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## PURDUE UNIVERSITY GRADUATE SCHOOL Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Nicholas R. Skok

#### Entitled

EVALUATION OF COLLAPSE INDICATORS FOR SEISMICALLY VULNERABLE REINFORCED CONCRETE BUILDINGS

For the degree of Master of Science in Civil Engineering

Is approved by the final examining committee:

Santiago Pujol

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## EVALUATION OF COLLAPSE INDICATORS FOR SEISMICALLY VULNERABLE REINFORCED CONCRETE BUILDINGS

A Thesis

Submitted to the Faculty

of

Purdue University

by

Nicholas R. Skok

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Civil Engineering

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West Lafayette, Indiana

To my parents.

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#### ABSTRACT

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Older reinforced concrete buildings can be prone to column shear and compression failures during earthquakes because of inadequate transverse reinforcement. Cities in seismic areas still have large inventories of older and potentially deficient buildings. To analyze every building and estimate its vulnerability in detail is costly. A simple method to rank quickly older buildings according to their seismic vulnerability is needed to help engineers prioritize the use of resources for rehabilitating the most vulnerable buildings.

Four indicators of building damage or collapse were evaluated using numerical analysis and prior data from building surveys: column index (Hassan and Sozen, 1997), R factor, ratio of column shear capacity to plastic shear demand, and ratio of column moment capacity to beam moment capacity. Idealized building frames were studied using nonlinear numerical analysis. Numerical models of these building frames with different spans, column sizes, numbers of floors, and transverse reinforcement ratios were analyzed with 44 ground motion records. Each numerical analysis used an algorithm to estimate whether a hypothetical building represented by a numerical model was likely to be severely damaged by strong ground motion.

Among the four indicators studied, the column index was observed to be 1) the simplest and 2) the one with the best correlation with estimates of vulnerability to damage. Approximately 3/5 of the hypothetical building frames represented by numerical models with column indices not exceeding 0.2% were classified as buildings likely to be severely damaged by strong ground motion. Buildings with column indices not exceeding 0.2% were 2 to 4 times more likely to be classified as having severe

damage than those with column indices exceeding 0.2% for ground motions with PGVs between 40 cm/s and 120 cm/s. The prior building surveys supported these observations.

### 1. INTRODUCTION

#### 1.1 Background

Older reinforced concrete buildings were not always designed to prevent failure of columns in shear and compression. Code provisions to help designers prevent shear and compression failures were not published until the early 1970s. Inventories of older reinforced concrete buildings not satisfying these guidelines exist in seismic regions in the United States and elsewhere. The Concrete Coalition has estimated that there are approximately 17,000 reinforced concrete buildings vulnerable to failure in the most seismic regions of California (EERI, 2011). Identifying the most vulnerable buildings among these 17,000 structures is an urgent challenge.

A structural assessment is required to determine if a building poses a large risk to its occupants. Engineers may inspect and run numerical analyses to evaluate a building. Building details are required to construct numerical models, and this information may be unavailable to engineers. In regions with large sets of vulnerable buildings, it is too cumbersome for engineers to inspect and analyze each building. A simple method to identify the most vulnerable buildings is required. Collapse indicators are simple measures to help engineers identify the most critical structures. Within this subset of vulnerable buildings, engineers can then perform detailed analyses to prioritize the use of resources for building rehabilitation.

#### 1.2 Objective

The objective of this study is to evaluate simple collapse indicators that engineers can use to identify the most vulnerable reinforced concrete buildings in an inventory. This report focuses on evaluating four indicators: column index (Hassan and Sozen, 1997), R factor, ratio of column shear capacity to plastic shear demand, and ratio of column moment capacity to beam moment capacity. Appendix A discusses alternative building measures.

#### 1.3 Scope

Thirty numerical models representing hypothetical reinforced concrete building frames were used to represent a large inventory of buildings. Each numerical model was studied using nonlinear analysis with 44 strong ground motions. The software package OpenSees (PEER, 2013) was used for analysis. Analysis cases were classified as cases with severe damage if a minimum of one column shear or compression failure was estimated to have occurred. The numerical models included nonlinear spring elements calibrated to estimate occurrences of shear and compression column failures using the formulations described in Section 3.3. The numerical frame models had the following properties:

- Two- and four-stories with four bays (Figures 3.1 and 3.2)
- Span lengths  $(L_{span})$ : 12, 15, 20, 25, and 30 feet (Note: The spans of 12 and 15 feet were unrealistic for some numerical models but were used to generate a broad range of indicator values.)
- Concrete compressive strength  $(f'_c)$ : 4000 psi
- Uniform distributed floor weight: 165 psf
- Nominal longitudinal reinforcement yield stress  $(f_y)$ : 60 ksi
- Nominal transverse reinforcement yield stress  $(f_{yt})$ : 60 ksi
- Square column sections: 18, 24, and 30 inches square
- Column longitudinal reinforcement ratios ( $\rho$ ): 0.7, 1.1, and 2.0%
- Column transverse reinforcement ratios ( $\rho_t$ ): 0.06, 0.08, and 0.10%

- Column transverse reinforcement spacing (s): 12 inches
- Column axial loads: 0.01 through 0.46  $f'_c A_g$
- Beam cross-section (b and h): 18 by 28 inches
- Beam longitudinal reinforcement ratios (ρ' and ρ): 0.9% near the top and 0.5% near the bottom
- Beam transverse reinforcement ratio ( $\rho_t$ ): 0.15%

The following modeling assumptions were used in the numerical models:

- Two-dimensional planar models
- Rigid foundation
- Rayleigh damping using 2% of critical damping
- Lumped plasticity for beam and column elements
- Beam and column elements connected with rigid joint with lengths equal to half of the section height
- Cracked beam section moment of inertia equal to 60% of cross-sectional moment of inertia
- Cracked column section moment of inertia equal to 30% of cross-sectional moment of inertia
- Concentrated axial loads based on tributary area of the columns (Figure 3.4)
- Nonlinear flexural behavior using a Clough moment-rotation formulation with hysteresis implemented by Ibarra et al. (2005) (Figures 3.8 and 3.9)
- Elwood and Moehle (2003) formulation for estimating capacities and drifts at failure for shear and compression in columns.
- Strong ground motions with PGVs between 40 and 120 cm/s

## 2. DESCRIPTION OF COLLAPSE INDICATORS

#### 2.1 Introduction

For large inventories of older buildings, the time and effort required for engineers to evaluate thoroughly each building is prohibitive. Simple parameters are required to evaluate the risk of older reinforced concrete buildings. Collapse indicators are simple measures of a structure that can be used to rank buildings according to their vulnerability. This study considers four collapse indicators: column index, R factor, ratio of column shear capacity to plastic shear demand, and ratio of column moment capacity to beam moment capacity. Appendix A discusses alternative building measures. A combination of indicators may be able to identify critical buildings within a deficient building inventory.

#### 2.2 Column Index

Hassan and Sozen (1997) developed the column index for monolithic, reinforced concrete buildings based on their seismic vulnerability. The column index was calibrated after the 1992 Erzincan earthquake as part of the priority index. The priority index includes a term to consider the presence of walls. Because this study focused on reinforced concrete frames, only the column index was applicable.

The column index is calculated using half of the total cross-sectional area of all columns in the first story divided by the total floor area above ground floor area (Equation 2.1). As the column index increases, the stiffness and strength increases for a building. This indicator is attractive because its calculation is quick and requires minimal information about a structure.

$$CI = \frac{1}{2} \frac{A_{col}}{\Sigma A_{fl}} \tag{2.1}$$

The column index was evaluated by building surveys after events in Erzincan (Hassan and Sozen, 1997), Duzce (Donmez and Pujol, 2005), Bingol (Ozcebe et al., 2003), Peru (DataHub, 2014), Wenchuan (Zhou et al., 2013), and Haiti (O'Brien et al., 2011). Surveyed buildings were ranked as either having reinforced concrete elements with light, moderate, or severe damage. Light damage was assigned to structures with hairline cracks in structural members. Moderate damage was defined as spalling of concrete. Buildings with member failures were classified as severely damaged. The column indices were calculated from drawings or field measurements of the buildings.

This report combined previous building surveys and excluded buildings with masonry or reinforced concrete structural walls. From the combined surveys, Figure 2.1 shows the percentages of buildings classified as severely damaged versus column index. The percentage of severely damaged buildings decreased as the column index increased. 3/5 of buildings with column indices not exceeding 0.2% were classified as having severe damage. Buildings with column indices not exceeding 0.2% were twice as likely to be classified as having severe damage than buildings with column indices exceeding 0.2%.

#### 2.3 R factor

Engineers estimate the design lateral loads induced by strong ground motion for a structure by using its weight and design acceleration. The design acceleration is computed from a design spectrum for a single degree of freedom system (SDOF). Design forces are reduced to levels deemed appropriate by professional consensus by using "R factor". In this study, for the numerical models representing the hypothetical buildings described in Section 3, the R factor is computed with Equation 2.2. In it, base shear strength is  $V_{max}$ , building weight is  $W_b$ , and linear spectral acceleration is  $S_a$  (g).

$$R = \frac{S_a(T_1) \times W_b}{V_{max}} \tag{2.2}$$

 $V_{max}$  was computed for each numerical building model using a nonlinear limit analysis with an assumed triangular lateral load distribution. The weight of each hypothetical frame (Section 3.2) was used for  $W_b$ . The spectral acceleration for each numerical model was computed using a linear spectrum for the 44 ground motion records described in Section 3.4 and the following procedure:

- 1. Compute the uncracked fundamental period for each numerical building model.
- Generate the 44 acceleration spectra for the ground motion records in Section
   3.4 using SDOFs with 2% of critical damping.
- 3. Create an acceleration spectrum by computing the mean plus one standard deviation of the 44 spectral accelerations at each SDOF period.
- 4. Find the  $S_a$  from the spectrum created in (3) using the period calculated in (1).

Using R factor in an evaluation presumes knowledge about the anticipated ground motions and requires a detailed structural analysis. Detailed building drawings may not always be available to engineers but are necessary for a structural analysis.

#### 2.4 Ratio of Column Shear Capacity to Plastic Shear Demand

The column shear capacity to column shear demand ratio,  $V_n/V_p$ , is an indicator of whether a column is vulnerable to shear failure. Values less than one indicate that a column does not have enough capacity to develop flexural plastic hinges. The  $V_n/V_p$  ratio is calculated for all of the columns in the numerical models representing hypothetical buildings described in Section 3.2.

The column shear capacity  $(V_n)$  was computed using equations for nominal shear strength provided by ACI 318-11 (Equation 2.3). In it,  $N_u$  is the axial load,  $A_g$  is the gross cross-sectional area,  $f'_c$  is concrete compressive strength,  $b_w$  is the width of the section,  $A_{sh}$  is the cross-sectional area of the transverse reinforcement,  $f_{yt}$  is the yield strength of the transverse reinforcement, d is the distance from extreme compression fiber to centroid of longitudinal steel, and s is the spacing of the transverse reinforcement.

$$V_n = 2\left(1 + \frac{N_u}{2000A_g}\right)\sqrt{f'_c}b_w d + \frac{A_{sh}f_{yt}d}{s}$$
(2.3)

The plastic shear demand for each column was calculated using  $V_p = 2M_p/h$ . Plastic moment capacity  $(M_p)$  of a column was assumed to be 1.2 times the yield moment. The yield moment was computed using the program FLECHA (Pujol and Villalobos, 2014) and the assumptions discussed in Section 3.2. The clear height of each column was h.

The  $V_n/V_p$  ratio was extended to represent vulnerability of the numerical models representing hypothetical building frames using a procedure proposed in ATC-78 (ATC, 2011). This study defined the term as  $\alpha$ , and its value was computed as follows:

- 1. Calculate  $V_n/V_p$  for all the columns in a numerical model.
- 2. Determine the average  $V_n/V_p$  for each story.
- 3. Select the minimum value from (2) for  $\alpha$ .

The parameter  $\alpha$  is a simplified indicator to rank the vulnerability of a building to column shear failures. Computing  $\alpha$  requires the knowledge of sizes, placement, and material properties of the longitudinal and transverse reinforcing steel in the columns. This information may be unavailable or difficult to obtain for a large inventory of older buildings.

#### 2.5 Ratio of Column Moment Capacity to Beam Moment Capacity

ACI 318-11 calls for each joint in a frame to have a column moment capacity to beam moment capacity ratio,  $\Sigma M_c / \Sigma M_b$ , larger than 6/5. This requirement aims to enforce the "strong-column weak-beam" design idea where hinging occurs mostly in the beams to avoid weak stories.

The column moment capacity to beam moment capacity ratio was calculated for the joints in the studied numerical models.  $\Sigma M_c$  was the sum of the nominal column moment capacities at the face of the joint. Column moment capacities were calculated using FLECHA (Pujol and Villalobos, 2014) and axial loads caused by gravity.  $\Sigma M_b$ was the sum of the nominal beam capacities at the joint face. Slab contributions to the beam moment capacity were neglected.

The ratio of column moment capacity to beam moment capacity can vary for each joint in a building. ATC-78 (ATC, 2011) proposed a procedure to use this indicator to represent an entire building. This study defined the term as  $\beta$ , and its value was computed as follows:

- 1. Compute the  $\Sigma M_c / \Sigma M_b$  for the joints at each floor in a numerical model except the roof.
- 2. Determine the average  $\Sigma M_c / \Sigma M_b$  for each floor.
- 3. Select the minimum value from (2) for  $\beta$ .

The parameter  $\beta$  is a simplified indicator used to estimate the vulnerability of a building for developing weak stories.  $\Sigma M_c / \Sigma M_b$  requires knowledge about the longitudinal reinforcement for columns and beams. Drawings with this information may not be available for older reinforced concrete buildings in a large inventory.

#### 3. NUMERICAL MODELS

#### 3.1 Introduction

Building inventories can potentially have thousands of older reinforced concrete structures. These buildings have variety of configurations and properties. To represent these variations, numerical models of idealized building frames with different numbers of stories, column sizes, and span lengths, and transverse reinforcement ratios were studied.

#### 3.2 Description of Models

To evaluate the four collapse indicators described in Chapter 2, 30 numerical models representing hypothetical building frames were analyzed in the software package OpenSees (PEER, 2013). The numerical models represented two- and four-story frames with different column sections, span lengths, and transverse reinforcement ratios. The numerical models were designated using three characters "SX-X". The second character was the number of stories. The third character identified the model number. Tables 3.1 and 3.2 summarize the properties and modeling assumptions for the numerical models.

The hypothetical frames had four bays with equal span lengths (Figures 3.1 and 3.2). Five span lengths were considered: 12, 15, 20, 25, and 30 feet. These lengths refer to the distance between column centerlines. (Note: The spans of 12 and 15 feet are unrealistic but were used to generate a broad range of indicator values.) The tributary width for each frame was assumed to be equal to its span length. The frames had three square column sections: 18, 24, and 30 inches square. The same

column section was used for all stories (Figures 3.1 and 3.2). The concrete compressive strength was assumed to be 4000 psi.

Each column section had three layers of #8 Gr. 60 bars for longitudinal reinforcement and #3 Gr. 60 ties with two legs in each direction spaced at 12 inches on center (Figure 3.3). Table 3.3 lists the cross-sectional properties for the column sections. Column axial gravity loads were computed using a uniformly distributed load of 165 psf and the tributary area for a column (Figure 3.4). The columns had axial gravity loads between 1% and 46%  $P/(A_g f'_c)$  (Tables B.1 - B.30).

One beam section was used in the numerical models (Figure 3.5). The beam section had 5-#8 Gr. 60 longitudinal bars near the top and 3-#8 Gr. 60 longitudinal bars near the bottom. The beam had #4 Gr. 60 stirrups with two legs spaced at 10 inches on center. Table 3.3 lists a complete set of section properties for the beam.

Nonlinear flexural behavior was modeled using rotational springs at the ends of linear beam and column elements (Figures 3.6 and 3.7). The column elements had an additional horizontal and vertical spring to model shear and axial failures (Figure 3.6). The rotational springs followed the hysteresis model proposed by Clough and implemented by Ibarra et al. (2005) (Figures 3.8 and 3.9). This was defined by using yield moment  $(M_y)$ , plastic moment  $(M_p)$ , plastic rotation  $(\theta_p)$ , post-capping rotation  $(\theta_{pc})$ , cyclic deterioration  $(\lambda)$ , and residual moment  $(M_{res})$ . The parameters for each numerical model are listed in Tables B.1 - B.30.

In this study, yield moments were calculated at the point of first yielding in the steel for beam and column cross-sections. The yield moments were calculated using the program FLECHA (Pujol and Villalobos, 2014) and section properties in Table 3.3. Yield moments for the columns were calculated considering axial gravity loads. For beams and columns  $M_p$  was assumed to be  $1.2M_y$ .

For the columns  $M_{res}$  was set equal to  $M_p$  to maintain a plateau in the momentrotation backbone curve (Figure 3.8). This was done to avoid numerical convergence issues with the shear spring (Section 3.3.1) discussed by Elwood and Moehle (2003). Because the columns maintained a constant plastic moment, the same values for  $\theta_p$  and  $\theta_{pc}$  were used in all models for simplicity. The value  $\lambda$  was set as zero to enable flexural strength deterioration for the columns.

For the beams  $M_{res}$  was 10% of  $M_p$  (Figure 3.9). The beam rotations  $\theta_p$  and  $\theta_{pc}$ were calculated using the effective depth of the section and computed curvatures from FLECHA. The curvatures were calculated for concrete compression strains of 0.004 and 0.008 in the outermost fiber. The value for  $\lambda$  was selected based on a similar beam section used in ATC-78 (2011).

The linear elastic elements connecting the beam and column springs had reduced moments of inertia to account for concrete cracking. For the columns, 30% of the cross-sectional moment of inertia was used for the cracked moments of inertia as recommended by ASCE 41 (2006). For the beams, 60% of the cross-sectional moment of inertia was used for the cracked moments of inertia to account for the contribution from the slab to the beam stiffness. The modulus of elasticity was assumed to be 3600 ksi for the beam and column linear elements.

#### **3.3** Representation of Shear and Axial Response of Columns

The addition of horizontal and vertical springs allowed the numerical models to estimate the likelihood of column shear and compression failures. Two springs are attached to the top of each column (Figure 3.6). The springs followed a formulation for shear and compression force capacities and drifts at failure proposed by Elwood and Moehle (2003). Analysis cases were classified as severely damaged if the algorithm estimated a minimum of one column shear or compression failure during a dynamic analysis. Beam shear failure was not considered.

#### 3.3.1 Shear Response

Elwood and Moehle (2003) developed a formulation to estimate the shear capacity and drift at which a column failure occurs after plastic hinging. A shear failure is estimated to take place when the limiting shear (Equation 3.1) is exceeded in a column element. In Equation 3.1,  $\Delta_s/l$  is inter-story drift ratio,  $\rho_t$  is transverse reinforcement ratio, P is axial load in the column,  $A_g$  is gross cross-sectional area,  $f'_c$  and is concrete compressive strength.

$$V_n = 500 \left( A_g \sqrt{f'_c} \left( 0.03 + 4\rho_t - \frac{\Delta_s}{l} - \frac{1}{40} \frac{P}{A_g f'_c} \right) \right)$$
(3.1)

Equation 3.1 was computed for each column considering its current drift ratio and axial load during a dynamic analysis. A shear failure was estimated to have occurred when the shear demand in a column exceeded the capacity computed by Equation 3.1. Analysis cases were classified as likely to have severe damage after a minimum of one estimated column shear failure.

#### 3.3.2 Axial Response

Axial compression capacities and drifts at failure for columns were estimated using a formulation by Elwood and Moehle (2003). Compression in a column is transferred through shear friction after a shear failure has occurred. Equation 3.2 computes the limiting axial load where  $\theta = 65^{\circ}$  is the crack angle,  $A_{sh}$  is area of transverse reinforcing steel,  $f_{yt}$  is yield strength of the transverse reinforcement, d is effective depth, s is spacing of the transverse reinforcing steel, and  $\Delta_a$  is inter-story drift ratio.

$$P_n = \left(\frac{1 + (\tan\theta)^2}{25\Delta_a} - \tan\theta\right) \frac{A_{sh} f_{yt} d}{s} \tan\theta$$
(3.2)

Equation 3.2 was computed for each column at each time-step during an analysis. A column compression failure was estimated to take place when the demand exceeded the calculated limiting axial capacity from Equation 3.2. The analysis was stopped and classified as likely to have severe damage after the capacity was exceeded.

#### 3.4 Ground Motion Records

Numerical models representing hypothetical building frames described in Section 3.2 were analyzed using the FEMA P-695 "Far-Field" record set (ATC, 2009). This record set contained 44 ground motions summarized in Table 3.4. The ground motions were recorded from epicentral distances between 8 km and 100 km during events with magnitudes between 6.5 and 7.6. The peak ground accelerations (PGAs) varied from about 0.2 g to 0.8 g, and peak ground velocities (PGVs) were calculated to be between 15 cm/s and 115 cm/s. The linear acceleration spectra were using 2% of critical damping (Figure 3.10). These spectra were used as described in Section 2.3 to compute the R factors shown in Table 3.1 for the hypothetical building frames.

Each numerical model was analyzed using a set of 220 scaled ground motions from the FEMA P-695 "Far-Field" record set. The 44 records were scaled using multiples of 1.0, 1.5, 2.0, 2.5, and 3.0 times the original acceleration. These scale factors were used so that numerical models were analyzed with a range of PGVs for each record. The analysis procedure is discussed in Section 4.1.

## 4. EVALUATION OF INDICATORS

#### 4.1 Introduction

The four collapse indicators described in Chapter 2 were evaluated in this chapter: column index, R factor, column moment capacity to beam moment capacity, and column shear capacity to plastic shear demand. Alternative indicators are discussed in Appendix A. This evaluation was done using the results from dynamic analyses of the hypothetical building models described in Chapter 3. Each numerical model was analyzed using a set of 220 ground motion records described in Section 3.4. Each analysis was conducted until:

- 1. the end of the record was reached, or
- 2. a column shear or compression failure as defined in Section 3.3 was estimated to have occurred by the algorithms described in Sections 3.3.1 and 3.3.2.

All cases in which estimated column shear or compression failures were computed by the algorithm were classified as instances of building responses that were more likely to exhibit severe damage or collapse. To organize all analysis results a parameter, called the Mean Collapse PGV, was defined as follows:

- 1. For each of the 44 records used, select the minimum scale factor (see Section 3.4) leading to an instance of severe damage for a given numerical building model.
- 2. Compute the PGV for the 44 scaled versions of the records selected in (1) using the corresponding scale factor.
- 3. Calculate the mean of the 44 values of PGV from (2).

Each numerical model representing an instance of a hypothetical building structure (with a fixed number of stories, span length, etc.) was associated with a single Mean Collapse PGV. Correlation between Mean Collapse PGV and a given collapse indicator was interpreted to suggest that the indicator can help identify vulnerable structures. Additionally, the percentage of analysis instances in which estimated shear or compression failures of columns occurred was also used to evaluate the collapse indicators. This was achieved by:

- Remove analysis instances where the scale factor produced PGVs outside of 40 cm/s < PGV ≤ 120 cm/s for all cases. (This is the range of PGV for the field data described in Section 2.2)
- 2. Group analysis cases with similar collapse indicators into statistical bins
- 3. Divide the number of cases with severe damage by the number of analysis cases for each bin in (2).

Earthquakes with PGVs exceeding 120 cm/s were viewed as infrequent, so analysis cases with PGVs exceeding 120 cm/s were not considered. A lower bound of 40 cm/s was used to exclude moderate and light ground motions. Item 3 was used to identify the percentage of severely damaged cases for hypothetical models within a collapse indicator bin. Table 4.1 displays a summary of the analysis results. A total of 1592 cases were classified as instances of severe damage out of 4560 cases.

