

Nonlinear Base Isolation Analysis

by

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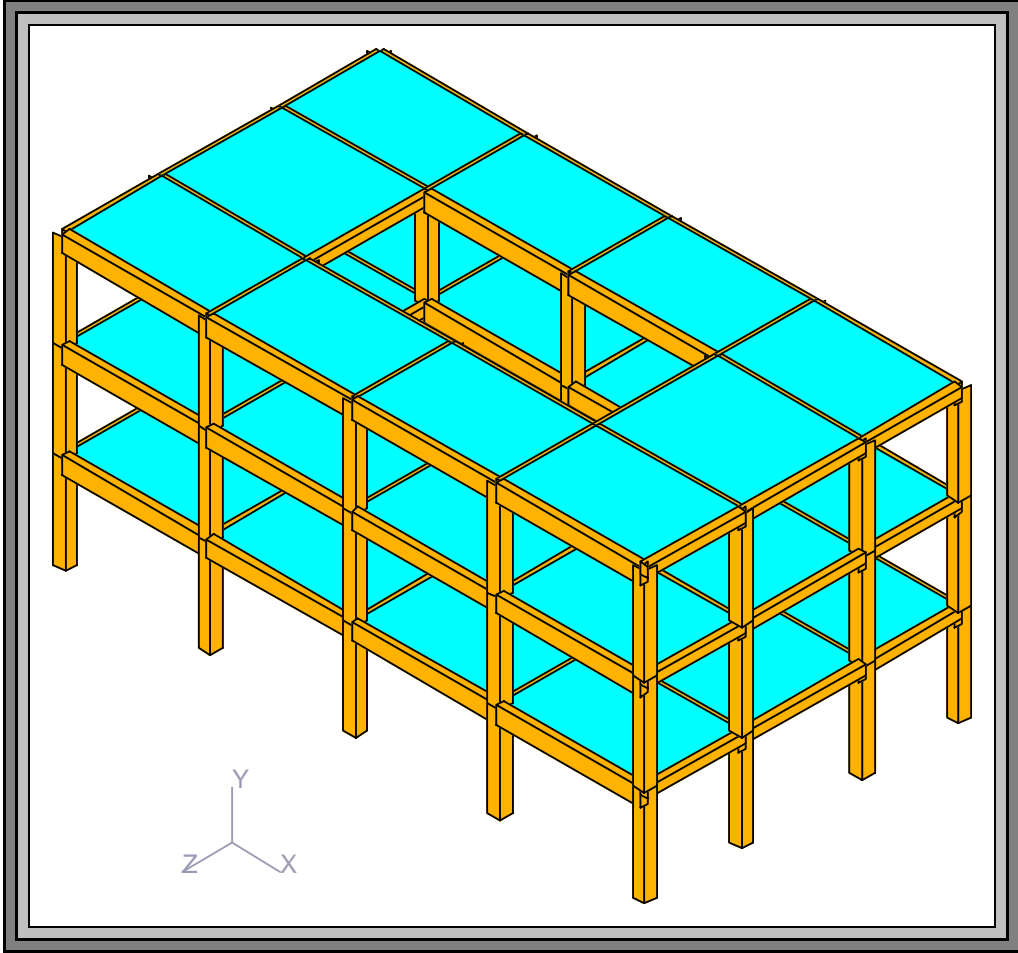
A Nonlinear Base Isolation Analysis using GTSTRUDL 29Beta of a structure with the following characteristics will be described:

Number of:

| | | |
|----------------------------------|---|-----|
| Joints | = | 80 |
| Space Frame Members | = | 150 |
| SBHQ6 FE's | = | 30 |
| Friction Pendulum Base Isolators | = | 20 |

The Friction Pendulum Base Isolators will be located as follows:

1. In demonstration #1, the Friction Pendulum Base Isolators are located at the bottom of each of the 20 bottom story columns.
2. In demonstration #2, the Friction Pendulum Base Isolators are located at the mid-height of each of the 20 bottom story columns.
3. In demonstration #3, the Friction Pendulum Base Isolators are located at the top of each of the 20 bottom story columns.
4. In demonstration #4, no Friction Pendulum Base Isolators are used.



