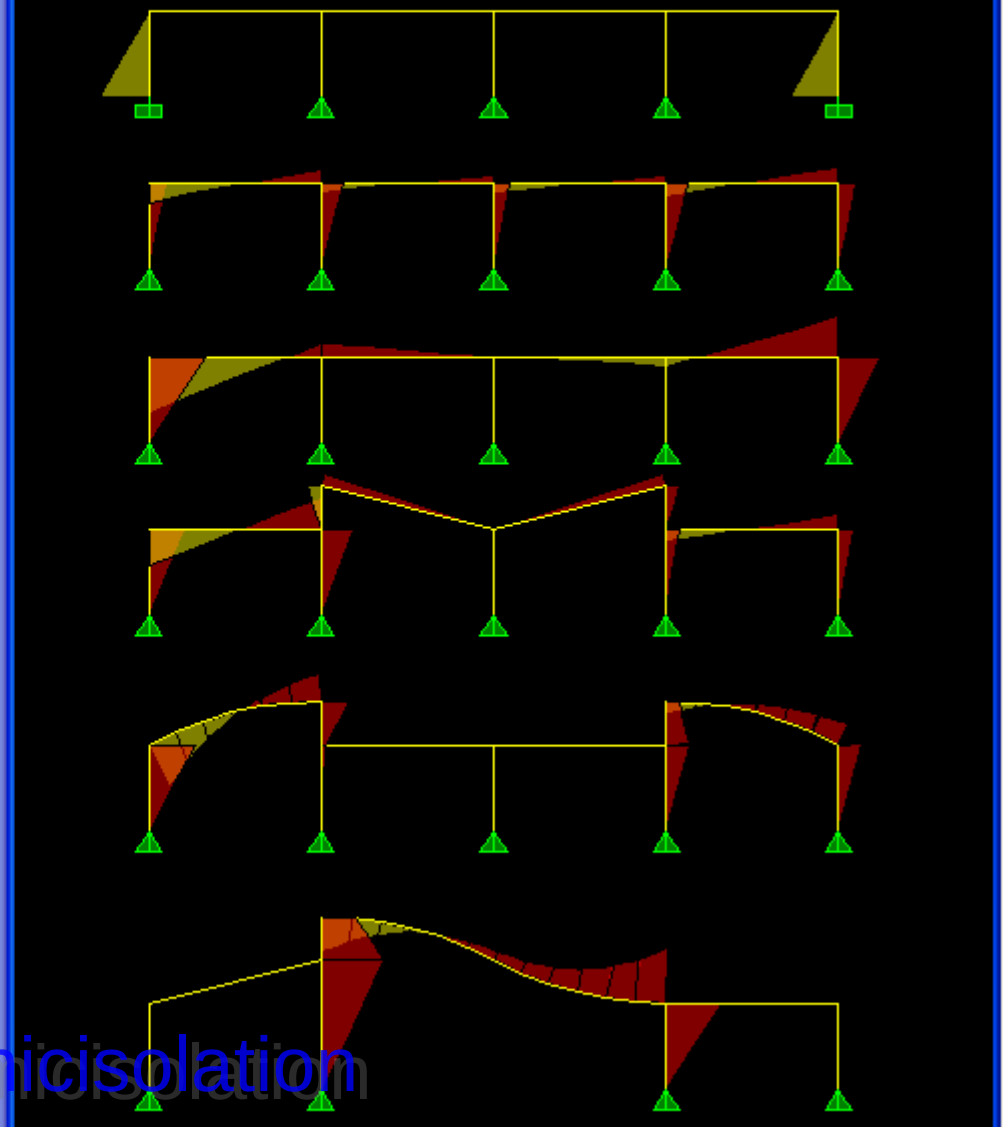
View Define Draw Select Assign Analyze Display Design Options Help

3-d

Moment 3-3 Diagram (COMB1)



Moment 3-3 Diagram (WL)



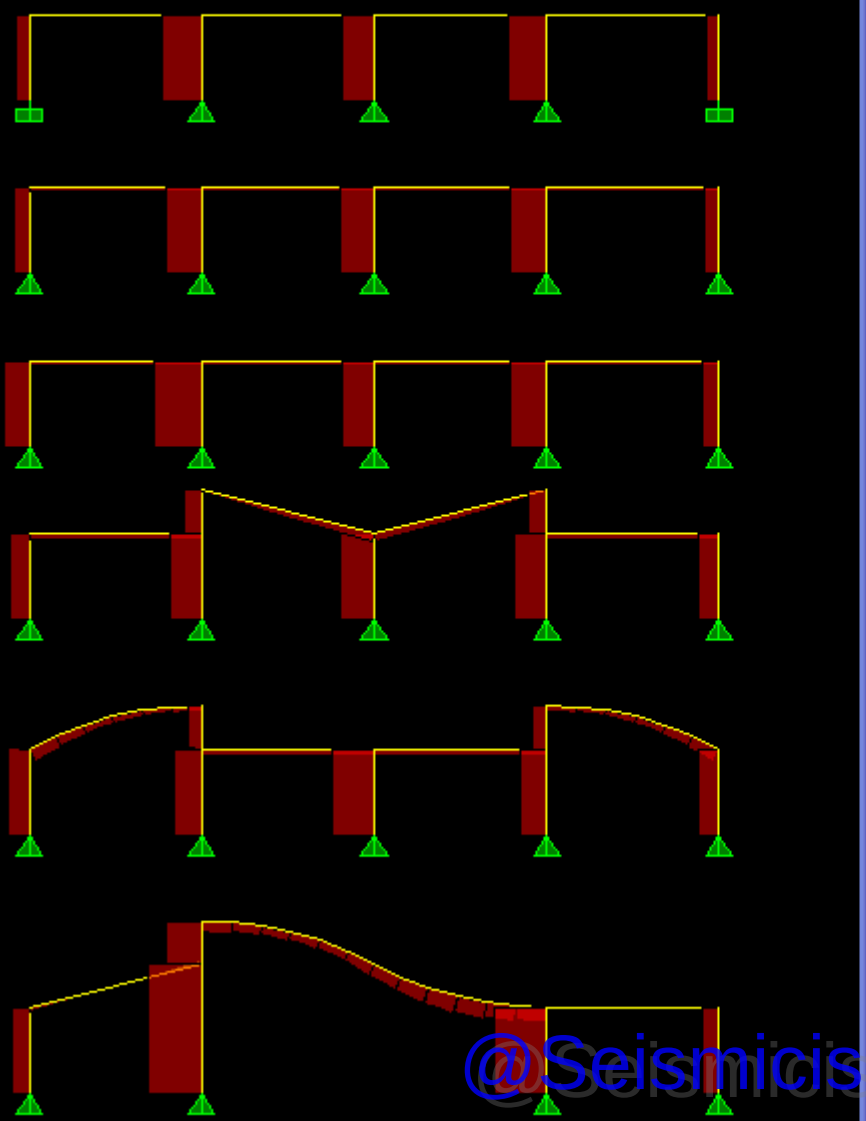
@Seismicisolation

SAP2000 - Ex. 7.9 mutibay frames_V8

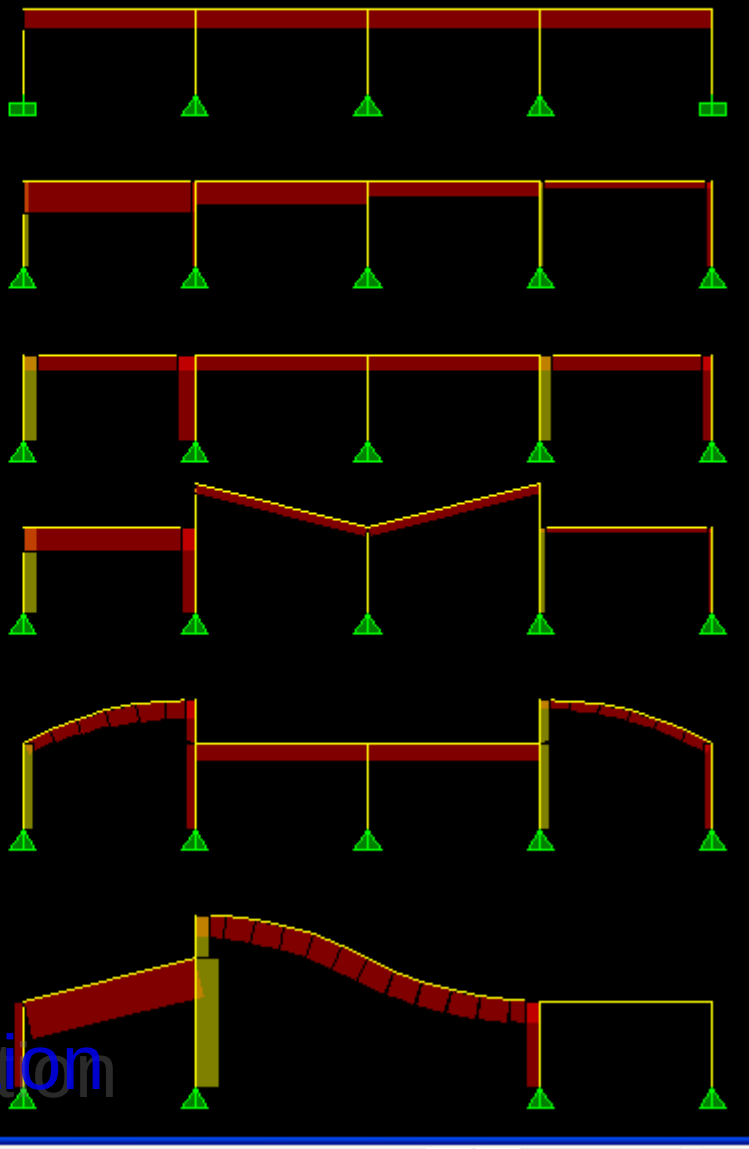
File Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Axial Force Diagram (COMB1)



Axial Force Diagram (WL)



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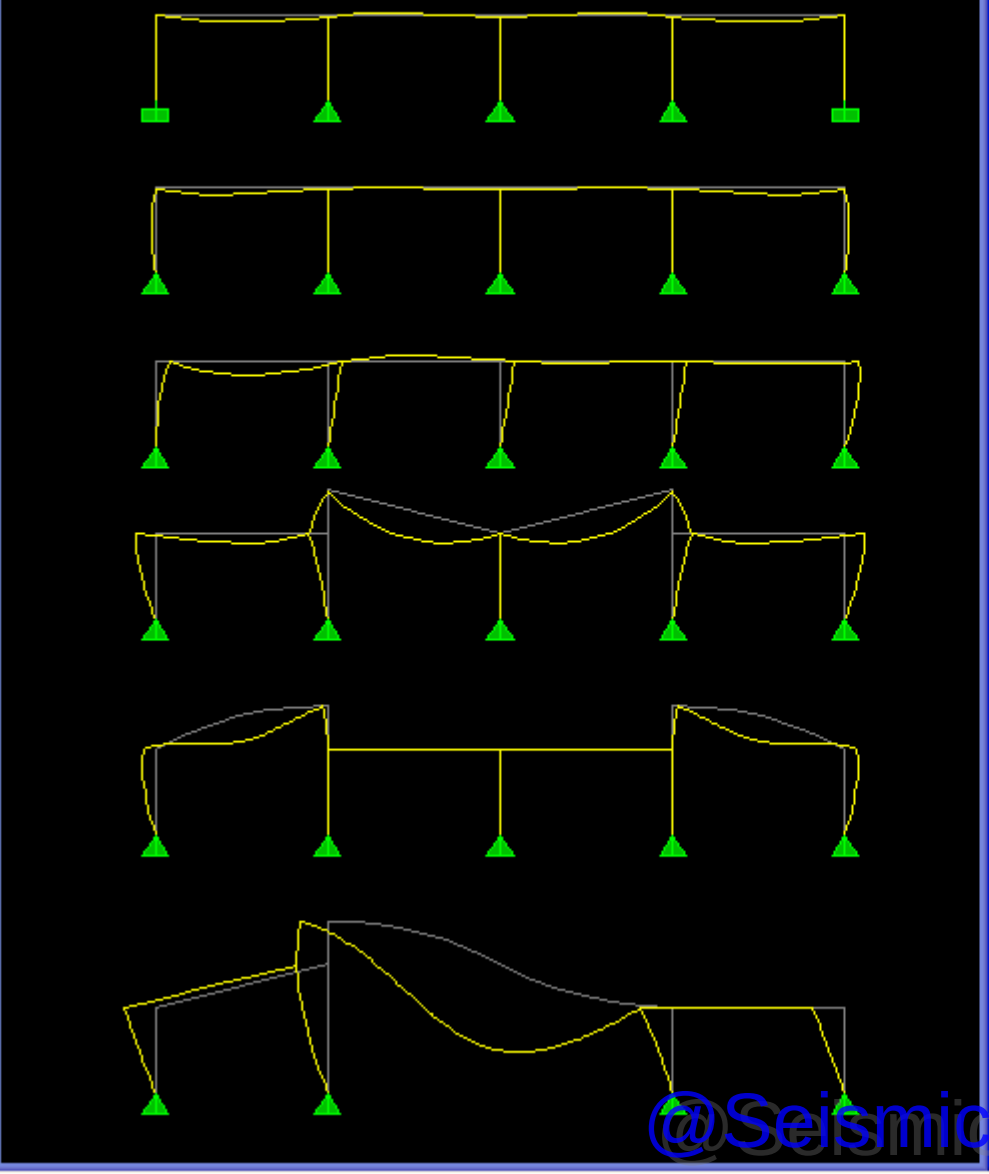
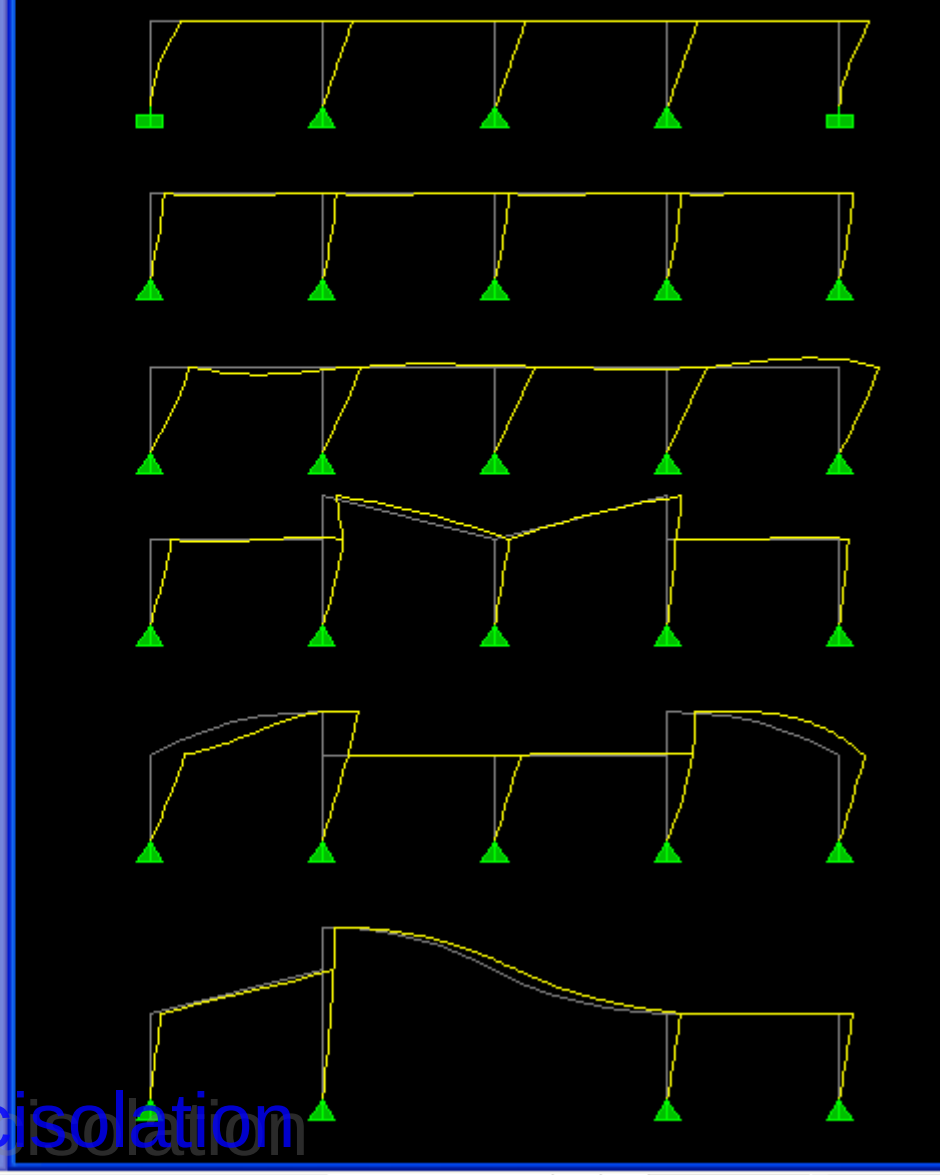
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Deformed Shape (COMB1)



Deformed Shape (WL)



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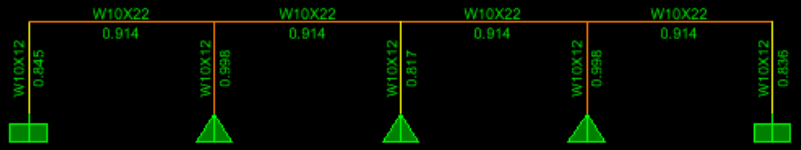
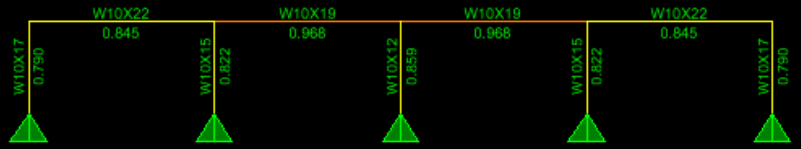
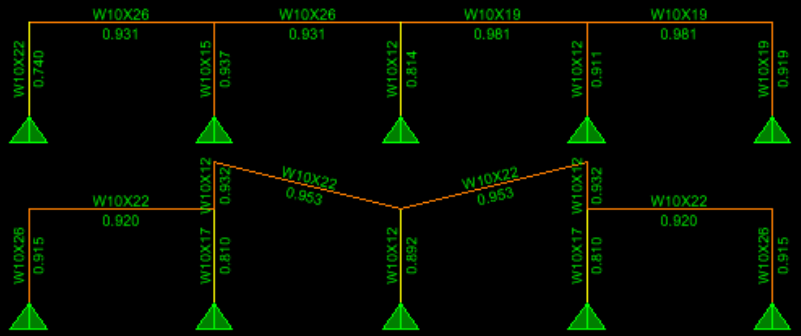
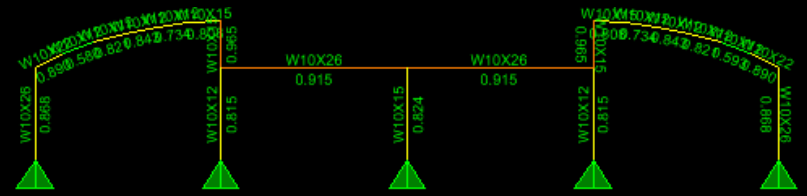
Click on any joint for displacement values

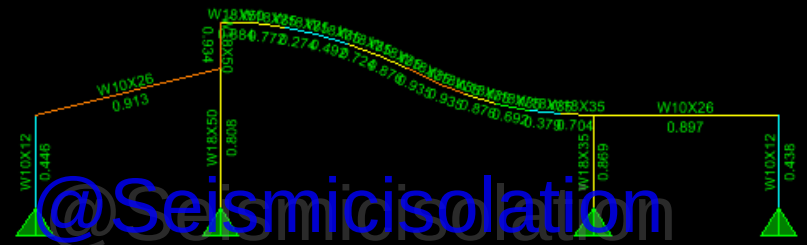
Start Animation GLOBAL Kip, ft, F











@Seismicisolation

European Court of Justice, Luxemburg, 2008, *Dominique Perrault*

@Seismicisolation


@Seismicisolation

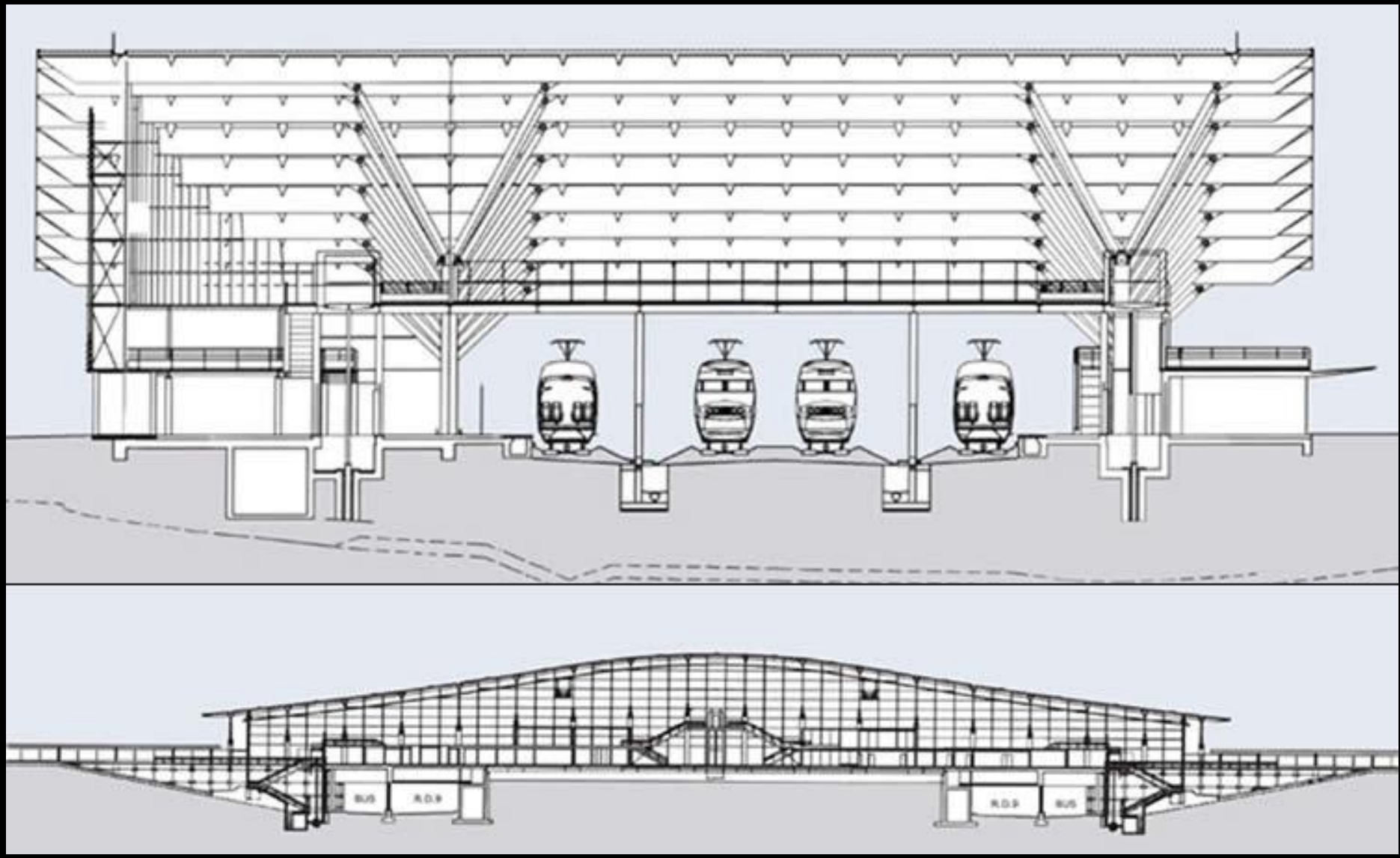

@Seismicisolation

European Court of Justice, Luxemburg, 1994, Atelier d'Architecture Paczowski Fritsch & Associés