#### 4.2 Column Index

The column index (Section 2.2) proposed by Hassan and Sozen (1997) was evaluated using the numerical models representing hypothetical buildings and previous building surveys described in Section 2.2. Figure 4.1 plots the Mean Collapse PGV versus column index. As the column index increased, the Mean Collapse PGV increased. The Mean Collapse PGV of the numerical models increased faster for column indices between 0% and 0.2%. That is, Mean Collapse PGV was more sensitive to column indices less than 0.2%, so focusing resources for rehabilitation on this range may likely yield the greatest benefit. Figure 4.2 shows a plot of the percentage of numerical building models and field cases (see Section 2.2) classified as instances of severe damage versus column index. The percentage of numerical building models classified as vulnerable to severe damage decreased as column index increased. Numerical models representing hypothetical buildings with column indices not exceeding 0.2% were classified as likely to have severe damage in approximately 3/5 of the analysis cases. Models with column indices not exceeding 0.2% were 4 times more likely to be classified as having severe damage than those with column indices exceeding 0.2%. The prior buildings classified as likely to have severe damage as column index increased. Nearly 3/5 of surveyed buildings with column indices not exceeding 0.2% were classified as having severe damage with column index increased. Nearly 3/5 of surveyed buildings with column indices not exceeding 0.2% were classified as having severe damage. Buildings with column indices not exceeding 0.2% were twice as likely to be classified as having severe damage.

The numerical model and field data both showed that column index can be used to rank buildings by seismic vulnerability. Buildings with column indices not exceeding 0.2% may be studied in detail first with an emphasis on the buildings with the lowest column indices and any captive columns. O'Brien et al. (2011) observed increases in the likelihood of severe damage for buildings with captive columns.

#### 4.3 R Factor

The R factor described in Section 2.3 was evaluated exclusively using the numerical analyses of the models representing hypothetical building frames. The available field data did not have the required detail for its use in evaluating 1/R. The inverse of the R factor (1/R) was compared with the numerical results to determine whether lower indicator values of 1/R corresponded to hypothetical building models which were most likely to be vulnerable to severe damage. Figure 4.3 plots Mean Collapse PGV versus 1/R. The Mean Collapse PGV increased as 1/R increased.

Figure 4.4 shows a plot of the percentage of analysis cases for numerical building models classified as likely to have severe damage versus 1/R. The percentage of analysis cases classified as likely to have severe damage decreased as 1/R increased. Nearly 3/5 of analysis cases for numerical models representing frames with 1/R not exceeding 0.2 were classified as likely to have severe damage. Cases for numerical models with 1/R not exceeding 0.2 were 3 times more likely to be classified as having sever damage than analysis cases for numerical models with 1/R exceeding 0.2.

Figure 4.5 plots 1/R and column index for the numerical models representing hypothetical buildings. Each numerical building model was assigned a data marker which represented the percentage (out of 152 cases) that were classified as vulnerable to severe damage. This plot was used to determine if 1/R can be used to eliminate analysis cases for buildings models with column indices not exceeding 0.2% and not likely to have severe damage ("false positives"). Figure 4.5 shows a linear trend between 1/R and column index for the numerical building models studied. This was inferred to mean that 1/R and column index can be used to produce the same ranking of the most vulnerable buildings in an inventory of older reinforced concrete buildings. Nearly 2/3 of analysis cases representing hypothetical buildings with 1/R not exceeding 0.2 and column index not exceeding 0.2% were classified as likely to have severe damage.

The numerical models of hypothetical buildings showed that 1/R can be used to rank building vulnerable in an inventory of older reinforced concrete buildings. Using 1/R with column index identified a larger percentage of damaged numerical models than column index alone. However, the R factor requires detailed drawings and structural analyses for its calculation as described in Section 2.3. Computing the column index is simpler and its use would be less expensive.

#### 4.4 Ratio of Column Shear Strength to Plastic Shear Demand

Ratio of column shear strength to plastic shear demand was represented using  $\alpha$  (Section 2.4) and evaluated using the numerical analysis results. The available field data did not have the required detail for its use in evaluating  $\alpha$ . Figure 4.6 plots the Mean Collapse PGV versus  $\alpha$ . The Mean Collapse PGV increased as  $\alpha$  increased. Numerical building models associated with  $\alpha$  not exceeding 1.1 were more sensitive to Mean Collapse PGV than cases with values of  $\alpha$  exceeding this limit.

The percentage of analysis cases for hypothetical frames classified as vulnerable to severe damage versus  $\alpha$  is shown in Figure 4.7. As  $\alpha$  increased, the percentage of analysis cases classified as likely to have severe damage decreased. Approximately 2/3 of analysis cases for numerical models representing frames with  $\alpha$  not exceeding 1.1 were classified as likely to have severe damage. Numerical models with  $\alpha$  not exceeding 1.1 were 4 times more likely to be classified as vulnerable to severe damage than numerical models with  $\alpha$  exceeding 1.1.

Figure 4.8 is a plot of  $\alpha$  and the column index for the numerical models representing hypothetical buildings. Each numerical model was assigned a data marker which represented the percentage (out of 152 cases) classified as vulnerable to severe damage. This plot was used to determine if  $\alpha$  could be used to eliminate model instances of hypothetical frames in which column indices were less than 0.2% and classified as not likely to experience severe damage ("false positives"). 7/10 of the analysis cases representing hypothetical buildings with  $\alpha$  not exceeding 1.1 and column index not exceeding 0.2% were classified as vulnerable to severe damage.

The numerical results suggest that  $\alpha$  can be used to rank building vulnerability in an inventory of older reinforced concrete buildings. Using  $\alpha$  with column index identified a larger percentage of severely damaged numerical models than column index alone. The parameter  $\alpha$  should be considered after an initial filtering of a building inventory based on column index.

#### 4.5 Ratio of Column Moment Strength to Beam Moment Strength

Ratio of column moment strength to beam moment strength was represented here as  $\beta$  (Section 2.5) and was evaluated exclusively using the numerical analyses of the hypothetical building models. The available field data did not have the required detail for its use in evaluating  $\beta$ . Figure 4.9 plots Mean Collapse PGV versus  $\beta$ . There were three distinct sets of points. Each set corresponded to hypothetical building models with the same column size (18, 24, and 30 inches square). Each set showed a decrease in the Mean Collapse PGV as  $\beta$  increased. This trend corresponded with increases in building spans for the same column sizes. More axial load was sustained in the columns as the span increased, so the column moment strength increased. Additionally, frames had to resist more inertia as the spans increased, so the Mean Collapse PGVs decreased.

Figure 4.10 shows the percentage of numerical building models classified as likely to have severe damage versus  $\beta$ . There was not a clear trend between the percentage of hypothetical buildings classified as likely to have severe damage and  $\beta$ . Column moment capacity to beam moment capacity was not an efficient indicator of seismic vulnerability for the studied hypothetical building frames.

#### 5. CONCLUSIONS

Four collapse indicators were evaluated using numerical analysis to determine their efficiency in identifying the most seismically vulnerable reinforced concrete buildings from a large inventory of older structures. Numerical models represented hypothetical building frames with different span lengths, column sizes, numbers of floors, and transverse reinforcement ratios. The considered ranges are listed in Table 3.1 and Section 1.3. The collapse indicators considered were: column index (Hassan and Sozen, 1997), R factor, ratio of column shear capacity to plastic shear demand, and ratio of column moment capacity to beam moment capacity.

Out of the four indicators evaluated, the column index was observed to be the simplest, and the one with the best correlation with estimates of vulnerability to damage.

For strong ground motions with PGVs betwen 40 cm/s and 120 cm/s, approximately 3/5 of the numerical models representing hypothetical buildings with column indices not exceeding 0.2% were classified as likely to have to severe damage. Models with column indices not exceeding 0.2% were 4 times more likely to be classified as likely to have severe damage than those with column indices exceeding 0.2%. Field data from prior building surveys also showed that nearly 3/5 of building frames with column indices not exceeding 0.2% were classified as having severe damage. Buildings with column indices not exceeding 0.2% were twice as likely to have severe damage than those with column indices exceeding 0.2%. REFERENCES

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TABLES

Model	$L_{span}$	$b_{col}$	Stories	$T_1$	$W_b$	V <sub>max</sub>	CI	R	α	β
	(ft)	(in)		(s)	(kip)	(kip)	(%)			
S2-0	12	18	2	0.22	190	188	0.49	1.7	1.23	0.62
S2-1	15	18	2	0.28	297	201	0.31	2.6	1.19	0.65
S2-2	20	18	2	0.38	528	223	0.18	3.7	1.04	0.75
S2-3	25	18	2	0.49	825	219	0.11	6.6	1.04	0.78
S2-4	30	18	2	0.61	1188	225	0.08	7.2	1.02	0.83
S2-5	12	24	2	0.14	190	278	0.87	1.0	1.38	0.91
S2-6	15	24	2	0.18	297	286	0.56	1.6	1.36	0.94
S2-7	20	24	2	0.26	528	301	0.31	3.2	1.30	1.02
S2-8	25	24	2	0.34	825	308	0.20	4.6	1.25	1.08
S2-9	30	24	2	0.42	1188	317	0.14	6.4	1.16	1.18
S2-10	12	30	2	0.14	190	349	1.36	1.2	1.59	1.18
S2-11	15	30	2	0.20	297	352	0.87	2.5	1.55	1.24
S2-12	20	30	2	0.27	528	357	0.49	4.0	1.49	1.32
S2-13	25	30	2	0.34	825	366	0.31	5.4	1.38	1.42
S2-14	30	30	2	0.11	1188	380	0.22	0.7	1.26	1.56
S4-0	12	18	4	0.40	380	220	0.24	2.8	1.02	0.71
S4-1	15	18	4	0.51	594	214	0.16	4.9	1.02	0.73
S4-2	20	18	4	0.71	1056	220	0.09	5.9	0.99	0.75
S4-3	25	18	4	0.92	1650	219	0.06	7.3	1.01	0.78
S4-4	30	18	4	1.15	2376	205	0.04	7.9	0.99	0.83
S4-5	12	24	4	0.27	380	353	0.43	1.9	1.31	0.91
S4-6	15	24	4	0.35	594	307	0.28	3.3	1.24	0.94
S4-7	20	24	4	0.51	1056	282	0.16	6.6	1.12	1.02
S4-8	25	24	4	0.67	1650	288	0.10	7.4	1.03	1.08

Table 3.1: Properties for the hypothetical building models

continued on next page

Model	$L_{span}$	$b_{col}$	Stories	$T_1$	$W_b$	V <sub>max</sub>	CI	R	α	β
	(ft)	(in)		(s)	(kip)	(kip)	(%)			
S4-9	30	24	4	0.85	2376	293	0.07	8.2	0.95	1.18
S4-10	12	30	4	0.21	380	321	0.68	2.0	1.47	1.18
S4-11	15	30	4	0.29	594	325	0.43	3.2	1.28	1.24
S4-12	20	30	4	0.42	1056	330	0.24	5.5	1.25	1.32
S4-13	25	30	4	0.56	1650	339	0.16	7.8	1.11	1.42
S4-14	30	30	4	0.71	2376	356	0.11	8.1	1.00	1.56

Table 3.1: *continued* 

	Modeling Assumptions
Туре	Assumptions
	- Rigid foundation
	- Two-dimensions with rigid joints connecting elements
	- Lumped-plasticity to model the behavior of the column
Frames	and beam elements
	- Tributary width equal to span length
	- Weight calculated using the frame tributary area and
	uniform distributed load of 165 psf
	- $2\%$ of critical damping using Rayleigh damping
	- Rotational springs to model moment-rotation at the
	ends of a linear elastic line element
	- Horizontal spring to estimate shear and drift ratio at
Column Elemente	failure for columns (Elwood and Moehle, 2003)
Column Elements	- Vertical spring to estimate axial compression and drift
	ratio at failure for a column (Elwood and Moehle, 2003)
	- Cracked moment of inertia taken as $30\%$ of cross-
	sectional moment of inertia
	- Tributary weight applied as a concentrated load
	- Rotational springs to model moment-rotation at the
Deem Flomenta	ends of a linear elastic line element
Deam Elements	- Cracked moment of inertia taken as 60% of nominal
	moment of inertia

## Table 3.2: Assumptions for the numerical models

	Modeling Assumptions
Type	Assumptions
	- Moment-rotation using a Clough model with hysteresis
	and parameters $M_y, M_c, M_{res}, \theta_p, \theta_{pc}$ , and $\lambda$ (Ibarra
	et al., $2005$ )
	- $M_y$ is the moment at first steel yielding calculated using
	FLECHA (Pujol and Villalobos, 2014)
Section Properties	- $M_p$ is the plastic moment and is assumed to be equal
	to 1.2 times $M_y$
	- $M_{res}$ is the residual moment and is equal to $M_p$ for
	columns and $0.1M_y$ for the beams
	- $\theta_p$ is the plastic rotation (Figures 3.8 and 3.9)
	- $\theta_{pc}$ is the post-capping rotation (Figures 3.8 and 3.9)
	- $\lambda$ is a parameter for cyclic deterioration
БІ Б <u>С</u> НА	- Elastic perfectly plastic stress-strain steel relationship
ΓLEUΠΑ	- Hognestad (1951) stress-strain concrete relationship

 Table 3.2: continued

Section	q	h	$C_{c}$	d	$A_g$	$I_g$	$A_s$	$A_s'$	φ	ρ'	$A_{sh}$	S	$\rho_t$
	(in)	(in)	(in)	(in)	$(in^2)$	$(in^4)$	$(in^2)$	$(in^2)$	(%)	(%)	$(in^2)$	(in)	(%)
Α	18	18	2.5	15.5	324	8748	6.32	I	2.0	I	0.22	12	0.10
В	24	24	2.5	21.5	576	27650	6.32	I	1.1	I	0.22	12	0.08
C	30	30	2.5	27.5	900	67500	6.32	I	0.7	I	0.22	12	0.06
D	18	28	2.0	26.0	504	32900	2.37	3.95	0.5	0.9	0.4	10	0.15

Table 3.3: Cross-sectional properties

Location	Date	Epicentral	Mag.	Dir.	PGA	PGV
		Distance				
		(km)			(g)	(cm/s)
	I 17 1004	10.0	0.7	N09E	0.42	59
Northridge, CA	Jan. 17, 1994	13.3	0.7	N81W	0.52	63
	I 17 1004		0.7	NS	0.41	43
Northridge, CA	Jan. 17, 1994	26.5	0.7	EW	0.48	45
	N. 10 1000	41.9	7 1	N21E	0.73	56
Duzce, Turkey	Nov. 12, 1999	41.3	(.1	S69E	0.82	62
Harden Miner ClA	0 + 10 1000		<b>P</b> 1	NS	0.27	29
Hector Mine, CA	Oct. 16, 1999	20.5	(.1	EW	0.34	42
	Oct 15 1070	22.7	C F	S82W	0.24	26
Imperial valley, CA	Oct. 15, 1979	əə.7	0.0	N08W	0.35	33
	Oct 15 1070	20.4	GE	S40E	0.36	34
Imperial valley, CA	Oct. 15, 1979	29.4	0.0	S50W	0.38	42
Kaha Japan	Lap. 16 1005	07	6.0	NS	0.51	37
Kobe, Japan	Jan. 10, 1995	0.1	0.9	EW	0.50	37
Kaha Japan	Lap. 16 1005	46.0	6.0	NS	0.24	38
Kobe, Japan	Jan. 10, 1995	40.0	0.9	EW	0.21	28
Kasali Turkov	Aug. 17, 1000	08.0	75	NS	0.31	59
Kocaen, Turkey	Aug. 17, 1999	98.2	1.5	EW	0.36	46
Kasaali Tumbou	Aug 17 1000	527	75	NS	0.22	18
Rocaell, Turkey	Aug. 17, 1999	JJ.1	1.0	EW	0.15	40
Landara CA	Jun 90 1000	<u> </u>	7 9	NS	0.15	30
Landers, UA	Jun. 20, 1992	00.0	6.1	EW	0.24	51

Table 3.4: Summary of the FEMA P-695 ground motion records

continued on next page

 Table 3.4: continued

Location	Date	Epicentral	Mag.	Dir.	PGA	PGV
		Distance				
		(km)			(g)	(cm/s)
Landana CA	J 98 1009	00.1	7.0	NS	0.28	26
Landers, CA	Jun. 28, 1992	82.1	1.3	EW	0.42	42
Lama Driata CA	Ort 10 1000	0.8	6.0	NS	0.53	35
Loma Prieta, CA	Oct. 18, 1989	9.8	0.9	EW	0.44	29
Lomo Drioto, CA	Oct 19 1090	21 /	6.0	NS	0.56	36
Loma Prieta, CA	Oct. 18, 1989	31.4	0.9	EW	0.37	45
Maniil Inan	Jun 20 1000	40.4	7 4	NS	0.51	42
Manjii, fran	Jun. 20, 1990	40.4	1.4	EW	0.50	52
Superstition Hills,	Nov. 94 1087	25.0	65	NS	0.36	46
CA	NOV. 24, 1987	55.8	0.0	EW	0.26	41
Superstition Hills,	No. 94 1097	11.0	GE	NS	0.30	33
СА	Nov. 24, 1987	11.2	0.0	EW	0.45	36
Cape Mendocino,	App. 25, 1002	00.7	7.0	NS	0.55	42
СА	Apr. 25, 1992	22.1	7.0	EW	0.39	44
Chi Chi Taiwan	Sop 20 1000	22.0	7.6	NS	0.44	115
Cm-Cm, Taiwan	Sep. 20, 1999	52.0	1.0	EW	0.35	71
Chi Chi Taiwan	Sop 20 1000	77 K	7.6	NS	0.51	39
Cin-Cin, Taiwan	Sep. 20, 1999	11.5	1.0	EW	0.47	37
Son Formanda, CA	Fab. 0, 1071	20 F	6.6	NS	0.17	15
San Fernando, CA	reb. 9, 1971	59.5	0.0	EW	0.21	19
Friuli Italy	May 6 1076	20.2	65	NS	0.35	22
riiuii, itaiy	wiay 0, 1970	20.2	0.0	EW	0.31	31

Model	Co	llapse l	Indicat	ors	Results within 40 $<$	$< PGV \le 120 \text{ cm/s}$
	CI	1/R	$\alpha$	$\beta$	Number of Severe	Number of
	(%)				Cases	Cases
S2-0	0.49	0.58	1.23	0.62	21	152
S2-1	0.31	0.38	1.19	0.65	45	152
S2-2	0.18	0.27	1.04	0.75	89	152
S2-3	0.11	0.15	1.04	0.78	111	152
S2-4	0.08	0.14	1.02	0.83	132	152
S2-5	0.87	1.02	1.38	0.91	1	152
S2-6	0.56	0.62	1.36	0.94	8	152
S2-7	0.31	0.31	1.30	1.02	36	152
S2-8	0.20	0.22	1.25	1.08	60	152
S2-9	0.14	0.16	1.16	1.18	75	152
S2-10	1.36	1.40	1.59	1.18	0	152
S2-11	0.87	0.83	1.55	1.24	1	152
S2-12	0.49	0.41	1.49	1.32	10	152
S2-13	0.31	0.25	1.38	1.42	24	152
S2-14	0.22	0.19	1.26	1.56	44	152
S4-0	0.24	0.36	1.02	0.71	47	152
S4-1	0.16	0.21	1.02	0.73	60	152
S4-2	0.09	0.17	0.99	0.75	103	152
S4-3	0.06	0.14	1.01	0.78	141	152
S4-4	0.04	0.13	0.99	0.83	152	152
S4-5	0.43	0.52	1.31	0.91	10	152
S4-6	0.28	0.30	1.24	0.94	22	152
S4-7	0.16	0.15	1.12	1.02	43	152

Table 4.1: Summary of the analysis cases

continued on next page

Model	Co	llapse l	Indicat	ors	Results within 40 $<$	$< PGV \le 120 \text{ cm/s}$
	CI	1/R	α	β	Number of Severe	Number of
	(%)				Cases	Cases
S4-8	0.10	0.13	1.03	1.08	83	152
S4-9	0.07	0.12	0.95	1.18	119	152
S4-10	0.68	0.50	1.47	1.18	3	152
S4-11	0.43	0.31	1.28	1.24	11	152
S4-12	0.24	0.18	1.25	1.32	21	152
S4-13	0.16	0.13	1.11	1.42	41	152
S4-14	0.11	0.12	1.00	1.56	79	152

 Table 4.1: continued

FIGURES



Figure 2.1: Percentage of previously surveyed buildings classified as severely damaged vs column index



Figure 3.1: Typical two-story frame of the hypothetical building models



Figure 3.2: Typical four-story frame of the hypothetical building models





Figure 3.3: Column cross-sections for the hypothetical building models



(d) Interior column





(e) Exterior column Figure 3.4: Typical tributary areas for the columns



Figure 3.5: Beam cross-section D in the hypothetical building models



Figure 3.6: Diagram of a column element in OpenSees



Figure 3.7: Diagram of a beam element in OpenSees



Figure 3.8: Moment-rotation backbone for column elements



Figure 3.9: Moment-rotation backbone for beam elements



Figure 3.10: Linear acceleration spectra for the FEMA P-695 "Far-Field" ground motion records with 2% of critical damping



Figure 4.1: Mean Collapse PGV for the numerical building models vs column index



Figure 4.2: Percentage of numerical building models classified as likely to have severe damage vs column index



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Figure 4.3: Mean Collapse PGV for the numerical building models vs 1/R



Figure 4.4: Percentage of numerical building models classified as likely to have severe damage vs  $1/{\rm R}$ 



Figure 4.5: Percentage of numerical building models classified as likely to have severe damage vs 1/R and column index



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Figure 4.6: Mean Collapse PGV of the numerical building models vs  $\alpha$ 



Figure 4.7: Percentage of numerical building models classified as likely to have severe damage vs  $\alpha$ 



Figure 4.8: Percentage of numerical building models classified as likely to have severe damage vs  $\alpha$  and column index



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Figure 4.9: Mean Collpase PGV of the numerical building models vs  $\beta$ 



Figure 4.10: Percentage of numerical building models classified as likely to have severe damage vs  $\beta$ 

APPENDICES

## **Appendix A: Alternative Building Measures**

A parameter called the Mean Collapse PGA was computed for each model using the same procedure used for the Mean Collapse PGV described in Section 4.1. Mean Collapse PGA was used as an alternative measure of resistance to ground motion for a building. Figure A.1 shows a plot of Mean Collapse PGA versus column index for the numerical models representing hypothetical buildings. The Mean Collapse PGA increased as column index increased. Figure A.1 shows a good correlation between Mean Collapse PGA and column index. This was interpreted to mean that Mean Collapse PGA may be used as a measure of building resistance.

Fundamental periods were used as an alternative collapse indicator for the hypothetical frames. Frame periods were divided by the number of stories to compare the two- and four-story models. The Mean Collapse PGV versus period is plotted in Figure A.2. The Mean Collapse PGV decreased as period increased. Figure A.2 shows a good correlation between Mean Collapse PGV and fundamental period. This suggested that the fundamental period may be used as an indicator of vulnerability.

The use of maximum column axial load ratio as an alternative collapse indicator was also studied. Figure A.3 shows a plot of Mean Collapse PGV versus axial load ratio. The Mean Collapse PGV decreased as the axial load ratio increased. Figure A.3 shows a good correlation between Mean Collapse PGV and axial load ratio. This suggested that the axial load ratio may be used as an indicator of vulnerability.