3-Story_Ecc-Static&NonlinearDyn&ColumnBaselsolation-1.gti

Friction Pendulum Base Isolators are located at the bottom of each of the 20 bottom story columns.

```
STRUDL 'Bldg-1' 'Base isolation elements at support joints'
$ Eccentricities and floor slabs

LARGE PROBLEM SIZE 3 $ 1 to 5 is acceptable

OPEN USERDATA FILE '0-RC_Table.ds' READ EXISTING $ Read only

PRINT GENERATE OFF
UNITS M KN
GENERATE 5 JOINTS ID 1 1 X 0 6 Z 18
REPEAT 3 ID 5 Z DIFF -4 -5 -4
REPEAT 3 ID 20 Y 4
STATUS SUPPORT JOINTS 1 TO 20
$
TYPE SPACE FRAME
$ X-DIRECTION BEAMS
GENERATE 4 MEMBERS ID 'XB-1' 1 F 21 1 T 22 1
REPEAT 3 ID 4 F 5
REPEAT 2 ID 16 F 20

$ Z-DIRECTION BEAMS
GENERATE 3 MEMBERS ID 'ZB-1' 1 F 21 5 T 26 5
REPEAT 4 ID 3 F 1
REPEAT 2 ID 15 F 20

$ Y-DIRECTION COLUMNS
GENERATE 5 MEMBERS ID 'YC-1' 1 F 1 1 T 21 1
REPEAT 3 ID 5 F 5
REPEAT 2 ID 20 F 20

$ FLOOR SLABS
GENERATE 4 ELEMENTS ID 'SLAB-1' 1 F 21 1 T 22 1 T 27 1 T 26 1
REPEAT 2 ID 4 F 5
REPEAT 2 ID 12 F 20

MATERIAL CONC
$
UNITS CM
MEMBER PROPERTIES TABLE 'RC-RECT'
  'XB-1' TO 'XB-48' T 'RC30X70'
  'ZB-1' TO 'ZB-45' T 'RC30X40'
  'YC-1' TO 'YC-60' T 'RC50-SQ'

DEFINE GROUP 'COLUMNS' MEMBERS 'YC-1' TO 'YC-60'

MEMBER ECCENTRICITIES
  'XB-1' TO 'XB-48' START Y -35 END Y -35
  'ZB-1' TO 'ZB-45' START Y -20 END Y -20
ELEMENT PROPERTIES
  'SLAB-1' TO 'SLAB-36' TYPE 'SBHQ6' THICK 30
$
$ CREATE 8-STORY ATRIUM AT CENTER OF BUILDING
DELETIONS
MEMBERS 'ZB-8' TO 'ZB-38' BY 15
ELEMENTS 'SLAB-6' TO 'SLAB-30' BY 12
ELEMENTS 'SLAB-7' TO 'SLAB-31' BY 12
ADDITIONS
$
UNITS KN M
SELF WEIGHT 'SELFWT' 'SELF WEIGHT OF MEMBERS AND FINITE ELEMENTS' DIRECTION -Y -
INCLUDE FINITE ELEMENTS ALL MEMBERS
```

LOAD 2 'LIVE LOADS'

MEMBER LOADS

EXISTING 'XB-1' TO 'XB-48' FORCE Y GLOB UNI FR W -7.0
EXISTING 'ZB-1' TO 'ZB-45' FORCE Y GLOB UNI FR W -5.0

LOADING 3 'WL+X'

JOINT LOADS

21 TO 36 BY 5 FORCE X 10.0
41 TO 56 BY 5 FORCE X 20.0
61 TO 76 BY 5 FORCE X 30.0

FORM LOAD 100 'SELF WEIGT + LIVE LOADS' FROM 'SELFWT' 1.0 2 1.0

LOAD COMBINATION 11 'DL+LL+WLX' SPECS 100 1.0 3 1.0

\$ #####

\$ -----
\$ DEFINE NONLINEAR BASE ISOLATION ELEMENTS

\$ -----

JOINT RELEASES

1 TO 20 FORCE X Y Z

UNITS LBS INCH

\$ RD = RADIUS OF BEARING SURFACE (= 0.0 IS A FLAT SURFACE)

\$ UY = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE

\$ AND IS A VIRTUAL CHANGE IN LENGTH OF A VIRTUAL SPRING IN THE SLIDING DIRECTION

\$ WHICH IS THE SAME DIRECTION AS THE VELOCITY OF THE SLIDING SUPPORT JOINT

\$ ON THE FRICTION BEARING SURFACE, AFTER WHICH SLIDING OCCURS

\$ THE STIFFNESS OF THIS VIRTUAL SLIDING RESISTING SPRING

\$ = BREAKAWAY FORCE / UY = (NORMAL FORCE IN THE VIRTUAL NORMAL SPRING x FC) / UY

\$ FC = FRICTION COEFFICIENT (FC USED FOR CONSTANT FRICTION SURFACE RATHER THAN VARIABLE FRICTION SURFACE)

\$ KAX = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE

\$ AND IS REPRESENTED BY A STIFFNESS OF A VIRTUAL SPRING PERPENDICULAR TO THE PLANE OF SLIDING

\$ AND IS A FUNCTION OF THE BEARING SURFACE CHARACTERISTICS.

\$ THIS IS USED TO COMPUTE THE FORCE NORMAL TO THE SLIDING FRICTION SURFACE.

\$ THE DEFAULT VALUE = 1.0E9 LBS/INCH

BASE ISOLATION ELEMENT DATA

'BI-1' TO 'BI-20' -

ATTACHED TO 1 TO 20 -

TYPE FRICTION BEARING PLANE XZ RD 50.0 UY 0.05 KAX 1.0E9 FRICTION CONSTANT FC 0.05

END

\$ 'BI-1' TO 'BI-10' ATTACHED TO 1 TO 10 TYPE FRICTION BEARING PLANE XZ -

\$ RD 0.0 UY 0.01 KAX 1.0E9 FRICTION CONSTANT FC 0.05

\$ 'BI-11' TO 'BI-20' ATTACHED TO JOINTS 11 TO 20 TYPE FRICTION BEARING PLANE XZ -

\$ RD 50.0 UY 0.01 KAX 1.0E9 FRICTION CONSTANT FC 0.05

\$ #####

\$ ---LINEAR STATIC ANALYSIS NEXT-----

\$ Perform linear static analysis

QUERY

STIFFNESS ANALYSIS GTSES \$ <<<-----GT X-Static Equation Solver

UNITS CM CYCLES SECS

LIST DISPLACEMENTS JOINTS 61 65 76 80

UNITS M

LIST FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'