@Seismicisolation

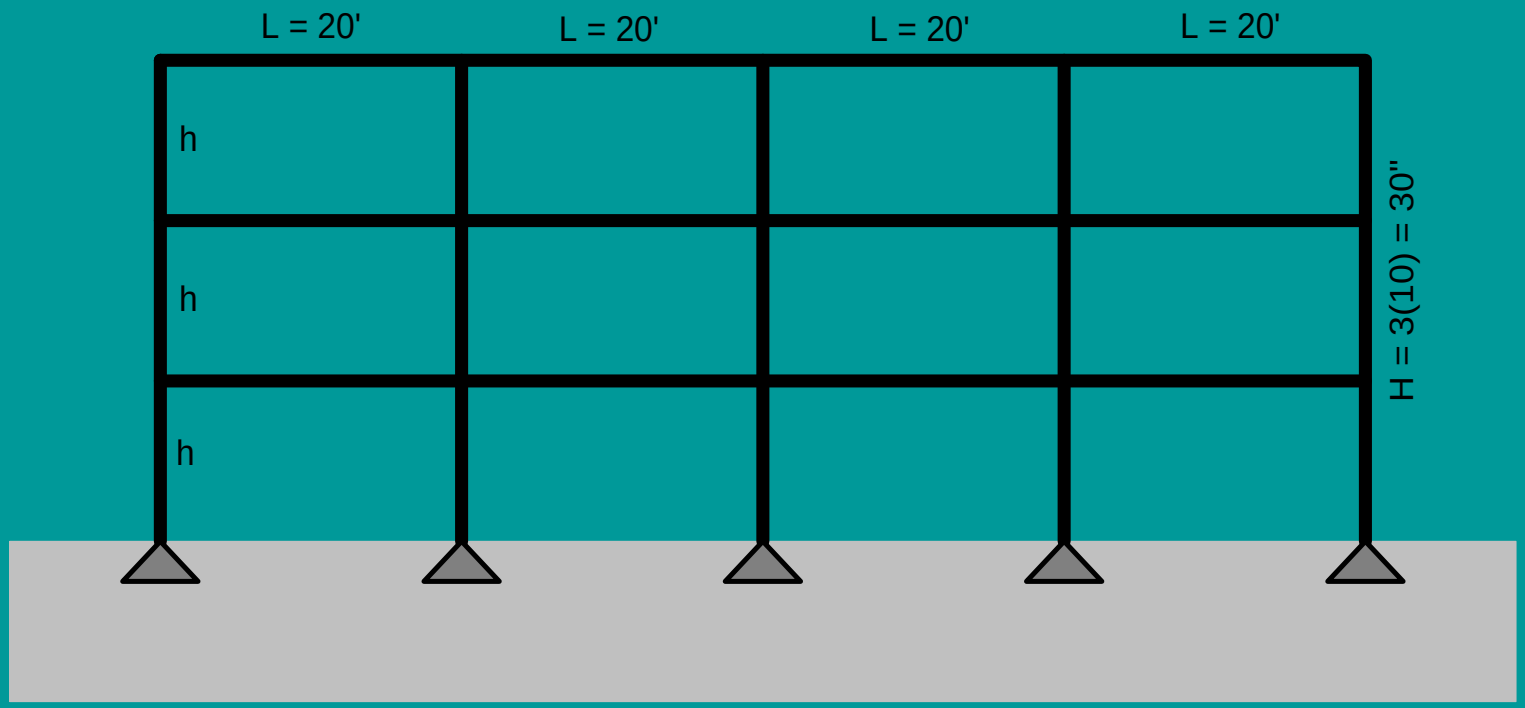
Gare TGV, Aix en Provence, France, 2001, Jean-Marie Dutilleul

@Seismicisolation



@Seismicisolation

@Seismicisolation



LOW-RISE, MULTI-STORY, MULTI-BAY RIGID FRAME

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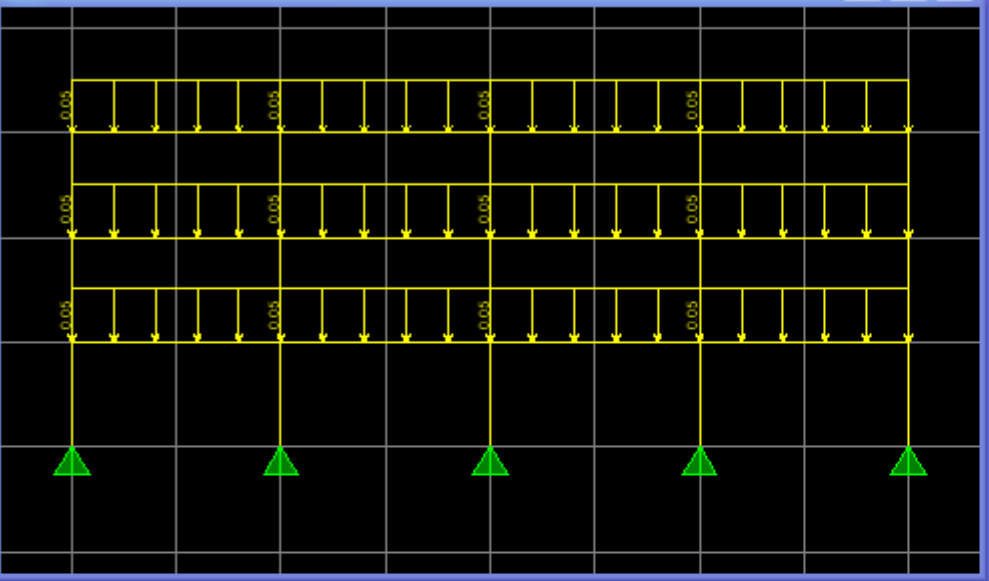
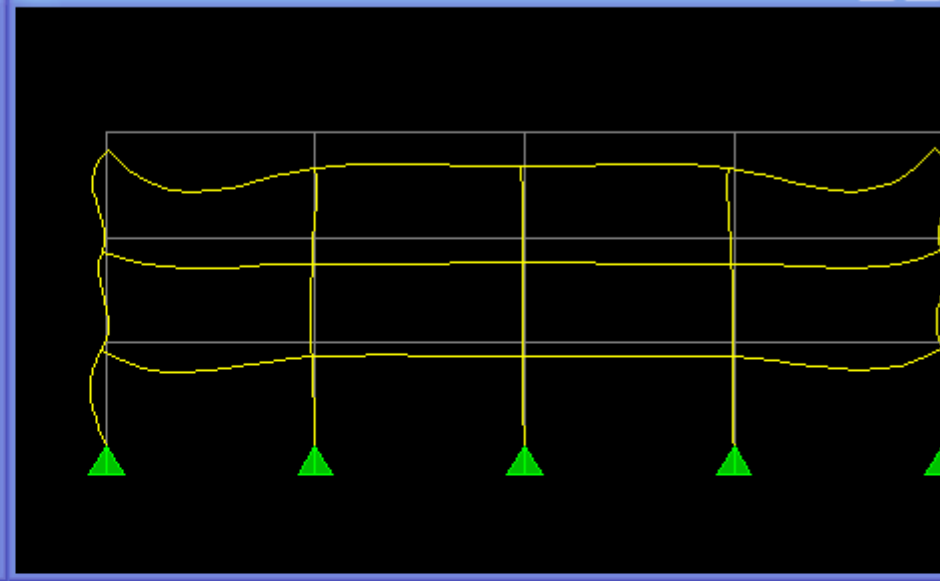
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

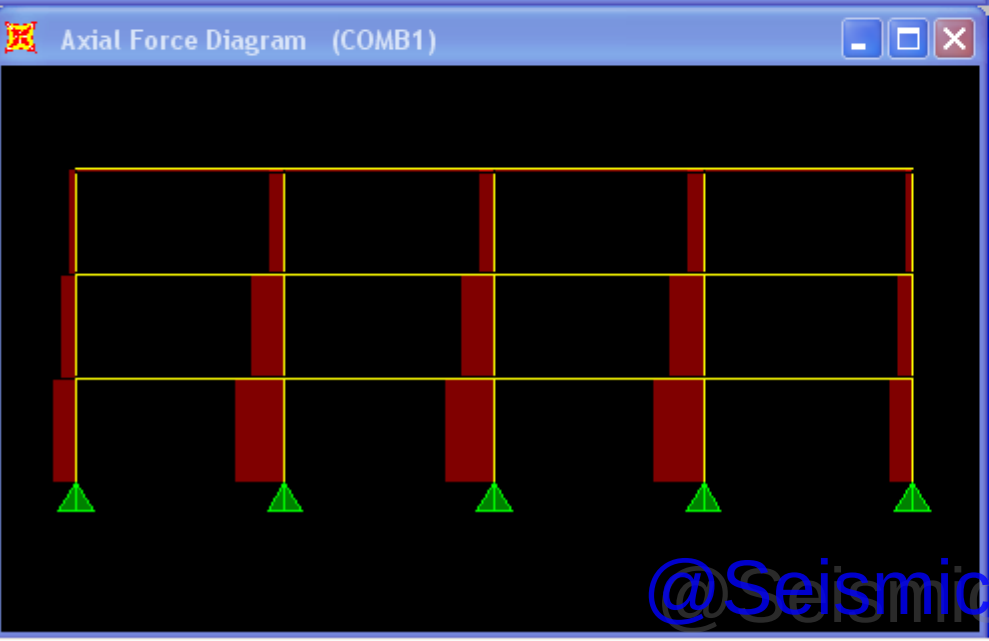
Frame Span Loads (D) (As Defined)



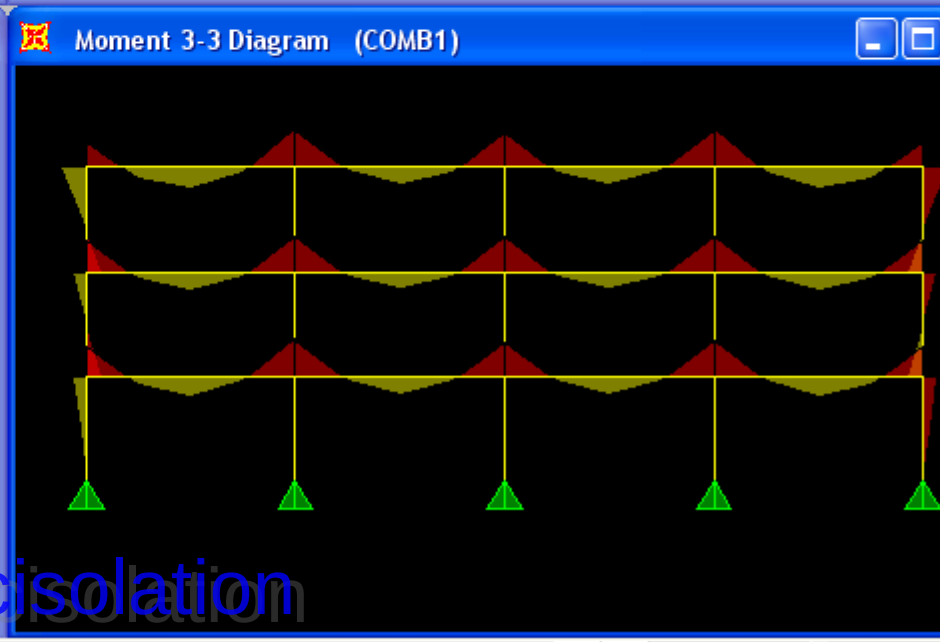
Deformed Shape (COMB1)



Axial Force Diagram (COMB1)



Moment 3-3 Diagram (COMB1)



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Click on any Frame Element for detailed diagram

GLOBAL

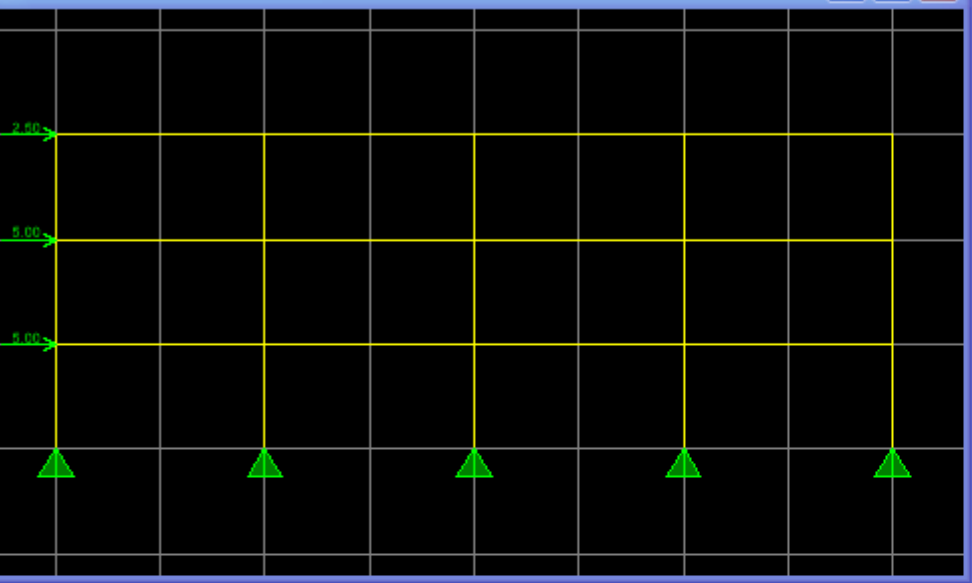
Kip, in, F

P2000 - Ex. 7.10 three-story frame_V8

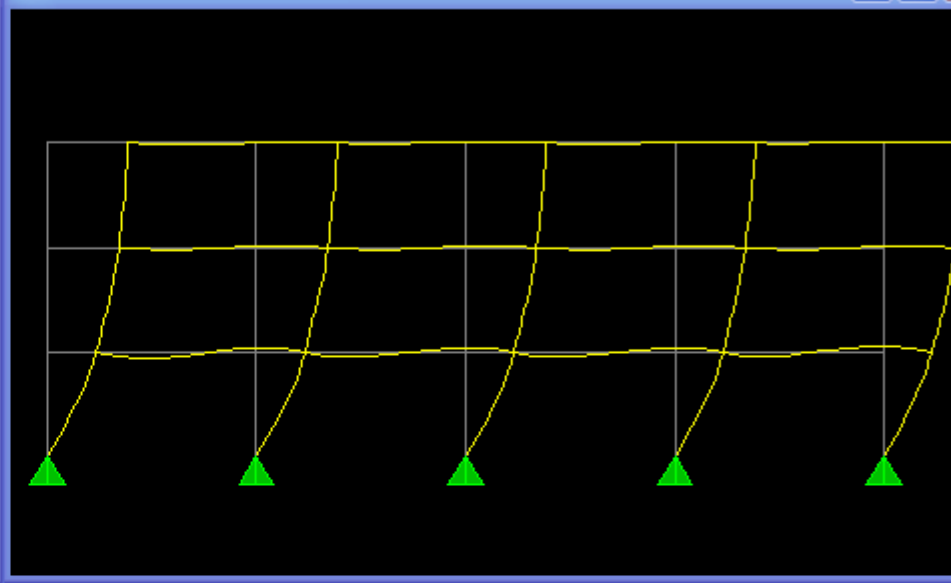
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

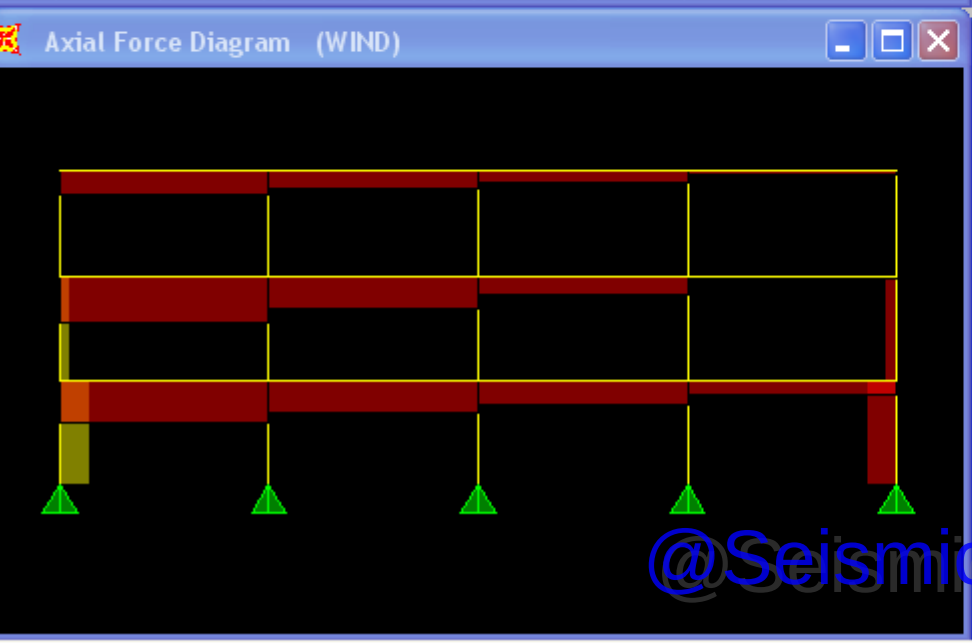
Joint Loads (W) (As Defined)



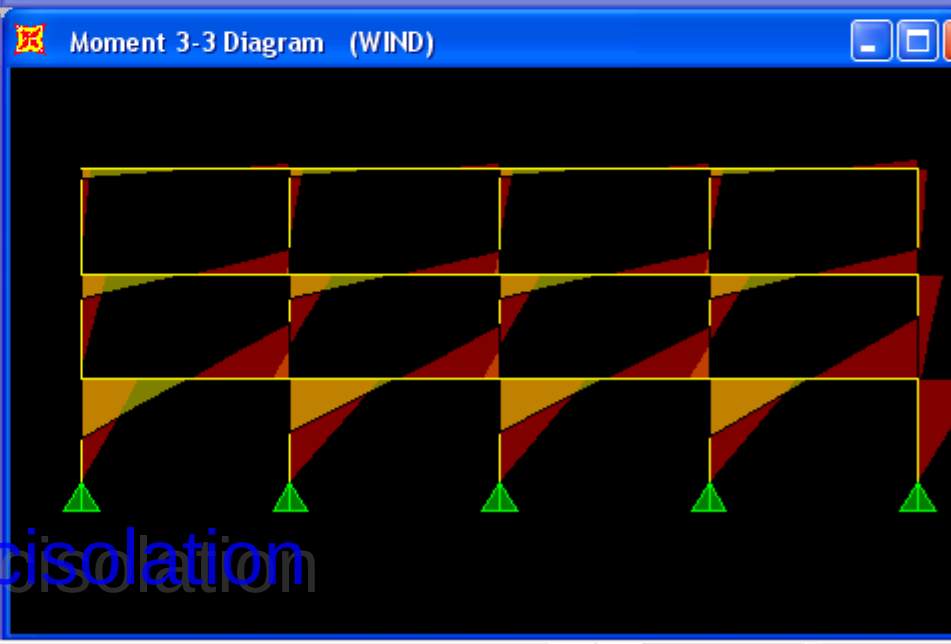
Deformed Shape (WIND)



Axial Force Diagram (WIND)



Moment 3-3 Diagram (WIND)



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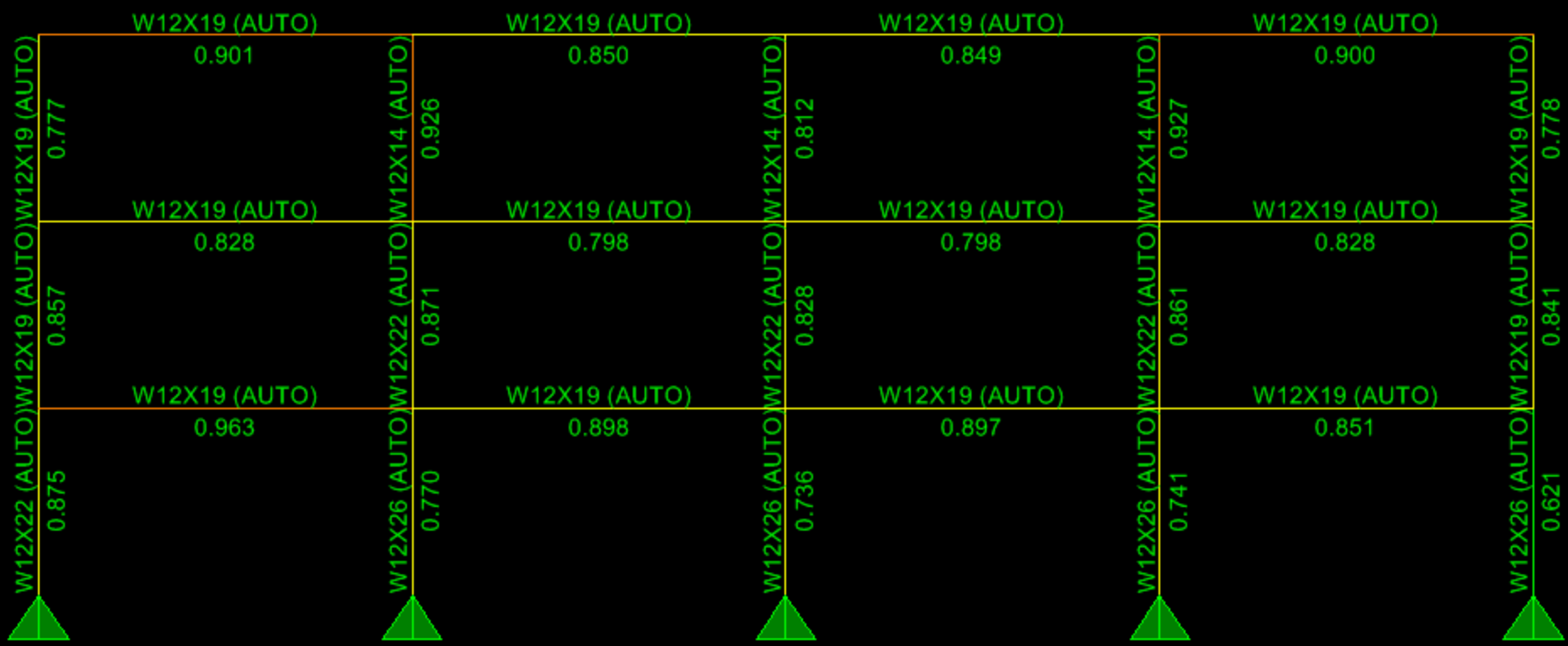
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Steel P-M Interaction Ratios (AISC-ASD89)



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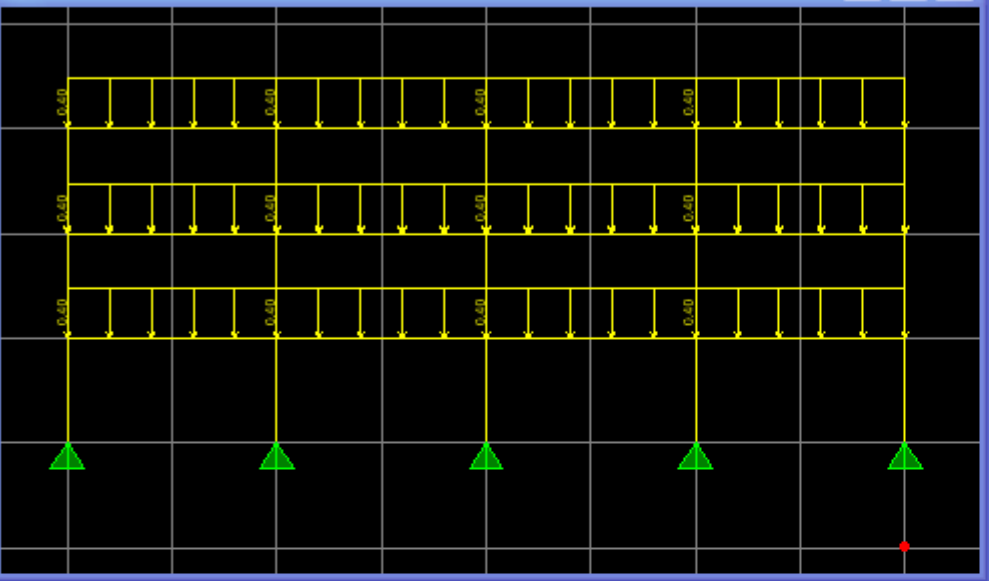
0.00 0.50 0.70 0.90 1.00