●2-Story ■4-Story

Figure A.1: Mean Collapse PGA vs column index



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Figure A.2: Mean Collapse PGV vs fundamental period



Figure A.3: Mean Collapse PGV vs axial load ratio

## Appendix B: Flexural Properties for the Numerical Models

$\frac{P_{grav}}{f_c'A_g}$	(%)	I	I	0.9	1.8	1.8	3.7
$P_{grav}$	(kip)	0	0	12	24	24	48
$\prec$		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$ heta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	$(kip{-}in)$	426	690	2640	2760	2760	3000
$M_p$	(kip-in)	4260	0069	2640	2760	2760	3000
$M_y$	(kip-in)	3550	5750	2200	2300	2300	2500
$A_g$	$(in^2)$	504	504	324	324	324	324
$I_g$	$(in^4)$	32900	32900	8750	8750	8750	8750
Col. Size Sq.	(in)	I	I	18	18	18	18
Story		11 V	ΠV	2		2	1
Member		Beams +	Beams -	Exterior	Columns	Interior	Columns

Table: B.1: Moment-rotation properties for S2-0

$\frac{P_{grav}}{f_c'A_g}$	(%)	I	I	1.4	2.9	2.9	5.7
$P_{grav}$	(kip)	0	0	19	37	37	74
$\prec$		64	64	0	0	0	0
$\theta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$\theta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	(kip-in)	426	690	2760	2880	2880	3360
$M_p$	(kip- $in)$	4260	0069	2760	2880	2880	3360
$M_y$	$(kip{-}in)$	3550	5750	2300	2400	2400	2800
$A_g$	$(in^2)$	504	504	324	324	324	324
$I_g$	$(in^4)$	32900	32900	8750	8750	8750	8750
Col. Size So.	(in)	I	I	18	18	18	18
Story			III	2		2	1
Member		$\operatorname{Beams} +$	Beams -	Exterior	Columns	Interior	Columns

Table: B.2: Moment-rotation properties for S2-1

$\frac{P_{grav}}{f_c'A_g}$	(%)	I	I	2.5	5.1	5.1	10.2
$P_{grav}$	(kip)	0	0	33	66	66	132
$\prec$		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$\theta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	(kip-in)	426	690	3240	3360	3360	3720
$M_p$	(kip- $in)$	4260	0069	3240	3360	3360	3720
$M_y$	$(kip{-}in)$	3550	5750	2700	2800	2800	3100
$A_g$	$(in^2)$	504	504	324	324	324	324
$I_g$	$(in^4)$	32900	32900	8750	8750	8750	8750
Col. Size Sq.	(in)	I	I	18	18	18	18
Story		11 V	ΠV	2	<del>, -</del>	2	1
Member		Beams +	Beams -	Exterior	Columns	Interior	Columns

Table: B.3: Moment-rotation properties for S2-2

$\frac{P_{grav}}{f_c'A_g}$	(%)	I	I	4.0	8.0	8.0	15.9
$P_{grav}$	(kip)	0	0	52	103	103	206
$\boldsymbol{\prec}$		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$ heta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	$(kip{-}in)$	426	690	3300	3480	3480	3840
$M_p$	(kip-in)	4260	0069	3300	3480	3480	3840
$M_y$	(kip-in)	3550	5750	2750	2900	2900	3200
$A_g$	$(in^2)$	504	504	324	324	324	324
$I_g$	$(in^4)$	32900	32900	8750	8750	8750	8750
Col. Size Sq.	(in)	I	ı	18	18	18	18
Story			III	2	1	2	1
Member		$\operatorname{Beams} +$	Beams -	Exterior	Columns	Interior	Columns

Table: B.4: Moment-rotation properties for S2-3

$\frac{P_{grav}}{f_c'A_g}$		(%)	I	I	5.7	11.5	11.5	22.9
$P_{grav}$		(kip)	0	0	74	149	149	297
X			64	64	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3360	3720	3720	4080
$M_p$		(kip-in)	4260	0069	3360	3720	3720	4080
$M_y$		(kip-in)	3550	5750	2800	3100	3100	3400
$A_g$		$(in^2)$	504	504	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750
Col. Size	Sq.	(in)	I	I	18	18	18	18
Story			11 V	ΠV	2	1	2	1
Member			$\operatorname{Beams} +$	Beams -	Exterior	Columns	Interior	Columns

Table: B.5: Moment-rotation properties for S2-4

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$\frac{P_{grav}}{f'_c A_g}$	(%)	I	I	0.5	1.0	1.0	2.1
$P_{grav}$	(kip)	0	0	12	24	24	48
$\prec$		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$\theta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	(kip-in)	426	690	3960	4080	4080	4320
$M_p$	(kip-in)	4260	0069	3960	4080	4080	4320
$M_y$	(kip-in)	3550	5750	3300	3400	3400	3600
$A_g$	$(in^2)$	504	504	576	576	576	576
$I_g$	$(in^4)$	32900	32900	27650	27650	27650	27650
Col. Size Sq.	(in)	I	I	24	24	24	24
Story		11 V	ΠV	2	1	2	1
Member		Beams +	Beams -	Exterior	Columns	Interior	Columns

Table: B.6: Moment-rotation properties for S2-5

$\frac{P_{grav}}{f_c'A_g}$	(%)	I	ı	0.8	1.6	1.6	3.2
$P_{grav}$	(kip)	0	0	19	37	37	74
$\prec$		64	64	0	0	0	0
$\theta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$\theta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	$(kip{-}in)$	426	690	3960	4200	4200	4560
$M_p$	(kip-in)	4260	0069	3960	4200	4200	4560
$M_y$	$(kip{-}in)$	3550	5750	3300	3500	3500	3800
$A_g$	$(in^2)$	504	504	576	576	576	576
$I_g$	$(in^4)$	32900	32900	27650	27650	27650	27650
Col. Size	(in)	I	I	24	24	24	24
Story		11 V	ΠV	2		2	1
Member		Beams +	Beams -	Exterior	Columns	Interior	Columns

Table: B.7: Moment-rotation properties for S2-6

Member	Story	Col. Size	$I_g$	$A_g$	$M_y$	$M_p$	$M_{res}$	$\theta_p$	$ heta_{pc}$	$\prec$	$P_{grav}$	$\frac{P_{grav}}{f'_c A_g}$
		Sq.										1
		(in)	$(in^4)$	$(in^2)$	$(kip{-}in)$	$(kip{-}in)$	$(kip{-}in)$	(rad)	(rad)	~	(kip)	(%)
$\operatorname{Beams} +$		I	32900	504	3550	4260	426	0.05	0.08	64	0	I
Beams -	III	I	32900	504	5750	6900	690	0.04	0.08	64	0	I
Exterior	2	24	27650	576	3400	4080	4080	0.06	10	0	33	1.4
Columns		24	27650	576	3800	4560	4560	0.05	10	0	66	2.9
Interior	2	24	27650	576	3800	4560	4560	0.06	10	0	66	2.9
Columns	1	24	27650	576	4250	5100	5100	0.05	10	0	132	5.7

S2-7
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Table: I
$\frac{P_{grav}}{f'_c A_g}$
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$P_{grav}$
$\prec$
$ heta_{pc}$
$\theta_p$
$M_{res}$
$M_p$
$M_y$
$A_g$
$I_g$
Col. Size Sq.
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Table: B.9: Moment-rotation properties for S2-8

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$\frac{P_{grav}}{f_c^\prime A_g}$	(%)	I	I	3.2	6.4	6.4	12.9
$P_{grav}$	(kip)	0	0	74	149	149	297
$\prec$		64	64	0	0	0	0
$\theta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$ heta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	(kip-in)	426	690	4560	5280	5280	6600
$M_p$	(kip- $in)$	4260	0069	4560	5280	5280	6600
$M_y$	(kip-in)	3550	5750	3800	4400	4400	5500
$A_g$	$(in^2)$	504	504	576	576	576	576
$I_g$	$(in^4)$	32900	32900	27650	27650	27650	27650
Col. Size Sq.	(in)	I	I	24	24	24	24
Story		11 V	III	2	<del>, _ 1</del>	2	1
Member		$\operatorname{Beams}$ +	Beams -	Exterior	Columns	Interior	Columns

Table: B.10: Moment-rotation properties for S2-9

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$\frac{P_{grav}}{f_c'A_g}$	(%)	I	I	0.3	0.7	0.7	1.3
$P_{grav}$	(kip)	0	0	12	24	24	48
$\prec$		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$ heta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	$(kip{-}in)$	426	690	5160	5280	5280	5640
$M_p$	(kip-in)	4260	0069	5160	5280	5280	5640
$M_y$	(kip-in)	3550	5750	4300	4400	4400	4700
$A_g$	$(in^2)$	504	504	006	000	900	000
$I_g$	$(in^4)$	32900	32900	67500	67500	67500	67500
Col. Size Sq.	(in)	I	I	30	30	30	30
Story		11 V	ΠV	2	<del>, _ 1</del>	2	1
Member		$\operatorname{Beams}$ +	Beams -	Exterior	Columns	Interior	Columns

Table: B.11: Moment-rotation properties for S2-10

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$\frac{P_{grav}}{f'_c A_g}$		(%)	I	I	0.5	1.0	1.0	2.1
$P_{grav}$		(kip)	0	0	19	37	37	74
$\boldsymbol{\kappa}$			64	64	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$		(kip-in)	426	690	5160	5520	5520	0009
$M_p$		(kip-in)	4260	0069	5160	5520	5520	6000
$M_y$		(kip-in)	3550	5750	4300	4600	4600	5000
$A_g$		$(in^2)$	504	504	006	006	900	006
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	ı	30	30	30	30
Story			11 V	ΠV	2	H	2	H.
Member			Beams +	Beams -	Exterior	Columns	Interior	Columns

Table: B.12: Moment-rotation properties for S2-11

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$\frac{P_{grav}}{f'_c A_g}$	(%)	I	1	0.9	1.8	1.8	3.7
$P_{grav}$	(kip)	0	0	33	66	99	132
~		64	64	0	0	0	0
$ heta_{pc}$	(rad)	0.08	0.08	10	10	10	10
$\theta_p$	(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$	(kip-in)	426	690	5280	5880	5880	6720
$M_p$	$(kip{-}in)$	4260	6900	5280	5880	5880	6720
$M_y$	(kip-in)	3550	5750	4400	4900	4900	5600
$A_g$	$(in^2)$	504	504	006	000	006	006
$I_g$	$(in^4)$	32900	32900	67500	67500	67500	67500
Col. Size Sq.	(in)	I	I	30	30	30	30
Story		11 V	ΠV	2	1	2	
Member		$\operatorname{Beams}$ +	Beams -	Exterior	Columns	Interior	Columns

Table: B.13: Moment-rotation properties for S2-12

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$\frac{P_{grav}}{f'_c A_g}$		(%)	I	I	1.4	2.9	2.9	5.7
$P_{grav}$		(kip)	0	0	52	103	103	206
$\prec$			64	64	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	5640	6360	6360	7680
$M_p$		(kip-in)	4260	0069	5640	6360	6360	7680
$M_y$		(kip-in)	3550	5750	4700	5300	5300	6400
$A_g$		$(in^2)$	504	504	900	000	900	000
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30
Story			11 V	ΠV	2	<del>, -</del>	2	<del>, -</del>
Member			$\operatorname{Beams}$ +	Beams -	Exterior	Columns	Interior	Columns

Table: B.14: Moment-rotation properties for S2-13

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$\frac{P_{grav}}{f_c'A_g}$		(%)	I	I	2.1	4.1	4.1	8.3
$P_{grav}$		(kip)	0	0	74	149	149	297
X			64	64	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.06	0.05	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	6000	6960	6960	8760
$M_p$		(kip-in)	4260	0069	6000	0969	6960	8760
$M_y$		(kip-in)	3550	5750	5000	5800	5800	7300
$A_g$		$(in^2)$	504	504	900	006	900	900
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30
Story			11 V	ΠV	2	1	2	1
Member			$\operatorname{Beams}$ +	Beams -	Exterior	Columns	Interior	Columns

Table: B.15: Moment-rotation properties for S2-14

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properties
Moment-rotation
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Table:

$\frac{P_{grav}}{f'_c A_q}$	1	(%)	I	I	0.9	1.8	2.8	3.7	1.8	3.7	5.5	7.3
$P_{grav}$		(kip)	0	0	12	24	36	48	24	48	71	95
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3120	3180	3240	3300	3180	3300	3480	3600
$M_p$		(kip-in)	4260	0069	3120	3180	3240	3300	3180	3300	3480	3600
$M_y$		$(kip{-}in)$	3550	5750	2600	2650	2700	2750	2650	2750	2900	3000
$A_g$		$(in^2)$	504	504	324	324	324	324	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750	8750	8750	8750	8750
Col. Size	Sq.	(in)	I	I	18	18	18	18	18	18	18	18
Story			11 V	ЧI	4	က	2	Η	4	က	2	<del>,</del>
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

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$\frac{P_{grav}}{f'A_q}$	1	(%)	I	I	1.4	2.9	4.3	5.7	2.9	5.7	8.6	11.5
$P_{grav}$		(kip)	0	0	19	37	56	74	37	74	111	149
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3120	3240	3360	3480	3240	3480	3600	3720
$M_p$		$(kip{-}in)$	4260	6900	3120	3240	3360	3480	3240	3480	3600	3720
$M_y$		$(kip{-}in)$	3550	5750	2600	2700	2800	2900	2700	2900	3000	3100
$A_g$		$(in^2)$	504	504	324	324	324	324	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750	8750	8750	8750	8750
Col. Size	Sq.	(in)	I	I	18	18	18	18	18	18	18	18
Story			11 V	ΠV	4	က	2		4	က	2	<del>,</del> 1
Member			$\operatorname{Beams} +$	Beams -		Exterior	Columns			Interior	Columns	

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Moment-rotation
B.18:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	I	I	2.5	5.1	7.6	10.2	5.1	10.2	15.3	20.4
$P_{grav}$		(kip)	0	0	33	66	66	132	66	132	198	264
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3240	3360	3600	3720	3360	3720	3960	4200
$M_p$		$(kip{-}in)$	4260	6900	3240	3360	3600	3720	3360	3720	3960	4200
$M_y$		(kip-in)	3550	5750	2700	2800	3000	3100	2800	3100	3300	3500
$A_g$		$(in^2)$	504	504	324	324	324	324	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750	8750	8750	8750	8750
Col. Size	Sq.	(in)	I	I	18	18	18	18	18	18	18	18
Story			11 V	ΠV	4	က	2	1	4	c,	2	1
Member			$\operatorname{Beams} +$	Beams -		Exterior	Columns			Interior	Columns	

S4-3
$\operatorname{for}$
properties
Moment-rotation
B.19:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	I	ı	4.0	8.0	11.9	15.9	8.0	15.9	23.9	31.8
$P_{grav}$		(kip)	0	0	52	103	155	206	103	206	309	413
$\prec$			64	64	0	0	0	0	0	0	0	0
$ heta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3300	3480	3720	3840	3480	3840	4200	4800
$M_p$		$(kip{-}in)$	4260	6900	3300	3480	3720	3840	3480	3840	4200	4800
$M_y$		$(kip{-}in)$	3550	5750	2750	2900	3100	3200	2900	3200	3500	4000
$A_g$		$(in^2)$	504	504	324	324	324	324	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750	8750	8750	8750	8750
Col. Size	Sq.	(in)	L	I	18	18	18	18	18	18	18	18
Story				ЧП	4	က	2		4	က	2	
Member			$\operatorname{Beams}$ +	Beams -		Exterior	Columns			Interior	Columns	

S4-4
$\operatorname{for}$
properties
Moment-rotation
B.20:
Table:

$\frac{P_{grav}}{f'_c A_q}$	1	(%)	I	I	5.7	11.5	17.2	22.9	11.5	22.9	34.4	45.8
$P_{grav}$		(kip)	0	0	74	149	223	297	149	297	446	594
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3360	3720	3960	4080	3720	4080	4800	4200
$M_p$		(kip-in)	4260	0069	3360	3720	3960	4080	3720	4080	4800	4200
$M_y$		(kip-in)	3550	5750	2800	3100	3300	3400	3100	3400	4000	3500
$A_g$		$(in^2)$	504	504	324	324	324	324	324	324	324	324
$I_g$		$(in^4)$	32900	32900	8750	8750	8750	8750	8750	8750	8750	8750
Col. Size	Sq.	(in)	I	I	18	18	18	18	18	18	18	18
Story			11 V	IIV	4	က	2	Η	4	3	2	1
Member			$\operatorname{Beams} +$	Beams -		Exterior	Columns			Interior	Columns	

S4-5
$\operatorname{for}$
properties
Moment-rotation
B.21:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	I	I	0.5	1.0	1.5	2.1	1.0	2.1	3.1	4.1
$P_{grav}$		(kip)	0	0	12	24	36	48	24	48	71	95
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	3960	4080	4200	4320	4080	4320	4440	4680
$M_p$		(kip- $in)$	4260	6900	3960	4080	4200	4320	4080	4320	4440	4680
$M_y$		(kip-in)	3550	5750	3300	3400	3500	3600	3400	3600	3700	3900
$A_g$		$(in^2)$	504	504	576	576	576	576	576	576	576	576
$I_g$		$(in^4)$	32900	32900	27650	27650	27650	27650	27650	27650	27650	27650
Col. Size	Sq.	(in)	L	I	24	24	24	24	24	24	24	24
Story				IIV	4	33	2	1	4	က	2	
Member			$\operatorname{Beams}$ +	Beams -		Exterior	Columns			Interior	Columns	

S4-6
$\operatorname{for}$
properties
Moment-rotation
B.22:
Table:

$\frac{P_{grav}}{f'_c A_g}$	) 	(%)	I	1	0.8	1.6	2.4	3.2	1.6	3.2	4.8	6.4
$P_{gran}$		(kip)	0	0	19	37	56	74	37	74	111	149
$\boldsymbol{\prec}$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		(kip-in)	426	069	3960	4200	4320	4560	4200	4560	4920	5280
$M_p$		(kip-in)	4260	0069	3960	4200	4320	4560	4200	4560	4920	5280
$M_y$		(kip-in)	3550	5750	3300	3500	3600	3800	3500	3800	4100	4400
$A_g$		$(in^2)$	504	504	576	576	576	576	576	576	576	576
$I_g$		$(in^4)$	32900	32900	27650	27650	27650	27650	27650	27650	27650	27650
Col. Size	Sq.	(in)	-	ı	24	24	24	24	24	24	24	24
Story				ЧП	4	က	2		4	က	2	
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

S4-7
$\operatorname{for}$
properties
Moment-rotation
B.23:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	ı	I	1.4	2.9	4.3	5.7	2.9	5.7	8.6	11.5
$P_{grav}$		(kip)	0	0	33	66	66	132	66	132	198	264
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	4080	4560	4800	5100	4560	5100	5760	6300
$M_p$		(kip-in)	4260	0069	4080	4560	4800	5100	4560	5100	5760	6300
$M_y$		(kip-in)	3550	5750	3400	3800	4000	4250	3800	4250	4800	5250
$A_g$		$(in^2)$	504	504	576	576	576	576	576	576	576	576
$I_g$		$(in^4)$	32900	32900	27650	27650	27650	27650	27650	27650	27650	27650
Col. Size	Sq.	(in)	I	I	24	24	24	24	24	24	24	24
Story			11 V	ΠV	4	အ	2	Η	4	က	2	<del>,</del>
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

S4-8
$\operatorname{for}$
properties
Moment-rotation
B.24:
Table:

$\frac{P_{grav}}{f'_c A_q}$	1	(%)	I	I	2.2	4.5	6.7	9.0	4.5	9.0	13.4	17.9
$P_{grav}$		(kip)	0	0	52	103	155	206	103	206	309	413
$\prec$	~		64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	4320	4800	5280	5760	4800	5760	6720	7560
$M_p$		$(kip{-}in)$	4260	6900	4320	4800	5280	5760	4800	5760	6720	7560
$M_y$		(kip-in)	3550	5750	3600	4000	4400	4800	4000	4800	5600	6300
$A_g$		$(in^2)$	504	504	576	576	576	576	576	576	576	576
$I_g$		$(in^4)$	32900	32900	27650	27650	27650	27650	27650	27650	27650	27650
Col. Size	Sq.	(in)	I	I	24	24	24	24	24	24	24	24
Story			11 V	ЧI	4	က	2		4	33	2	<del>,</del> 1
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

S4-9
$\operatorname{for}$
properties
Moment-rotation
B.25:
Table:

$\frac{P_{grav}}{f'_c A_q}$	1	(%)	I	I	3.2	6.4	9.7	12.9	6.4	12.9	19.3	25.8
$P_{grav}$		(kip)	0	0	74	149	223	297	149	297	446	594
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	4560	5280	6000	6600	5280	6600	7800	8760
$M_p$		(kip-in)	4260	0069	4560	5280	6000	6600	5280	6600	7800	8760
$M_y$		(kip-in)	3550	5750	3800	4400	5000	5500	4400	5500	6500	7300
$A_g$		$(in^2)$	504	504	576	576	576	576	576	576	576	576
$I_g$		$(in^4)$	32900	32900	27650	27650	27650	27650	27650	27650	27650	27650
Col. Size	Sq.	(in)	I	I	24	24	24	24	24	24	24	24
Story			11 V	ΠV	4	3	2	1	4	3	2	<del>, _ 1</del>
Member			$\operatorname{Beams} +$	Beams -		Exterior	Columns			Interior	Columns	

S4-10
$\operatorname{for}$
properties
Moment-rotation
B.26:
Table:

$\frac{P_{grav}}{f_c'A_g}$	1	(%)	I	I	0.3	0.7	1.0	1.3	0.7	1.3	2.0	2.6
$P_{grav}$		(kip)	0	0	12	24	36	48	24	48	71	95
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	5160	5280	5400	5640	5280	5640	6000	6240
$M_p$		$(kip{-}in)$	4260	6900	5160	5280	5400	5640	5280	5640	6000	6240
$M_y$		$(kip{-}in)$	3550	5750	4300	4400	4500	4700	4400	4700	5000	5200
$A_g$		$(in^2)$	504	504	900	000	000	006	000	000	000	000
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30	30	30	30	30
Story			11 V	ΠV	4	3	2	Ц	4	3	2	1
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

4
$\mathbf{v}$
for
properties
Moment-rotation
B.27:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	I	I	0.5	1.0	1.5	2.1	1.0	2.1	3.1	4.1
$P_{grav}$		(kip)	0	0	19	37	56	74	37	74	111	149
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	5160	5520	6960	6000	5520	6000	6480	6960
$M_p$		$(kip{-}in)$	4260	0069	5160	5520	6960	6000	5520	6000	6480	0969
$M_y$		(kip-in)	3550	5750	4300	4600	5800	5000	4600	5000	5400	5800
$A_g$		$(in^2)$	504	504	900	000	000	000	900	000	000	000
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30	30	30	30	30
Story			11 V	ЧI	4	က	2	Η	4	3	2	<del>,</del>
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

S4-12
$\operatorname{for}$
properties
Moment-rotation
B.28:
Table:

$\frac{P_{grav}}{f'_c A_g}$	1	(%)	I	ı	0.9	1.8	2.8	3.7	1.8	3.7	5.5	7.3
$P_{grav}$		(kip)	0	0	33	66	66	132	66	132	198	264
$\prec$			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	5280	5880	6240	6720	5880	6720	7560	8400
$M_p$		$(kip{-}in)$	4260	6900	5280	5880	6240	6720	5880	6720	7560	8400
$M_y$		$(kip{-}in)$	3550	5750	4400	4900	5200	5600	4900	5600	6300	7000
$A_g$		$(in^2)$	504	504	000	000	000	000	000	000	000	006
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	ı	30	30	30	30	30	30	30	30
Story			11 V	ΠV	4	က	2	Η	4	3	2	
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

S4-13
$\operatorname{for}$
properties
Moment-rotation
B.29:
Table:

$\frac{P_{grav}}{f'_c A_q}$	1	(%)	I	I	1.4	2.9	4.3	5.7	2.9	5.7	8.6	11.5
$P_{grav}$		(kip)	0	0	52	103	155	206	103	206	309	413
$\prec$	~		64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	5640	6360	7080	7680	6360	7680	9000	10080
$M_p$		(kip-in)	4260	0069	5640	6360	7080	7680	6360	7680	0006	10080
$M_y$		(kip-in)	3550	5750	4700	5300	5900	6400	5300	6400	7500	8400
$A_g$		$(in^2)$	504	504	900	000	000	000	900	000	000	000
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30	30	30	30	30
Story			11 V	ЧI	4	က	2	Η	4	3	2	1
Member			$\operatorname{Beams} +$	Beams -		Exterior	Columns			Interior	Columns	