LIST SUM REACTIONS

\$ -----

```

$ -----
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----
$ -----

TRANSIENT LOAD 'EQ-XYZ'
SUPPORT ACCELERATION
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Y FILE 'ELCENTRO' FACTOR 0.35
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005
END TRANSIENT LOAD

INERTIA OF JOINTS LUMPED          $ MASS OF ALL MEMBERS AND FINITE ELEMENTS
INERTIA OF JOINTS FROM LOAD 2 ALL DOF $ MASS FROM STATIC LOAD 2

$ *****
$ ***** DYNAMIC PARAMETERS *****
$ *****
DYNAMIC PARAMETERS
  MAXIMUM NUMBER OF EQUILIBRIUM CYCLES 1000
  CONVERGENCE TOLERANCE 0.001
  PRINT MAX
  STORE VELOCITIES OFF
  STORE ACCELERATIONS OFF
$ USE EXTERNAL FILE SOLVER <<<-----This is the default for nonlinear dynamic analysis
  RESULTS FILE NAME 'BaseIsolation-1'
  INITIAL STRESS LOAD 100
END DYNAMIC PARAMETERS
$ *****

DAMPING PROPORTIONAL TO STIFFNESS 0.0001 MASS 1.35

$ $*****
$ ***** DYNAMIC ANALYSIS NONLINEAR *****
$ *****

LOAD LIST 'EQ-XYZ'

$ =====
$ Nonlinear Transient Dynamic Analysis (GTSTRUDL 29Beta)
$ The Georgia Tech Advanced Nonlinear Transient Dynamic Analysis Solver ("GTSES" or "GTSMS")
$ in GTSTRUDL 29Beta is a super-fast "in-core" nonlinear dynamic analysis solver that is
$ particularly fast for extremely large structural models.

QUERY
DYNAMIC ANALYSIS NONLINEAR GTSES $ <<<-----GT X-Nonlinear Transient Dynamic Analysis Equation Solver
$ =====

  COMPUTE TRANSIENT FORCE      TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT STRESS     TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT REACTION   TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT LOAD       TIME FROM 0.00 TO 20.00 AT 0.005

SAVE 'BaseIsolation-1.gts'

$ -----
  UNIT MM RAD
  LIST TRANSIENT MAXIMUM DISPLACEMENTS JOINTS 61 65 76 80
$ -----

  UNIT M KN RAD
$ Max Force
  LIST TRANSIENT MAXIMUM FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'

LOAD LIST ALL

CINPUT
$ FIN

```

3-Story_Ecc-Static&NonlinearDyn&ColumnBaselsolation-1a.gti

Same as 1.gti, except Y-component of the earthquake is eliminated:

```
$ -----  
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----  
$ -----
```

```
TRANSIENT LOAD 'EQ-XYZ'  
SUPPORT ACCELERATION  
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707  
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707  
$ TRANSL Y FILE 'ELCENTRO' FACTOR 0.35  
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005  
END TRANSIENT LOAD
```

3-Story_Ecc-Static&NonlinearDyn&ColumnBaseIsolation-2.gti

Friction Pendulum Base Isolators are located at the mid-height of each of the 20 bottom story columns.

```
STRU DL 'Bldg-2' 'Base isolation elements at middle of bottom story columns'  
$ Eccentricities and floor slabs
```

```
LARGE PROBLEM SIZE 3 $ 1 to 5 is acceptable
```

```
OPEN USERDATA FILE '0-RC_Table.ds' READ EXISTING $ Read only
```

```
PRINT GENERATE OFF  
UNITS M KN
```

```
$ SUPPORT JOINTS
```

```
GENERATE 5 JOINTS ID 'S1' 1 X 0 6 Z 18  
REPEAT 3 ID 5 Z DIFF -4 -5 -4
```

```
$ JOINTS AT MIDHEIGHT OF COLUMNS OF FIRST STORY
```

```
GENERATE 5 JOINTS ID 101 1 X 0 6 Y 2 Z 18  
REPEAT 3 ID 5 Z DIFF -4 -5 -4
```

```
GENERATE 5 JOINTS ID 1 1 X 0 6 Y 2 Z 18  
REPEAT 3 ID 5 Z DIFF -4 -5 -4  
REPEAT 3 ID 20 Y DIFF 2 4 4
```

```
STATUS SUPPORT JOINTS 'S1' TO 'S20'
```

```
TYPE SPACE FRAME
```

```
$ X-DIRECTION BEAMS
```

```
GENERATE 4 MEMBERS ID 'XB-1' 1 F 21 1 T 22 1  
REPEAT 3 ID 4 F 5  
REPEAT 2 ID 16 F 20
```

```
$ Z-DIRECTION BEAMS
```

```
GENERATE 3 MEMBERS ID 'ZB-1' 1 F 21 5 T 26 5  
REPEAT 4 ID 3 F 1  
REPEAT 2 ID 15 F 20
```

```
$ Y-DIRECTION COLUMNS
```

```
GENERATE 5 MEMBERS ID 'YCS-1' 1 F 'S1' 1 T 101 1  
REPEAT 3 ID 5 F 5
```

```
GENERATE 5 MEMBERS ID 'YC-1' 1 F 1 1 T 21 1  
REPEAT 3 ID 5 F 5  
REPEAT 2 ID 20 F 20
```

```
$ FLOOR SLABS
```

```
GENERATE 4 ELEMENTS ID 'SLAB-1' 1 F 21 1 T 22 1 T 27 1 T 26 1  
REPEAT 2 ID 4 F 5  
REPEAT 2 ID 12 F 20
```

```
MATERIAL CONC
```

```
$
```

```
UNITS CM
```

```
MEMBER PROPERTIES TABLE 'RC-RECT'
```

```
'XB-1' TO 'XB-48' T 'RC30X70'  
'ZB-1' TO 'ZB-45' T 'RC30X40'  
'YC-1' TO 'YC-60' T 'RC50-SQ'  
'YCS-1' TO 'YCS-20' T 'RC50-SQ'
```

```
DEFINE GROUP 'COLUMNS' MEMBERS 'YC-1' TO 'YC-60'
```