Plane @ Y=50 X23.26 Y50.00 Z-4.89 GLOBAL Kip, ft, F

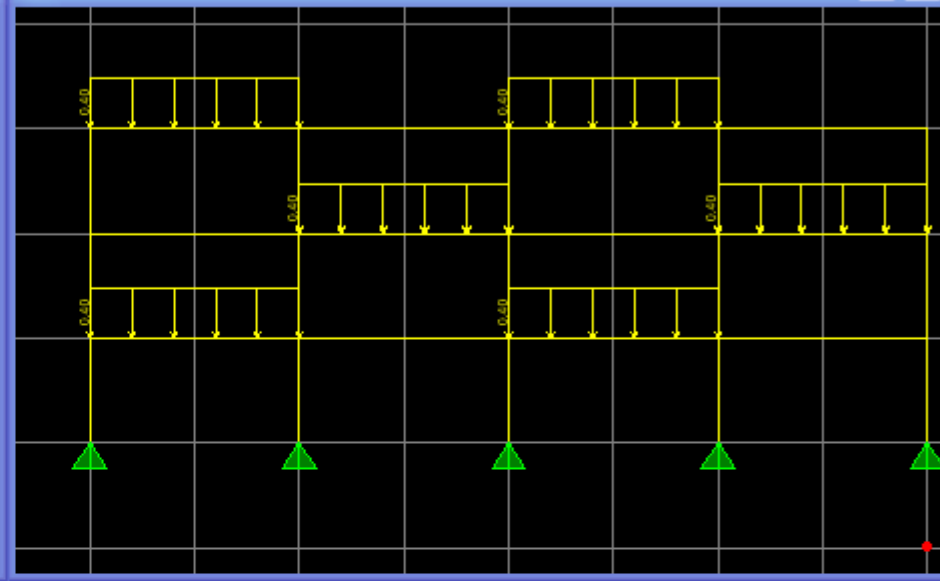
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

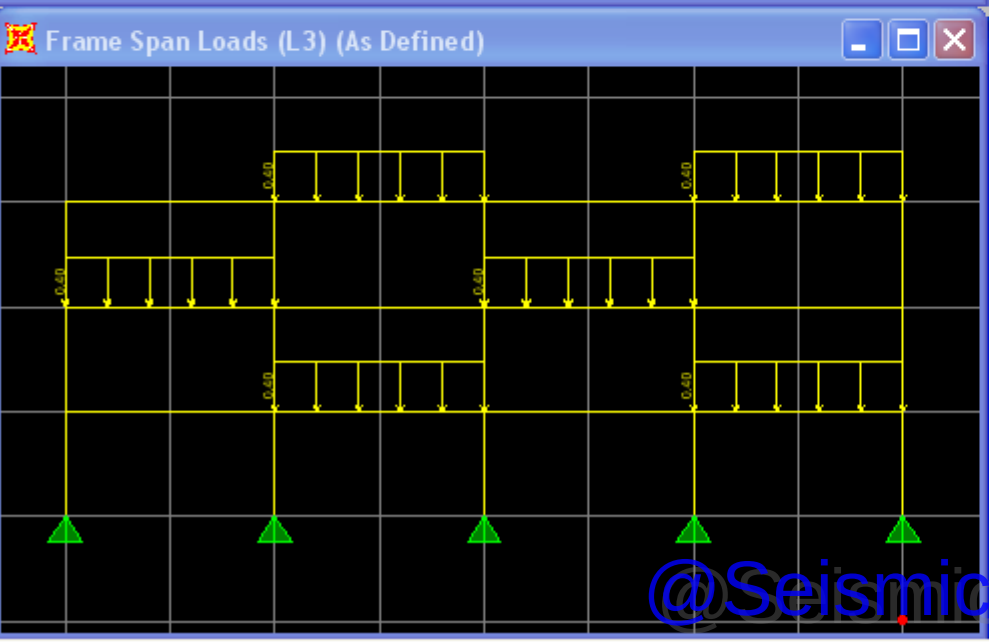
Frame Span Loads (L1) (As Defined)



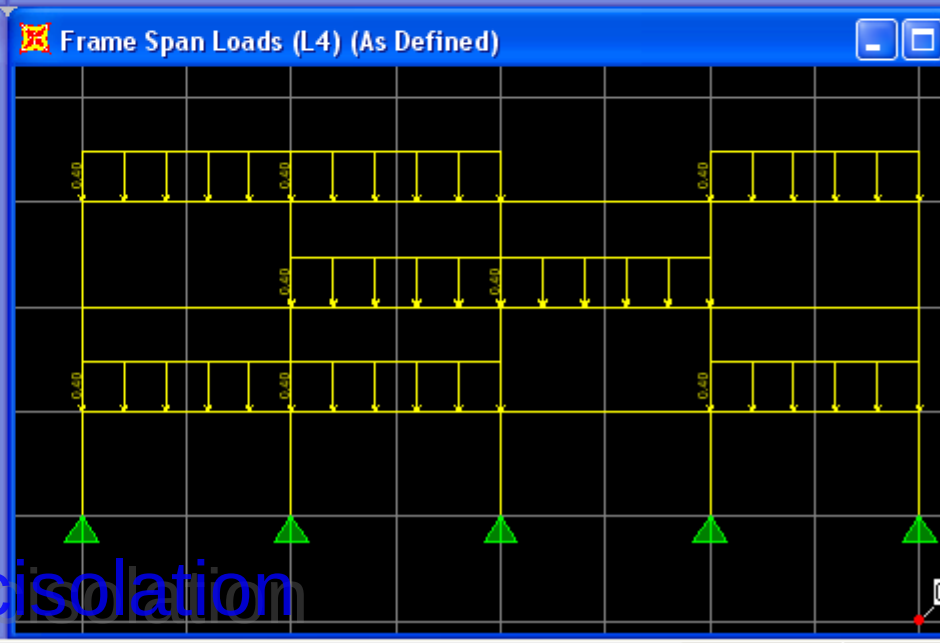
Frame Span Loads (L2) (As Defined)



Frame Span Loads (L3) (As Defined)



Frame Span Loads (L4) (As Defined)



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Plane @ Y=50

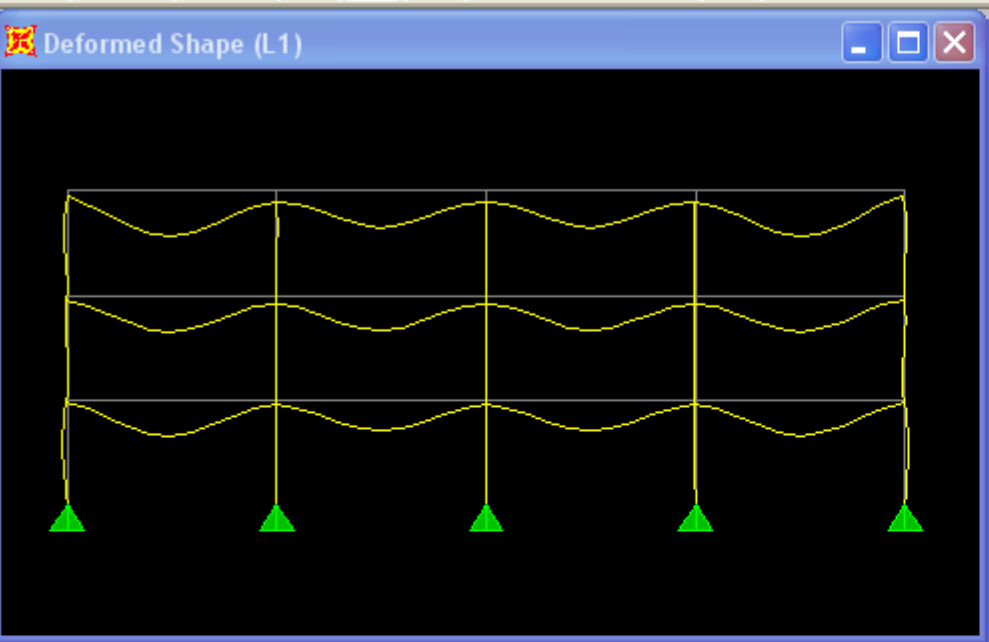
X55.00 Y50.00 Z0.00

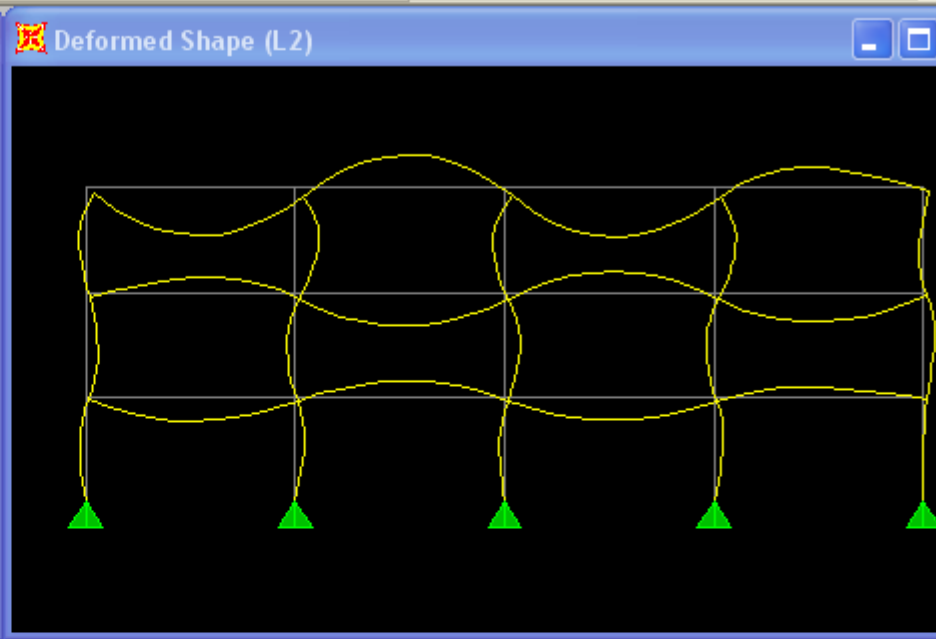
GLOBA

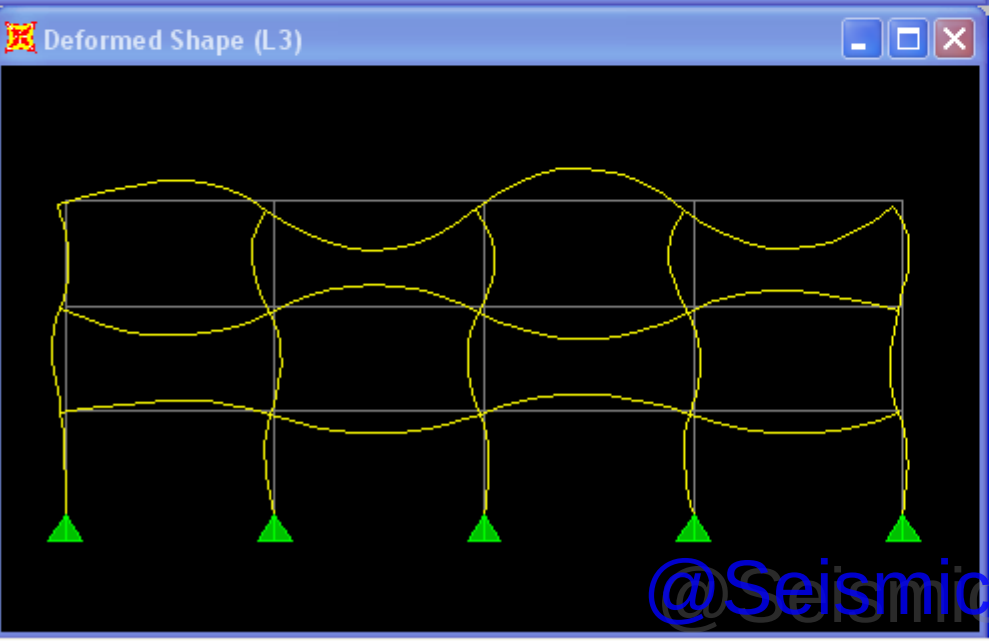
Thursday, April 22

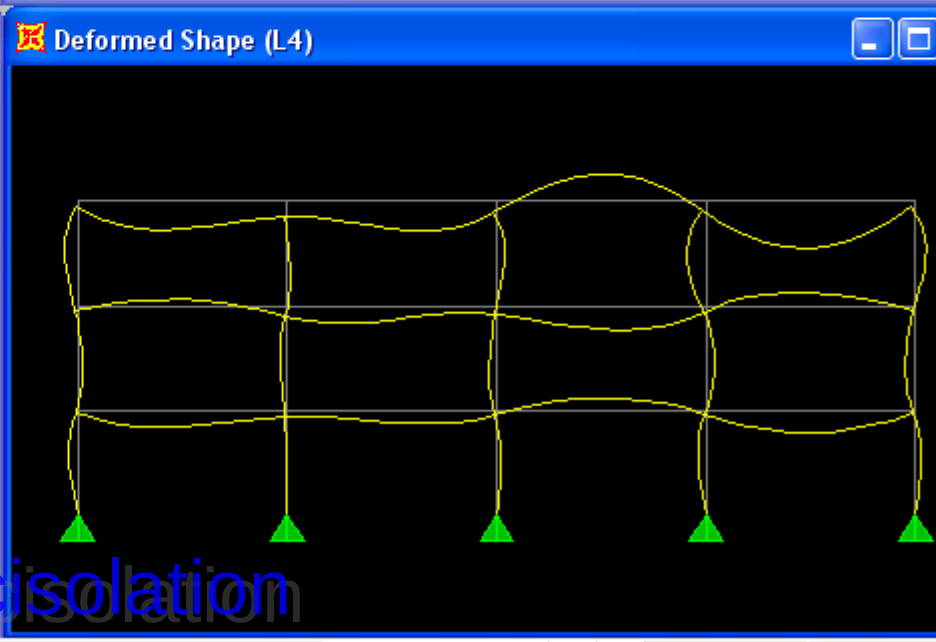
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d









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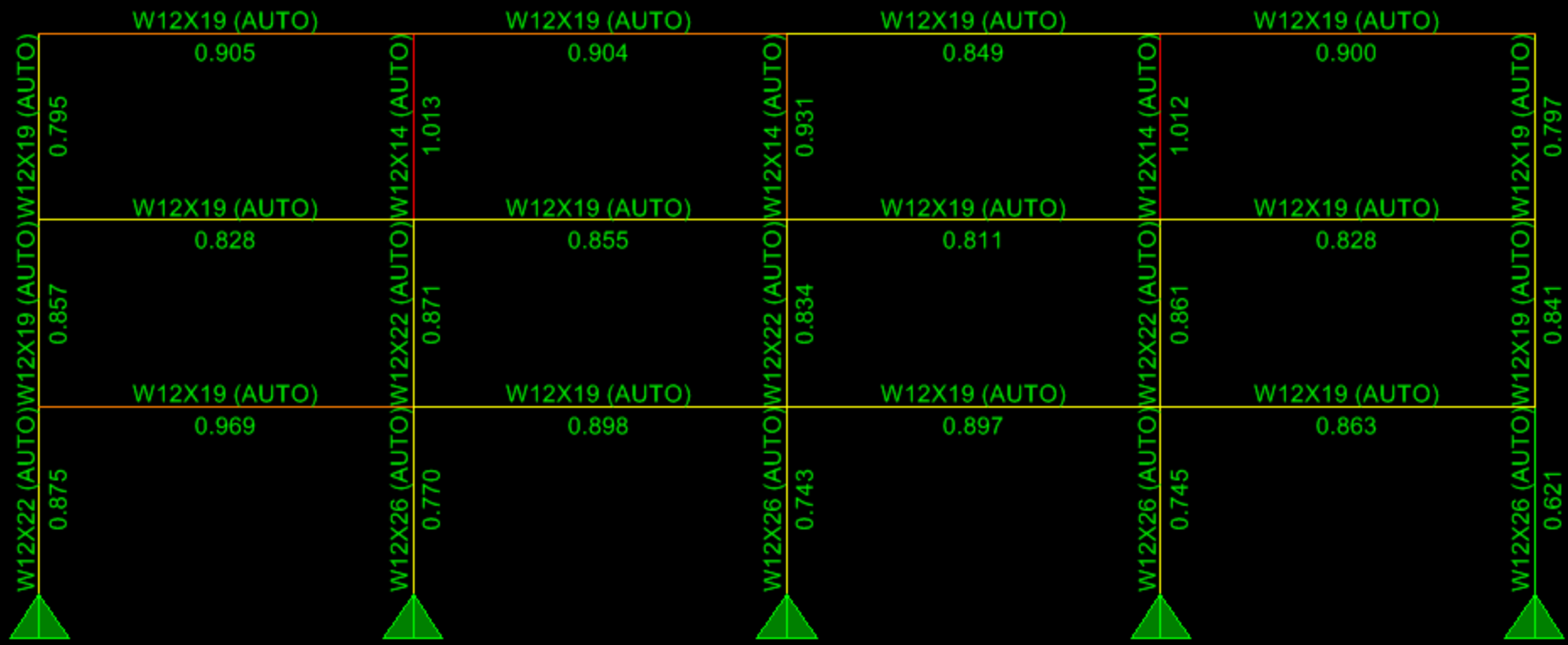
Click on any joint for displacement values

Start Animation GLOBAL Kip, ft, F

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d

Steel P-M Interaction Ratios (AISC-ASD89)



0.00 0.50 0.70 0.90 1.00

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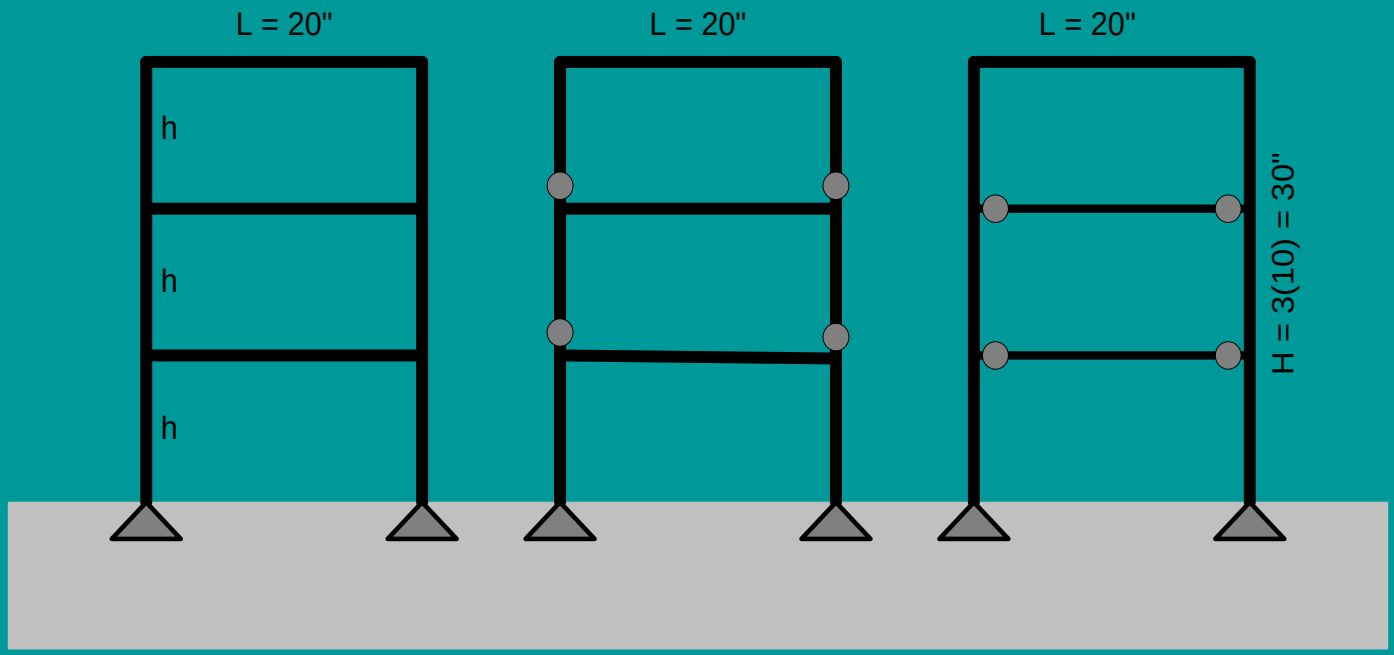
Plane @ Y=50 X8.77 Y50.00 Z-4.75 GLOBAL Kip, ft, F



LOW-RISE, SINGLE-BAY, MULTI-STORY FRAMES

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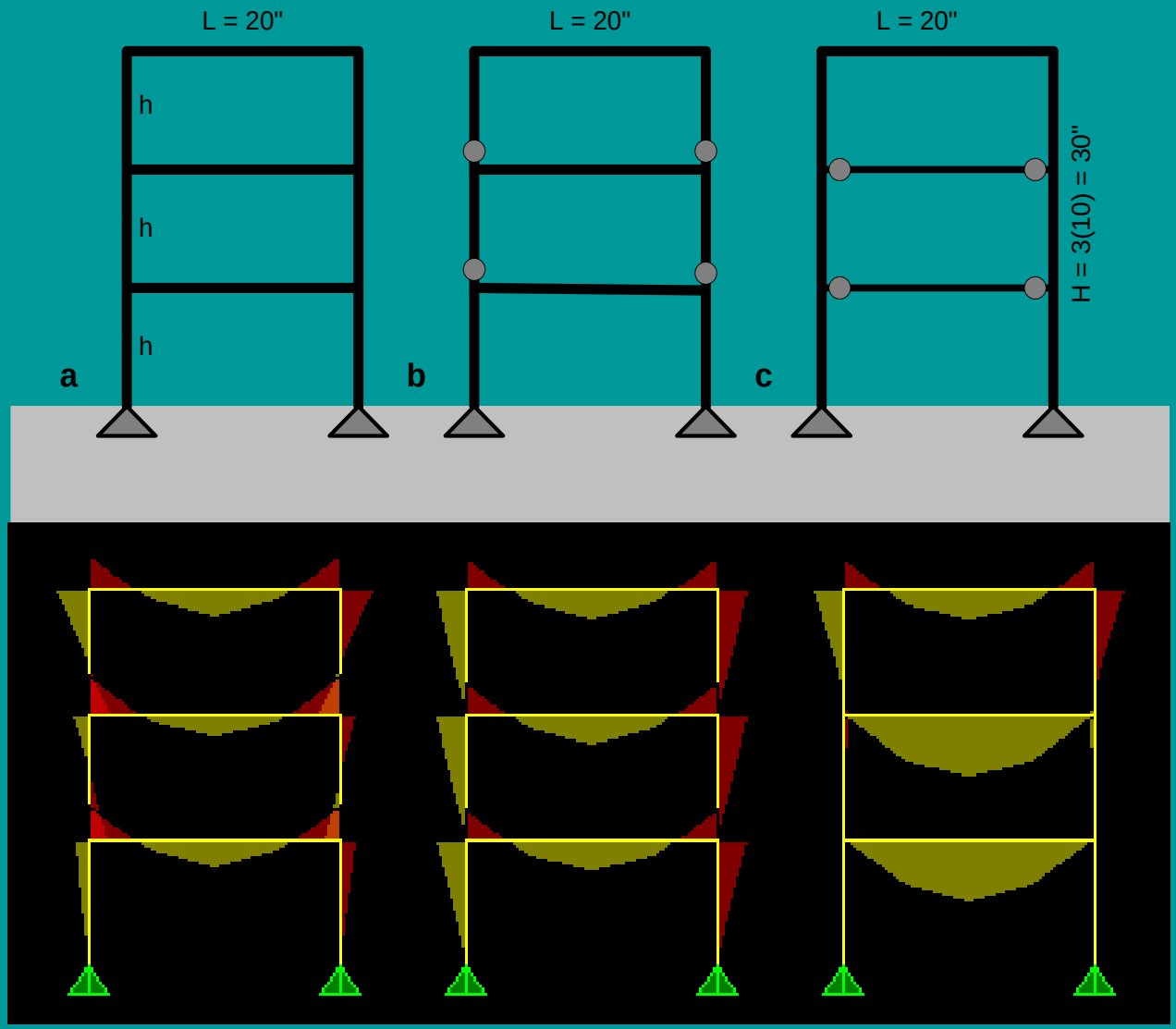