<u> </u>
S4-
$\operatorname{for}$
properties
Moment-rotation
B.30:
Table:

$\frac{P_{grav}}{f_c'A_g}$	1	(%)	I	I	2.1	4.1	6.2	8.3	4.1	8.3	12.4	16.5
$P_{grav}$		(kip)	0	0	74	149	223	297	149	297	446	594
X			64	64	0	0	0	0	0	0	0	0
$\theta_{pc}$		(rad)	0.08	0.08	10	10	10	10	10	10	10	10
$\theta_p$		(rad)	0.05	0.04	0.064	0.06	0.06	0.05	0.06	0.06	0.06	0.05
$M_{res}$		$(kip{-}in)$	426	690	6000	6960	7920	8760	6960	8760	10560	12120
$M_p$		$(kip{-}in)$	4260	6900	6000	6960	7920	8760	6960	8760	10560	12120
$M_y$		$(kip{-}in)$	3550	5750	5000	5800	6600	7300	5800	7300	8800	10100
$A_g$		$(in^2)$	504	504	006	000	000	000	000	000	000	000
$I_g$		$(in^4)$	32900	32900	67500	67500	67500	67500	67500	67500	67500	67500
Col. Size	Sq.	(in)	I	I	30	30	30	30	30	30	30	30
Story			11 V	ЧП	4	3	2		4	3	2	
Member			Beams +	Beams -		Exterior	Columns			Interior	Columns	

## Appendix C: Sample Numerical Model Files

Listing C.1: Code for the S2-0 Model

```
2
3
   4
   ## S2-0 Shear-Axial
5
6
    # define structure-geometry parameters
     set Nstories 2; # number of stories
7
     set Nbays 4; # number of frame bays (excludes bay for P-delta column)
8
9
      set Wbay1
                      [expr 12.0*12.0]; # bay width in inches
10
      set Wbav2
                       expr 12.0*12.0; # bay width in inches
11
      set HStory1
                       [expr 12.0*12.0]; # 1st story height in inches
12
      set HStoryTyp
                      [expr 12.0*12.0]; # story height of other stories in inches
13
      set HBuilding
                      [expr  $HStory1 + ($Nstories -1)*$HStoryTyp]; # height of building
14
    # calculate locations of beam/column joints:
15
16
     set Pier1
                 0.0; # leftmost column line
17
      set Pier2
                 [expr \$Pier1 + \$Wbay1];
      set Pier3
                  expr Pier1 + Wbay1 + (Nbays - 3) * Wbay2];
18
     set Pier4
                 [expr \$Pier1 + \$Wbay1 + (\$Nbays - 2) * \$Wbay2];
19
                 [expr \$Pier1 + \$Wbay1 + (\$Nbays - 1) * \$Wbay2];
20
      set Pier5
21
22
      set Floor1 0.0; # ground floor
23
      set Floor2 [expr $Floor1 + $HStory1];
24
      set Floor3 [expr $Floor2 + ($Nstories -1)*$HStoryTyp];
25
26
   # calculate joint offset distance for beam plastic hinges
27
28
      set phlat23
                      [expr 0.0]; # lateral dist from beam-col joint to loc of hinge (
         beams only)
                      [expr 28.0/4]; # lateral dist from beam-col joint to loc of hinge
29
      set phlatcols1
          (beams only)
30
      set phlatbeams1 [expr 18.0/4];
      set phlatbeams2 [expr 18.0/4] ;
31
32
33
     # calculate nodal masses -- lump floor masses at frame nodes
34
35
      set g 386.4; # acceleration due to gravity
36
      set deadWeight [expr 165./144./1000.] ; # 165 psf
37
      set load_I [expr $deadWeight*$Wbay1**2]
38
39
      set load_E [expr $load_I/2.]
      set mNode [expr $load_E/$g]
40
41
42
      set P_1i
                [expr 2.*$load_I]
43
      set P_2i
               [expr 1.*$load_I]
44
45
      set P le
                [expr 2.*$load_E]
                [expr 1.*$load_E]
46
      set P_2e
47
      set Dload [expr $deadWeight*$Wbay1]
48
49
50
      set T1_damp 0.22;
51
      set T3_damp 0.08;
52
53
     # Calculation of Total Building Weight
54
     #Define Nodal Mass Values
55
56
57
      set NodalMass2 $mNode;
      set Negligible 1e-9; # a very small number to avoid problems with zero
58
59
   \# define nodes and assign masses to beam-column intersections of frame
60
     # command: node nodeID xcoord ycoord -mass mass_dof1 mass_dof2 mass_dof3 # nodeID convention: "xy" where <math>x = Pier \# and y = Floor \#
61
62
63
```

```
64
      node 11 $Pier1 $Floor1 ;
65
      node 21 $Pier2 $Floor1
      node 31 $Pier3 $Floor1
66
67
      node 41 $Pier4 $Floor1
68
      node 51 $Pier5 $Floor1 ;
69
     # define extra nodes for plastic hinge rotational springs
70
                            "xya" where x = Pier \#, y = Floor \#, a = location relative to
71
      # nodeID convention:
           beam-column joint
      # "a" convention: 2 = left; 3 = right;
# "a" convention: 6 = below; 7 = above;
 72
73
74
75
      # column hinges at bottom of Story 1 (base)
      node 117 $Pier1 $Floor1 ;
76
77
      node 217 $Pier2 $Floor1 ;
78
      node 317 $Pier3 $Floor1 ;
79
      node 417 $Pier4 $Floor1
80
      node 517 $Pier5 $Floor1
81
82
      # column hinges at top of Story 1
      node 126 $Pier1 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
83
          $Negligible
84
      node 226 $Pier2 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
          $Negligible;
85
      node 326 $Pier3 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
          $Negligible;
86
      node 426 $Pier4 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
          $Negligible;
87
      node 526 $Pier5 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
          $Negligible;
 88
89
      # column hinges at bottom of Story 2
      node 127 $Pier1 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
90
          $Negligible;
91
      node 227 $Pier2 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
92
      node 327 $Pier3 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
      node 427 $Pier4 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
93
          $Negligible;
      node 527 $Pier5 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
94
          $Negligible;
95
      # column hinges at top of Story 2
96
      node 136 $Pier1 [expr $Floor3-$phlatcols1-$phlat23]
97
98
      node 236 $Pier2 [expr $Floor3-$phlatcols1-$phlat23]
99
      node 336 $Pier3
                      [expr $Floor3-$phlatcols1-$phlat23]
100
      node 436 $Pier4
                      [expr $Floor3-$phlatcols1-$phlat23]
101
      node 536 $Pier5 [expr $Floor3-$phlatcols1-$phlat23]
102
    103
104
    ## Define Rigid Offsets for joints
105
    106
107
      # column hinges at top of Story 1
      node 10126 $Pier1 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
108
          $Negligible;
109
      node 10226 $Pier2 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
      node 10326 $Pier3 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
110
          $Negligible;
111
      node 10426 $Pier4 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
112
      node 10526 $Pier5 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
113
      \# column hinges at bottom of Story 2
114
115
      node 10127 $Pier1 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
```

116	node 10227 \$Pier2 [expr \$Floor2+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible:
117	node 10327 \$Pier3 [expr \$Floor2+\$phlatcols1] -mass \$Negligible \$Negligible
118	node 10427 \$Pier4 [expr \$Floor2+\$phlatcols1] -mass \$Negligible \$Negligible
119	node 10527 \$Pier5 [expr \$Floor2+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible:
120	
$121 \\ 122$	# column hinges at top of Story 2 node 10136 \$Pier1 [expr \$Floor3-\$phlatcols1] -mass \$Negligible \$Negligible
123	\$Negligible; node 10236 \$Pier2 [expr \$Floor3-\$phlatcols1] -mass \$Negligible \$Negligible
124	\$Negligible; node 10336 \$Pier3 [expr \$Floor3-\$phlatcols1] -mass \$Negligible \$Negligible
	\$Negligible;
125	node 10436 \$Pier4 [expr \$Floor3-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible;
126	node 10536 \$Pier5 [expr \$Floor3-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible:
127	
128	# column hinges at bottom of Story 3
129	SNegligible:
130	node 10237 \$Pier2 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible
131	node 10337 \$Pier3 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible
132	node 10437 \$Pier4 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible
133	<pre>\$Negligible; node 10537 \$Pier5 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible</pre>
194	\$Negligible;
$134 \\ 135$	# beam offset at Floor 2
136	node 9122 [expr \$Pier1 - \$phlatbeams2] \$Floor2 -mass \$Negligible \$Negligible
137	node 9123 [expr \$Pier1 + \$phlatbeams2] \$Floor2 -mass [expr \$NodalMass2/1]
138	node 9222 [expr \$Pier2 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1]
139	\$Negligible \$Negligible; node 9223 [evpr \$Pier2 + \$phlatbeams1] \$Floor2mass [evpr \$NodalMass2/1]
100	\$Negligible \$Negligible;
140	node 9322 [expr \$Pier3 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible;
141	<pre>node 9323 [expr \$Pier3 + \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible;</pre>
142	node 9422 [expr \$Pier4 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible:
143	node 9423 [expr \$Pier4 + \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1]
144	node 9522 [expr \$Pier5 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1]
145	\$Negligible \$Negligible; node 9523 [expr \$Pier5 + \$phlatbeams1] \$Floor2 -mass \$Negligible \$Negligible
146	\$Negligible;
$140 \\ 147$	# beam offset at Floor 3
148	node 9132 [expr \$Pier1 - \$phlatbeams2] \$Floor3 -mass \$Negligible \$Negligible
149	node 9133 [expr \$Pier1 + \$phlatbeams2] \$Floor3 -mass [expr \$NodalMass2/1]
150	node 9232 [expr \$Pier2 - \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1]
151	<pre>\$Negligible \$Negligible; node 9233 [expr \$Pier2 + \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1]</pre>
151 152	<pre>\$Negligible \$Negligible; node 9233 [expr \$Pier2 + \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible; node 9332 [expr \$Pier3 - \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1]</pre>

153	node 9333 [expr \$Pier3 + \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1]
	\$Negligible \$Negligible;
154	node 9432 [expr \$Pier4 - \$phlatbeams1] \$Floor3 -mass [expr \$NodalMass2/1]
155	\$Negligible \$Negligible;
199	node 9433 [expr 3F16r4 + 3pniatbeams1] 3F100r3 -mass [expr 3NodalMass2/1]
156	• Negligible • Negligible; node 0522 [avpr @Diarts @phlatheams1] @Fleer3 mass [avpr @NodelMass2/1]
100	Nordigible Shortigible.
157	node 9533 [ever Spier5 + Sublatheams1] \$Floor3 _mass \$Negligible \$Negligible
107	SNeeligible
158	•····S···S······,
159	<del>#####################################</del>
160	<del>/////////////////////////////////////</del>
$101 \\ 162$	# beam hinges at Floor 2
163	$\pi$ both minipole as interval. $\pi$ and $\pi$ an
100	\$Negligible \$Negligible:
164	node 222 [expr \$Pier2 - \$phlatbeams1 + \$phlat23] \$Floor2 -mass \$Negligible
	\$Negligible \$Negligible;
165	node 223 [expr \$Pier2 + \$phlatbeams1 + \$phlat23] \$Floor2 -mass \$Negligible
	\$Negligible \$Negligible;
166	node 322 [expr \$Pier3 - \$phlatbeams1 + \$phlat23] \$Floor2 -mass \$Negligible
	\$Negligible \$Negligible;
167	node 323 [expr \$Pier3 + \$phlatbeams1 + \$phlat23] \$Floor2 -mass \$Negligible
100	\$Negligible \$Negligible;
168	node 422 [expr \$Pier4 - \$pniatbeams1 + \$pniat23] \$Floor2 -mass \$Negligible
160	The second secon
109	node 425 [expr srier4 + spinateams1 + spinat25] srioor2 -mass snegligible
170	$\varphi$ regulation $\varphi$ version $\varphi$ , $\varphi$ and $\varphi$ a
110	SNeeligible SNeeligible -
171	***************************************
172	# beam hinges at Floor 3
173	node 133 [expr \$Pier1 + \$phlatbeams2 + \$phlat23] \$Floor3 -mass \$Negligible
1 - 4	\$Negligible \$Negligible;
174	node 232 [expr \$Pier2 - \$phiatbeams1 + \$phiat23] \$Floor3 -mass \$Negligible
175	a Negligible a Negligible;
110	Negligible SNegligible
176	node 332 [expr $\$$ Pier3 - $\$$ phlatbeams1 + $\$$ phlat23] $\$$ Floor3 - mass $\$$ Negligible
110	\$Negligible \$Negligible:
177	node 333 [expr \$Pier3 + \$phlatbeams1 + \$phlat23] \$Floor3 -mass \$Negligible
	\$Negligible \$Negligible;
178	node 432 [expr \$Pier4 - \$phlatbeams1 + \$phlat23] \$Floor3 -mass \$Negligible
	\$Negligible \$Negligible;
179	node 433 [expr \$Pier4 + \$phlatbeams1 + \$phlat23] \$Floor3 -mass \$Negligible
	\$Negligible \$Negligible;
180	node 532 [expr \$Pier5 - \$phlatbeams1 + \$phlat23] \$Floor3 -mass \$Negligible
181	\$Negligible \$Negligible;
182	uniaxialMaterial Elastic 666 [expr 50 *4500000]
183	
184	element Joint2D 7777712 10126 9123 10127 9122 12 666 1
185	element Joint2D 7777713 10136 9133 10137 9132 13 666 1
187	element Joint2D 7777722 10226 9223 10227 9222 22 666 1
188	element Joint2D 7777723 10236 9233 10237 9232 23 666 1
189	
190	element Joint2D 7777732 10326 9323 10327 9322 32 666 1
$191 \\ 192$	CICILICITY JULIU2 1111100 10000 7000 10001 7002 00 000 1
193	element Joint2D 7777742 10426 9423 10427 9422 42 666 1
194	element Joint2D 7777743 10436 9433 10437 9432 43 666 1
195 106	element Joint 2D 7777752 10526 0523 10527 0522 52 666 1
$190 \\ 197$	element Joint2D 7777753 10526 9533 10537 9532 53 666 1
198	
199	
$\frac{200}{201}$	# assign boundary conditions # command: fix nodeID dxFixity dyFixity rzFixity
201	" commenter fix noteers axi ixity ayrixity fixity

```
82
```

```
\# fixity values: 1 = constrained; 0 = unconstrained
\# fix the base of the building; pin P-delta column at base
202
203
204
       fix 11 1 1 1;
205
206
       fix 21 1 1 1;
207
       fix 31 1 1 1;
       fix 41 1 1 1;
208
209
       fix 51 1 1 1;
210
211
       # Define Section Properties and Elements
212
    213
214
    # define material properties
       set Ec 3600.; # concrete Young's modulus
215
216
    # set up geometric transformations of element
   set PDeltaTransf 10;
217
218
219
       geomTransf PDelta $PDeltaTransf ; # PDelta transformation
220
221
       set LinearTransf 20;
222
       geomTransf Linear $LinearTransf; # PDelta transformation
223
224
    225
    # Column Elements Properties
226
227
228
    229
230
    231
    # General Properties of Column Cross Sections
232
    233
234
       set Ec 3600.;
                        # concrete Young's modulus
235
    # define column section 20"x20" for Storey 1,2 & 3
236
237
      Interior Columns
    #
       set Acol_123 324.; # cross-sectional area
set modcolscrack1 0.3 ; #if 1 cracking of elastic section of beam not taken into
account - if 0.3 taken into account
238
239
240
       set Icol_123 [expr $modcolscrack1* 8748.]; # moment of inertia
241
242
    #Exterior Columns
       set Acol_1231 324.;
       set Acol_1231 324.; # cross-sectional area
set modcolscrack1 0.3 ; #if 1 cracking of elastic section of beam not taken into
243
244
           \operatorname{account} - if 0.3 taken into account
       set Icol_1231 [expr $modcolscrack1* 8748.]; # moment of inertia
245
246
247
       set w1 18.
       set h1 18.
248
249
       set w2 18.
250
251
       set h2 18.
252
253
       set rho1int 0.00102 ;
254
       set Fsw1int 17.
255
       set rho2int 0.00102
256
       set Fsw2int 17.
257
258
       set rholext 0.00102 ;
259
       set Fswlext 17.
260
       set rho2ext 0.00102
261
       set Fsw2ext 17.
262
      \# determine stiffness modifications to equate the stiffness of the spring-elastic
263
           element-spring subassembly to the stiffness of the actual frame member

    # Reference: Ibarra, L. F., and Krawinkler, H. (2005). "Global collapse of frame structures under seismic excitations," Technical Report 152,
    # The John A. Blume Earthquake Engineering Research Center, Department

264
265
      of Civil Engineering, Stanford University, Stanford, CA.
# calculate modified section properties to account for spring stiffness being in
266
       series with the elastic element stiffness
set n 10.0; # stiffness multiplier for rotational spring
set n1 100.0; # stiffness multiplier for shear and axial spring
267
268
269
270
       # calculate modified moment of inertia for elastic elements
271
      #Interior
```

```
272
            set Icol_123mod [expr Icol_123*(n+1.0)/n]; # modified moment of inertia for
                   columns in Story 1,2
273
274
            #Exterior
275
            set Icol_1231mod [expr \$Icol_1231*(\$n+1.0)/\$n]; # modified moment of inertia for the set of the s
                   columns in Story 1,2
276
            # calculate modified rotational stiffness for plastic hinge springs
277
278
            #Interior
            set Ks_col_1123
279
                                              [expr $n*6.0*$Ec*$Icol_123mod/$HStory1]; # rotational
                    stiffness of Story 1 column springs
280
            set Ks_col_2123
                                             [expr $n*6.0*$Ec*$Icol_123mod/$HStoryTyp]; # rotational
                    stiffness of Story 2 column springs
281
282
           #Exterior
                                               [expr $n*6.0*$Ec*$Icol_1231mod/$HStory1];
            set Ks_col_11231
283
                                                                                                                                  # rotational
                    stiffness of Story 1 column springs
                                            [expr $n*6.0*$Ec*$Icol_1231mod/$HStoryTyp]; # rotational
284
            set Ks_col_21231
                    stiffness of Story 2 column springs
285
286
287
        288
        # Parameters for Shear Limit State Material
289
        290
291
            set slpsh 10.0
292
            set s2psh 20.0
293
            set s3psh 90.0
294
            set s1nsh - 10.0
            set s2nsh -20.0
set s3nsh -90.0
295
296
297
            set pinchXsh 0.5
298
            set pinchYsh 0.5
299
                set damage1sh 0.05
300
            set damage2sh 0.05
301
            set betash 0
302
            set curveTypesh 2
303
304
            set Av_123 [expr (5./6.)*$Acol_123];
305
306
            set Ksh_col_1123
                                               [expr ($Ec/2.3)*$Av_123/$HStory1]; # Shear Stiffness G*Av/L
307
            set Ksh_col_2123
                                              [expr ($Ec/2.3)*$Av_123/$HStoryTyp]; # Shear Stiffness G*Av/L
308
309
            set Ksf_1i [expr -100.] ;
310
            set Ksf_1e [expr -100.];
311
            set Ksf_2i [expr -100.];
312
            set Ksf_2e [expr -100.];
313
314
315
        # Parameters for Axial Limit State Material
316
317
318
319
            set s1pax 10.0
320
            set s2pax 30.0
321
            set s3pax 90.0
322
            set s1nax - 10.0
323
            set s2nax - 30.0
            set s3nax - 90.0
324
325
            set pinchXax 0.5
            set pinchYax 0.5
326
327
                set damage1ax 0.05
328
            set damage2ax 0.05
329
            set betaax 0.0
330
            set curveTypeax 1
331
                                                [expr $n1*$Ec*$Acol_123/$HStory1]; # rotational stiffness of
332
            set Kax_col_1123
                    Story 1 column springs
333
            set Kax_col_2123
                                               [expr $n1*$Ec*$Acol_123/$HStoryTyp]; # rotational stiffness of
                   Story 2 column springs
334
                                             [expr -0.01*$Ec*$Acol_123/$HStory1]; # rotational stiffness of
335
            set Kad_col_1123
                     Story 1 column springs
```

336	set	Kad_col_212 Story 2 co	23 [expr - olumn spring	-0.01*\$ s	Ec*\$	Aco	l_123/\$HSte	oryTyp	p]; # rotation;	al stiffness of
337			, spring					,		
338	# def	ine elastic	column elem	ents u	1sing	″el ⊈ol	ement" con	nmand		trancfID
$339 \\ 340$	# cc # e	leID conven	tion: "1xv"	where	1  mm	oei col	x = Piei	r #. v	v = Story  #	
341	# C	olumns Story	7 1				,		5 11	
342	eler	nent elasticH ; # Pier	BeamColumn l	111	117	126	\$Acol_123	\$Ec	\$Icol_1231mod	\$PDeltaTransf
343	eler	nent elasticH # Pier 2	BeamColumn	121	217	226	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
344	eler	nent elasticH # Pier 3	BeamColumn	131	317	326	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
345	eler	nent elastic # Pier 4	BeamColumn	141	417	426	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
346	eler	$\stackrel{\#}{=}$ nent elastic $\stackrel{\#}{=}$ Pier 5	BeamColumn	151	517	526	$Acol_123$	Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
347		# 1101 0								
348	# C	olumns Story	7 2							
349	eler	nent elastic ; # Pier	BeamColumn l	112	127	136	\$Acol_123	Ec	\$Icol_1231mod	\$PDeltaTransf
350	eler	nent elastic # Pier 2	BeamColumn	122	227	236	\$Acol_123	\$Ec	\$Icol_123mod	\$PDeltaTransf;
351	eler	nent elasticI # Pier 3	BeamColumn	132	327	336	\$Acol_123	\$Ec	\$Icol_123mod	\$PDeltaTransf;
352	eler	nent elastic # Pier 4	BeamColumn	142	427	436	\$Acol_123	\$Ec	\$Icol_123mod	\$PDeltaTransf;
353	eler	nent elastic # Pier 5	BeamColumn	152	527	536	\$Acol_123	\$Ec	\$Icol_123mod	\$PDeltaTransf;
354	<i>щ</i> с	oft Electio	Matarial Sr	ning						
356 356	# S # T	Definition o	f Soft Mater	rial						
357	uni	axialMateri	al Elastic 1	99.9						
$358 \\ 359$	#Colur	nn Hinge Pr	operties							
$\frac{360}{361}$	# Ger	neral input	values for C	olumn	spri	ngs				
362	4	1.01 0.0	// h : -					(	···· 1····· //	1: .
303	set	LSI 0.0; dotoriorati	# Dasic	streng	tn a	letei	rioration	(a ve	ry large $\# = 1$	io cyclic
364	set	LK1 0.0;	# unload	ing st	iffn	ess	deteriorat	tion	(a very large ≠	∉ = no cyclic
365	sot	LA1 0 0	on) # accele	rated	relo	adin	a stiffnes	e de	terioration (a	very large # -
300	set	no cvclic	deterioratio	on)	1610	auin	.g stillies	ss ue	terioration (a	very large # -
366	set	LD1 0.0 ;	# post-c	apping	str	engt	h deterior	ratior	n (a very large	e # = no
367		deteriorati	011)							
368	$\operatorname{set}$	LS2 0.0;	# basic	streng	th d	leter	rioration	(a vei	ry large $\# = 1$	no cyclic
369	set	LK2 0.0;	on) # unload	ing st	iffn	ess	deteriorat	tion	(a very large #	⊭ = no cyclic
370	$\operatorname{set}$	deteriorati LA2 0.0;	on) # accele	rated	relo	adin	g stiffnes	ss de	terioration (a	very large # =
371	set	no cyclic LD2 0.0 :	deterioratio # post-c	on) apping	str	engt	h deterior	ratior	n (a verv large	e # = no
		deteriorati	on)	11 0		0			<b>X V U</b>	
372				_						
373	set	cS 1.0;	# expone	nt for	bas	ic s	strength d	eterio	oration $(c = 1)$	.0 for no
374	$\operatorname{set}$	cK 1.0;	# expone	nt for	unl	oadi	ng stiffne	ess d	eterioration (d	c = 1.0 for no
375	set	cA 1.0;	on) # expone	nt for	acc	eler	ated reloa	nding	stiffness det	erioration ( $c =$
376	$\operatorname{set}$	1.0 for no cD 1.0;	o deteriorat # expone	ion) nt for	pos	t-ca	apping stre	ength	deterioration	(c = 1.0  for)
377		no deterior	ration)		-			-		
378	$\operatorname{set}$	th_pc1P 10	.0; # po	st-cap	ping	rot	capacity	for	pos loading	
379	set	th_pc1N 10	.0; # po	st-cap	ping	rot	capacity	for	neg loading	
380 381	set	in_pc2P_10 et_th_pc2N	.0; # po 10.0· #	st-cap	ping	rot י no	capacity	tor j	pos loading r neg loading	
382	6	co un-peziv	, #	P051-C	appi		capach	.y 101	neg roading	
383	$\operatorname{set}$	$\operatorname{ResP}$ 1.00;	# resi	dual s	stren	gth	ratio for	pos	loading	