MEMBER ECCENTRICITIES

'XB-1' TO 'XB-48' START Y -35 END Y -35
'ZB-1' TO 'ZB-45' START Y -20 END Y -20

ELEMENT PROPERTIES

'SLAB-1' TO 'SLAB-36' TYPE 'SBHQ6' THICK 30

\$ CREATE 8-STORY ATRIUM AT CENTER OF BUILDING

DELETIONS

MEMBERS 'ZB-8' TO 'ZB-38' BY 15
ELEMENTS 'SLAB-6' TO 'SLAB-30' BY 12
ELEMENTS 'SLAB-7' TO 'SLAB-31' BY 12

ADDITIONS

UNITS KN M

SELF WEIGHT 'SELFWT' 'SELF WEIGHT OF MEMBERS AND FINITE ELEMENTS' DIRECTION -Y -
INCLUDE FINITE ELEMENTS ALL MEMBERS

LOAD 2 'LIVE LOADS'

MEMBER LOADS

EXISTING 'XB-1' TO 'XB-48' FORCE Y GLOB UNI FR W -7.0
EXISTING 'ZB-1' TO 'ZB-45' FORCE Y GLOB UNI FR W -5.0

LOADING 3 'WL+X'

JOINT LOADS

21 TO 36 BY 5 FORCE X 10.0
41 TO 56 BY 5 FORCE X 20.0
61 TO 76 BY 5 FORCE X 30.0

FORM LOAD 100 'SELF WEIGT + LIVE LOADS' FROM 'SELFWT' 1.0 2 1.0

LOAD COMBINATION 11 'DL+LL+WLX' SPECS 100 1.0 3 1.0

\$ #####
\$ -----
\$ DEFINE NONLINEAR BASE ISOLATION ELEMENTS
\$ -----

UNITS LBS INCH

\$ RD = RADIOUS OF BEARING SURFACE (= 0.0 IS A FLAT SURFACE)
\$ UY = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE
\$ AND IS A VIRTUAL CHANGE IN LENGTH OF A VIRTUAL SPRING IN THE SLIDING DIRECTION
\$ WHICH IS THE SAME DIRECTION AS THE VELOCITY OF THE SLIDING SUPPORT JOINT
\$ ON THE FRICTION BEARING SURFACE, AFTER WHICH SLIDING OCCURS
\$ THE STIFFNESS OF THIS VIRTUAL SLIDING RESISTING SPRING
\$ = BREAKAWAY FORCE / UY = (NORMAL FORCE IN THE VIRTUAL NORMAL SPRING x FC)/UY
\$ FC = FRICTION COEFFICIENT (FC USED FOR CONSTANT FRICTION SURFACE RATHER THAN VARIABLE FRICTION SURFACE)
\$ KAX = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE
\$ AND IS REPRESENTED BY A STIFFNESS OF A VIRTUAL SPRING PERPENDICULAR TO THE PLANE OF SLIDING
\$ AND IS A FUNCTION OF THE BEARING SURFACE CHARACTERISTICS.
\$ THS IS USED TO COMPUTE THE FORCE NORMAL TO THE SLIDING FRICTION SURFACE.
\$ THE DEFAULT VALUE = 1.0E9 LBS/INCH

BASE ISOLATION ELEMENT DATA

'BI-1' TO 'BI-20' -
INCIDENCES START 101 TO 120 END 1 TO 20 -
TYPE FRICTION BEARING PLANE XZ RD 50.0 UY 0.05 KAX 1.0E9 FRICTION CONSTANT FC 0.05