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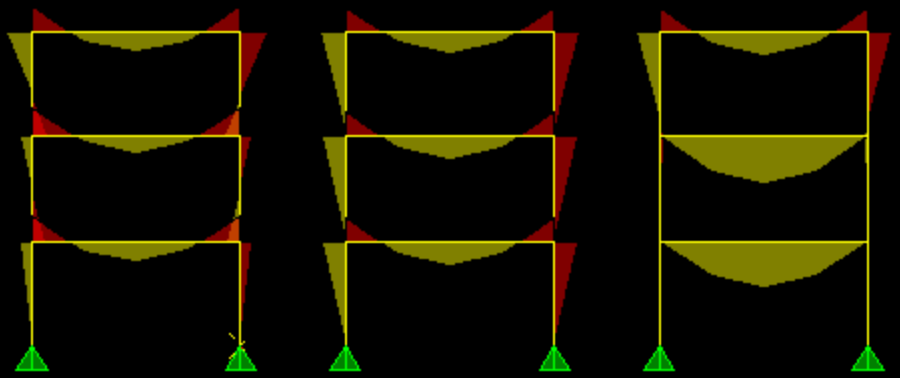

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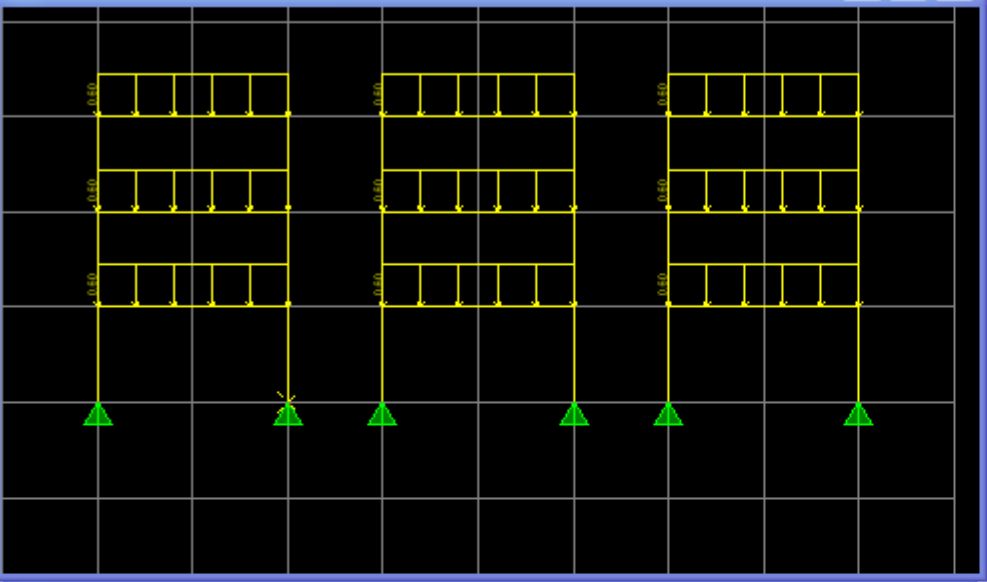
AP2000 - Problem 7.7 lowrise single bay frames_V8

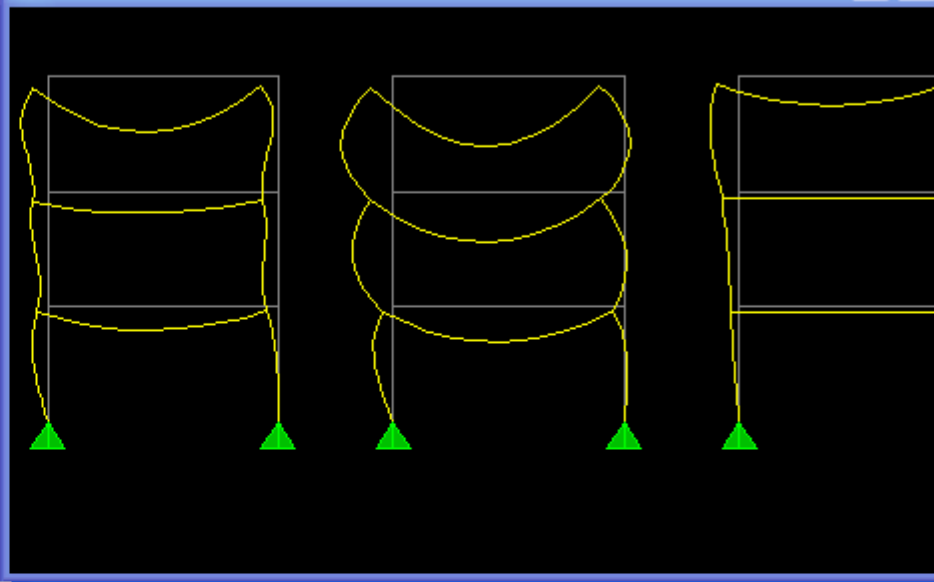
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xz

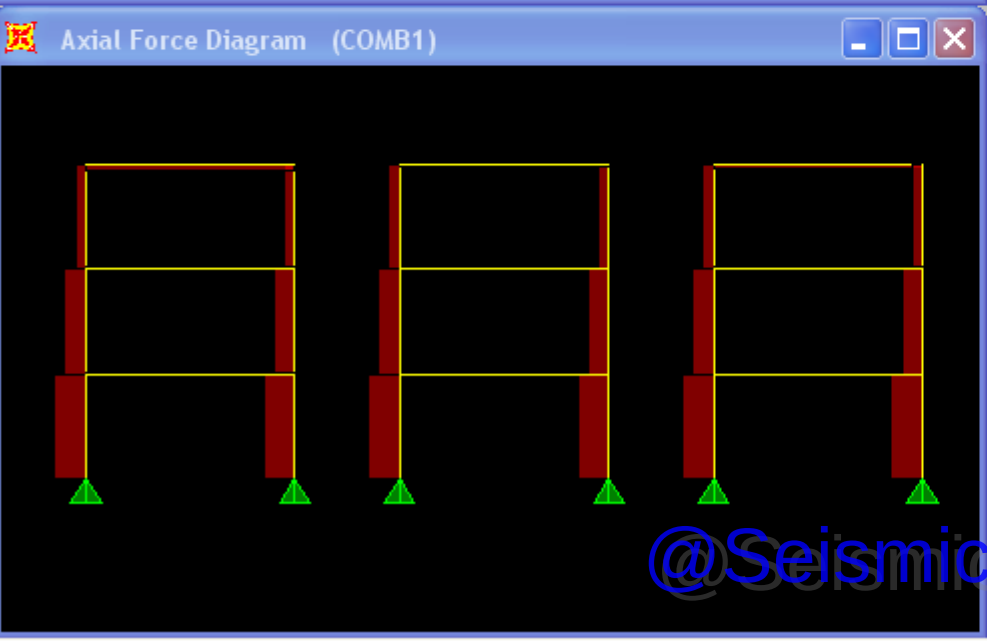
Frame Span Loads (D) (As Defined)



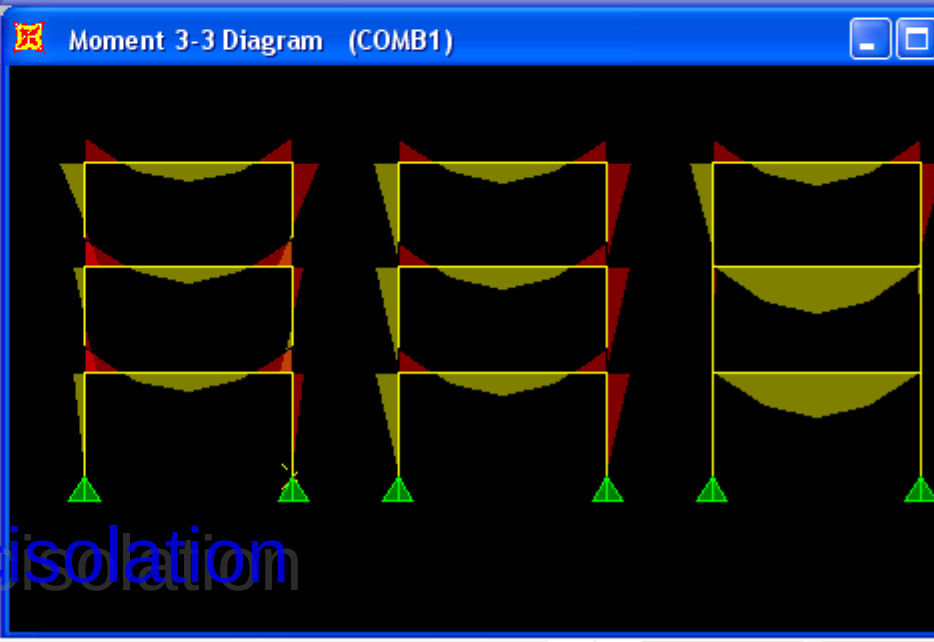
Deformed Shape (COMB1)



Axial Force Diagram (COMB1)



Moment 3-3 Diagram (COMB1)



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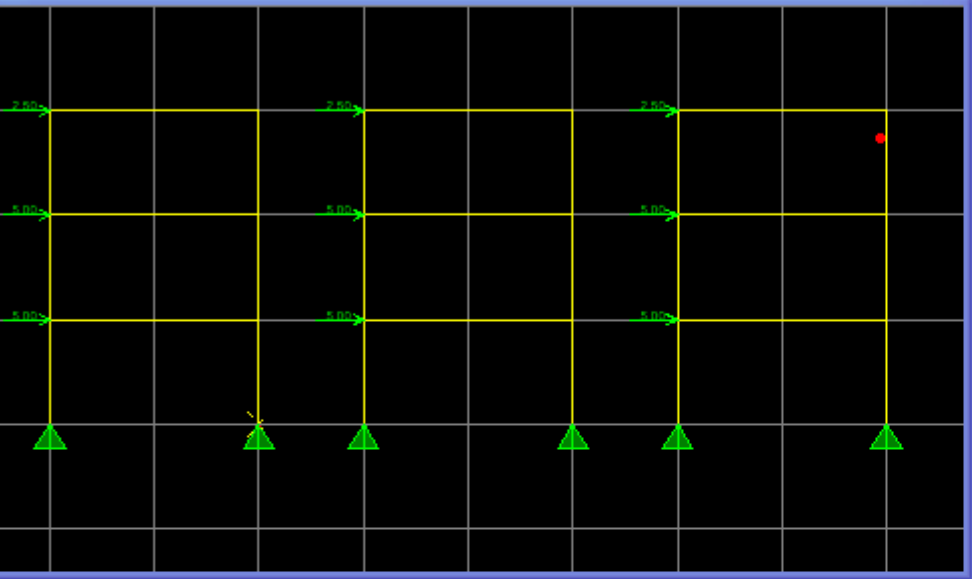
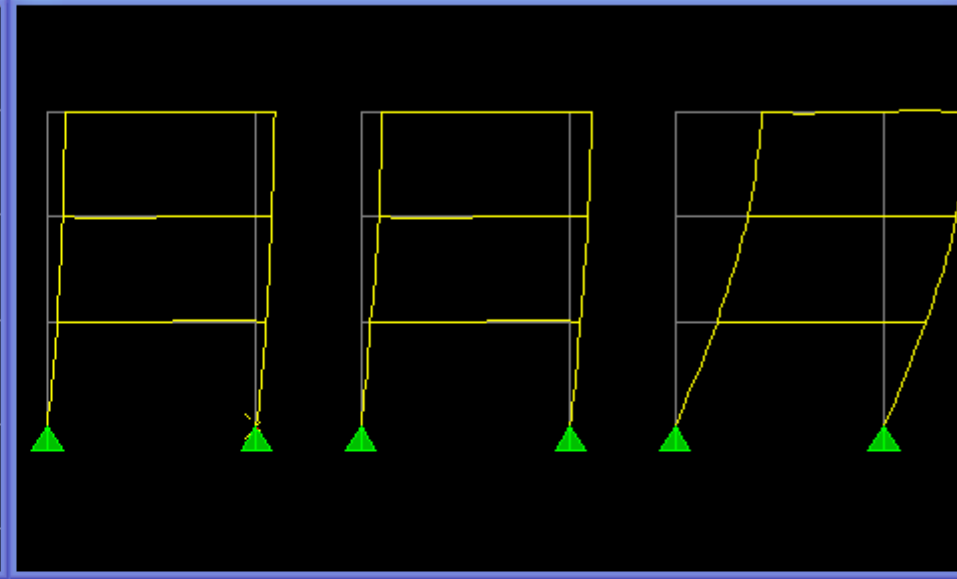
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xz

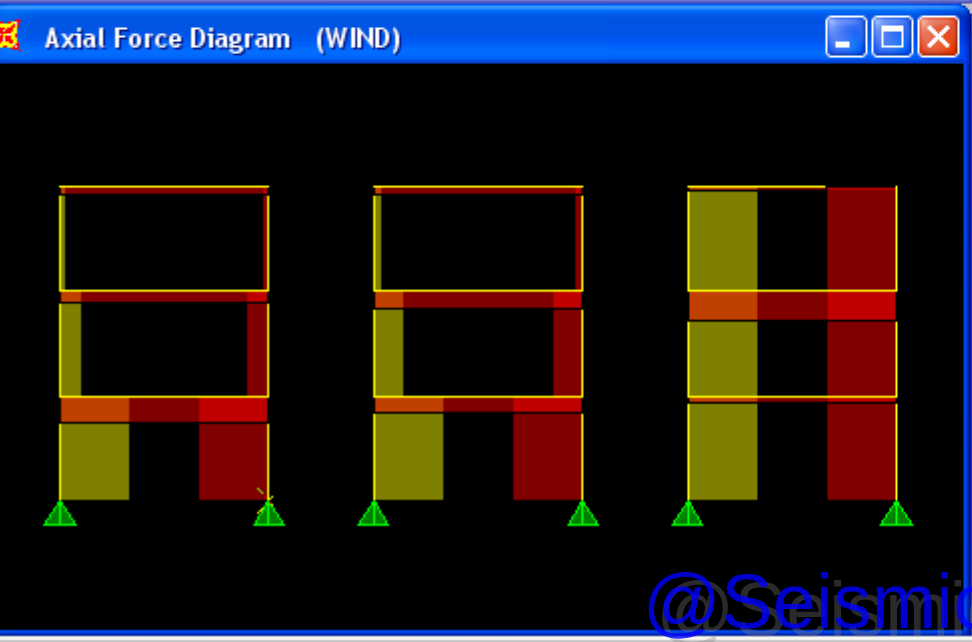
Joint Loads (W) (As Defined)



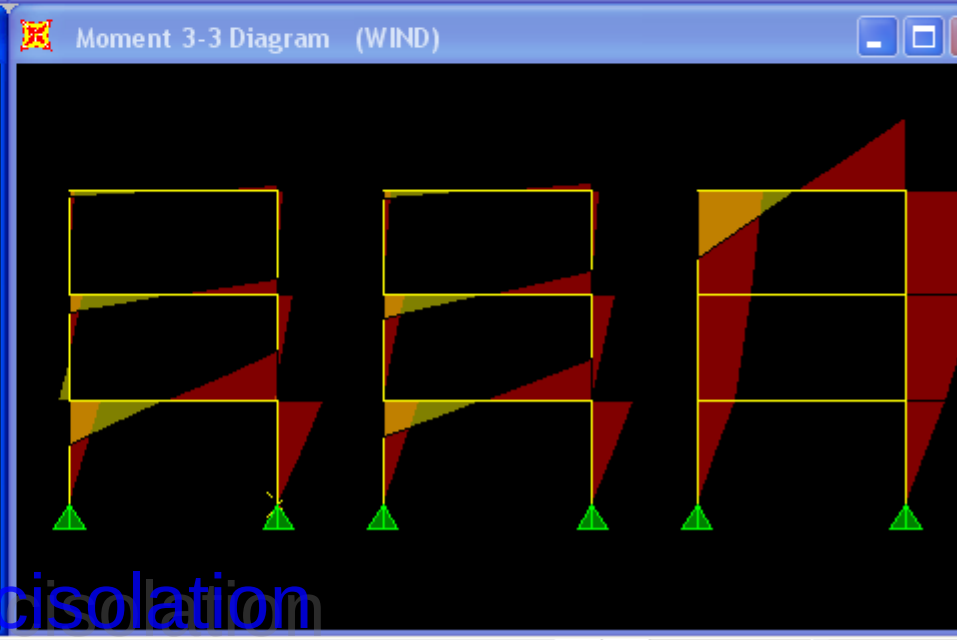
Deformed Shape (WIND)



Axial Force Diagram (WIND)



Moment 3-3 Diagram (WIND)



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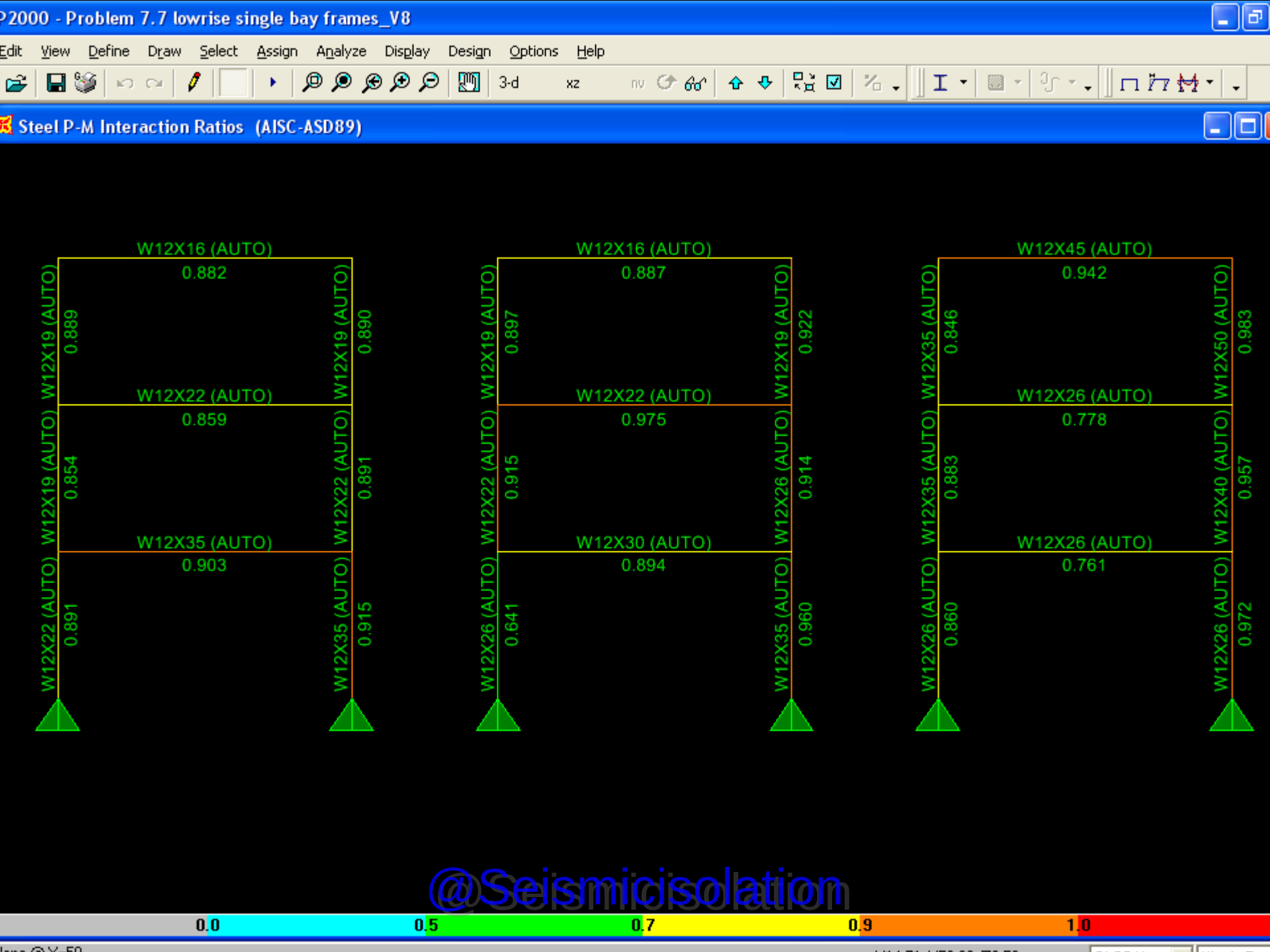
Selected