 $\begin{array}{c} \text{set} \ \operatorname{ResN} \ 1.00;\\ \text{set} \ \mathrm{th}\_\mathrm{uP} \ 10.1; \end{array}$ 384 # residual strength ratio for neg loading 385# ultimate rot capacity for pos loading 386 set th\_uN 10.1; # ultimate rot capacity for neg loading 387 388 set DP 1.0; # rate of cyclic deterioration for pos loading 389 set DN 1.0; # rate of cyclic deterioration for neg loading 390 391 set McMy1 1.20 392393 set th\_p1P 0.048; set th\_p1N 0.048; 394set th\_p2P 0.060; 395396 set th\_p2N 0.060; 397 398 set My\_c1i 2500. 399 set My\_c2i 2300. 400401 set My\_c1e 2300. 402set My\_c2e 2200. 403 # define column springs # Spring ID: "3xya", where 3 = col spring, x = Pier #, y = Story #, a = location in 404405story # "a" convention: 1 = bottom of story, 2 = top of story406 # command: rotSpring2DModIKModel id ndR ndC K McMy MyPos MyNeg LS LK LA LD cS cK cA cD th\_p+ th\_p- th\_pc+ th\_pc-Res+ Res- th\_u+ th\_u- D+ D-407 Res-D+  $th_u+$ 408 # col springs @ bottom of Story 1 (at base) 409 410 rotSpring2DModIKModel 3111 11 117 \$Ks\_col\_11231 \$McMy1 [expr \$My\_c1e] [expr -\$My\_c1e] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3211 21 217 \$Ks\_col\_1123 \$McMy1 411 [expr \$My\_c1i] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; pring2DModIKModel 3311 31 317 \$Ks\_col\_1123 \$McMy1 [expr \$My\_cli] [expr -\$My\_cli] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N 412rotSpring2DModIKModel 3311 31 317 \$Ks\_col\_1123 \$McMy1 \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 413rotSpring2DModIKModel 3411 41 417 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3511 51 517 \$Ks\_col\_11231 \$McMy1 [expr \$My\_c1e] [expr -414\$My\_cle] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 415#col springs @ top of Story 1 (below Floor 2) 416 rotSpring2DModIKModel2 3112 10126 126 \$w1 \$h1 \$Ks\_col\_11231 \$McMy1 417 [expr \$My\_c1e [ expr -\$My\_c1e] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rholext \$Fswlext \$Ksf\_le 418\$s1pax [expr \$s1pax/\$Kax\_col\_1123] \$s2pax [expr \$s2pax/\$Kax\_col\_1123] \$s3pax [expr \$s3pax/\$Kax\_col\_1123] \$s1nax [expr \$s1nax/\$Kax\_col\_1123] \$s2nax [expr \$s2nax/ \$Kax\_col\_1123] \$s3nax [expr \$s3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123 419rotSpring2DModIKModel2 3212 10226 226 \$w1 \$h1 \$Ks\_col\_1123 \$McMy1 420 [expr \$My\_c1i ] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [
expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf\_1i\ 421\$s1pax [expr \$s1pax/\$Kax\_col\_1123] \$s2pax [expr \$s2pax/\$Kax\_col\_1123] \$s3pax [expr \$s3pax/\$Kax\_col\_1123] \$s1nax [expr \$s1nax/\$Kax\_col\_1123] \$s2nax [expr \$s2nax/ \$Kax\_col\_1123 | \$s3nax [expr \$s3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123

- 422 rotSpring2DModIKModel2 3312 10326 326 \$w1 \$h1 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i ] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf\_1i\
- 423 \$s1pax [expr \$s1pax/\$Kax\_col\_1123] \$s2pax [expr \$s2pax/\$Kax\_col\_1123] \$s3pax [expr \$s3pax/\$Kax\_col\_1123] \$s1nax [expr \$s1nax/\$Kax\_col\_1123] \$s2nax [expr \$s2nax/ \$Kax\_col\_1123] \$s3nax [expr \$s3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123]
- 424 rotSpring2DModIKModel2 3412 10426 426 \$w1 \$h1 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i ] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf\_1i\
- 425 \$\$1pax [expr \$\$1pax/\$Kax\_col\_1123] \$\$2pax [expr \$\$2pax/\$Kax\_col\_1123] \$\$3pax [expr \$\$3pax/\$Kax\_col\_1123] \$\$1nax [expr \$\$1nax/\$Kax\_col\_1123] \$\$2nax [expr \$\$2nax/ \$Kax\_col\_1123] \$\$3nax [expr \$\$3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123]
- 426 rotSpring2DModIKModel2 3512 10526 526 \$w1 \$h1 \$Ks\_col\_11231 \$McMy1 [expr \$My\_c1e] [expr -\$My\_c1e ] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf\_1e\
- 427 \$\$1pax [expr \$\$1pax/\$Kax\_col\_1123] \$\$2pax [expr \$\$2pax/\$Kax\_col\_1123] \$\$3pax [expr \$\$3pax/\$Kax\_col\_1123] \$\$1nax [expr \$\$1nax/\$Kax\_col\_1123] \$\$2nax [expr \$\$2nax/ \$Kax\_col\_1123] \$\$3nax [expr \$\$3nax/\$Kax\_col\_1123] \$\$pinchXax \$pinchYax \$\$damage1ax \$\$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123]
- 428
- 429 # col springs @ bottom of Story 2 (above Floor 2)
- 430 rotSpring2DModIKModel 3121 10127 127 \$Ks\_col\_21231 \$McMy1 [expr \$My\_c2e] [ expr -\$My\_c2e ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 431 rotSpring2DModIKModel 3221 10227 227 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i ] [ expr -\$My\_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 432 rotSpring2DModIKModel 3321 10327 327 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i ] [ expr -\$My\_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 433 rotSpring2DModIKModel 3421 10427 427 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i ] [ expr -\$My\_c2i ] \$LS2 \$LK2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 434 rotSpring2DModIKModel 3521 10527 527 \$Ks\_col\_21231 \$McMy1 [expr \$My\_c2e] [ expr -\$My\_c2e ] \$LS2 \$LK2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 435
- 436 #col springs @ top of Story 2 (below Floor 3)
- 438 \$\$1pax [expr \$\$1pax/\$Kax\_col\_2123] \$\$2pax [expr \$\$2pax/\$Kax\_col\_2123] \$\$3pax [expr \$\$3pax/\$Kax\_col\_2123] \$\$3pax [expr \$\$3pax/\$Kax\_col\_2123] \$\$2pax [expr \$\$2pax/\$Kax\_col\_2123] \$\$pax [expr \$\$2pax/\$Kax\_col\_2123] \$\$pax [expr \$\$2pax/\$Kax\_col\_2123] \$\$pax [expr \$\$2pax/\$Kax\_col\_2123] \$\$pax [expr \$\$pax [expr \$\$xad\_col\_2123] \$\$pax [expr \$\$pax [expr \$\$xad\_col\_2123] \$\$pax [expr \$\$pax [expr
- 439 rotSpring2DModIKModel2 3222 10236 236 \$w1 \$h1 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i ] [expr -\$My\_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr

\$s1psh/\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2i 440\$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123 441rotSpring2DModIKModel2 3322 10336 336 \$w1 \$h1 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P [expr -\$My\_c2i ] \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2i\ 442\$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123; 443rotSpring2DModIKModel2 3422 10436 436 \$w1 \$h1 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i [expr -\$My\_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2i\ \$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr 444\$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123; rotSpring2DModIKModel2 3522 10536 536 \$w1 \$h1 \$Ks\_col\_21231 \$McMy1 445[expr \$My\_c2e [expr -\$My\_c2e ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2e\ 446\$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123 447 448 449# Beam Elements Properties 450451452453454# General Properties of Beam Cross Sections 455<del>```</del> 456457set Ec 3600.; # concrete Young's modulus 458# define beam section 18"x28" for Floor 2,3 & 4 459460 set modbeamscrack 0.6461set Abeam\_234 504.; # cross-sectional area (full section properties) set Ibeam\_234 [expr \$modbeamscrack\*32928.]; # moment of inertia (full section 462properties) 463# define beam section 16"x28" for Floor 5,6 & 7 464 465 # set Abeam\_567 448; # cross-sectional area (full section properties) 466# cross-sectional area (full section properties) 467 set Abeam\_567 504.; set Ibeam\_567 [expr \$modbeamscrack \* 32928.]; # moment of inertia (full section 468 properties) 469470# determine stiffness modifications to equate the stiffness of the spring-elastic element-spring subassembly to the stiffness of the actual frame member

471	# Reference: Ibarra, L. F., and Krawinkler, H. (2005). "Global collapse of frame
472	# The John A. Blume Earthquake Engineering Research Center, Department of Civil Engineering, Stanford University, Stanford, CA.
473	# calculate modified section properties to account for spring stiffness being in series with the elastic element stiffness
$474 \\ 475$	set n 10.0; # stiffness multiplier for rotational spring
$476 \\ 477$	# calculate modified moment of inertia for elastic elements
478	<pre>set Ibeam_234mod [expr \$Ibeam_234*(\$n+1.0)/\$n]; # modified moment of inertia for beams in Floor 2,3 &amp; 4</pre>
479	<pre>set Ibeam_567mod [expr \$Ibeam_567*(\$n+1.0)/\$n]; # modified moment of inertia for beams in Floor 5,6 &amp; 7</pre>
480 481	
482	<pre>set Ks_beam_1234 [expr \$n*6.0*\$Ec*\$Ibeam_234mod/\$Wbay1]; # rotational stiffness of Floor 2,3 &amp; 4 beam springs</pre>
483	<pre>set Ks_beam_2234 [expr \$n*6.0*\$Ec*\$Ibeam_234mod/\$Wbay2]; # rotational stiffness of Floor 2,3 &amp; 4 beam springs</pre>
484	<pre>set Ks_beam_1567 [expr \$n*6.0*\$Ec*\$Ibeam_567mod/\$Wbay1]; # rotational stiffness of Floor 2,3 &amp; 4 beam springs</pre>
485	<pre>set Ks_beam_2567 [expr \$n*6.0*\$Ec*\$Ibeam_567mod/\$Wbay2]; # rotational stiffness of Floor 2,3 &amp; 4 beam springs</pre>
$486 \\ 487$	
488	# Elastic Beam Column Elements
489	
490 491	# elelD convention: "2xy" where $2 = \text{beam}$ , $x = \text{Bay} \#$ , $y = \text{Floor} \#$ # Beams Story 1
492	" lement elasticBeamColumn 212 123 222 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf:
493	element elasticBeamColumn 222 223 322 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf:
494	element elasticBeamColumn 232 323 422 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf:
495	element elasticBeamColumn 242 423 522 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf:
496	
497	# Beams Story 2
498	element elasticBeamColumn 213 133 232 \$Abeam_234 \$Ec \$lbeam_234mod \$LinearTransf;
499	element elasticBeamColumn 223 233 332 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf;
500	element elasticBeamColumn 233 333 432 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf;
501	element elasticBeamColumn 243 433 532 \$Abeam_234 \$Ec \$Ibeam_234mod \$LinearTransf;
502 503	
$503 \\ 504$	# Define Rotational Springs for Plastic Hinges
505	<del>/////////////////////////////////////</del>
506 507	# General input values for Beam Springs
$508 \\ 509$	set LS13 64.0; # basic strength deterioration (a very large $\# =$ no cyclic deterioration)
510	set LK13 0.0; # unloading stiffness deterioration (a very large $\#$ = no cyclic deterioration)
511	set LA13 0.0; # accelerated reloading stiffness deterioration (a very large $\# = no$
512	set LD13 64.0; $\#$ post-capping strength deterioration (a very large $\#$ = no deterioration)
513	deterioration)
514	<pre>set LS14 64.0; # basic strength deterioration (a very large # = no cyclic deterioration)</pre>
515	set LK14 0.0; # unloading stiffness deterioration (a very large $\#$ = no cyclic deterioration)
516	set LA14 0.0; $\#$ accelerated reloading stiffness deterioration (a very large $\#$ = no

cyclic deterioration)

517set LD14 64.0; # post-capping strength deterioration (a very large # = no deterioration) 518519set cS 1.0; # exponent for basic strength deterioration (c = 1.0 for no deterioration) 520set cK 1.0; # exponent for unloading stiffness deterioration (c = 1.0 for no deterioration) 521set cA 1.0; # exponent for accelerated reloading stiffness deterioration (c = 1.0for no deterioration) 522set cD 1.0; # exponent for post-capping strength deterioration (c = 1.0 for no deterioration) 523524set th\_pc13P 0.076; # post-capping rot capacity for pos loading 525set th\_pc13N 0.076; # post-capping rot capacity for neg loading 526527set th\_pc14P 0.076; # post-capping rot capacity for pos loading set th\_pc14N 0.076; # post-capping rot capacity for neg loading 528529set ResP 0.10; # residual strength ratio for pos loading set ResN\_0.10; # residual strength ratio for neg loading 530531set th\_uP 0.20; # ultimate rot capacity for pos loading 532set th\_uN 0.20; # ultimate rot capacity for neg loading 533 534535set DP 1.0; # rate of cyclic deterioration for pos loading 536set DN 1.0; # rate of cyclic deterioration for neg loading 537 set McMy13 1.20 538539set McMy14 1.20 540541set th\_p13P 0.049; set th\_p13N 0.043; 542543set th\_p14P 0.046; 544545set th\_p14N 0.046; 546547set My\_bP 3550. 548set My\_bN [expr -5750.] 549#Story 1 550551552#beam springs at Floor 2 rotSpring2DModIKModel 4121 9123 123 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 553 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 554rotSpring2DModIKModel 4122 9222 222 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4221 9223 223 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 555\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 556rotSpring2DModIKModel 4222 9322 322 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4321 9323 323 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 557\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4322 9422 422 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 558\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4421 9423 423 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 559\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 560rotSpring2DModIKModel 4422 9522 522 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 561# Story 2 562563 564#beam springs at Floor 3

565rotSpring2DModIKModel 4131 9133 133 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 566 rotSpring2DModIKModel 4132 9232 232 \$Ks\_beam\_1234 \$McMv13 \$Mv\_bP \$Mv\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4231 9233 233 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 567\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4232 9332 332 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 568\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4331 9333 333 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 569 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4332 9432 432 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 570\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 571rotSpring2DModIKModel 4431 9433 433 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4432 9532 532 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 572\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 573574575576577 # apply gravity loads  $\# command: pattern PatternType \ \$PatternID \ TimeSeriesType$ 578579 pattern Plain 1010 Constant { 580# point loads on leaning column nodes # command: load node Fx Fy Mz 581582583 584set P\_PD1 [expr -\$load\_E]; # Pier 1 set P\_PD2 [expr -\$load\_I]; # Pier 2 585586set PPD3 [expr -\$load\_I]; # Pier 3 587 set P\_PD4 [expr -\$load\_I]; # Pier 4 set P\_PD5 [expr -\$load\_E]; # Pier 5 588589 ; # Pier 1 590load 10127 0.0 \$P\_PD1 0.0 ; # Pier 2 load 10227 0.0 \$P\_PD2 0.0 591; # Pier 3 592load 10327 0.0 \$P\_PD3 0.0 ; # Pier 4 load 10427 0.0  $P_{\rm D}0.0$ 593 ; # Pier 5 594load 10527 0.0 \$P\_PD5 0.0 595596 597load 10137 0.0 \$P\_PD1 0.0 ; # Pier 1 ; # Pier 2 598load 10237 0.0 \$P\_PD2 0.0 599 load 10337 0.0 \$P\_PD3 0.0 ; # Pier 3 load 10437 0.0  $P_PD4 0.0$ ; # Pier 4 600 601 load 10537 0.0 \$P\_PD5 0.0 ; # Pier 5 602 603 } 604605 606 # define DAMPING 607 608 # apply Rayleigh DAMPING from \$xDamp 609 # D=\$alphaM\*M + \$betaKcurr\*Kcurrent + \$betaKcomm\*KlastCommit + \$betaKinit\*\$Kinitial 610 611 set xDamp 0.02; # 2% damping ratio 612 613 set omega1 [expr 6.2832/\$T1\_damp] 614 set omega3 [expr 6.2832/\$T3\_damp] 615 616set alpha1 [expr \$xDamp\*2\*\$omega1\*\$omega3/(\$omega1+\$omega3)]; set alpha2 [expr 2.\*\$xDamp/(\$omega1+\$omega3)]; 617

```
618
619
      set alphaM [expr $xDamp*2*$omega1*$omega3/($omega1+$omega3)];
620
      set betaKcurr 0.:
621
      set betaKcomm 0.;
622
      set betaKinit [expr 2.*$xDamp/($omega1+$omega3)];
623
      set betaKinit_mod [expr $betaKinit*1.1];
624
625
    # define damping
    # Beam Regions by Bay
626
627
      region 555 -eleRange 212 213 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
      region 556 -eleRange 222 223 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
628
629
      region 557 -eleRange 232 233 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
630
      region 558 -eleRange 242 243 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
631
632
      # Column Regions by Pier
633
      region 560 -eleRange 111 112 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
634
      region 561 -eleRange 121 122 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
635
      region 562 -eleRange 131 132 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
      region 563 -eleRange 141 142 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
636
637
      region 564 -eleRange 151 152 -rayleigh 0.0 $betaKcurr $betaKinit_mod $betaKcomm;
638
      region 1 -- node 10126 9123 10127 9122 -- rayleigh $alphaM 0.0 0.0 0.0; # assign mass
639
          proportional damping to structure (assign to nodes with mass)
      region 2 -node 10136 9133 10137 9132 -rayleigh $alphaM 0.0 0.0 0.0;
640
641
642
      region 8 -node 10226 9223 10227 9222 -rayleigh $alphaM 0.0 0.0 0.0;
643
      region 9 -node 10236 9233 10237 9232 -rayleigh $alphaM 0.0 0.0 0.0;
644
      region 15 -node 10326 9323 10327 9322 -rayleigh $alphaM 0.0 0.0 0.0;
645
646
      region 16 -node 10336 9333 10337 9332 -rayleigh $alphaM 0.0 0.0 0.0;
647
      region 21 -node 10426 9423 10427 9422 -rayleigh $alphaM 0.0 0.0 0.0;
648
649
      region 22 -node 10436 9433 10437 9432 -rayleigh $alphaM 0.0 0.0 0.0;
650
651
      region 27 -node 10526 9523 10527 9522 -rayleigh $alphaM 0.0 0.0 0.0;
      region 28 -node 10536 9533 10537 9532 -rayleigh $alphaM 0.0 0.0 0.0;
652
653
    654
655
    656
    ### DEFINE ANALYSIS OPTIONS, NEEDED LISTS OF STUFF TO RECORD, ETC.
    \# Define control nodes for monotonic and cyclic pushover – at top of leaning column
657
658
         set poControlNodeNum
                                         13
         set poControlNodeNumCyclic
659
                                         13
    # Define a list of element numbers to record - record the columns or primary frame
660
        and leaning column - these are used for computing base shear and story shear
661
        set elementNumToRecordLIST { 111 121
                                                112 \ 122 
662
663
    # Define a list of joint numbers to record - all joints of primary frame
664
        set jointNumToRecordLIST {}
665
    \# Define a list of node numbers to record - top/bottom node of joint in left column
666
        of each floor, leaning column nodes, base spring nodes
        set nodeNumToRecordLIST { 126 226 10126 10226 11 12 13
667
                                                                   31 \ 32 \ 33
    set springnodeNumToRecordLIST { 116 126 216 226 316 326 }
# Define a list of hinge elements to record - these are the springs at the base of
668
669
        the columns (elastic foundation + column PH)
670
        set hingeElementsToRecordLIST {}
671
672
    # Define a list of column numbers at the base of the frame (including the leaning
        column); this is for base shear calculations
        set columnNumsAtBaseLIST { 111 121 131 141 151}
673
674
    # Define a list of column numbers at each story (including the leaning column); this
675
        is for story shear calculations
676
        set columnNumsAtEachStoryLIST { { 111 121 131 141 151 }
677
        \{ 112 \ 122 \ 132 \ 142 \ 152 \ \} 
678
679
    680
681
      set zerolengthelementNumToRecordLIST { { 3112 3212 3312 3412 3512
                                                \{ 3122 \ 3222 \ 3322 \ 3422 \ 3522 \}
682
```
```
683
684
   685
686
   # Define a list of heights of each floor (for computing story drifts)
687
       set floorHeightsLIST { 0 144 288}
688
   \# Define a list of the node numbers at each floor (always use node 3 of the joint
689
       because it is at the slab level and we measure all height to there)
       set nodeNumsAtEachFloorLIST \{-1 \ 12 \ 13\}
690
691
692
   693
     set nodeNums1stFloorSpringsLIST {12 22 32 42 52};
set nodeNums2ndFloorSpringsLIST {13 23 33 43 53};
694
695
696
697
      set springnodeNums1stFloorSpringsLIST {126 226 326 426 526};
      set springnodeNums2ndFloorSpringsLIST {136 236 336 436 536};
698
699
700
   701
   702
703
704
       set columnRhoLIST { { 0.00102 0.00102 0.00102 0.00102 0.00102 } 
 { 0.00102 0.00102 0.00102 0.00102 0.00102 }}
705
706
707
708
       set columnFswLIST { { { 17. 17. 17. 17. 17. 17. } }
709
        \{ 17. 17. 17. 17. 17. 17. \} \}
710
       set columnWidthLIST { { 18. 18. 18. 18. 18.
711
712
        \{ 18. 18. 18. 18. 18. 18. \} \}
713
714
       set columnDepthLIST { { 15.5 15.5 15.5 15.5 15.5 }
715
        \{15.5 \ 15.5 \ 15.5 \ 15.5 \ 15.5 \}
716
   set fpc_NRS 4000. ##### END NRS
717
718
719
```