END

\$ #####

\$ ---LINEAR STATIC ANALYSIS NEXT-----

\$ Perform linear static analysis

QUERY

STIFFNESS ANALYSIS GTSES \$ <<<-----GT X-Static Equation Solver

```

UNITS CM CYCLES SECS
LIST DISPLACEMENTS JOINTS 61 65 76 80
UNITS M
LIST FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'
LIST SUM REACTIONS
$ -----
$ -----
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----
$ -----
TRANSIENT LOAD 'EQ-XYZ'
SUPPORT ACCELERATION
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Y FILE 'ELCENTRO' FACTOR 0.35
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005
END TRANSIENT LOAD

INERTIA OF JOINTS LUMPED          $ MASS OF ALL MEMBERS AND FINITE ELEMENTS
INERTIA OF JOINTS FROM LOAD 2 ALL DOF $ MASS FROM STATIC LOAD 2

$ *****
$ ***** DYNAMIC PARAMETERS
$ *****
DYNAMIC PARAMETERS
  MAXIMUM NUMBER OF EQUILIBRIUM CYCLES 1000
  CONVERGENCE TOLERANCE 0.001
  PRINT MAX
  STORE VELOCITIES OFF
  STORE ACCELERATIONS OFF
$ USE EXTERNAL FILE SOLVER <<<-----This is the default for nonlinear dynamic analysis
  RESULTS FILE NAME 'BaseIsolation-2'
  INITIAL STRESS LOAD 100
END DYNAMIC PARAMETERS
$ *****

  DAMPING PROPORTIONAL TO STIFFNESS 0.0001 MASS 1.35

$ $$$*****
$ ***** DYNAMIC ANALYSIS NONLINEAR
$ *****
LOAD LIST 'EQ-XYZ'

$ =====
$ Nonlinear Transient Dynamic Analysis (GTSTRU DL 29Beta)
$ The Georgia Tech Advanced Nonlinear Transient Dynamic Analysis Solver ("GTSES" or "GTSMS")
$ in GTSTRU DL 29Beta is a super-fast "in-core" nonlinear dynamic analysis solver that is
$ particularly fast for extremely large structural models.

QUERY
DYNAMIC ANALYSIS NONLINEAR GTSES $ <<<-----GT X-Nonlinear Transient Dynamic Analysis Equation Solver
$ =====
  COMPUTE TRANSIENT FORCE      TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT STRESS     TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT REACTION   TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT LOAD       TIME FROM 0.00 TO 20.00 AT 0.005

SAVE 'BaseIsolation-2.gts'
$ -----
  UNIT MM RAD
  LIST TRANSIENT MAXIMUM DISPLACEMENTS JOINTS 61 65 76 80
$ -----
  UNIT M KN RAD
$ Max Force
  LIST TRANSIENT MAXIMUM FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'
LOAD LIST ALL
CINPUT
$ FIN

```

3-Story_Ecc-Static&NonlinearDyn&ColumnBaselsolation-2a.gti

Same as 2.gti, except Y-component of the earthquake is eliminated:

```
$ -----  
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----  
$ -----
```

```
TRANSIENT LOAD 'EQ-XYZ'  
SUPPORT ACCELERATION  
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707  
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707  
$ TRANSL Y FILE 'ELCENTRO' FACTOR 0.35  
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005  
END TRANSIENT LOAD
```

3-Story_Ecc-Static&NonlinearDyn&ColumnBaseIsolation-3.gti

Friction Pendulum Base Isolators are located at the top of each of the 20 bottom story columns.

```
STRUDL 'Bldg-3' 'Base isolation elements at top of bottom story columns'  
$ Eccentricities and floor slabs
```

```
LARGE PROBLEM SIZE 3 $ 1 to 5 is acceptable
```

```
OPEN USERDATA FILE '0-RC_Table.ds' READ EXISTING $ Read only
```

```
PRINT GENERATE OFF
```

```
UNITS M KN
```

```
GENERATE 5 JOINTS ID 1 1 X 0 6 Y 0 Z 18
```

```
REPEAT 3 ID 5 Z DIFF -4 -5 -4
```

```
REPEAT 3 ID 20 Y 4
```

```
$ JOINTS AT TOP OF COLUMNS OF FIRST STORY
```

```
GENERATE 5 JOINTS ID 101 1 X 0 6 Y 4 Z 18
```

```
REPEAT 3 ID 5 Z DIFF -4 -5 -4
```

```
STATUS SUPPORT JOINTS 1 TO 20
```

```
$
```

```
TYPE SPACE FRAME
```

```
$ X-DIRECTION BEAMS
```

```
GENERATE 4 MEMBERS ID 'XB-1' 1 F 21 1 T 22 1
```

```
REPEAT 3 ID 4 F 5
```

```
REPEAT 2 ID 16 F 20
```

```
$ Z-DIRECTION BEAMS
```

```
GENERATE 3 MEMBERS ID 'ZB-1' 1 F 21 5 T 26 5
```

```
REPEAT 4 ID 3 F 1
```

```
REPEAT 2 ID 15 F 20
```

```
$ Y-DIRECTION COLUMNS
```

```
GENERATE 5 MEMBERS ID 'YC-1' 1 F 1 1 T 101 1
```

```
REPEAT 3 ID 5 F 5
```

```
GENERATE 5 MEMBERS ID 'YC-21' 1 F 21 1 T 41 1
```

```
REPEAT 3 ID 5 F 5
```

```
REPEAT 1 ID 20 F 20
```

```
$ FLOOR SLABS
```

```
GENERATE 4 ELEMENTS ID 'SLAB-1' 1 F 21 1 T 22 1 T 27 1 T 26 1
```

```
REPEAT 2 ID 4 F 5
```

```
REPEAT 2 ID 12 F 20
```

```
MATERIAL CONC
```

```
$
```

```
UNITS CM
```

```
MEMBER PROPERTIES TABLE 'RC-RECT'
```

```
'XB-1' TO 'XB-48' T 'RC30X70'
```

```
'ZB-1' TO 'ZB-45' T 'RC30X40'
```

```
'YC-1' TO 'YC-60' T 'RC50-SQ'
```

```
DEFINE GROUP 'COLUMNS' MEMBERS 'YC-1' TO 'YC-60'
```

```
MEMBER ECCENTRICITIES
```

```
'XB-1' TO 'XB-48' START Y -35 END Y -35
```

```
'ZB-1' TO 'ZB-45' START Y -20 END Y -20
```