GLOBAL Kip, ft, F



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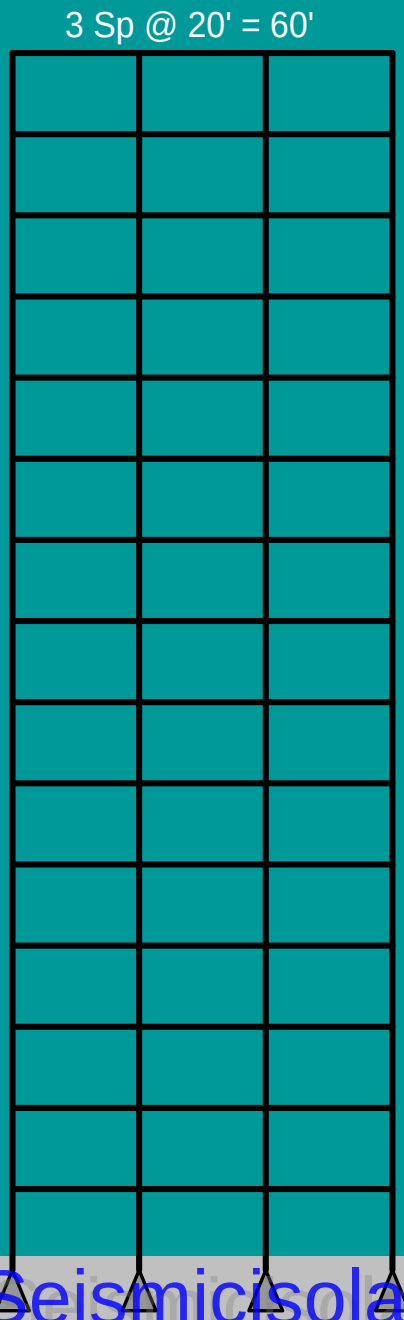
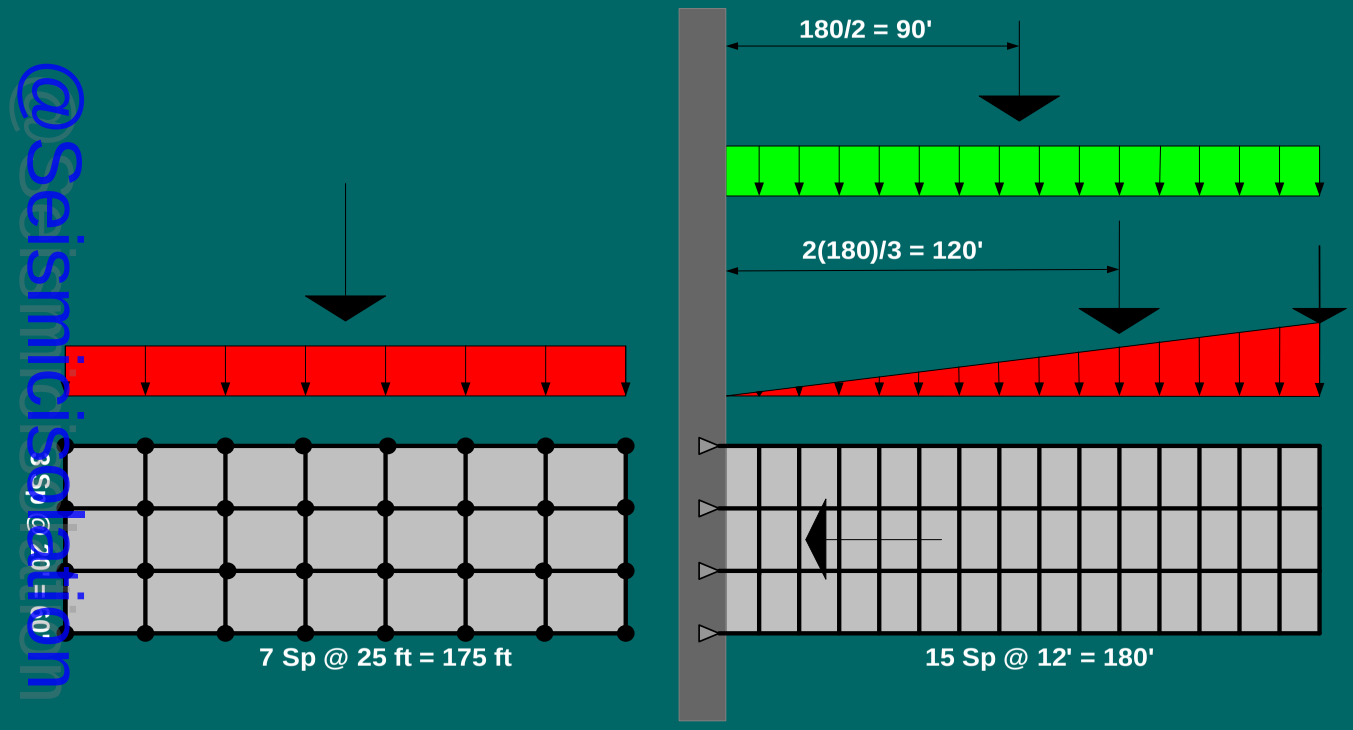


@Seismicisolation



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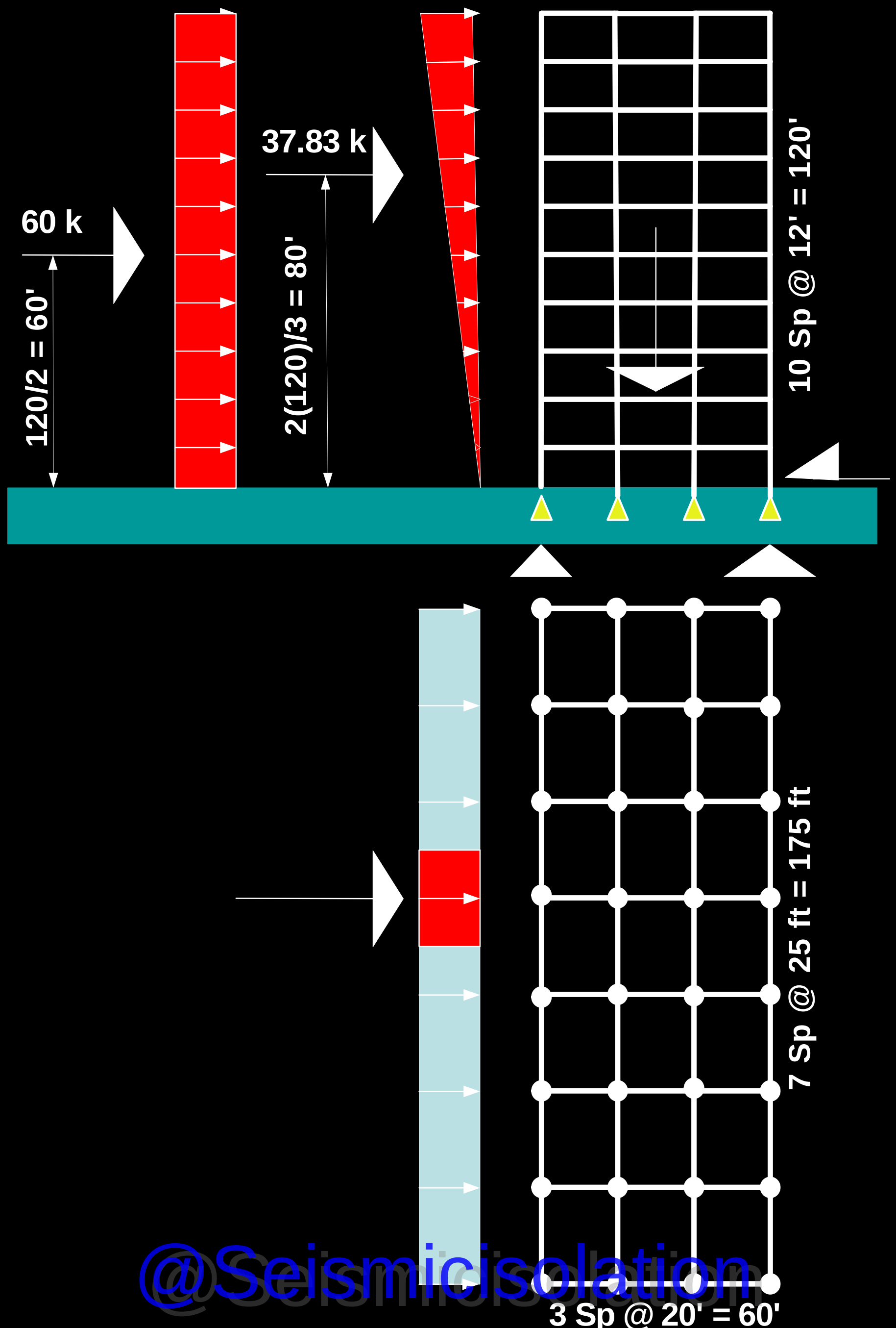

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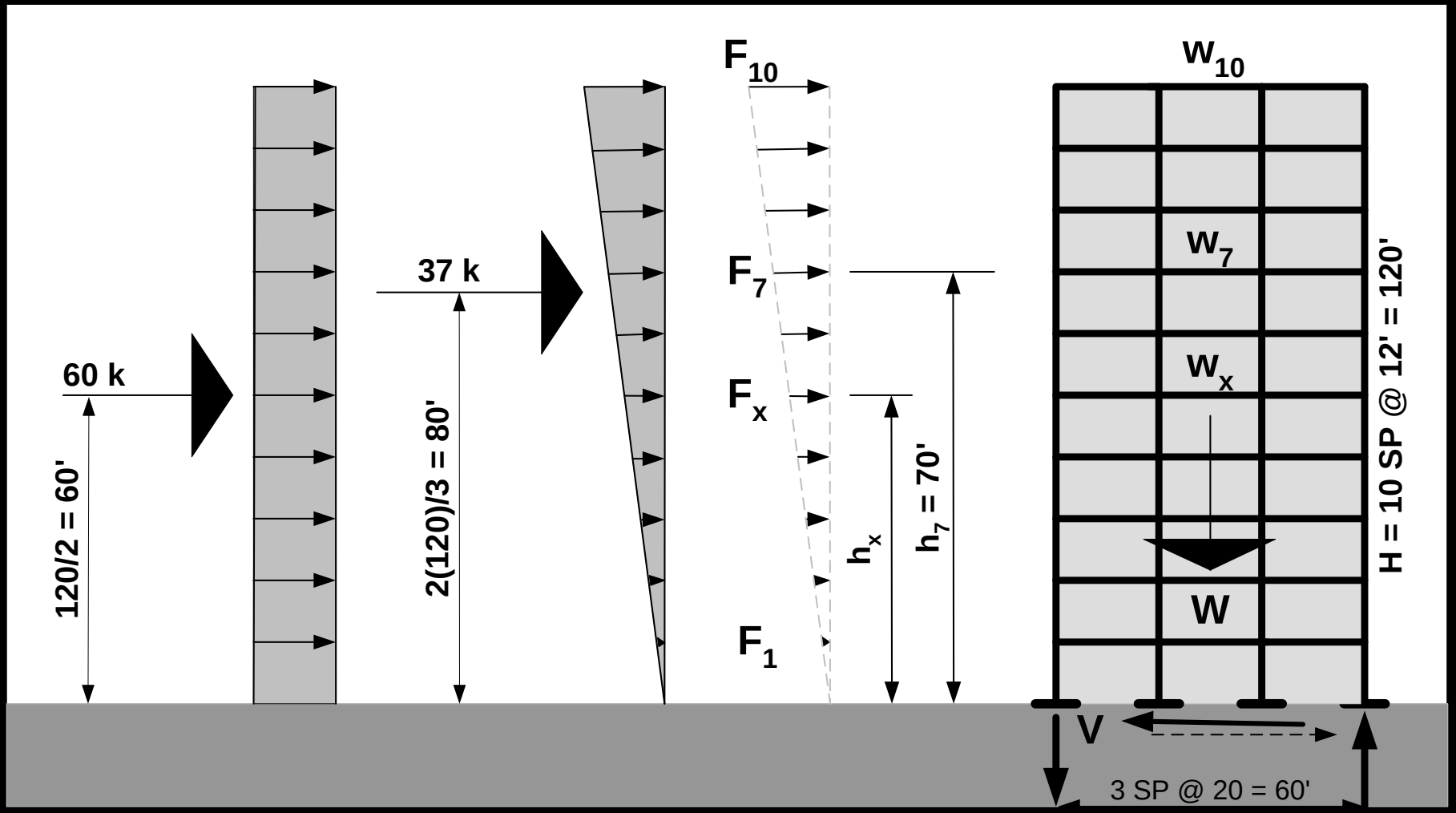

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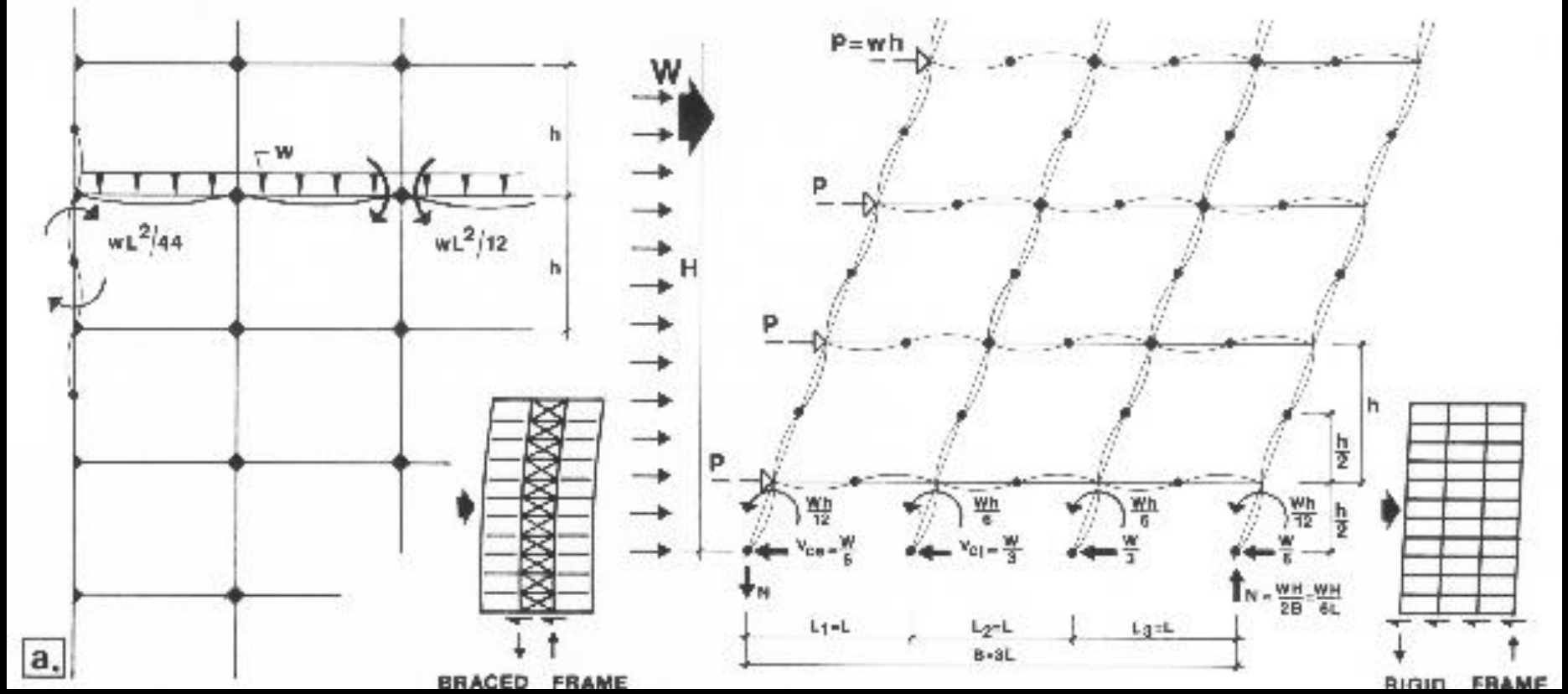

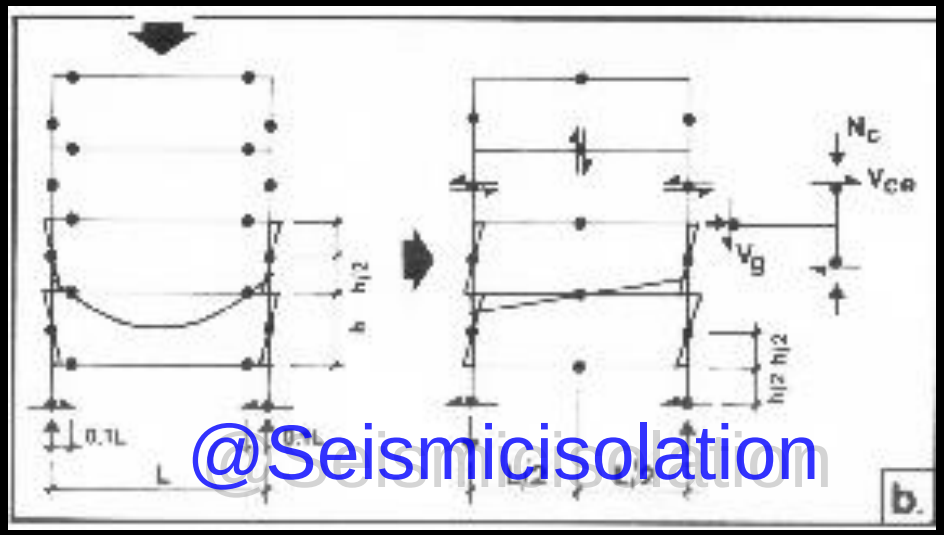

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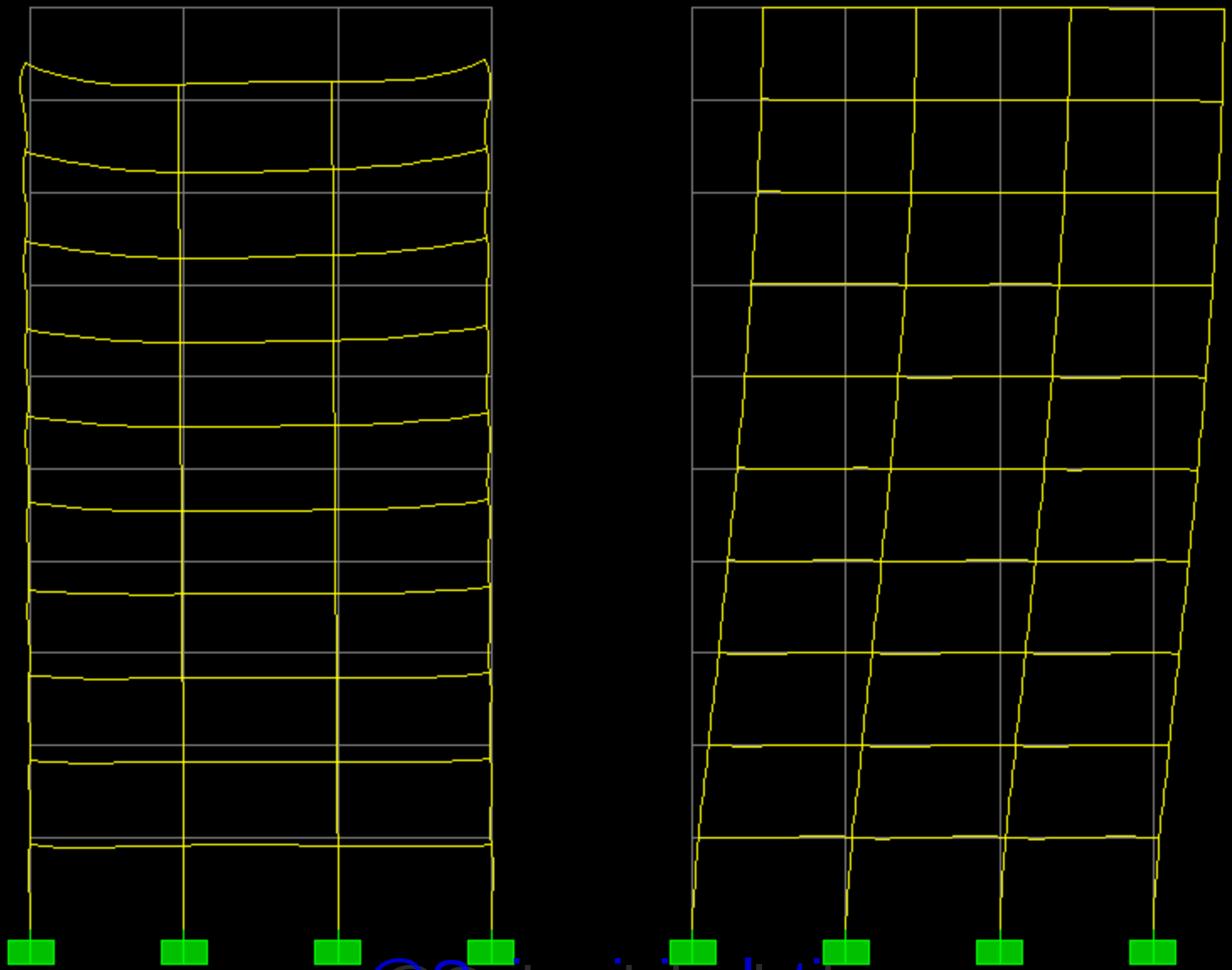

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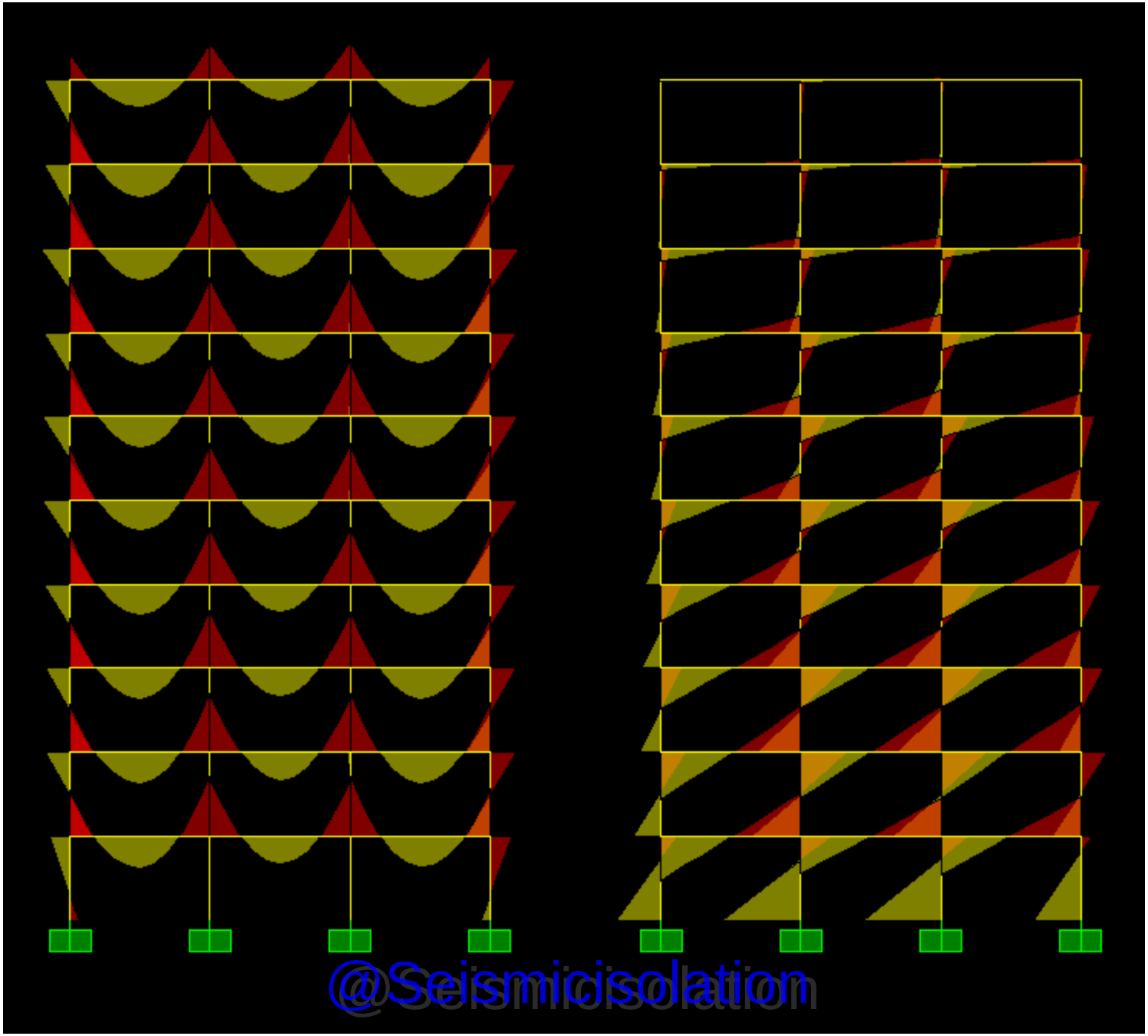
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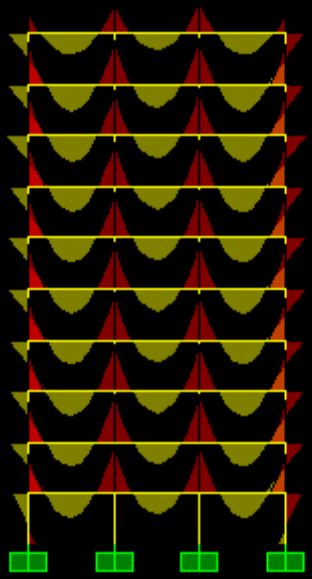