## Listing C.1: Code for the S4-0 Model

```
3
   4
   ## S4-0 Shear-Axial
5
    # define structure-geometry parameters
  set Nstories 4; # number of stories
6
7
8
     set Nbays 4; # number of frame bays (excludes bay for P-delta column)
9
     set Wbay1
                     [expr 12.0*12.0]; # bay width in inches
     set Wbay2
                      [expr 12.0*12.0]; \# bay width in inches
10
11
     set HStory1
                      [expr 12.0*12.0]; # 1st story height in inches
12
     set HStoryTyp
                      [expr 12.0*12.0]; # story height of other stories in inches
13
     set HBuilding
                     [expr $HStory1 + ($Nstories -1)*$HStoryTyp]; # height of building
14
    # calculate locations of beam/column joints:
15
                0.0; # leftmost column line
     set Pier1
16
17
     set Pier2
                 [expr $Pier1 + $Wbay1];
                 [expr \$Pier1 + \$Wbay1 + (\$Nbays - 3) *\$Wbay2];
18
     set Pier3
19
     set Pier4
                 [expr \$Pier1 + \$Wbay1 + (\$Nbays - 2) * \$Wbay2];
20
     set Pier5
                 [expr \$Pier1 + \$Wbay1 + (\$Nbays - 1) *\$Wbay2];
21
22
     set Floor1 0.0; # ground floor
     set Floor2 [expr $Floor1 + $HStory1];
23
     set Floor3 [expr $Floor2 + ($Nstories -3)*$HStoryTyp];
24
25
     set Floor4 [expr $Floor2 + ($Nstories -2)*$HStoryTyp];
     set Floor5 [expr $Floor2 + ($Nstories -1)*$HStoryTyp];
26
27
28
29
   # calculate joint offset distance for beam plastic hinges
30
                      [expr 0.0]; # lateral dist from beam-col joint to loc of hinge (
31
     set phlat23
         beams only)
                     [expr 28.0/4]; # lateral dist from beam-col joint to loc of hinge (
32
     set phlatcols1
         beams only)
33
     set phlatbeams1
                     [expr 18.0/4];
34
     set phlatbeams2 [expr 18.0/4];
35
   # calculate nodal masses -- lump floor masses at frame nodes
36
37
38
                        # acceleration due to gravity
     set g 386.4:
39
     set deadWeight [expr 165./144./1000.] ; # 165 psf
40
41
     set load_I [expr $deadWeight*$Wbay1**2]
42
     set load_E [expr $load_I/2.]
     set mNode [expr $load_E/$g]
43
44
45
     set P_1i
                [expr 4.*$load_I]
46
     set P_2i
                [expr 3.*$load_I]
     set P_3i
47
                [expr 2.*$load_I]
     set P_4i
                [expr 1.*$load_I]
48
49
     set P_{-1}e
50
                [expr 4.*$load_E]
51
     set P_2e
                [expr 3.*$load_E
     set P_3e
52
                [expr 2.*$load_E
53
     set P_4e
               [expr 1.*$load_E]
54
55
     set Dload [expr $deadWeight*$Wbay1]
     set T1_damp 0.40;
56
     set T3_damp 0.09;
57
58
59
     #Define Nodal Mass Values
60
     set NodalMass2 $mNode;
61
     set Negligible 1e-9; # a very small number to avoid problems with zero
62
63
   # define nodes and assign masses to beam-column intersections of frame
64
     # command: node nodeID xcoord ycoord -mass mass_dof1 mass_dof2 mass_dof3
65
     # nodeID convention: "xy" where x = Pier \# and y = Floor \#
66
67
```

```
68
       node 11 $Pier1 $Floor1 ;
 69
       node 21 $Pier2 $Floor1
70
       node 31 $Pier3 $Floor1
 71
       node 41 $Pier4 $Floor1
 72
       node 51 $Pier5 $Floor1 ;
 73
 74
     # define extra nodes for plastic hinge rotational springs
 75
                             "xya" where x = Pier \#, y = Floor \#, a = location relative to
      # nodeID convention:
           beam-column joint
      # "a" convention: 2 = left; 3 = right;
# "a" convention: 6 = below; 7 = above;
 76
 77
 78
 79
      # column hinges at bottom of Story 1 (base)
       node 117 $Pier1 $Floor1 ;
 80
 81
       node 217 $Pier2 $Floor1 ;
 82
       node 317 $Pier3 $Floor1 :
 83
       node 417 $Pier4 $Floor1
 84
       node 517 $Pier5 $Floor1
 85
 86
      # column hinges at top of Story 1
       node 126 $Pier1 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
 87
           $Negligible
 88
       node 226 $Pier2 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
           $Negligible;
 89
       node 326 $Pier3 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
           $Negligible;
 90
       node 426 $Pier4 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
           $Negligible;
 91
       node 526 $Pier5 [expr $Floor2-$phlatcols1-$phlat23] -mass $Negligible $Negligible
           $Negligible;
 92
 93
      # column hinges at bottom of Story 2
      node 127 $Pier1 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
 94
           $Negligible;
 95
       node 227 $Pier2 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
           $Negligible;
 96
       node 327 $Pier3 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
           $Negligible;
       node 427 $Pier4 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
 97
           $Negligible;
       node 527 $Pier5 [expr $Floor2+$phlatcols1+$phlat23] -mass $Negligible $Negligible
98
           $Negligible;
99
      # column hinges at top of Story 2
100
       node 136 $Pier1 [expr $Floor3-$phlatcols1-$phlat23]
101
102
       node 236 $Pier2 [expr $Floor3-$phlatcols1-$phlat23]
103
                        [expr $Floor3-$phlatcols1-$phlat23]
       node 336 $Pier3
104
       node 436 $Pier4
                        [expr $Floor3-$phlatcols1-$phlat23
       node 536 $Pier5 [expr $Floor3-$phlatcols1-$phlat23]
105
106
      # column hinges at bottom of Story 3
107
       node 137 $Pier1 [expr $Floor3+$phlatcols1+$phlat23] -mass $Negligible $Negligible
108
           $Negligible;
109
       node 237 $Pier2 [expr $Floor3+$phlatcols1+$phlat23] -mass $Negligible $Negligible
           $Negligible;
110
       node 337 $Pier3 [expr $Floor3+$phlatcols1+$phlat23] -mass $Negligible $Negligible
           $Negligible;
       node 437 $Pier4 [expr $Floor3+$phlatcols1+$phlat23] -mass $Negligible $Negligible
111
           $Negligible;
       node 537 $Pier5 [expr $Floor3+$phlatcols1+$phlat23] -mass $Negligible $Negligible
112
           $Negligible;
113
      # column hinges at top of Story 3
114
                        [expr $Floor4-$phlatcols1-$phlat23]
115
       node 146 $Pier1
       node 246 $Pier2
                        [expr $Floor4-$phlatcols1-$phlat23]
116
117
       node 346 $Pier3
                        [expr $Floor4-$phlatcols1-$phlat23]
118
       node 446 $Pier4
                        [expr $Floor4-$phlatcols1-$phlat23]
119
       node 546 $Pier5 [expr $Floor4-$phlatcols1-$phlat23]
120
```

```
121
      # column hinges at bottom of Story 4
122
      node 147 $Pier1 [expr $Floor4+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
123
      node 247 $Pier2 [expr $Floor4+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
124
      node 347 $Pier3 [expr $Floor4+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
125
      node 447 $Pier4 [expr $Floor4+$phlatcols1+$phlat23] -mass $Negligible $Negligible
          $Negligible;
      node 547 $Pier5 [expr $Floor4+$phlatcols1+$phlat23] -mass $Negligible $Negligible
126
          $Negligible;
127
      # column hinges at top of Story 4
128
129
      node 156 $Pier1
                      [expr $Floor5-$phlatcols1-$phlat23]
                      [expr $Floor5-$phlatcols1-$phlat23]
130
      node 256 $Pier2
                      [expr $Floor5-$phlatcols1-$phlat23]
131
      node 356 $Pier3
132
      node 456 $Pier4 [expr $Floor5-$phlatcols1-$phlat23]
133
      node 556 $Pier5 [expr $Floor5-$phlatcols1-$phlat23]
134
    135
136
    137
138
139
      # column hinges at top of Story 1
140
      node 10126 $Pier1 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
      node 10226 $Pier2 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
141
          $Negligible;
142
      node 10326 $Pier3 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
      node 10426 $Pier4 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
143
          $Negligible;
144
      node 10526 $Pier5 [expr $Floor2-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
145
      # column hinges at bottom of Story 2
146
      node 10127 $Pier1 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
147
          $Negligible;
148
      node 10227 $Pier2 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
149
      node 10327 $Pier3 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
      node 10427 $Pier4 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
150
          $Negligible;
151
      node 10527 $Pier5 [expr $Floor2+$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
152
153
      # column hinges at top of Story 2
154
      node 10136 $Pier1 [expr $Floor3-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
155
      node 10236 $Pier2 [expr $Floor3-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
156
      node 10336 $Pier3 [expr $Floor3-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
157
      node 10436 $Pier4 [expr $Floor3-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
158
      node 10536 $Pier5 [expr $Floor3-$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
159
160
      # column hinges at bottom of Story 3
161
      node 10137 $Pier1 [expr $Floor3+$phlatcols1] -mass $Negligible $Negligible
162
          $Negligible;
163
      node 10237 $Pier2 [expr $Floor3+$phlatcols1] -mass $Negligible $Negligible
          $Negligible;
      node 10337 $Pier3 [expr $Floor3+$phlatcols1] -mass $Negligible $Negligible
164
          $Negligible;
```

165node 10437 \$Pier4 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; node 10537 \$Pier5 [expr \$Floor3+\$phlatcols1] -mass \$Negligible \$Negligible 166 \$Negligible; 167# column hinges at top of Story 3 168 169node 10146 \$Pier1 [expr \$Floor4-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 170node 10246 \$Pier2 [expr \$Floor4-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 171node 10346 \$Pier3 [expr \$Floor4-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 172node 10446 \$Pier4 [expr \$Floor4-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 173node 10546 \$Pier5 [expr \$Floor4-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 174175# column hinges at bottom of Story 4 node 10147 \$Pier1 [expr \$Floor4+\$phlatcols1] -mass \$Negligible \$Negligible 176\$Negligible; 177node 10247 \$Pier2 [expr \$Floor4+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; node 10347 \$Pier3 [expr \$Floor4+\$phlatcols1] -mass \$Negligible \$Negligible 178\$Negligible; node 10447 \$Pier4 [expr \$Floor4+\$phlatcols1] -mass \$Negligible \$Negligible 179\$Negligible; 180node 10547 \$Pier5 [expr \$Floor4+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 181 182 # column hinges at top of Story 4 183node 10156 \$Pier1 [expr \$Floor5-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 184node 10256 \$Pier2 [expr \$Floor5-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 185node 10356 \$Pier3 [expr \$Floor5-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 186node 10456 \$Pier4 [expr \$Floor5-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 187node 10556 \$Pier5 [expr \$Floor5-\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 188 189# column hinges at bottom of Story 5 node 10157 \$Pier1 [expr \$Floor5+\$phlatcols1] -mass \$Negligible \$Negligible 190 \$Negligible; 191node 10257 \$Pier2 [expr \$Floor5+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; node 10357 \$Pier3 [expr \$Floor5+\$phlatcols1] -mass \$Negligible \$Negligible 192\$Negligible; 193node 10457 \$Pier4 [expr \$Floor5+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible: 194node 10557 \$Pier5 [expr \$Floor5+\$phlatcols1] -mass \$Negligible \$Negligible \$Negligible; 195196# beam offset at Floor 2 197node 9122 [expr \$Pier1 - \$phlatbeams2] \$Floor2 -mass \$Negligible \$Negligible \$Negligible; node 9123 [expr \$Pier1 + \$phlatbeams2] \$Floor2 -mass [expr \$NodalMass2/1] 198 \$Negligible \$Negligible; node 9222 [expr \$Pier2 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] 199 \$Negligible \$Negligible; 200node 9223 [expr \$Pier2 + \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible; 201node 9322 [expr \$Pier3 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible; 202 node 9323 [expr \$Pier3 + \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible; 203node 9422 [expr \$Pier4 - \$phlatbeams1] \$Floor2 -mass [expr \$NodalMass2/1] \$Negligible \$Negligible;

204	node 9423 [expr	<pre>\$Pier4 + \$phlatbeams1]</pre>	\$Floor2	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
205	node 9522 [expr	\$Pier5 - \$phlatbeams1]	\$Floor2	-mass	[expr \$NodalMass2/1]
206	\$Negligible	\$Negligible;	¢ El a a n 9		<sup>e</sup> Nomlinihlo <sup>e</sup> Nomlinihlo
200	Negligible:	sriers + spilatbeamsi	ðr 100r2	-mass	an egligible an egligible
207	witegingible,				
208	# beam offset at	Floor 3			
209	node 9132 [expr	<pre>\$Pier1 - \$phlatbeams2]</pre>	\$Floor3	-mass	<pre>\$Negligible \$Negligible</pre>
010	\$Negligible;		<b>AD</b> 1 A		
210	node 9133 [expr	\$Pier1 + \$phlatbeams2]	\$Floor3	-mass	[expr \$NodalMass2/1]
011	\$Negligible	\$Negligible;	¢ El a a n 2		[own PNodelMess2 /1]
211	Negligible	\$Negligible:	9F10013	-mass	[expr \$NodalMass2/1]
212	node 9233 [expr	Pier2 + Pier2	\$Floor3	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
213	node 9332 [expr	\$Pier3 - \$phlatbeams1]	\$Floor3	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
214	node 9333 [expr	\$Pier3 + \$phlatbeams1]	\$Floor3	-mass	[expr \$NodalMass2/1]
015	\$Negligible	\$Negligible;	<b>AD</b> 1 A		
215	node 9432 [expr	\$Pier4 - \$phlatbeams1]	\$Floor3	-mass	[expr \$NodalMass2/1]
216	a Negligible	SNegligible;	\$Floor?	magg	[ovpr \$NodalMass2 /1]
210	Negligible	\$Negligible ·	φ1 <sup>,</sup> 10013	-111255	[expl #NoualMass2/1]
217	node 9532 [expr	\$Pier5 - \$phlatbeams1]	\$Floor3	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
218	node 9533 [expr	<pre>\$Pier5 + \$phlatbeams1]</pre>	\$Floor3	-mass	<pre>\$Negligible \$Negligible</pre>
	<pre>\$Negligible;</pre>				
219					
220	# beam offset at	Floor 4			
221	node 9142 [expr	<pre>\$Pier1 - \$phlatbeams2]</pre>	\$Floor4	-mass	\$Negligible \$Negligible
000	\$Negligible;	P. and . Cohlathear 2	¢Eleer4		[own PNodelMess2 /1]
222	node 9143 [expr	\$Nogligible:	\$F100r4	-mass	[expr \$NodalMass2/1]
223	node 9242 [expr	\$Pier2 - \$phlatheams1]	\$Floor4	-mass	[expr_\$NodalMass2/1]
	\$Negligible	\$Negligible;	Q1 1001 1	mabb	
224	node 9243 [expr	\$Pier2 + \$phlatbeams1]	\$Floor4	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
225	node 9342 [expr	<pre>\$Pier3 - \$phlatbeams1]</pre>	Floor4	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
226	node 9343 [expr	\$Pier3 + \$phlatbeams1]	\$Floor4	-mass	[expr \$NodalMass2/1]
227	\$Negligible	\$Negligible; \$Pion4 \$Phlatheomal]	¢ Eloor 4	maga	[own WodelMess2 /1]
221	Negligible	\$Negligible:	\$F10014	-mass	[expl #NodalMass2/1]
228	node 9443 [expr	Pier4 + Pier4	\$Floor4	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;	Q1 1001 1	mabb	
229	node 9542 [expr	\$Pier5 - \$phlatbeams1]	\$Floor4	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
230	node 9543 [expr	<pre>\$Pier5 + \$phlatbeams1]</pre>	Floor4	-mass	<pre>\$Negligible \$Negligible</pre>
0.01	\$Negligible;				
231					
232	# beam offset at	Ploor o	Ф. <b>Б.</b> 1 <b>Г</b>		ΦNI
233	node 9152 [expr	\$Pierl - \$phlatbeams2]	\$Floor5	-mass	\$Negligible \$Negligible
234	node 9153 [expr	\$Pier1 + \$phlatheams2]	\$Floor5	-mass	[expr_\$NodalMass2/1]
-01	\$Negligible	\$Negligible :	Q1 10010	mabb	
235	node 9252 [expr	\$Pier2 - \$phlatbeams1]	\$Floor5	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
236	node 9253 [expr	<pre>\$Pier2 + \$phlatbeams1]</pre>	\$Floor5	-mass	[expr \$NodalMass2/1]
	\$Negligible	\$Negligible;			
237	node 9352 [expr	\$Pier3 - \$phlatbeams1]	\$Floor5	-mass	[expr \$NodalMass2/1]
000	\$Negligible	\$Negligible;	ф. <b>П</b> 1 <b>-</b>		
238	node 9353 [expr	<pre>\$\sigma ries + \$\sigma phiatbeams1   \$\sigma ries + \$\sigma phiatbeams1   \$\sigma ries + \$\</pre>	3F100r5	-mass	[expr \$NodalMass2/1]
230	onegiigidie node 9452 [evor	$\varphi_{13} = \varphi_{13} = \varphi$	\$Floor5	-mass	[evpr_\$NodalMass2/1]
200	\$Negligible	\$Negligible:	Ψ <b>1</b> 10010	111033	
	~SS-D-C				

240	node 9453 [expr \$Pier4 + \$phlatbeams1]		\$Floor5	-mass	[exp	r \$No	dalMass2/1]
941	\$Negligible \$Negligible; node 0552 [ever \$Pier5 \$phletheeme1]	1	¢ Floor 5	meaa	[ own	n ¢No.	dolMocc9 /1]
241	\$Negligible \$Negligible \$		\$F10015 ·	-mass	lexb	1 0100	uaimass2/1]
242	node 9553 [expr \$Pier5 + \$phlatbeams1]		\$Floor5	-mass	\$Ne	gligibl	e \$Negligible
243	unegligible,						
$244 \\ 245 \\ 246$	++++++++++++++++++++++++++++++++++++++	-    -	-  -  -  -  -  -  -  -  -  -  -   -  -		-/////////////////////////////////////	# #	
$240 \\ 247$	# beam hinges at Floor 2						
248	node 123 [expr \$Pier1 + \$phlatbeams2 +	+	<pre>\$phlat23]</pre>	\$Flo	or2	-mass	\$Negligible
249	node 222 [expr \$Pier2 - \$phlatbeams1 +	F	\$phlat23]	\$Flo	or2	-mass	\$Negligible
250	sNegligible SNegligible; node 223 [expr \$Pier2 + \$phlatbeams1 +	F	<pre>\$phlat23]</pre>	\$Flo	or2	-mass	\$Negligible
951	\$Negligible \$Negligible;		@	¢ E La	~ <b>n D</b>		¢ No mli mihlo
201	\$Negligible \$Negligible;	-	∂pniat25]	<b>ФГ</b> 10	012	-mass	anegiigibie
252	node 323 [expr \$Pier3 + \$phlatbeams1 + \$Negligible \$Negligible :	F	\$phlat23]	\$Flo	or2	-mass	\$Negligible
253	node 422 [expr \$Pier4 - \$phlatbeams1 +	F	<pre>\$phlat23 ]</pre>	\$Flo	or2	-mass	\$Negligible
254	node 423 [expr \$Pier4 + \$phlatbeams1 +	ŀ	<pre>\$phlat23]</pre>	\$Flo	or2	-mass	\$Negligible
255	\$Negligible \$Negligible; node 522 [expr \$Pier5 – \$phlatbeams1 +	⊦	\$phlat23]	\$Flo	or2	-mass	\$Negligible
256	<pre>\$Negligible \$Negligible ;</pre>						
257	# beam hinges at Floor $3$						
258	node 133 [expr \$Pier1 + \$phlatbeams2 + \$Negligible \$Negligible:	Ē	\$phlat23]	\$Flo	or3	-mass	\$Negligible
259	node 232 [expr \$Pier2 - \$phlatbeams1 +	F	<pre>\$phlat23 ]</pre>	\$Flo	or3	-mass	\$Negligible
260	node 233 [expr \$Pier2 + \$phlatbeams1 +	+	\$phlat23]	\$Flo	or3	-mass	\$Negligible
261	sNegligible SNegligible; node 332 [expr \$Pier3 - \$phlatbeams1 +	⊦	\$phlat23]	\$Flo	or3	-mass	\$Negligible
262	\$Negligible \$Negligible; node 333 [expr \$Pier3 + \$phlatbeams1 +	F	\$phlat23]	\$Flo	or3	-mass	\$Negligible
263	\$Negligible \$Negligible; node 432 [expr \$Pier4 - \$phlatbeams1 +	F	\$phlat23]	\$Flo	or3	-mass	\$Negligible
264	<pre>\$Negligible \$Negligible; node 433 [expr \$Pier4 + \$phlatbeams1 +</pre>	F	<pre>\$phlat23]</pre>	\$Flo	or3	-mass	\$Negligible
265	\$Negligible \$Negligible;		\$phlat23]	¢Flo	org	mass	«Nagligibla
200	\$Negligible \$Negligible;	_	opinat25]	Φ1 <sup>,</sup> 10	015	-111855	anegiigibie
$\frac{266}{267}$	# beam hinges at Floor 4						
268	node 143 [expr \$Pier1 + \$phlatbeams2 +	+	\$phlat23]	\$Flo	or4	-mass	\$Negligible
269	\$Negligible \$Negligible; node 242 [evpr \$Pier2 - \$phlatheams1 +	L	\$phlat23]	\$Flo	or4	-mass	\$Negligible
200	\$Negligible \$Negligible;		•pmat20]	0110		mass	
270	node 243 [expr \$Pier2 + \$phlatbeams1 + \$Negligible \$Negligible;	-	\$phlat23]	\$Flo	or4	-mass	\$Negligible
271	node 342 [expr \$Pier3 - \$phlatbeams1 + \$Negligible \$Negligible:	F	<pre>\$phlat23 ]</pre>	\$Flo	or4	-mass	\$Negligible
272	node 343 [expr \$Pier3 + \$phlatbeams1 + \$Negligible \$Negligible:	+	\$phlat23]	\$Flo	or4	-mass	\$Negligible
273	node 442 [expr \$Pier4 - \$phlatbeams1 +	⊦	<pre>\$phlat23 ]</pre>	\$Flo	or4	-mass	\$Negligible
274	node 443 [expr \$Pier4 + \$phlatbeams1 +	+	\$phlat23]	\$Flo	or4	-mass	\$Negligible
275	sNegligible sNegligible; node 542 [expr \$Pier5 - \$phlatbeams1 +	⊦	<pre>\$phlat23]</pre>	\$Flo	or4	-mass	\$Negligible
976	<pre>\$Negligible \$Negligible;</pre>						
$270 \\ 277$	# beam hinges at Floor 5						
278	node 153 [expr \$Pier1 + \$phlatbeams2 + \$Negligible \$Negligible:	F	<pre>\$phlat23]</pre>	\$Flo	or5	-mass	\$Negligible
	**************************************						

```
279
       node 252 [expr $Pier2 - $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
           $Negligible $Negligible;
       node 253 [expr $Pier2 + $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
280
           $Negligible $Negligible;
281
       node 352 [expr $Pier3 - $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
           $Negligible $Negligible;
282
       node 353 [expr $Pier3 + $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
           $Negligible $Negligible;
       node 452 [expr $Pier4 - $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
283
           $Negligible $Negligible;
284
       node 453 [expr $Pier4 + $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
           $Negligible $Negligible;
285
       node 552 [expr $Pier5 - $phlatbeams1 + $phlat23] $Floor5 -mass $Negligible
           $Negligible $Negligible;
286
       uniaxialMaterial Elastic 666 [expr 50.*4500000.]
287
288
289
    # Create rigid joints
       element Joint2D 7777712 10126 9123 10127 9122
element Joint2D 7777713 10136 9133 10137 9132
element Joint2D 7777714 10146 9143 10147 9142
290
                                                          12 \ 666 \ 1
291
                                                          13 \ 666 \ 1
292
                                                          14 666 1
293
       element Joint2D 7777715 10156 9153 10157 9152
                                                         15 \ 666 \ 1
294
       element Joint2D 7777722 10226 9223 10227 9222 22 666 1 element Joint2D 7777723 10236 9233 10237 9232 23 666 1 element Joint2D 7777724 10246 9243 10247 9242 24 666 1 element Joint2D 7777725 10256 9253 10257 9252 25 666 1
295
296
297
298
299
       element Joint2D 7777732 10326 9323 10327 9322 32 666 1
300
       element Joint2D 7777733 10336 9333 10337 9332 33 666 1
element Joint2D 7777734 10346 9343 10347 9342 34 666 1
element Joint2D 7777735 10356 9353 10357 9352 35 666 1
301
302
303
304
305
       element Joint2D 7777742 10426 9423 10427 9422 42 666 1 element Joint2D 7777743 10436 9433 10437 9432 43 666 1
306
       element Joint2D 7777744 10446 9443 10447 9442 44 666 1
307
308
       element Joint2D 7777745 10456 9453 10457 9452 45 666 1
309
       element Joint2D 7777752 10526 9523 10527 9522 52 666 1
element Joint2D 7777753 10536 9533 10537 9532 53 666 1
310
311
       element Joint2D 7777755 10556 9553 10547 9542 54 666 1
element Joint2D 7777755 10556 9553 10557 9552 55 666 1
312
313
314
315
    # assign boundary condidtions
       # command: fix nodeID dxFixity dyFixity rzFixity
316
317
       # fixity values: 1 = \text{constrained}; 0 = \text{unconstrained}
       \ddot{\#} fix the base of the building; pin P-delta column at base
318
319
320
       fix 11 1 1 1;
       fix 21 1 1 1;
321
       fix 31 1 1 1;
322
323
       fix 41 1 1 1;
324
       fix 51 1 1 1;
325
    326
327
    #
                 Define Section Properties and Elements
328
    329
    # define material properties
       set Ec 3600.;
330
                         # concrete Young's modulus
331
332
    # set up geometric transformations of element
       set PDeltaTransf 10;
333
334
       geomTransf PDelta $PDeltaTransf ; # PDelta transformation
335
336
       set LinearTransf 20;
337
       geomTransf Linear $LinearTransf; # PDelta transformation
338
339
    340
    Column Elements Properties
341
    #
342
    <del>```</del>
343
    344
```

```
General Properties of Column Cross Sections
346
347
    348
349
       set Ec 3600.; # concrete Young's modulus
350
351
    # Interior Columns
       set Acol_123 324.; \# cross-sectional area
set modcolscrack1 0.3 ; \# if 1 cracking of elastic section of beam not taken into
352
353
            account - if 0.3 taken into account
354
       set Icol_123 [expr $modcolscrack1* 8748.]; # moment of inertia
355
356
     \#Exterior Columns
357
       set Acol_1231 324.; # cross-sectional area
       set modcolscrack1 0.3 ; #if 1 cracking of elastic section of beam not taken into account - if 0.3 taken into account
358
359
       set Icol_1231 [expr $modcolscrack1* 8748.]; # moment of inertia
360
361
       set w1 18
362
       set h1 18
363
364
    # define column section 20"x20" for Storey 4,5 & 6
365
366
    #Interior Columns
       set Acol_456 324.; \# cross-sectional area
set modcolscrack2 0.3; \#if 1 cracking of elastic section of beam not taken into
367
368
            account - if 0.3 taken into account
369
       set Icol_456 [expr $modcolscrack2* 8748.]; # moment of inertia
     #Exterior Columns
370
       set Acol_4561 324.; # cross-sectional area
set modcolscrack2 0.3 ; #if 1 cracking of elastic section of beam not taken into
371
372
            account - if 0.3 taken into account
373
       set Icol_4561 [expr $modcolscrack2* 8748.]; # moment of inertia
374
375
       set w2 18
       set h2 18
376
377
       set rholint 0.00102 ;
378
379
       set Fsw1int 17.
       set rho2int 0.00102
380
381
       set Fsw2int 17.
382
       set rho3int 0.00102
383
       set Fsw3int 17.
384
       set rho4int 0.00102
385
       set Fsw4int 17.
386
387
       set rholext 0.00102
388
       set Fswlext 17.
389
       set rho2ext 0.00102
390
       set Fsw2ext 17.
391
       set rho3ext 0.00102
392
       set Fsw3ext 17.
       set rho4 \text{ext} 0.00102
393
394
       set Fsw4ext 17.
395
396
       # determine stiffness modifications to equate the stiffness of the spring-elastic
            element-spring subassembly to the stiffness of the actual frame member

    # Reference: Ibarra, L. F., and Krawinkler, H. (2005). "Global collapse of frame structures under seismic excitations," Technical Report 152,
    # The John A. Blume Earthquake Engineering Research Center, Department

397
398
            of Civil Engineering, Stanford University, Stanford, CA.
       # calculate modified section properties to account for spring stiffness being in
series with the elastic element stiffness
399
                      # stiffness multiplier for rotational spring
400
       set n 10.0;
401
       set n1 100.0;" # stiffness multiplier for shear and axial spring
402
403
       # calculate modified moment of inertia for elastic elements
404
       #Interior
405
                          [\exp  Icol_{123} * (n+1.0)/n]; \# modified moment of inertia for
       set Icol_123mod
            columns in Story 1,2 & 3
       set Icol_456mod [expr lcol_456*(n+1.0)/n]; # modified moment of inertia for
406
            columns in Story 2,3 & 4
407
408
       #Exterior
       set Icol_1231mod [expr Icol_1231*(n+1.0)/n]; # modified moment of inertia for
409
```