ELEMENT PROPERTIES

'SLAB-1' TO 'SLAB-36' TYPE 'SBHQ6' THICK 30

\$

\$ CREATE 8-STORY ATRIUM AT CENTER OF BUILDING

DELETIONS

MEMBERS 'ZB-8' TO 'ZB-38' BY 15

ELEMENTS 'SLAB-6' TO 'SLAB-30' BY 12

ELEMENTS 'SLAB-7' TO 'SLAB-31' BY 12

ADDITIONS

\$

UNITS KN M

SELF WEIGHT 'SELFWT' 'SELF WEIGHT OF MEMBERS AND FINITE ELEMENTS' DIRECTION -Y -

INCLUDE FINITE ELEMENTS ALL MEMBERS

LOAD 2 'LIVE LOADS'

MEMBER LOADS

EXISTING 'XB-1' TO 'XB-48' FORCE Y GLOB UNI FR W -7.0

EXISTING 'ZB-1' TO 'ZB-45' FORCE Y GLOB UNI FR W -5.0

LOADING 3 'WL+X'

JOINT LOADS

21 TO 36 BY 5 FORCE X 10.0

41 TO 56 BY 5 FORCE X 20.0

61 TO 76 BY 5 FORCE X 30.0

FORM LOAD 100 'SELF WEIGT + LIVE LOADS' FROM 'SELFWT' 1.0 2 1.0

LOAD COMBINATION 11 'DL+LL+WLX' SPECS 100 1.0 3 1.0

\$ #####

\$ -----

\$ DEFINE NONLINEAR BASE ISOLATION ELEMENTS

\$ -----

UNITS LBS INCH

\$ RD = RADIUS OF BEARING SURFACE (= 0.0 IS A FLAT SURFACE)

\$ UY = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE

\$ AND IS A VIRTUAL CHANGE IN LENGTH OF A VIRTUAL SPRING IN THE SLIDING DIRECTION

\$ WHICH IS THE SAME DIRECTION AS THE VELOCITY OF THE SLIDING SUPPORT JOINT

\$ ON THE FRICTION BEARING SURFACE, AFTER WHICH SLIDING OCCURS

\$ THE STIFFNESS OF THIS VIRTUAL SLIDING RESISTING SPRING

\$ = BREAKAWAY FORCE / UY = (NORMAL FORCE IN THE VIRTUAL NORMAL SPRING x FC) / UY

\$ FC = FRICTION COEFFICIENT (FC USED FOR CONSTANT FRICTION SURFACE RATHER THAN VARIABLE FRICTION SURFACE)

\$ KAX = A VALUE PROVIDED BY THE MANUFACTURER OF THE FRICTION BEARING DEVICE

\$ AND IS REPRESENTED BY A STIFFNESS OF A VIRTUAL SPRING PERPENDICULAR TO THE PLANE OF SLIDING

\$ AND IS A FUNCTION OF THE BEARING SURFACE CHARACTERISTICS.

\$ THIS IS USED TO COMPUTE THE FORCE NORMAL TO THE SLIDING FRICTION SURFACE.

\$ THE DEFAULT VALUE = 1.0E9 LBS/INCH

BASE ISOLATION ELEMENT DATA

'BI-1' TO 'BI-20' -

INCIDENCES START 101 TO 120 END 21 TO 40 -

TYPE FRICTION BEARING PLANE XZ RD 50.0 UY 0.05 KAX 1.0E9 FRICTION CONSTANT FC 0.05

END

\$ #####

\$ ---LINEAR STATIC ANALYSIS NEXT-----

\$ Perform linear static analysis

QUERY

STIFFNESS ANALYSIS GTSES \$ <<<-----GT X-Static Equation Solver

UNITS CM CYCLES SECS

LIST DISPLACEMENTS JOINTS 61 65 76 80

UNITS M

LIST FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'