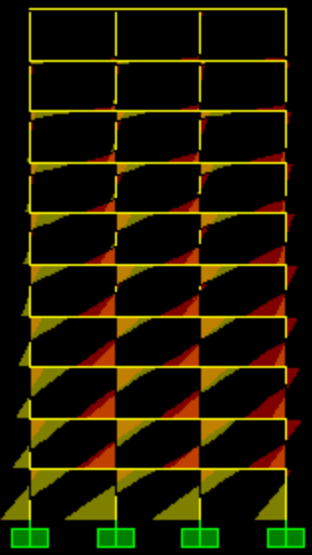

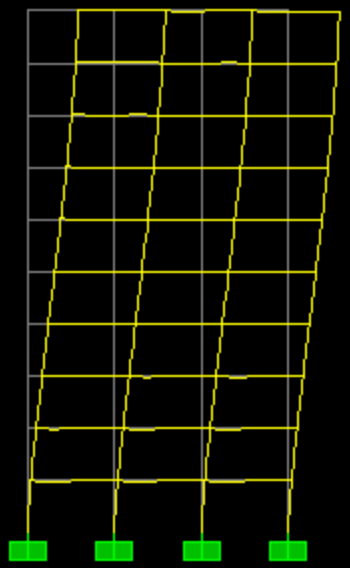

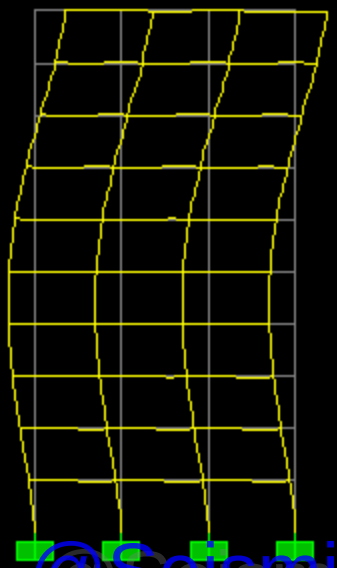

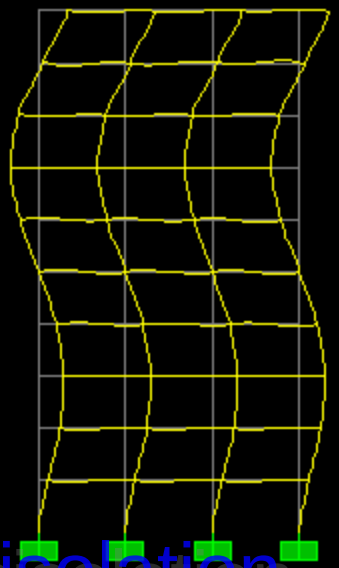

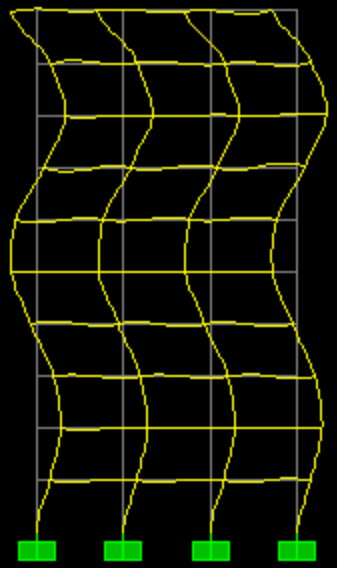

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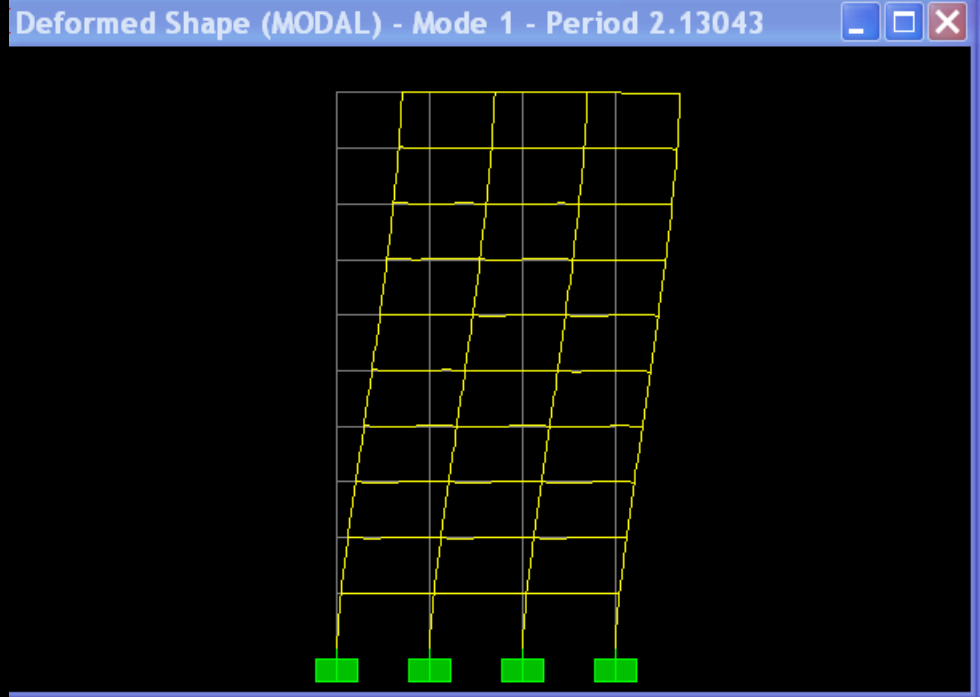

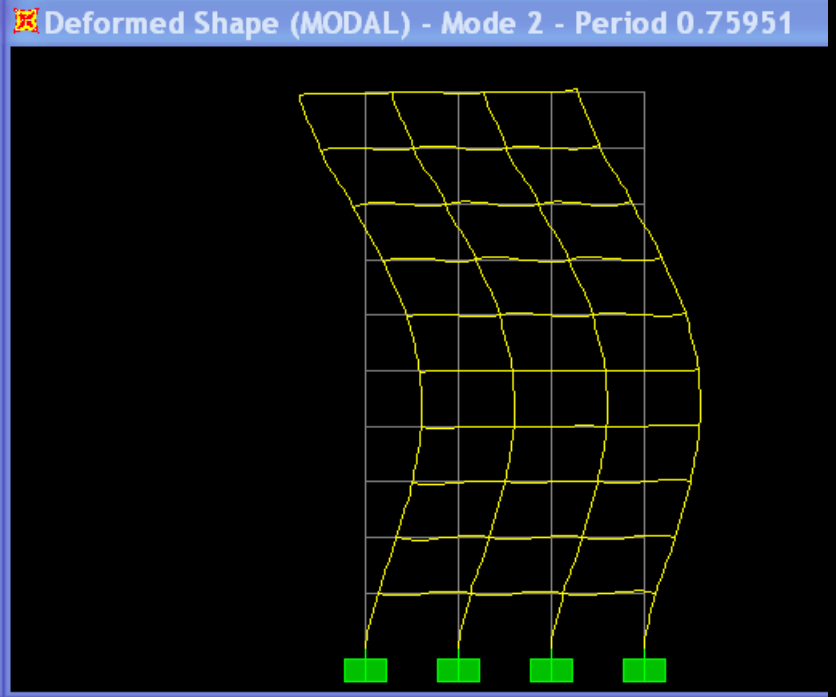

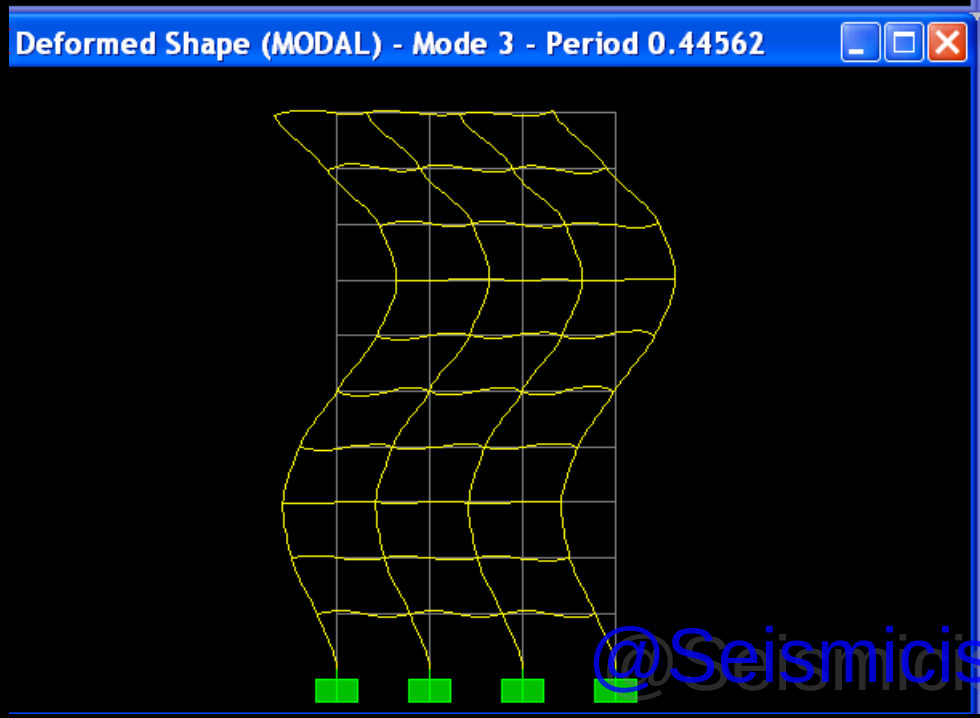

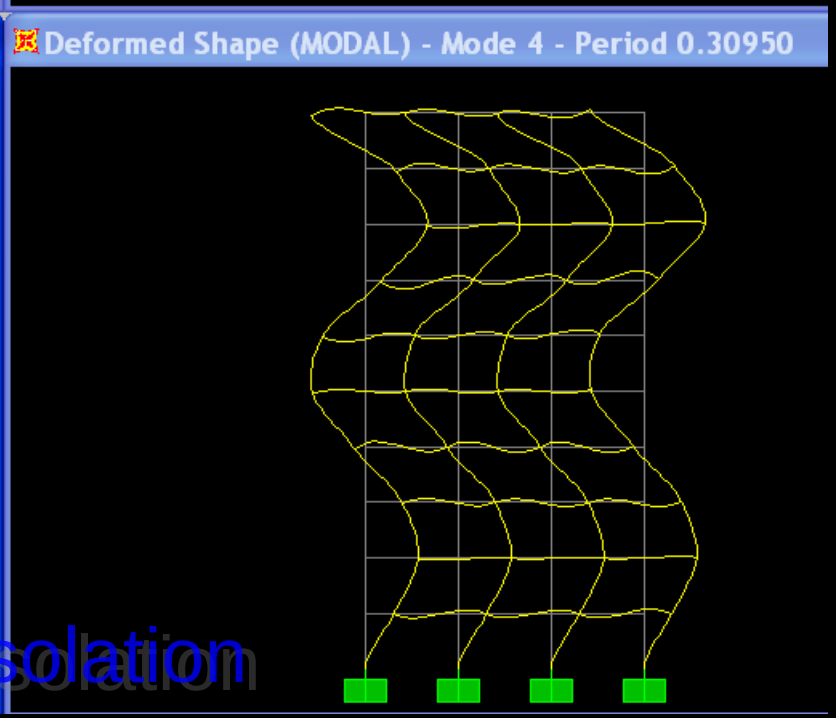

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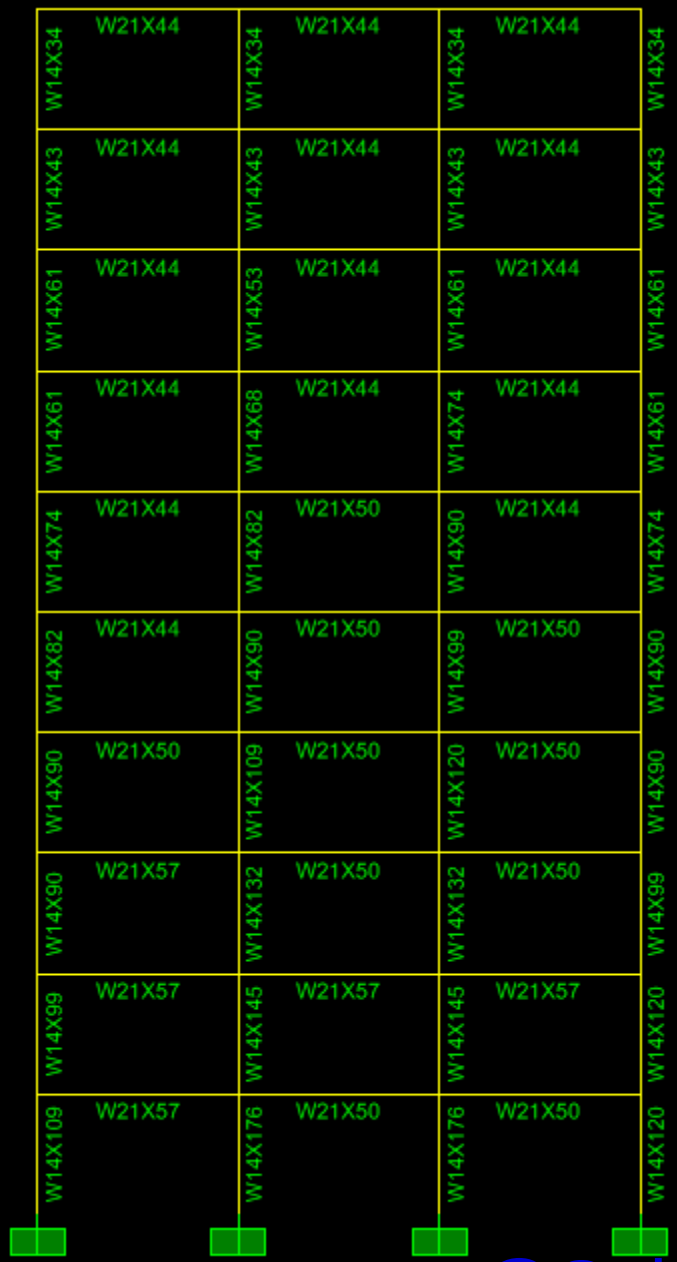

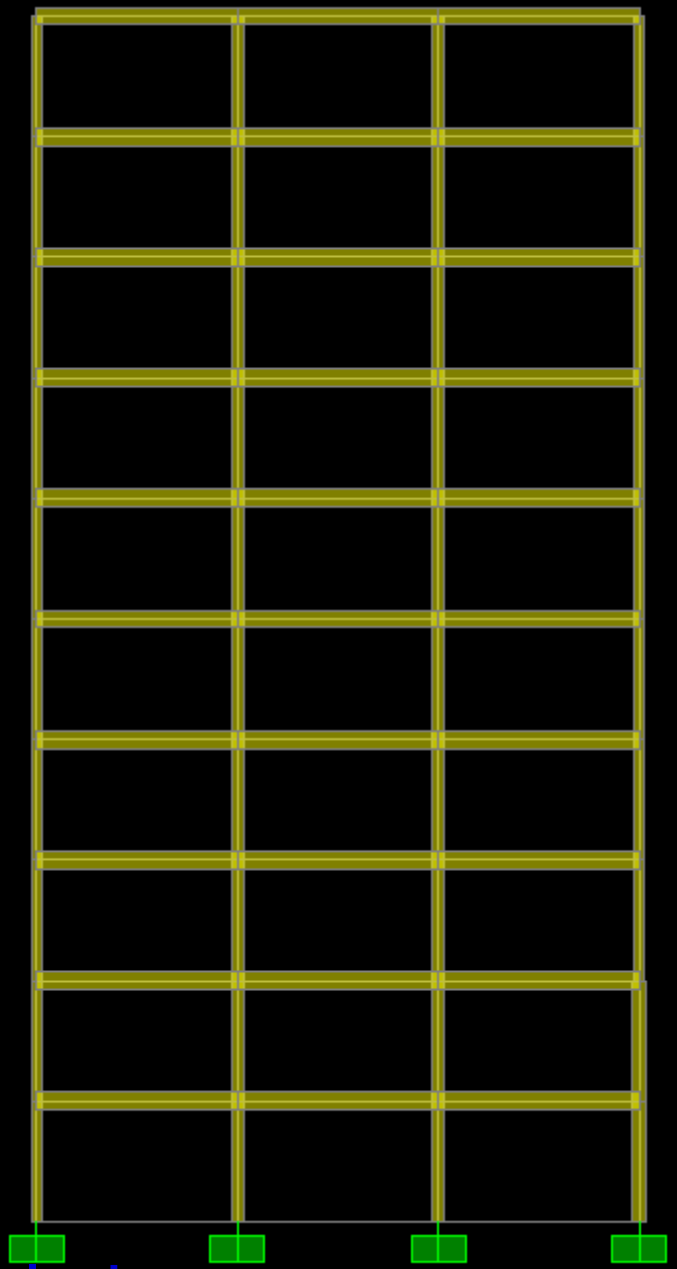

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Beijing Jian Wai SOHO, Shinjuku, Tokyo, Yamamoto, 2004

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Lehrter Bahnhof, Berlin, 2002, Gerkan, Marg & Partner, Mero

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Dresdner Bank, Verwaltungsgebäude, Leipzig, 1997, Engel und Zimmermann Arch


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House, Nuremberg, Germany

Design Museum, [illegible], [illegible], [illegible], **Volker Staab**

@Seismicisolation

House, Nuremberg, Germany

@Seismicisolation

Parkinggarage Otto Schillstr., Leipzig, Germany


Ausfahrt
@Seismicisolation


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Umspannwerk Mediapark, Koeln, 1996, Sandro Graf von Einsiedel Arch.

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Ningbo downtown, 2002,
Qingyun Ma

@Seismicisolation


@Seismicisolation

NIS, Nanjing, 2002, Qingyun Ma

Residential complex, Berlin, Herman Herzberger, 1997


26 9 2001
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Centraal Beheer Insurance Company, Apeldoorn, The Netherlands, 1972, Herman Herzberger

@Seismicisolation

@Seismicisolation

Administration Building, Ningbo Institute of Technology, Zhejiang University, Ningbo, 2002, Qingyun Ma

WDR Arcades/Broadcasting House, Cologne, 1996, Gottfried Böhm


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OCBC Center, Singapore, 1976, I.M. Pei, Arup,, concrete mega-frame

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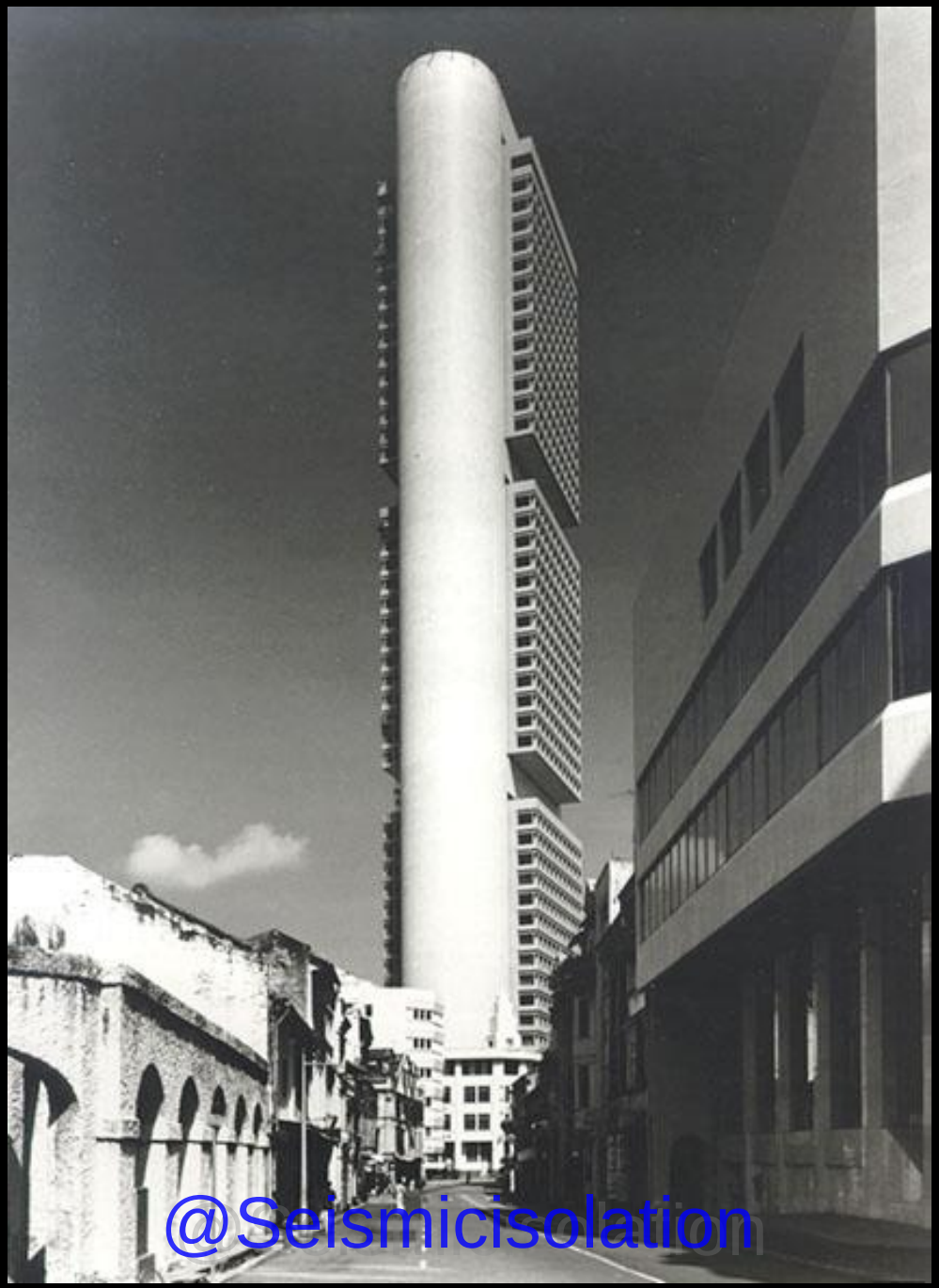
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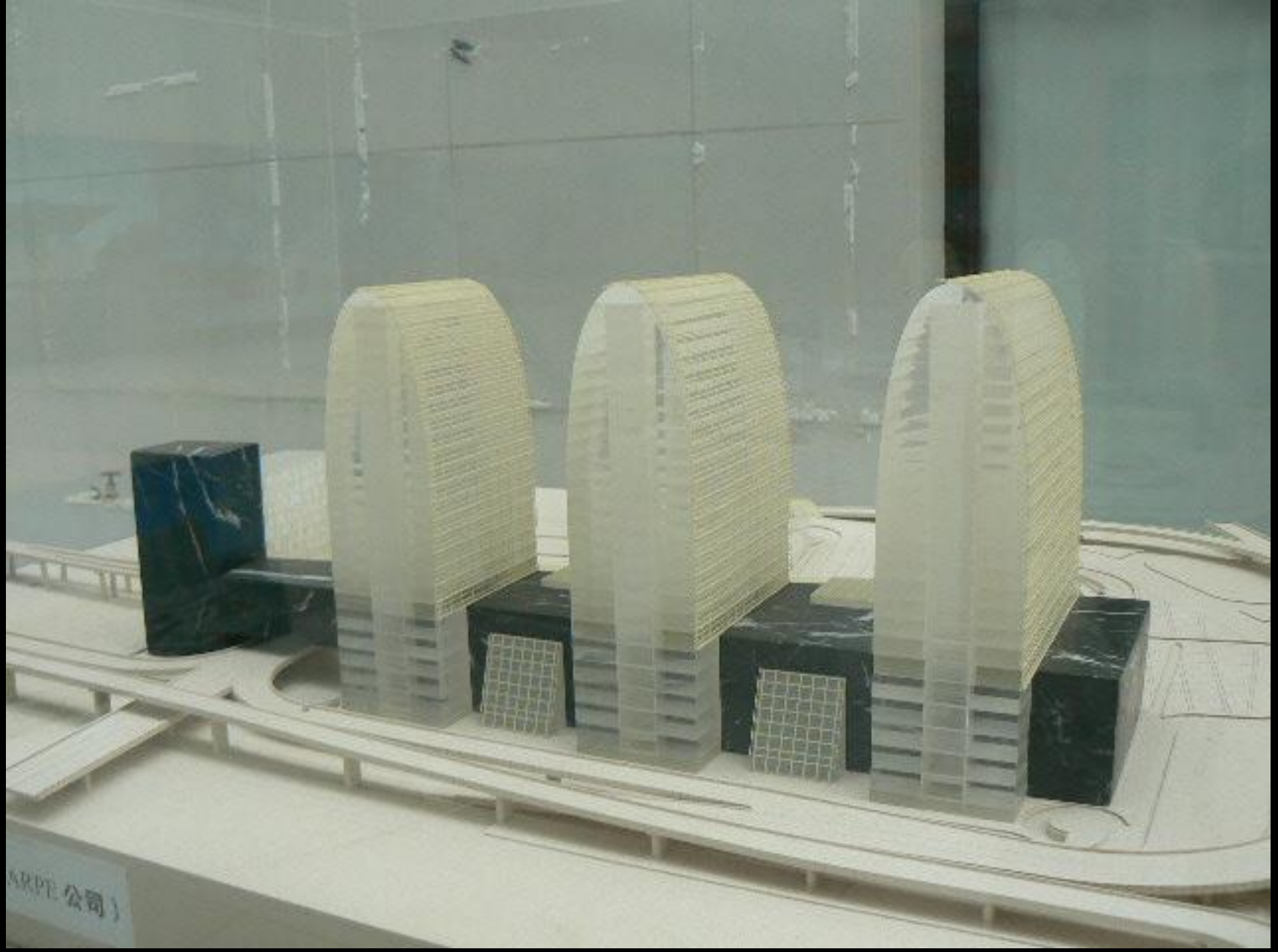
Tsinghua University, 2006