09 set Icol\_1231mod [expr \$Icol\_1231\*(\$n+1.0)/\$n]; # modified moment of inertia for columns in Story 1,2 & 3 410 set Icol\_4561mod  $[expr \$Icol_4561*(\$n+1.0)/\$n]; # modified moment of inertia for the set of the s$ columns in Story 2,3 & 4 411 # calculate modified rotational stiffness for plastic hinge springs 412413#Interior set Ks\_col\_1123 [expr \$n\*6.0\*\$Ec\*\$Icol\_123mod/\$HStory1]; 414 # rotational stiffness of Story 1 column springs [expr \$n\*6.0\*\$Ec\*\$Icol\_123mod/\$HStoryTyp]; # rotational 415set Ks\_col\_2123 stiffness of Story 2 column springs Ks\_col\_1456 [expr \$n\*6.0\*\$Ec\*\$Icol\_456mod/\$HStoryTyp]; # rotational stiffness of Story 2 column springs 416Ks\_col\_1456 set 417418 #Exterior [expr \$n\*6.0\*\$Ec\*\$Icol\_1231mod/\$HStory1]; set Ks\_col\_11231 419# rotational stiffness of Story 1 column springs 420 set Ks\_col\_21231 [expr \$n\*6.0\*\$Ec\*\$Icol\_1231mod/\$HStoryTyp]; # rotational stiffness of Story 2 column springs 421set Ks\_col\_14561 [expr \$n\*6.0\*\$Ec\*\$Icol\_4561mod/\$HStoryTyp]; # rotational stiffness of Story 2 column springs 422 423 424425426427 428 set s1psh 10.0set s2psh 20.0 429430set s3psh 90.0 431set s1nsh - 10.0set s2nsh -20.0set s3nsh -90.0432433434 set pinchXsh 0.5 435set pinchYsh 0.5 set damage1sh 0.05 436 set damage2sh 0.05437438 set betash 0 439set curveTypesh 2 440 441 set Av\_123 [expr (5./6.)\*\$Acol\_123]; 442set Av\_456 [expr (5./6.)\*\$Acol\_123]; 443 444set Ksh\_col\_1123 [expr (\$Ec/2.3)\*\$Av\_123/\$HStory1]; # Shear Stifness G\*Av/L 445set Ksh\_col\_2123 [expr (\$Ec/2.3)\*\$Av\_123/\$HStoryTyp]; # Shear Stifness G\*Av/L 446 set Ksh\_col\_1456 [expr (\$Ec/2.3)\*\$Av\_456/\$HStoryTyp]; # Shear Stifness G\*Av/L 447 448 set Ksf\_li [expr -100.]; [expr -100.]; 449 set Ksf\_1e 450451set Ksf\_2i [expr -100.];452set Ksf\_2e [expr -100.];453set Ksf 3i [expr -100.];454455set Ksf\_3e [expr -100.];456457set Ksf\_4i [expr -100.];[expr -100.];458set Ksf\_4e 459460461 # Parameters for Axial Limit State Material 462463464set slpax 10.0 465set s2pax 30.0 466 set s3pax 90.0 467 set slnax -10.0468 set s2nax - 30.0469 set s3nax - 90.0set pinchXax 0.5 470set pinchYax 0.5 471472set damagelax 0.05473set damage $\bar{2}ax 0.05$ set betaax 0.0474475set curveTypeax 1

$\begin{array}{c} 476 \\ 477 \end{array}$	set Kax_col_1123 [expr \$n1*\$Ec*	\$Acol_1	23/\$HStory	71];	# rotational	stiffness of
478	Story 1 column springs set Kax_col_2123 [expr \$n1*\$Ec*	\$Acol_1	23/\$HStory	Typ];	# rotational	stiffness of
479	set Kax_col_1456 [expr \$n1*\$Ec* Story 2 column springs	\$Acol_4	56/\$HStory	Typ];	# rotational	stiffness of
$     480 \\     481 $	set Kad_col_1123 [expr -0.01*\$E	c*\$Acol	l_123/\$HSto	orv1];	# rotationa	al stiffness of
482	Story 1 column springs set Kad_col_2123 [expr -0.01*\$E	c*\$Aco	//\$HSto	oryTyp	]; # rotationa	al stiffness of
483	Story 2 column springs set Kad_col_1456 [expr -0.01*\$E	c*\$Aco	l_456/\$HSto	oryTyp	]; # rotationa	al stiffness of
$\frac{484}{485}$	# define elastic column elements us	ing "el	ement" com	mand		
$486 \\ 487$	" # command: element elasticBeamColu	ımn \$el	eID \$iNode	e \$jNc	ode \$A \$E \$I \$t	ransfID
$\begin{array}{c} 488 \\ 489 \end{array}$	<pre># eleID convention: "1xy" where # Columns Story 1</pre>	1 = col	, x = Pier	•#, y	r = Story #	
490	element elasticBeamColumn 111 1 ; # Pier 1	17 126	\$Acol_123	\$Ec	\$Icol_1231mod	\$PDeltaTransf
491	element elasticBeamColumn 121 2 # Pier 2	17 226	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
492	element elasticBeamColumn 131 3 # Pier 3	17 326	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
493	element elasticBeamColumn 141 4 # Pier 4	17 426	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
494	element elasticBeamColumn 151 5 # Pier 5	17 526	\$Acol_123	\$Ec	\$Icol_123mod	<pre>\$PDeltaTransf;</pre>
$495 \\ 496$	# Columns Story 2					
497	element elasticBeamColumn 112 1 : # Pier 1	27 136	\$Acol_123	\$Ec	\$Icol_1231mod	\$PDeltaTransf
498	element elasticBeamColumn 122 2 # Pier 2	27 236	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
499	element elasticBeamColumn 132 3 # Pier 3	27 336	\$Acol_123	Ec	\$Icol_123mod	PDeltaTransf;
500	element elasticBeamColumn 142 4 # Pier 4	27 436	\$Acol_123	Ec	\$Icol_123mod	PDeltaTransf;
501	element elasticBeamColumn 152 5 # Pier 5	27 536	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
$502 \\ 503$	# Columns Story 3					
504	element elastic BeamColumn 113 1	37 146	\$Acol_123	\$Ec	\$Icol_1231mod	PDeltaTransf
505	element elasticBeamColumn 123 2	37 246	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
506	# Fiel 2 element elasticBeamColumn 133 3 # Pior 3	37 346	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
507	element elasticBeamColumn 143 4 # Pior 4	37 446	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
508	element elasticBeamColumn 153 5 # Pier 5	37 546	\$Acol_123	\$Ec	\$Icol_123mod	PDeltaTransf;
$509 \\ 510$	# Columns Story 4					
$510 \\ 511$	element elastic BeamColumn 114 1	47 156	\$Acol_456	\$Ec	\$Icol_4561mod	\$PDeltaTransf
512	element elasticBeamColumn 124 2	47 256	\$Acol_456	\$Ec	\$Icol_456mod	PDeltaTransf;
513	element elasticBeamColumn 134 3 # Pier 3	47 356	\$Acol_456	\$Ec	\$Icol_456mod	PDeltaTransf;
514	element elasticBeamColumn 144 4 # Pier 4	47 456	\$Acol_456	\$Ec	\$Icol_456mod	PDeltaTransf;
515	element elasticBeamColumn 154 5 # Pier 5	47 556	\$Acol_456	\$Ec	\$Icol_456mod	PDeltaTransf;
$516 \\ 517 \\ 518$	" uniaxialMaterial Elastic 1 99.9					
$519 \\ 520 \\ 521$	#Column Hinge Properties # General input values for Column s	prings				

522	$\operatorname{set}$	LS1 0.0; # basic strength deterioration (a very large $\# = no$ cyclic
		deterioration)
523	$\operatorname{set}$	LK1 0.0; # unloading stiffness deterioration (a very large $\# =$ no cyclic
		deterioration)
524	set	LA1 0.0. # accelerated reloading stiffness deterioration (a very large $\# = n_0$
021	500	(u  vol) angle $(u  vol)$ angle $(u  vol)$ angle $(u  vol)$
595	ant	$D_1 = 0$ , $\mathcal{H}$ post compiler strength deterioration (a very large $\mathcal{H}$ = no
525	set	LD 0.0, # post-capping strength deterioration (a very rarge # = no
FOC		deterioration)
520		
527	set	LS2 0.0; # basic strength deterioration (a very large $\# =$ no cyclic
		deterioration)
528	$\operatorname{set}$	LK2 0.0; # unloading stiffness deterioration (a very large $\# =$ no cyclic
		deterioration)
529	$\operatorname{set}$	LA2 0.0; # accelerated reloading stiffness deterioration (a very large $\# = no$
		cyclic deterioration)
530	set	LD2 0.0; $\#$ post-capping strength deterioration (a very large $\#$ = no
		deterioration)
531		······································
532	set	LS3 0.0: # basic strength deterioration (a very large $\#$ = no cyclic
		deterioration)
533	set	LK3 = 0.0 · # unloading stiffness deterioration (a very large # = no cyclic
000	500	deterioration)
E94		$1 \times 2 = 0$ , $M = conclusion + conclusion +$
054	set	LAS 0.0, $\#$ accelerated reloading stillness deterioration (a very large $\#$ = no
		cyclic deterioration)
535	set	LD3 0.0; $\#$ post-capping strength deterioration (a very large $\#$ = no
-		deterioration)
536		
537	set	LS4 0.0; # basic strength deterioration (a very large $\# =$ no cyclic
		deterioration)
538	$\operatorname{set}$	LK4 0.0; $\#$ unloading stiffness deterioration (a very large $\#$ = no cyclic
		deterioration)
539	$\operatorname{set}$	LA4 0.0; # accelerated reloading stiffness deterioration (a very large $\# = no$
		cyclic deterioration)
540	$\operatorname{set}$	LD4 0.0; $\#$ post-capping strength deterioration (a very large $\#$ = no
		deterioration)
541		······································
542	$\operatorname{set}$	cS 1.0; # exponent for basic strength deterioration ( $c = 1.0$ for no
		deterioration)
543	set	cK = 1.0; # exponent for unloading stiffness deterioration ( $c = 1.0$ for no
010	500	deterioration)
544	ent	cA = 1.0: # exponent for accelerated reloading stiffness deterioration ( $c = 1.0$ )
044	300	(c = 1.0)
EAE		$D_{1}$ is deterioration)
040	set	$c_{\rm D}$ 1.0; # exponent for post-capping strength deterioration (c = 1.0 for no
EAG		deterioration )
540 547	cot	th pc1P 10.0; # post capping not capacity for post loading
548	set	th pc11 10.0, $\#$ post-capping for capacity for postolating
549	set	th pc2P 10.0; $\#$ post-capping for capacity for nog loading
550	s	t th_pc2N 10.0; # post-capping rot capacity for neg loading
551	set	th_pc3P 10.0; $\#$ post-capping rot capacity for pos loading
552	$\operatorname{set}$	th_pc3N 10.0; $\#$ post-capping rot capacity for neg loading
553	$\operatorname{set}$	th-pc4P 10.0; $\#$ post-capping rot capacity for pos loading
554	$\mathbf{S}$	et th_pc4N 10.0; $\#$ post-capping rot capacity for neg loading
555		
556	set	ResP 1.00; # residual strength ratio for pos loading
557	set	ResN 1.00; # residual strength ratio for neg loading
008 550	set	th which is the ultimate rot capacity for postloading
560	set	theun 10.1, # ultimate for capacity for neg loading
561	set	DP 1.0. # rate of cyclic deterioration for posloading
562	set	DN 1.0, $\#$ rate of cyclic deterioration for per loading
563	500	$\pi$ fact of eyene deterioration for high bading
564	set	McMv1 1.20
565	$\operatorname{set}$	McMy2 1.20
566		-
567	$\operatorname{set}$	th_p1P_0.048;
568	$\operatorname{set}$	th_p1N_0.048;
569	$\operatorname{set}$	th_p2P_0.060;
570 571	set	$t_{\rm L}$ , p2N 0.000; +b p2D 0.060.
116	set	tn_pər 0.000;

104

set th\_p3N 0.060; set th\_p4P 0.064; 572573574set th\_p4N 0.064; 575576set My\_c1i 3000. set My\_c2i 2900. set My\_c3i 2750. 577578579set My\_c4i 2650. 580581set My\_c1e 2750. set My\_c2e 2700. 582583set My\_c3e 2650. 584set My\_c4e 2600. 585 # define column springs # Spring ID: "3xya", where 3 = col spring, x = Pier #, y = Story #, a = location in 586587 # "a" convention: 1 = bottom of story, 2 = top of story 588 # command: rotSpring2DModIKModel id ndR ndC K McMy MyPos MyNeg LS LK LA LD cS cK cA cD th\_p+ th\_p- th\_pc+ th\_pc-Res+ Res- th\_u+ th\_u- D+ D-589590591# col springs @ bottom of Story 1 (at base) rotSpring2DModIKModel 3111 11 117 \$Ks\_col\_11231 \$McMy1 592[expr \$My\_c1e] [expr -\$My\_c1e] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3211 21 217 \$Ks\_col\_1123 \$McMy1 593[expr \$My\_c1i] expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3311 31 317 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i] 594expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 595rotSpring2DModIKModel 3411 41 417 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3511 51 517 \$Ks\_col\_11231 \$McMy1 596[expr \$My\_c1e] expr -\$My\_cle] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 597#col springs @ top of Story 1 (below Floor 2) 598rotSpring2DModIKModel2 3112 10126 126 \$w1 \$h1 \$Ks\_col\_11231 \$McMy1 [expr \$My\_c1e 599 [expr -\$My\_c1e] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1ext \$Fsw1ext \$Ksf\_1e\ 600 \$s1pax [expr \$s1pax/\$Kax\_col\_1123] \$s2pax [expr \$s2pax/\$Kax\_col\_1123] \$s3pax [expr \$s3pax/\$Kax\_col\_1123] \$s1nax [expr \$s1nax/\$Kax\_col\_1123] \$s2nax [expr \$s2nax/ \$Kax\_col\_1123] \$s3nax [expr \$s3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123 601 602rotSpring2DModIKModel2 3212 10226 226 \$w1 \$h1 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i ] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$s1nsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rholint \$Fswlint \$Ksf\_1i\ 603\$s1pax [expr \$s1pax/\$Kax\_col\_1123] \$s2pax [expr \$s2pax/\$Kax\_col\_1123] \$s3pax [expr \$s3pax/\$Kax\_col\_1123] \$s1nax [expr \$s1nax/\$Kax\_col\_1123] \$s2nax [expr \$s2nax/ \$Kax\_col\_1123] \$s3nax [expr \$s3nax/\$Kax\_col\_1123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1123 604 rotSpring2DModIKModel2 3312 10326 326 \$w1 \$h1 \$Ks\_col\_1123 \$McMy1 [expr \$My\_c1i ] [expr -\$My\_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th\_p1P \$th\_p1N \$th\_pc1P \$th\_pc1N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh\_col\_1123] \$s2psh [expr \$s2psh/\$Ksh\_col\_1123] \$s3psh [expr \$s3psh/\$Ksh\_col\_1123] \$s1nsh [ expr \$slnsh/\$Ksh\_col\_1123] \$s2nsh [expr \$s2nsh/\$Ksh\_col\_1123] \$s3nsh [expr