LIST SUM REACTIONS

```

$ -----
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----
$ -----
TRANSIENT LOAD 'EQ-XYZ'
SUPPORT ACCELERATION
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Y FILE 'ELCENTRO' FACTOR 0.35
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005
END TRANSIENT LOAD

INERTIA OF JOINTS LUMPED          $ MASS OF ALL MEMBERS AND FINITE ELEMENTS
INERTIA OF JOINTS FROM LOAD 2 ALL DOF $ MASS FROM STATIC LOAD 2

$ *****
$ ***** DYNAMIC PARAMETERS
$ *****
DYNAMIC PARAMETERS
  MAXIMUM NUMBER OF EQUILIBRIUM CYCLES 1000
  CONVERGENCE TOLERANCE 0.001
  PRINT MAX
  STORE VELOCITIES OFF
  STORE ACCELERATIONS OFF
$ USE EXTERNAL FILE SOLVER <<<-----This is the default for nonlinear dynamic analysis
  RESULTS FILE NAME 'BaseIsolation-3'
  INITIAL STRESS LOAD 100
END DYNAMIC PARAMETERS
$ *****

DAMPING PROPORTIONAL TO STIFFNESS 0.0001 MASS 1.35

$ $*****
$ ***** DYNAMIC ANALYSIS NONLINEAR
$ *****

LOAD LIST 'EQ-XYZ'

$ =====
$ Nonlinear Transient Dynamic Analysis (GTSTRUDL 29Beta)
$ The Georgia Tech Advanced Nonlinear Transient Dynamic Analysis Solver ("GTSES" or "GTSMS")
$ in GTSTRUDL 29Beta is a super-fast "in-core" nonlinear dynamic analysis solver that is
$ particularly fast for extremely large structural models.

QUERY
DYNAMIC ANALYSIS NONLINEAR GTSES $ <<<-----GT X-Nonlinear Transient Dynamic Analysis Solver
$ =====

  COMPUTE TRANSIENT FORCE      TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT STRESS     TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT REACTION   TIME FROM 0.00 TO 20.00 AT 0.005
  COMPUTE TRANSIENT LOAD       TIME FROM 0.00 TO 20.00 AT 0.005

SAVE 'BaseIsolation-3.gts'

$ -----
UNIT MM RAD
  LIST TRANSIENT MAXIMUM DISPLACEMENTS JOINTS 61 65 76 80
$ -----

UNIT M KN RAD
$ Max Force
  LIST TRANSIENT MAXIMUM FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'

LOAD LIST ALL

CINPUT
$ FIN

```

3-Story_Ecc-Static&NonlinearDyn&ColumnBaselsolation-3a.gti

Same as 3.gti, except Y-component of the earthquake is eliminated:

```
$ -----  
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----  
$ -----
```

```
TRANSIENT LOAD 'EQ-XYZ'  
SUPPORT ACCELERATION  
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707  
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707  
$ TRANSL Y FILE 'ELCENTRO' FACTOR 0.35  
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005  
END TRANSIENT LOAD
```