@Seismicisolation


@Seismicisolation


Deutsche Bank
@Seismicisolation



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?, Beijing

Beijing

Dokumenta Urbana, Kassel, 1984, Otto Seidle

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Vierendeel bridge, Berlin

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Vierendeel bridge, Berlin


@Seismicisolation

House, Nuremberg

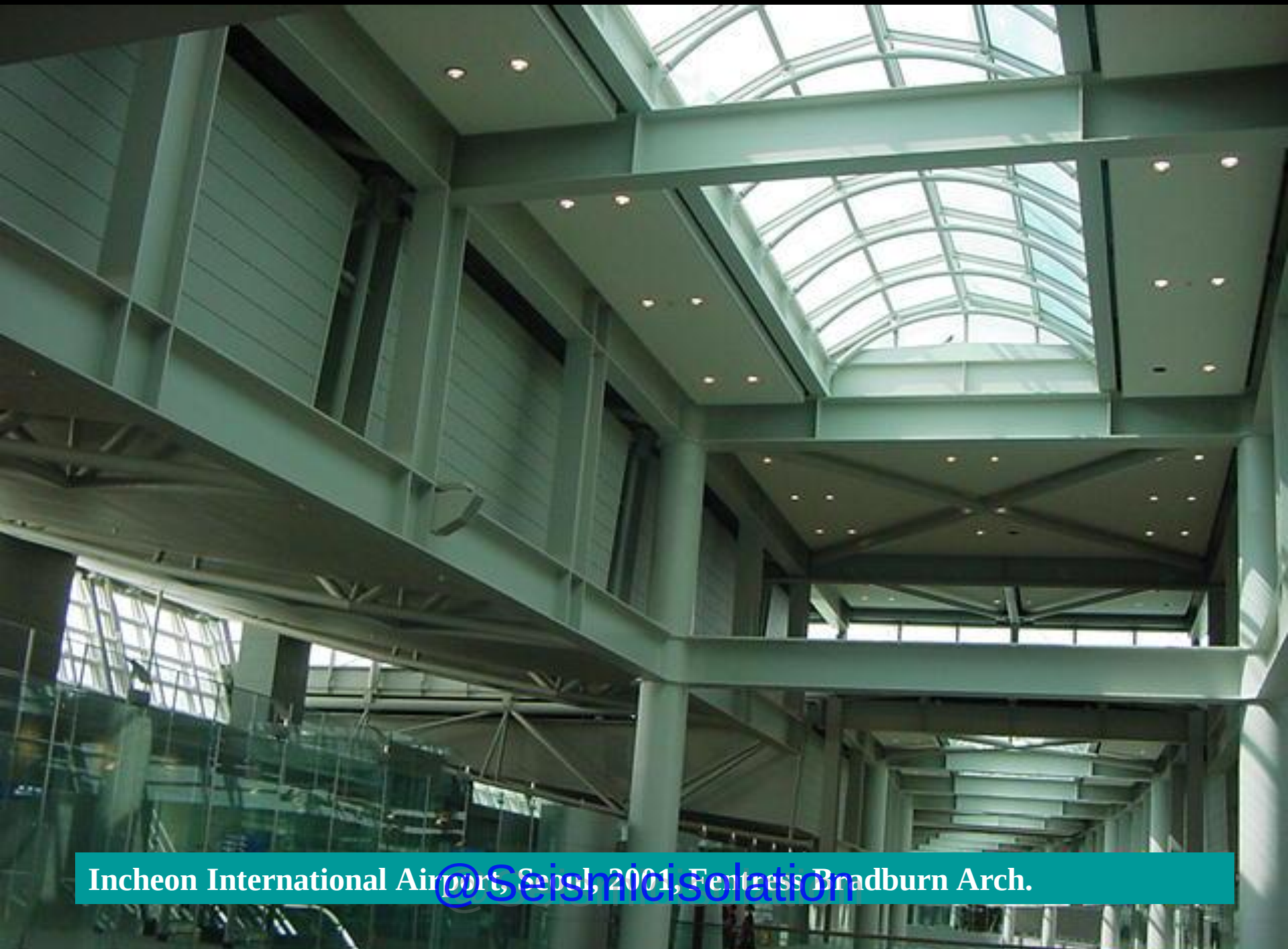
@Seismicisolation

@Seismicisolation

Landesvertretung von Baden-Wuertemberg, Berlin, 2000, Dietrich Bangert

@Seismicisolation

Embassy UK, Berlin, 2000, Michael Wilford



Incheon International Airport, Seoul, 2001, Fentress Bradburn Arch.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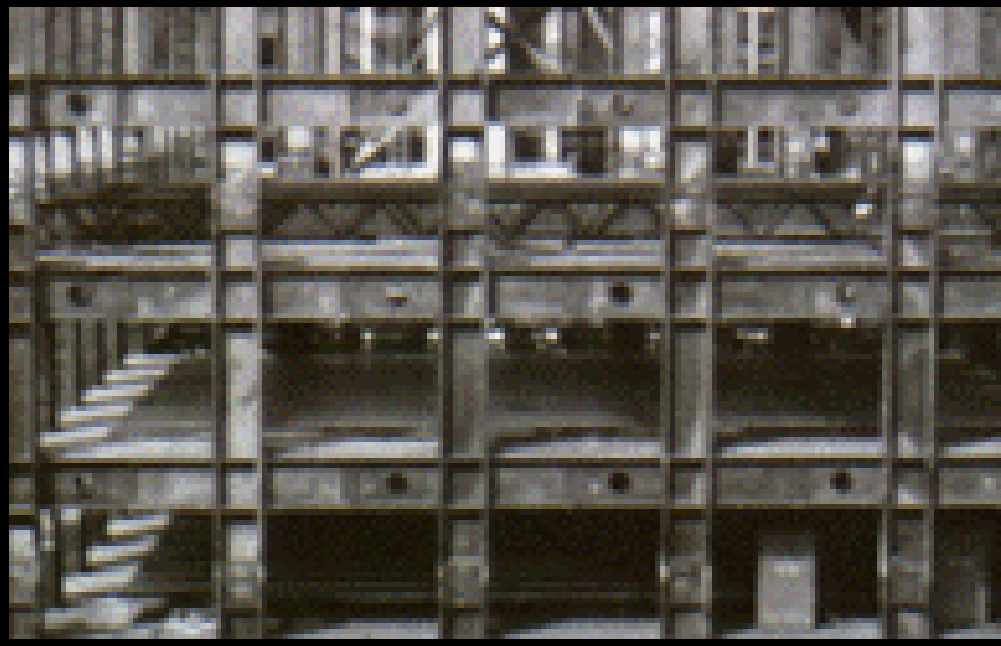

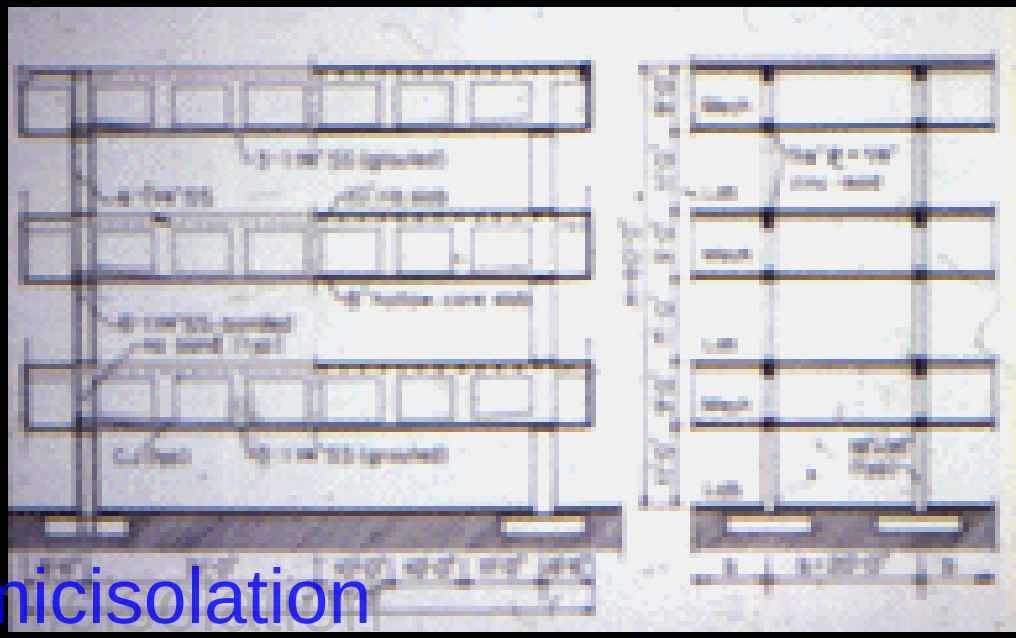

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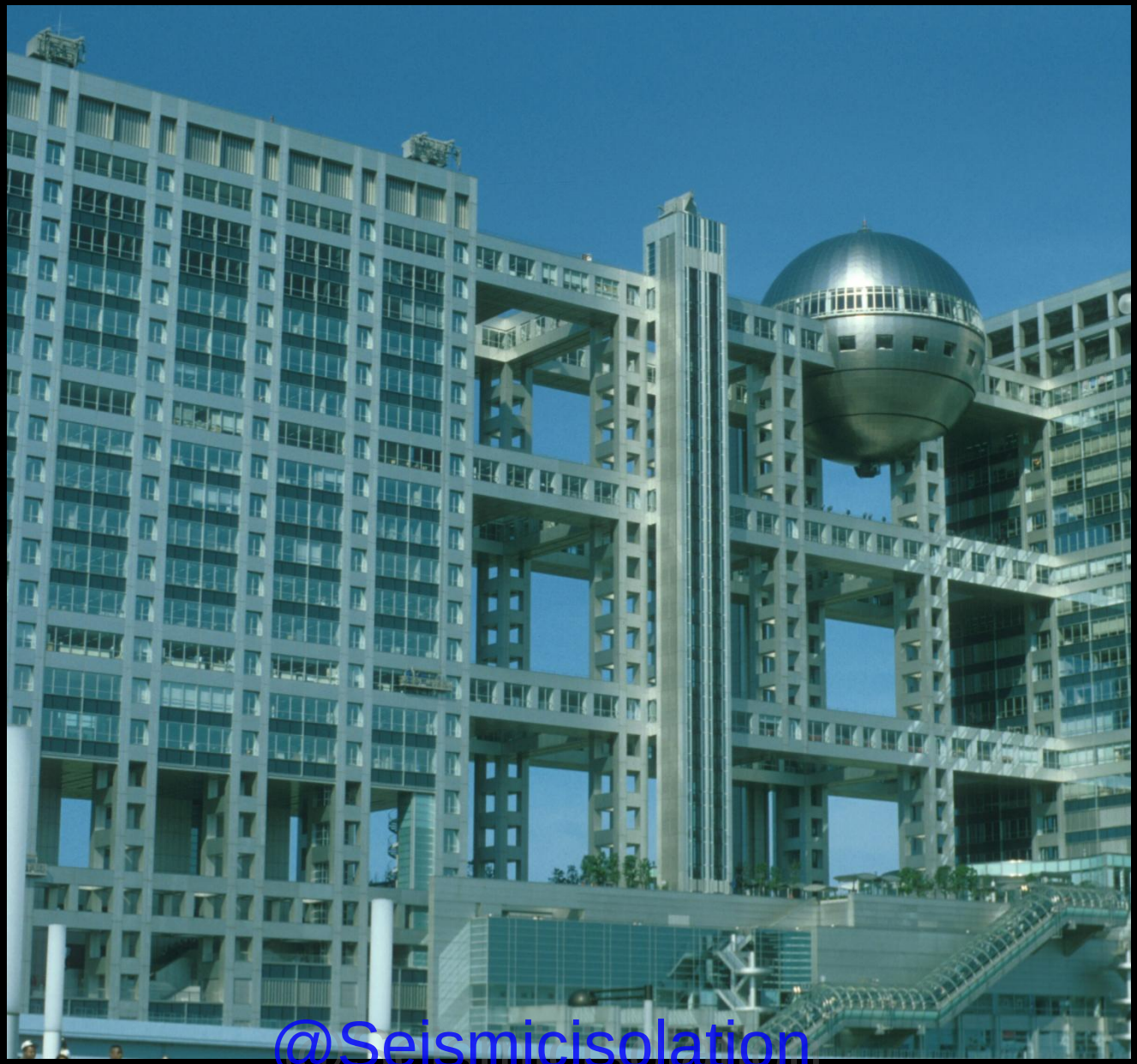
Salk Institute, La Jolla, California, 1966, Louis Kahn

@Seismicisolation

Fuji Television Headquarters, Tokyo, 1996, Kenzo Tange

@Seismicisolation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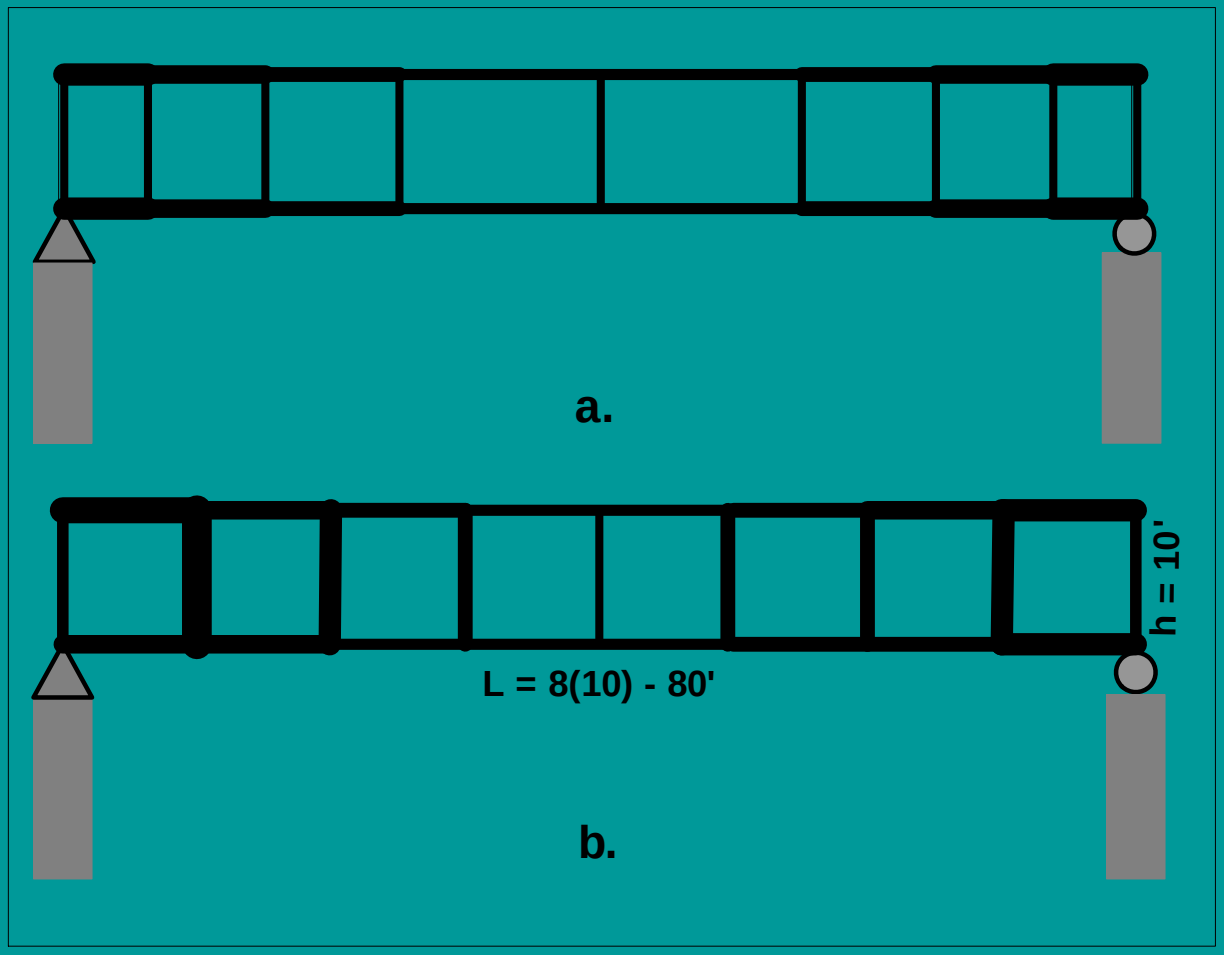
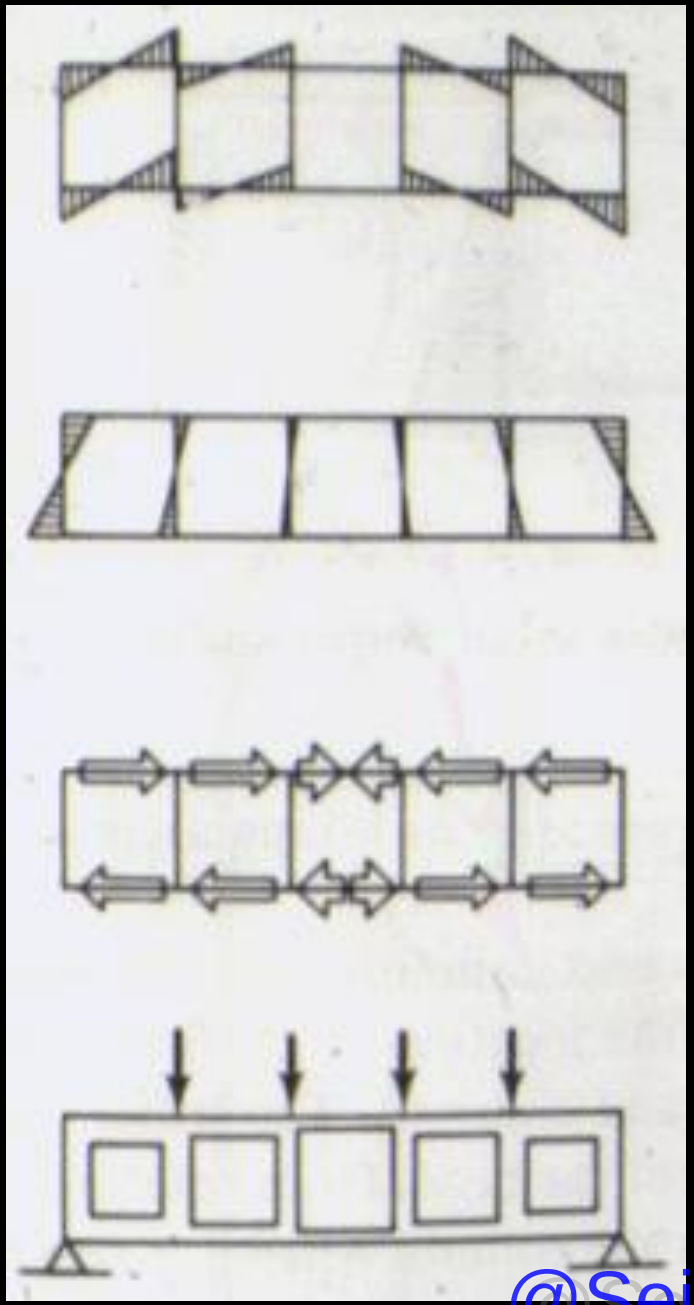


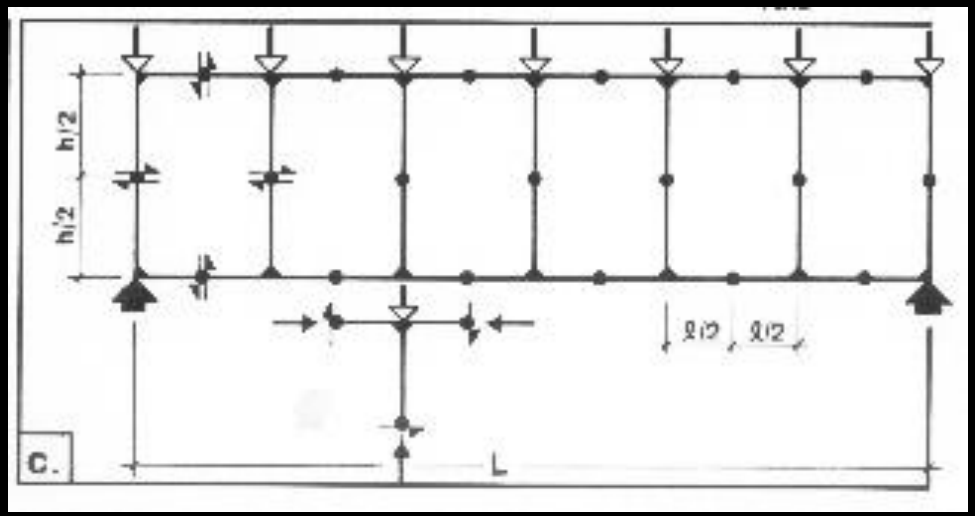
same member size

equal bay size

VIERENDEEL TRUSSES

@Seismicisolation





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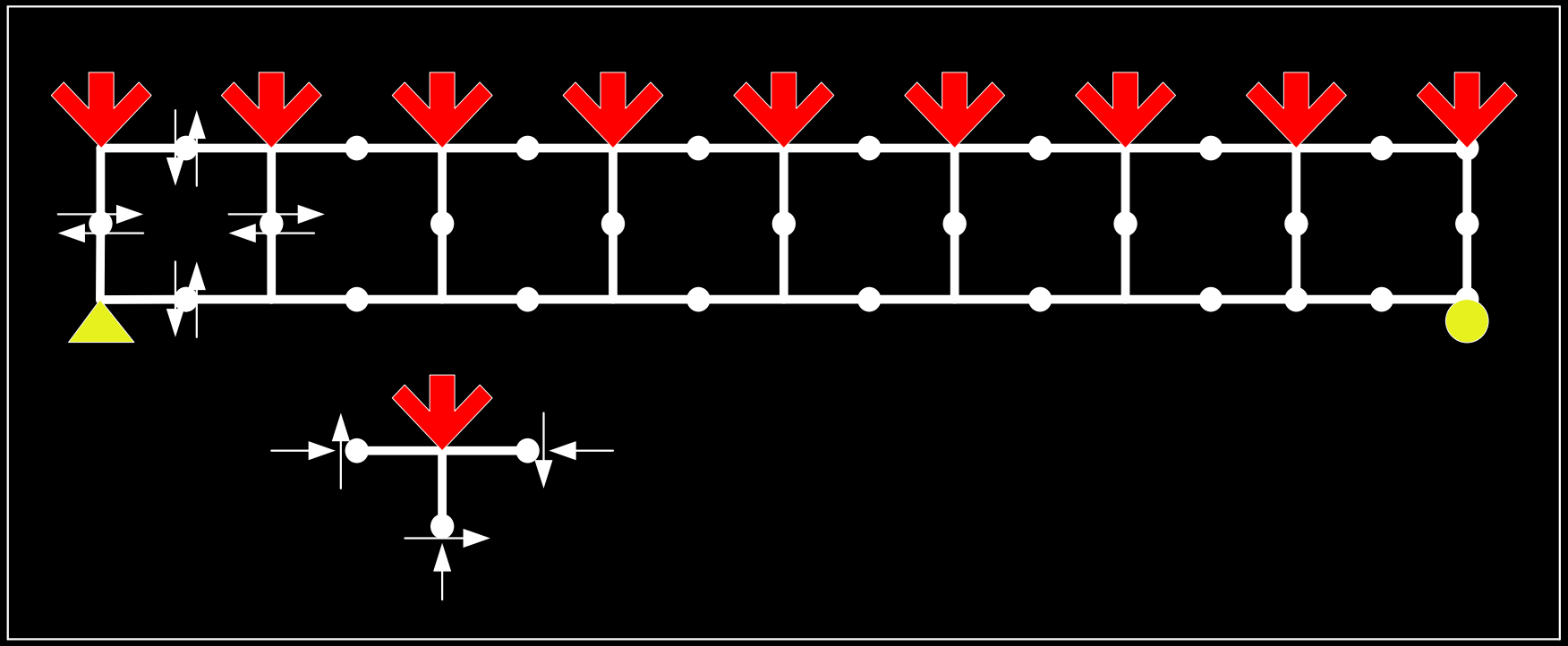

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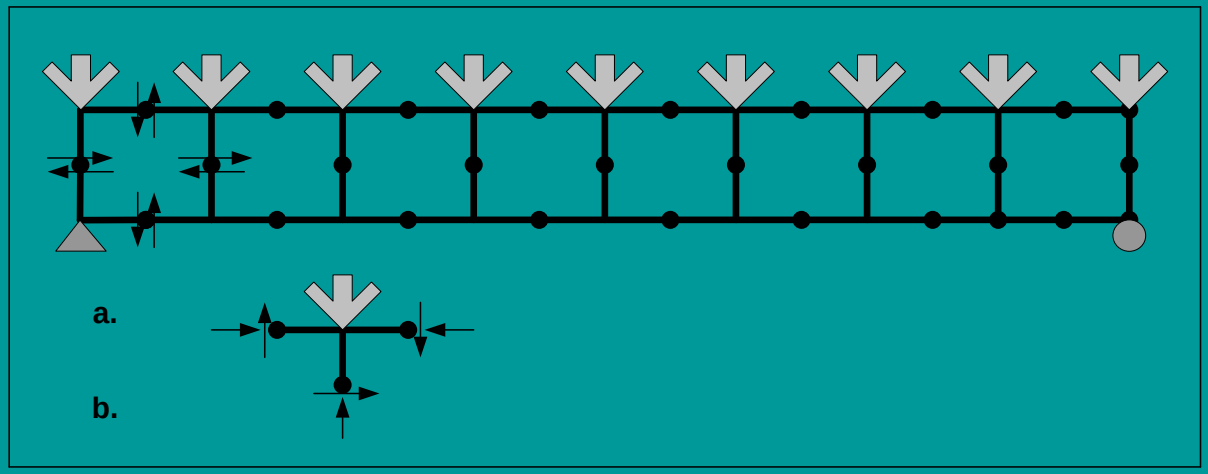

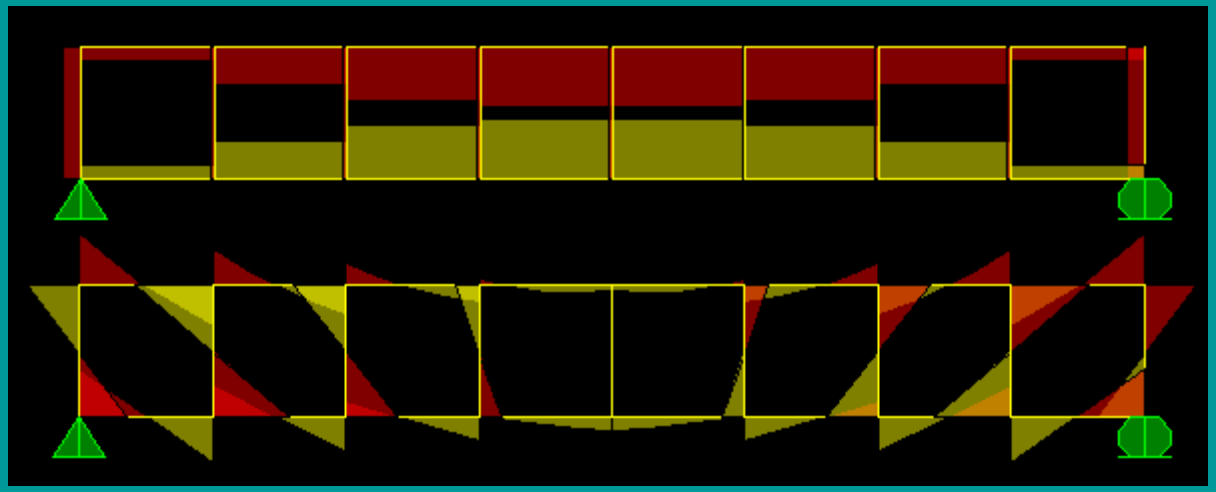

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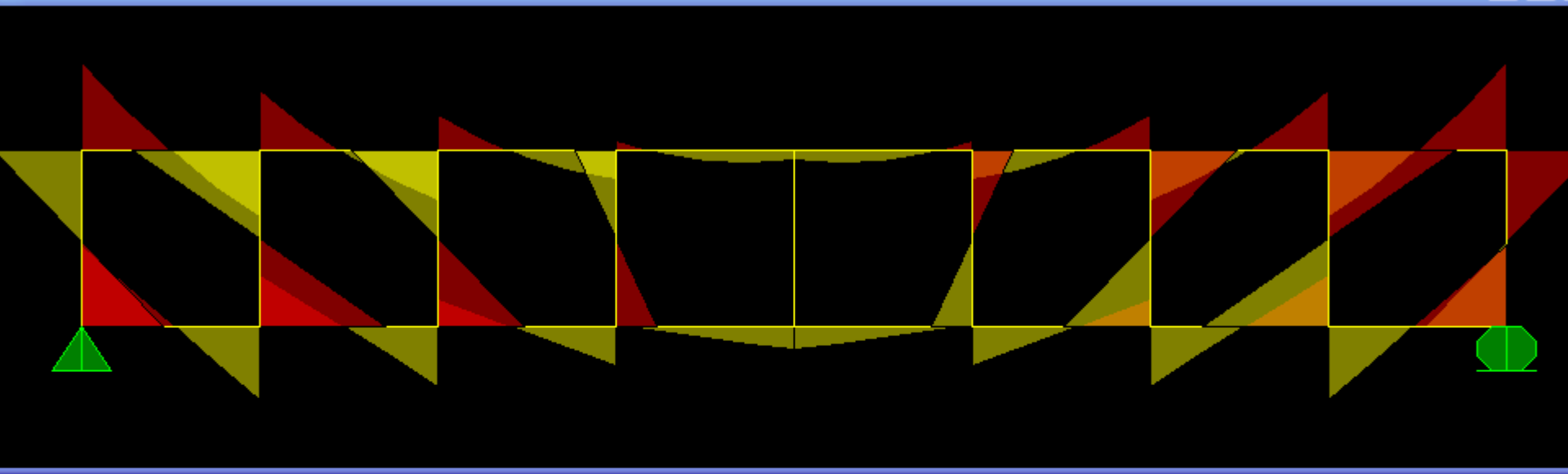
P2000 - Ex. 7.11 Viereendeel truss_V8

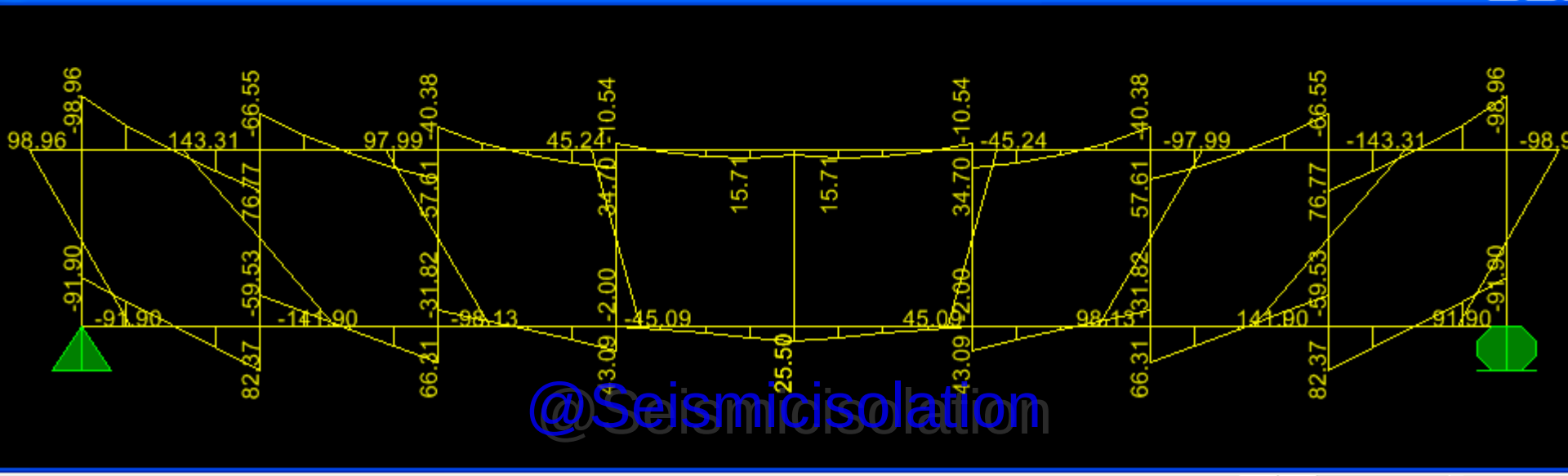
Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Moment 3-3 Diagram (COMB1)



Moment 3-3 Diagram (COMB1)



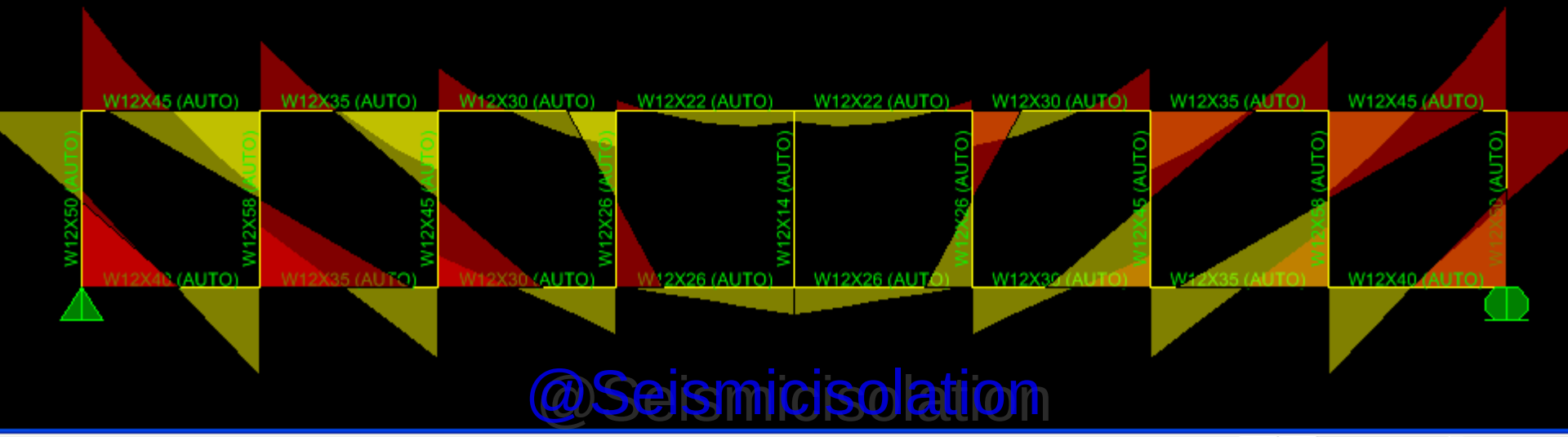
@Seismicisolation

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Axial Force Diagram (COMB1)

Moment 3-3 Diagram (COMB1)



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lick on any Frame Element for detailed diagram

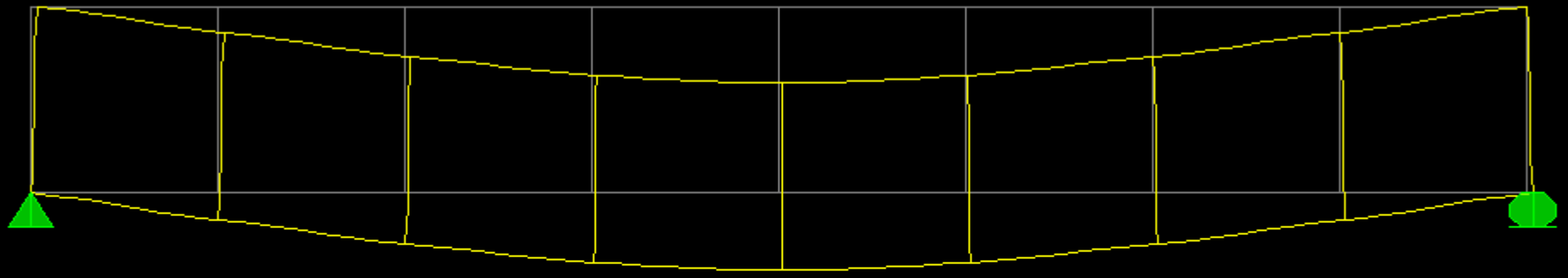
GLOBAL

Kip, ft, F

Edit View Define Draw Select Assign Analyze Display Design Options Help

3-d xy xz yz nv

Deformed Shape (COMB1)



Steel P-M Interaction Ratios (AISC-ASD89)

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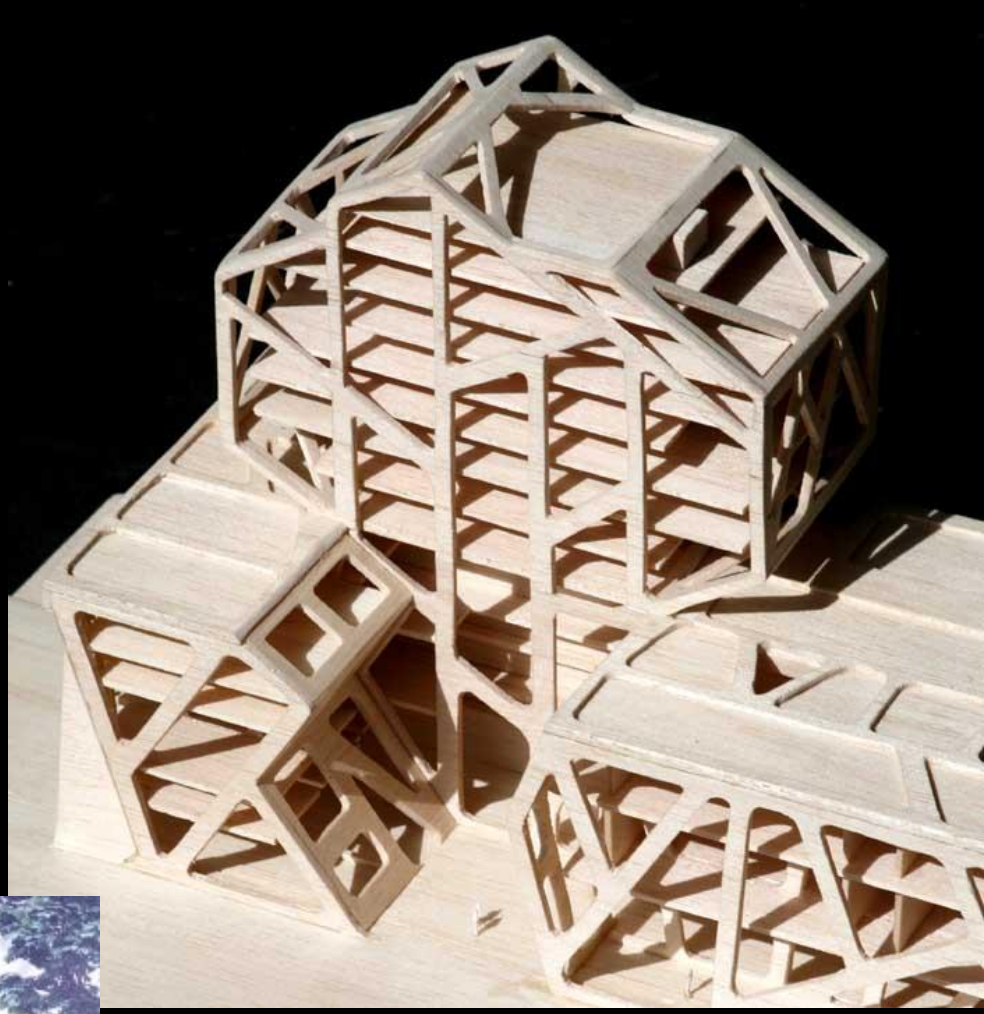
0.00 0.50 0.70 0.90 1.00

Plane @ Y=50 X30.69 Y50.00 Z14.36 GLOBAL Kip, ft, F



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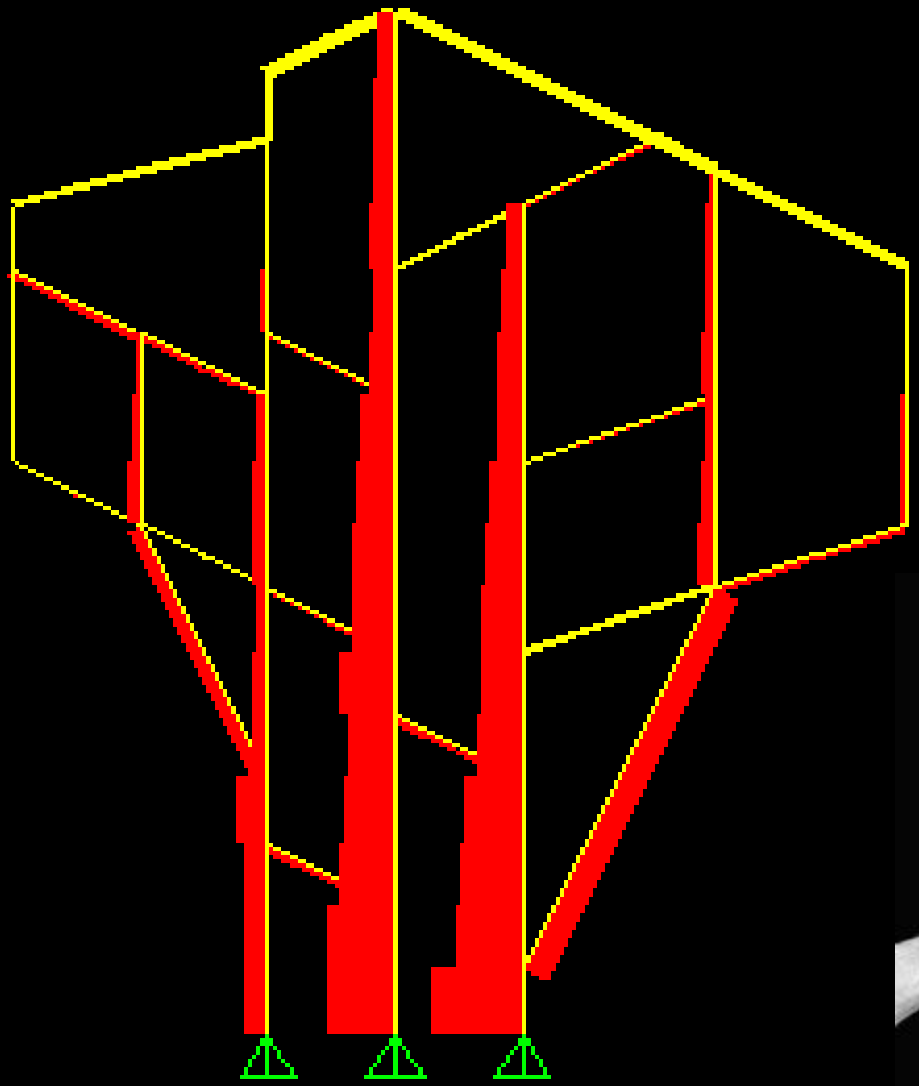
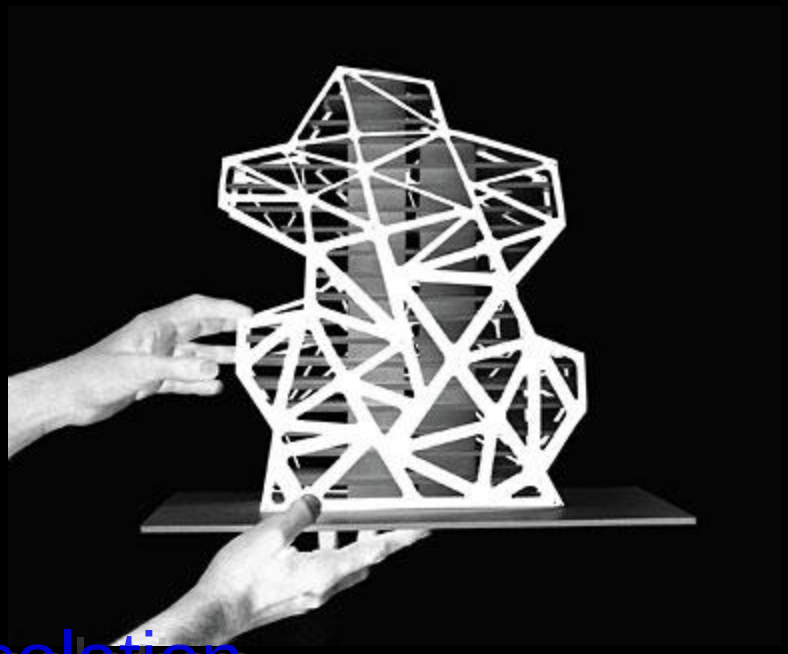
Court of Justice, Hasselt, Belgium, 2011, J. MAYER H. Architects





Axial Gravity Flow in Irregular Frame

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