3-Story_Ecc-Static&NonlinearDyn&NoBaselIsolation.gti

No Friction Pendulum Base Isolators are used.

```
STRU DL 'Bldg' 'No Base Isolation'
$ Eccentricities and floor slabs

LARGE PROBLEM SIZE 3 $ 1 to 5 is acceptable

OPEN USERDATA FILE '0-RC_Table.ds' READ EXISTING $ Read only

PRINT GENERATION OFF
UNITS M KN
GENERATE 5 JOINTS ID 1 1 X 0 6 Z 18
REPEAT 3 ID 5 Z DIFF -4 -5 -4
REPEAT 3 ID 20 Y 4
STATUS SUPPORT JOINTS 1 TO 20
$
TYPE SPACE FRAME
$ X-DIRECTION BEAMS
GENERATE 4 MEMBERS ID 'XB-1' 1 F 21 1 T 22 1
REPEAT 3 ID 4 F 5
REPEAT 2 ID 16 F 20

$ Z-DIRECTION BEAMS
GENERATE 3 MEMBERS ID 'ZB-1' 1 F 21 5 T 26 5
REPEAT 4 ID 3 F 1
REPEAT 2 ID 15 F 20

$ Y-DIRECTION COLUMNS
GENERATE 5 MEMBERS ID 'YC-1' 1 F 1 1 T 21 1
REPEAT 3 ID 5 F 5
REPEAT 2 ID 20 F 20

$ FLOOR SLABS
GENERATE 4 ELEMENTS ID 'SLAB-1' 1 F 21 1 T 22 1 T 27 1 T 26 1
REPEAT 2 ID 4 F 5
REPEAT 2 ID 12 F 20

MATERIAL CONC
$
UNITS CM
MEMBER PROPERTIES TABLE 'RC-RECT'
'XB-1' TO 'XB-48' T 'RC30X70'
'ZB-1' TO 'ZB-45' T 'RC30X40'
'YC-1' TO 'YC-60' T 'RC50-SQ'

DEFINE GROUP 'COLUMNS' MEMBERS 'YC-1' TO 'YC-60'

MEMBER ECCENTRICITIES
'XB-1' TO 'XB-48' START Y -35 END Y -35
'ZB-1' TO 'ZB-45' START Y -20 END Y -20
ELEMENT PROPERTIES
'SLAB-1' TO 'SLAB-36' TYPE 'SBHQ6' THICK 30
$
$ CREATE 8-STORY ATRIUM AT CENTER OF BUILDING
DELETIONS
MEMBERS 'ZB-8' TO 'ZB-38' BY 15
ELEMENTS 'SLAB-6' TO 'SLAB-30' BY 12
ELEMENTS 'SLAB-7' TO 'SLAB-31' BY 12
ADDITIONS
$
UNITS KN M
SELF WEIGHT 'SELFWT' 'SELF WEIGHT OF MEMBERS AND FINITE ELEMENTS' DIRECTION -Y -
INCLUDE FINITE ELEMENTS ALL MEMBERS
```

```

LOAD 2 'LIVE LOADS'
MEMBER LOADS
  EXISTING 'XB-1' TO 'XB-48' FORCE Y GLOB UNI FR W -7.0
  EXISTING 'ZB-1' TO 'ZB-45' FORCE Y GLOB UNI FR W -5.0

LOADING 3 'WL+X'
JOINT LOADS
  21 TO 36 BY 5   FORCE X 10.0
  41 TO 56 BY 5   FORCE X 20.0
  61 TO 76 BY 5   FORCE X 30.0

FORM LOAD 100 'SELF WEIGT + LIVE LOADS' FROM 'SELFWT' 1.0 2 1.0
LOAD COMBINATION 11 'DL+LL+WLX' SPECS 100 1.0 3 1.0

$ ---LINEAR STATIC ANALYSIS NEXT-----

$ Perform linear static analysis
QUERY
STIFFNESS ANALYSIS GTSES $ <<<-----GT X-Static Equation Solver

UNITS CM CYCLES SECS
LIST DISPLACEMENTS JOINTS 61 65 76 80
UNITS M
LIST FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'
LIST SUM REACTIONS
$ -----

$ -----
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----
$ -----

TRANSIENT LOAD 'EQ-XYZ'
SUPPORT ACCELERATION
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707
  TRANSL Y FILE 'ELCENTRO' FACTOR 0.35
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005
END TRANSIENT LOAD

INERTIA OF JOINTS LUMPED           $ MASS OF ALL MEMBERS AND FINITE ELEMENTS
INERTIA OF JOINTS FROM LOAD 2 ALL DOF $ MASS FROM STATIC LOAD 2

$ *****
$ ***** DYNAMIC PARAMETERS
$ *****
DYNAMIC PARAMETERS
  MAXIMUM NUMBER OF EQUILIBRIUM CYCLES 1000
  CONVERGENCE TOLERANCE 0.001
  PRINT MAX
  STORE VELOCITIES OFF
  STORE ACCELERATIONS OFF
$ USE EXTERNAL FILE SOLVER <<<-----This is the default for nonlinear dynamic analysis
  RESULTS FILE NAME 'NoBaseIsolation'
  INITIAL STRESS LOAD 100
END DYNAMIC PARAMETERS

  DAMPING PROPORTIONAL TO STIFFNESS 0.0001 MASS 1.35

$ *****
$ ***** DYNAMIC ANALYSIS NONLINEAR
$ *****
LOAD LIST 'EQ-XYZ'
$ =====
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$ in GTSTRU DL 29Beta is a super-fast "in-core" nonlinear dynamic analysis solver that is
$ particularly fast for extremely large structural models.

QUERY
DYNAMIC ANALYSIS NONLINEAR GTSES $ <<<-----GT X-Nonlinear Transient Dynamic Analysis Equation Solver
$ =====

```

```
COMPUTE TRANSIENT FORCE      TIME FROM 0.00 TO 20.00 AT 0.005
COMPUTE TRANSIENT STRESS    TIME FROM 0.00 TO 20.00 AT 0.005
COMPUTE TRANSIENT REACTION  TIME FROM 0.00 TO 20.00 AT 0.005
COMPUTE TRANSIENT LOAD      TIME FROM 0.00 TO 20.00 AT 0.005

SAVE 'NoBaseIsolation.gts'

$ -----
UNIT MM RAD
LIST TRANSIENT MAXIMUM DISPLACEMENTS JOINTS 61 65 76 80
$ -----

UNIT M KN RAD
$ Max Force
LIST TRANSIENT MAXIMUM FORCES MEMBERS 'XB-1' 'ZB-1' 'YC-1'

LOAD LIST ALL

CINPUT
$ FIN
```

3-Story_Ecc-Static&NonlinearDyn&NoBaselsolation-a.gti

Same as .gti, except Y-component of the earthquake is eliminated:

```
$ -----  
$ ---NONLINEAR DYNAMIC ANALYSIS NEXT-----  
$ -----
```

```
TRANSIENT LOAD 'EQ-XYZ'  
SUPPORT ACCELERATION  
  TRANSL X FILE 'ELCENTRO' FACTOR 0.707  
  TRANSL Z FILE 'ELCENTRO' FACTOR 0.707  
$ TRANSL Y FILE 'ELCENTRO' FACTOR 0.35  
  INTEGRATE FROM 0.0 TO 20.0 AT 0.005  
END TRANSIENT LOAD
```