	\$s3nsh/\$Ksh_col_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf_1i\
605	<pre>\$s1pax [expr \$s1pax/\$Kax_col_1123] \$s2pax [expr \$s2pax/\$Kax_col_1123] \$s3pax [expr \$s3pax/\$Kax_col_1123] \$s1nax [expr \$s1nax/\$Kax_col_1123] \$s2nax [expr \$s2nax/ \$Kax_col_1123] \$s3nax [expr \$s3nax/\$Kax_col_1123] \$pinchXax \$pinchYax</pre>
606	\$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad_col_1123 rotSpring2DModIKModel2 3412 10426 426 \$w1 \$h1 \$Ks_col_1123 \$McMy1 [expr \$My_c1i
	] [expr -\$My_c1i] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th_p1P \$th_p1N \$th_pc1P \$th_pc1N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr \$s1psh/\$Ksh_col_1123]
	\$s2psh [expr \$s2psh/\$Ksh_col_1123] \$s3psh [expr \$s3psh/\$Ksh_col_1123] \$s1nsh [ expr \$s1nsh/\$Ksh_col_1123] \$s2nsh [expr \$s2nsh/\$Ksh_col_1123] \$s3nsh [expr
	\$s3nsh/\$Ksh_col_1123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rholint \$Fswlint \$Ksf li\
607	\$s1pax [expr \$s1pax/\$Kax_col_1123] \$s2pax [expr \$s2pax/\$Kax_col_1123] \$s3pax [expr
	\$Kax_col_1123] \$s3nax [expr \$s3nax/\$Kax_col_1123] \$pinchXax \$pinchYax
608	\$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad_col_1123 rotSpring2DModIKModel2 3512 10526 526 \$w1 \$h1 \$Ks_col_11231 \$McMy1 [expr
	\$My_cle] [expr -\$My_cle ] \$LS1 \$LK1 \$LA1 \$LD1 \$cS \$cK \$cA \$cD \$th_p1P \$th_p1N \$th_pc1P \$th_pc1N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr \$s1psh/
	\$Ksh_col_1123] \$s2psh [expr \$s2psh/\$Ksh_col_1123] \$s3psh [expr \$s3psh/
	\$Ksn_col_1123] \$s1nsn [expr \$s1nsh/\$Ksn_col_1123] \$s2nsn [expr \$s2nsh/ \$Ksh_col_1123] \$s3nsh [expr \$s3nsh/\$Ksh_col_1123] \$pinchXsh \$pinchYsh
600	\$damage1sh \$damage2sh \$betash \$curveTypesh \$rho1int \$Fsw1int \$Ksf_1e\
009	\$\$1pax [expr \$\$1pax/\$Kax_col_1125] \$\$2pax [expr \$\$2pax/\$Kax_col_1125] \$\$5pax [expr \$\$3pax/\$Kax_col_1123] \$\$1nax [expr \$\$1nax/\$Kax_col_1123] \$\$2nax [expr \$\$2nax/
	\$Kax_col_1123] \$s3nax [expr \$s3nax/\$Kax_col_1123] \$pinchXax \$pinchYax
610	adamagerax adamagezax abetaax acurverypeax aKad_cor_1125
611	# col springs @ bottom of Story 2 (above Floor 2)
612	rotSpring2DModIKModel 3121 10127 127 \$Ks_col_21231 \$McMy1 [expr \$My_c2e] [ expr _\$My_c2e] \$L\$2 \$L\$2 \$L\$2 \$LD2 \$c\$ \$cK \$cA \$cD \$th p2P \$th p2N \$th pc2P
	\$th_pc2N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN;
613	rotSpring2DModIKModel 3221 10227 227 \$Ks_col_2123 \$McMy1 [expr \$My_c2i ] [ expr -\$My_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th_p2P \$th_p2N \$th_pc2P
614	stn_pc2N sResP sResN stn_uP stn_uN sDP sDN; rotSpring2DModIKModel 3321 10327 327 \$Ks_col_2123 \$McMy1 [expr \$My_c2i] [
	expr -\$My_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th_p2P \$th_p2N \$th_pc2P \$th_pc2P \$th_p2N \$th_pc2P
615	stn_pc2N sResP sResN stn_uP stn_uN sDP sDN; rotSpring2DModIKModel 3421 10427 427 \$Ks_col_2123 \$McMy1 [expr \$My_c2i] [
	expr -\$My_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th_p2P \$th_p2N \$th_pc2P
616	sth_pc2N sResP sResN sth_uP sth_uN sDP sDN; rotSpring2DModIKModel 3521 10527 527 \$Ks_col_21231 \$McMy1 [expr \$My_c2e] [
	expr -\$My_c2e ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th_p2P \$th_p2N \$th_pc2P \$th_pc2P \$th_pc2N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN:
617	•
618 610	#col springs @ top of Story 2 (below Floor 3) rotSpring2DModIKModel2 3122 10136 136 \$m1 \$h1 \$Ks col 21231 \$McMu1 [ovpr \$Mu c2o
013	$\begin{tabular}{lllllllllllllllllllllllllllllllllll$
	\$th_p2N \$th_pc2P \$th_pc2N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr \$s1psh (\$Kch col 2122] \$c2pch [expr \$c2pch ]
	\$Ksh_col_2123] \$s1nsh [expr \$s1nsh/\$Ksh_col_2123] \$s2nsh [expr \$s2nsh/
	\$Ksh_col_2123] \$s3nsh [expr \$s3nsh/\$Ksh_col_2123] \$pinchXsh \$pinchYsh
620	\$damage1sh \$damage2sh \$betash \$curve1ypesh \$rho2ext \$Fsw2ext \$Ks1_2e\ \$s1pax [expr \$s1pax/\$Kax_col_2123] \$s2pax [expr \$s2pax/\$Kax_col_2123] \$s3pax [expr
	\$s3pax/\$Kax_col_2123] \$s1nax [expr \$s1nax/\$Kax_col_2123] \$s2nax [expr \$s2nax/
	\$Kax_col_2123] \$s3nax [expr \$s3nax/\$Kax_col_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad_col_2123
621	rotSpring2DModIKModel2 3222 10236 236 \$w1 \$h1 \$Ks_col_2123 \$McMy1 [expr \$My_c2i
	] [expr -\$My_c21 ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th_p2P \$th_p2N \$th_pc2P \$th_pc2N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr
	\$s1psh/\$Ksh_col_2123] \$s2psh [expr \$s2psh/\$Ksh_col_2123] \$s3psh [expr \$s3psh/
	\$Ksh_col_2123  \$s1nsh  expr \$s1nsh/\$Ksh_col_2123  \$s2nsh  expr \$s2nsh/ \$Ksh_col_2123  \$s3nsh [expr_\$s3nsh/\$Ksh_col_2123] \$pinchXsh_\$pinchYsh
	\$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf_2i\

622 \$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123 623 rotSpring2DModIKModel2 3322 10336 336 \$w1 \$h1 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c2i [expr -\$My\_c2i ] \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2i\ \$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr 624\$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123; rotSpring2DModIKModel2 3422 10436 436 \$w1 \$h1 \$Ks\_col\_2123 \$McMy1 625[expr \$My\_c2i \$LS2 \$LK2 \$LA2 \$LD2 \$cS \$cK \$cA \$cD \$th\_p2P [expr -\$My\_c2i ] \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$\$1n\$h [expr \$\$1n\$h/\$Ksh\_col\_2123] \$\$2n\$h [expr \$\$2n\$h/ \$Ksh\_col\_2123] \$\$3n\$h [expr \$\$3n\$h/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2i\ 626 \$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_2123; rotSpring2DModIKModel2 3522 10536 536 \$w1 \$h1 \$Ks\_col\_21231 \$McMy1 627 [expr \$Mv\_c2e [expr -\$My\_c2e ]  $LS2 LK2 LA2 LD2 CS CK CA CD <math display="inline">th_p2P$ \$th\_p2N \$th\_pc2P \$th\_pc2N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho2int \$Fsw2int \$Ksf\_2e\ 628 \$s1pax [expr \$s1pax/\$Kax\_col\_2123] \$s2pax [expr \$s2pax/\$Kax\_col\_2123] \$s3pax [expr \$s3pax/\$Kax\_col\_2123] \$s1nax [expr \$s1nax/\$Kax\_col\_2123] \$s2nax [expr \$s2nax/ \$Kax\_col\_2123] \$s3nax [expr \$s3nax/\$Kax\_col\_2123] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_212 629 # col springs @ bottom of Story 3 (above Floor 3) 630 rotSpring2DModIKModel 3131 10137 137 \$Ks\_col\_21231 \$McMy1 [expr \$My\_c3e] 631expr -\$My\_c3e ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN 632rotSpring2DModIKModel 3231 10237 237 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c3i] expr -\$My\_c3i ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 3331 10337 337 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c3i] 633 expr -\$My\_c3i ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN rotSpring2DModIKModel 3431 10437 437 \$Ks\_col\_2123 \$McMy1 [expr \$My\_c3i] 634 [expr -\$My\_c3i ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN ; 635rotSpring2DModIKModel 3531 10537 537 \$Ks\_col\_21231 \$McMy1 [expr \$My\_c3e] expr -\$My\_c3e ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN ; 636 #col springs @ top of Story 3 (below Floor 4) 637 638 rotSpring2DModIKModel2 3132 10146 146 \$w1 \$h1 \$Ks\_col\_21231 \$McMy1 [expr \$Mv\_c3e] [expr -\$My\_c3e] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th\_p3P \$th\_p3N \$th\_pc3P \$th\_pc3N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh /\$Ksh\_col\_2123] \$s2psh [expr \$s2psh/\$Ksh\_col\_2123] \$s3psh [expr \$s3psh/ \$Ksh\_col\_2123] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_2123] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_2123] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_2123] \$pinchXsh \$pinchYsh

	<pre>\$Kax_col_2123] \$s3nax [expr \$s3nax/\$Kax_col_2123] \$pinchXax \$pinchYax</pre>
	\$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad_col_2123
640	rotSpring2DModIKModel2 3232 10246 246 \$w1 \$h1 \$Ks_col_2123 \$McMy1 [expr \$My_c3i]
	[expr -\$My_c3i ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th_p3P
	\$th_p3N \$th_pc3P \$th_pc3N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr \$s1psh
	/\$Ksh_col_2123]
	\$Ksh_col_2123] \$s1nsh [expr \$s1nsh/\$Ksh_col_2123] \$s2nsh [expr \$s2nsh/
	\$Ksh_col_2123] \$s3nsh [expr \$s3nsh/\$Ksh_col_2123] \$pinchXsh \$pinchYsh
	\$damage1sh \$damage2sh \$betash \$curveTypesh \$rho3ext \$Fsw3ext \$Ksf_3i\
641	\$s1pax [expr \$s1pax/\$Kax_col_2123] \$s2pax [expr \$s2pax/\$Kax_col_2123] \$s3pax [expr
	\$s3pax/\$Kax_col_2123] \$s1nax [expr \$s1nax/\$Kax_col_2123] \$s2nax [expr \$s2nax/
	\$Kax_col_2123] \$s3nax [expr \$s3nax/\$Kax_col_2123] \$pinchXax \$pinchYax
	\$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad_col_2123
642	rotSpring2DModIKModel2 3332 10346 346 \$w1 \$h1 \$Ks_col_2123 \$McMy1 [expr \$My_c3i]
	[expr -\$My_c3i ] \$LS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th_p3P \$th_p3N
	\$th_pc3P \$th_pc3N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN \$s1psh [expr \$s1psh/
	\$Ksh_col_2123] \$s2psh_[expr_\$s2psh/\$Ksh_col_2123] \$s3psh_[expr_\$s3psh/
	Kesh col 2123] Sslash [expr Sslash/SKsh col 2123] Ss2ash/
	\$Ksh col 2123] \$s3nsh [expr \$s3nsh/\$Ksh col 2123] \$pinchXsh \$pinchYsh
	sdamagelsh \$damage2sh \$betash \$curveTypesh \$rho3eyt \$Fsw3eyt \$Ksf 3i
643	\$slnax [evpr \$slnax/\$Kax col 2123] \$s2nax [evpr \$s2nax/\$Kax col 2123] \$s3nax [evpr
0.10	\$30pay/\$Kay col 2123] \$1pay [evpr \$1pay/\$Kay col 2123] \$2pay/evpr \$2pay/
	Skay col 2123] \$S3nay [evpr \$S3nay/\$Kay col 2123] \$pinch Yay \$pinch Yay
	Sdamagelay Sdamagelay Shetaay ScurveTyneay SKad col 2123
644	rotSpring2DModKModel2 3432 10446 446 \$w1 \$h1 \$Ks col 2123 \$McMy1 [evpr \$My c3i]
011	$\begin{bmatrix} [expr -\$My, c_3] \end{bmatrix}$ SLS3 \$LK3 \$LA3 \$LD3 \$cS \$cK \$cA \$cD \$th p3P \$th p3N
	th no2P the no2N the Back Sth up the uN the PON to he for the form the start of the start the st
	Keh ol 2123 Sepen levre servel/Skeh ol 2123 Search levre servel/
	Keh col 2123 Selneh [expr selneh/skeh col 2123] sopen [expr sopen/
	Keh col 2123] Seanch [expr Seanch/SKeh col 2123] SpinchVeh ShinchVeh
	stan-collelizio asonan [expl asonan avantaricolizio] apinenzan apinentan
645	sumagersh sumagezsh sobetash suuverypesh shnosekt siksiesh siksiesh seksekt siksiesh
040	$\psi$ sipax [expi $\psi$ sipax/ $\psi$ Kax_col_2125] $\psi$ Kax_col_2125
	$\phi$ so pax/ $\phi$ Kax-coi-2123 $\phi$ stilax [expl $\phi$ stilax/ $\phi$ Kax-coi-2123 $\phi$ stilax/ $\phi$ stilax/ $\phi$ Kax-coi-2123 $\phi$ stilax/ $\phi$
	stancol_2123 soliax [expl. soliax] star_col_2123 splitchaa splitch fax
CAC	suamagerax suamagerax suberaax scurverypeax sKau_cor_2123
040	$ \begin{array}{c} \text{rotspring2DModIRModel2}  50.52  10.340  540  5w1  5w1  5w5  \text{col}  221251  5wcmy1  [expr  5wy  c5e \\ \hline \\ $
	$\int \left[ exp(-\phi)(y,c)e^{-\phi} + bx^{2} + bx$
	$\phi$ the peak of peak of the peak $\phi$ the peak $\phi$ the peak $\phi$ peak $\phi$ peak $\phi$ peak $\phi$
	$\sigma Ksn_col_2l_2d_3 \sigma s_2psn_expr_{\sigma s_2psn_s} \sigma Ksn_col_2l_2d_3 \sigma s_5psn_expr_{\sigma s_2psn_s}$
	$\sigma Ksn_col_2125$ $\sigma sinsn [expr \sigma sinsn / \sigma Ksn_col_2125 \sigma szinsn [expr \sigma szinsn / \sigma Ksn_col_2125 \sigma szinsn / \sigma Ksn_col_2125 \sigma szinsn / \sigma Ksn_col_2125$
	$\frac{1}{2}$
C 4 7	Sdamagelsh Sdamage2sh Sbetash Scurvelypesh Srhošext SFsw3ext SKSL3e
647	ssipax [expr ssipax/sKax_col_2123] ss2pax [expr ss2pax/sKax_col_2123] ss3pax [expr
	\$s3pax/\$Kax_col_2123] \$s1nax [expr \$s1nax/\$Kax_col_2123] \$s2nax [expr \$s2nax/
	SKax_col_2123   Ss3nax [expr Ss3nax/SKax_col_2123] SpinchXax SpinchYax
C 10	Sdamagelax Sdamage2ax Sbetaax Scurvelypeax SKad_col_2123
040 640	" col arring @ bottom of Story 4 (chang Elean 4)
049 650	# consprings $@$ bottom of story 4 (above ricor 4)
050	$ \begin{array}{c} \text{rotspring2DModuRModel} 5141 10147 147 5 \text{Rs}_{\text{col}} 14501 5 \text{McMy2} & [\text{expr} 5 \text{My}_{\text{col}} 246] \\ \text{rotspring2DModuRModel} & [\text{rotspring2DModel} 147 147 5 \text{Rs}_{\text{col}} 246 5 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6$
	$expr = 5my_2c4e$ = $5L54$ $5LR4$ $5LR4$ $5c5$ $5cK$ $5cK$ $5cK$ $5cJ$ $5th_p4r$ $5th_p4r$ $5th_pc4r$
CF 1	$\delta tn$ -pc4N $\delta ResP$ $\delta ResN \delta tn_uP$ $\delta tn_u$ $\delta DP$ $\delta DN$ ;
001	rotspring2DModIKModel 3241 $10247$ 247 SS_COL_1450 SMCMy2 [expr 5My_c41] [ $10247$ [ $10247$ ] $10247$ [ $10247$ ]
	$\exp r = 5my_2c41$ ] $5L54$ $5LK4$ $5LL44$ $5c5$ $5cK$ $5cA$ $5cD$ $5tn_p4r$ $5tn_p4N$ $5tn_pc4P$
<b>650</b>	stn_pc4N skesp skesn stn_up stn_un sDP sDN;
652	rotSpring2DModIRModel 3341 10347 347 5Ks_col_1456 5McMy2 [expr 5My_c41]
	expr = \$My_c41 ] \$L\$4 \$L\$4 \$L\$4 \$L\$4 \$c\$ \$c\$ \$c\$ \$c\$ \$c\$ \$t_p4P \$th_p4N \$th_pc4P
	\$th_pc4N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN;
653	rotSpring2DModIKModel 3441 10447 447 \$Ks_col_1456 \$McMy2 [expr \$My_c4i]
	expr = \$My_c4i ] \$L\$4 \$LK4 \$LA4 \$LD4 \$c\$ \$cK \$cA \$cD \$th_p4P \$th_p4N \$th_pc4P
	\$th_pc4N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN;
654	rotSpring2DModIKModel 3541 10547 547 \$Ks_col_14561 \$McMy2 [expr \$My_c4e]
	expr =\$My_c4e ] \$LS4 \$LK4 \$LA4 \$LD4 \$cS \$cK \$cA \$cD \$th_p4P \$th_p4N \$th_pc4P
055	<pre>\$th_pc4N \$ResP \$ResN \$th_uP \$th_uN \$DP \$DN;</pre>
055	Weel environme @ ten of Sterry 4 (helen Elever 5)
000	$\pi$ col springs $@$ top of Story 4 (below Floor 5)

657 rotSpring2DModIKModel2 3142 10156 156 \$w2 \$h2 \$Ks\_col\_14561 \$McMy2 [expr \$My\_c4e ] [expr -\$My\_c4e ] \$LS4 \$LK4 \$LA4 \$LD4 \$cS \$cK \$cA \$cD \$th\_p4P \$th\_p4N \$th\_pc4P \$th\_pc4N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1456] \$s2psh [expr \$s2psh/\$Ksh\_col\_1456] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1456] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1456] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1456] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1456] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho4ext \$Fsw4ext \$Ksf\_4e \$s1pax [expr \$s1pax/\$Kax\_col\_1456] \$s2pax [expr \$s2pax/\$Kax\_col\_1456] \$s3pax [expr 658 \$s3pax/\$Kax\_col\_1456] \$s1nax [expr \$s1nax/\$Kax\_col\_1456] \$s2nax [expr \$s2nax/ \$Kax\_col\_1456] \$s3nax [expr \$s3nax/\$Kax\_col\_1456] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1456 rotSpring2DModIKModel2 3242 10256 256 \$w2 \$h2 \$Ks\_col\_1456 \$McMy2 [expr \$My\_c4i ] 659 [expr -\$My\_c4i ] \$LS4 \$LK4 \$LA4 \$LD4 \$cS \$cK \$cA \$cD \$th\_p4P \$th\_p4N \$th\_pc4P \$th\_pc4N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1456] \$s2psh [expr \$s2psh/\$Ksh\_col\_1456] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1456] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1456] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1456] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1456] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho4int \$Fsw4int \$Ksf\_4i\ 660 \$s1pax [expr \$s1pax/\$Kax\_col\_1456] \$s2pax [expr \$s2pax/\$Kax\_col\_1456] \$s3pax [expr \$s3pax/\$Kax\_col\_1456] \$s1nax [expr \$s1nax/\$Kax\_col\_1456] \$s2nax [expr \$s2nax/ \$Kax\_col\_1456] \$s3nax [expr \$s3nax/\$Kax\_col\_1456] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1456 661 rotSpring2DModIKModel2 3342 10356 356 \$w2 \$h2 \$Ks\_col\_1456 \$McMy2 [expr \$My\_c4i ] [expr -\$My\_c4i ] \$LS4 \$LK4 \$LA4 \$LD4 \$cS \$cK \$cA \$cD \$th\_p4P \$th\_p4N \$th\_pc4P \$th\_pc4N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1456] \$s2psh [expr \$s2psh/\$Ksh\_col\_1456] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1456] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1456] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1456] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1456] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho4int \$Fsw4int \$Ksf\_4i\ 662 \$s1pax [expr \$s1pax/\$Kax\_col\_1456] \$s2pax [expr \$s2pax/\$Kax\_col\_1456] \$s3pax [expr \$s3pax/\$Kax\_col\_1456] \$s1nax [expr \$s1nax/\$Kax\_col\_1456] \$s2nax [expr \$s2nax/ \$Kax\_col\_1456] \$s3nax [expr \$s3nax/\$Kax\_col\_1456] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1456 663 rotSpring2DModIKModel2 3442 10456 456 \$w2 \$h2 \$Ks\_col\_1456 \$McMy2 [expr \$My\_c4i ] [expr -\$My\_c4i ] \$LS4 \$LK4 \$LD4 \$cS \$cK \$cA \$cD \$th\_p4P \$th\_p4N \$th\_pc4P \$th\_pc4N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1456] \$s2psh [expr \$s2psh/\$Ksh\_col\_1456] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1456] \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1456] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1456] \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1456] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho4int \$Fsw4int \$Ksf\_4i\ 664 \$s1pax [expr \$s1pax/\$Kax\_col\_1456] \$s2pax [expr \$s2pax/\$Kax\_col\_1456] \$s3pax [expr \$s3pax/\$Kax\_col\_1456] \$s1nax [expr \$s1nax/\$Kax\_col\_1456] \$s2nax [expr \$s2nax/ \$Kax\_col\_1456] \$s3nax [expr \$s3nax/\$Kax\_col\_1456] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1456 665 rotSpring2DModIKModel2 3542 10556 556 \$w2 \$h2 \$Ks\_col\_14561 \$McMy2 [expr \$My\_c4e [expr -\$My\_c4e ] \$LS4 \$LK4 \$LA4 \$LD4 \$cS \$cK \$cA \$cD \$th\_p4P \$th\_p4N \$th\_pc4P \$th\_pc4N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN \$s1psh [expr \$s1psh/ \$Ksh\_col\_1456] \$s2psh [expr \$s2psh/\$Ksh\_col\_1456] \$s3psh [expr \$s3psh/ \$Ksh\_col\_1456 \$s1nsh [expr \$s1nsh/\$Ksh\_col\_1456] \$s2nsh [expr \$s2nsh/ \$Ksh\_col\_1456 \$s3nsh [expr \$s3nsh/\$Ksh\_col\_1456] \$pinchXsh \$pinchYsh \$damage1sh \$damage2sh \$betash \$curveTypesh \$rho4int \$Fsw4int \$Ksf\_4e 666 \$s1pax [expr \$s1pax/\$Kax\_col\_1456] \$s2pax [expr \$s2pax/\$Kax\_col\_1456] \$s3pax [expr \$s3pax/\$Kax\_col\_1456] \$s1nax [expr \$s1nax/\$Kax\_col\_1456] \$s2nax [expr \$s2nax/ \$Kax\_col\_1456] \$s3nax [expr \$s3nax/\$Kax\_col\_1456] \$pinchXax \$pinchYax \$damage1ax \$damage2ax \$betaax \$curveTypeax \$Kad\_col\_1456 667 668669 Beam Elements Properties 670 671 672 673674675General Properties of Beam Cross Sections 676 set Ec 3600.; # concrete Young's modulus 677 678

679 # define beam section 18"x28" for Floor 2,3 & 4

```
680
         set modbeamscrack 0.6
       set Abeam_234 504.; # cross-sectional area (full section properties)
681
       set Ibeam_234 [expr $modbeamscrack*32928.]; # moment of inertia (full section
682
           properties)
683
    \# define beam section 16" x28" for Floor 5,6 & 7
684
    # set Abeam_567 448; # cross-sectional area (full section properties)
685
686
687
       set Abeam_567 504.; # cross-sectional area (full section properties)
688
       set Ibeam_567 [expr $modbeamscrack * 32928.]; # moment of inertia (full section
           properties)
689
690
    \# determine stiffness modifications to equate the stiffness of the spring-elastic
         element-spring subassembly to the stiffness of the actual frame member
      # Reference: Ibarra, L. F., and Krawinkler, H. (2005). "Global collapse of frame
structures under seismic excitations," Technical Report 152,
# The John A. Blume Earthquake Engineering Research Center, Department
691
692
           of Civil Engineering, Stanford University, Stanford, CA.
693
       \# calculate modified section properties to account for spring stiffness being in
           series with the elastic element stiffness
n 10.0; \# stiffness multiplier for rotational spring
694
       set n 10.0;
695
       # calculate modified moment of inertia for elastic elements
696
697
698
       set Ibeam_234mod [expr Ibeam_234*(n+1.0)/n]; # modified moment of inertia for
           beams in Floor 2,3 & 4
       set Ibeam_567mod [expr $Ibeam_567*($n+1.0)/$n]; # modified moment of inertia for
699
           beams in Floor 5,6 & 7
700
701
702
       set Ks_beam_1234 [expr $n*6.0*$Ec*$Ibeam_234mod/$Wbay1]; # rotational stiffness of
           Floor 2,3 & 4 beam springs
703
       set Ks_beam_2234 [expr $n*6.0*$Ec*$Ibeam_234mod/$Wbay2]; # rotational stiffness of
           Floor 2,3 & 4 beam springs
       set Ks_beam_1567 [expr $n*6.0*$Ec*$Ibeam_567mod/$Wbay1]; # rotational stiffness of
704
           Floor 2,3 & 4 beam springs
       set Ks_beam_2567 [expr $n*6.0*$Ec*$Ibeam_567mod/$Wbay2]; # rotational stiffness of
Floor 2,3 & 4 beam springs
705
706
    \# Elastic Beam Column Elements
707
708
       \# eleID convention: "2xy" where 2 = beam, x = Bay \#, y = Floor \#
709
710
       # Beams Story 1
711
       element elasticBeamColumn
                                    212 123 222 $Abeam_234 $Ec $Ibeam_234mod
           $LinearTransf;
712
       element elasticBeamColumn
                                     222
                                          223 322 $Abeam_234 $Ec
                                                                     $Ibeam 234mod
           $LinearTransf;
713
       element elasticBeamColumn
                                     232
                                          323 422 $Abeam_234 $Ec
                                                                     $Ibeam 234mod
           $LinearTransf;
714
       element elasticBeamColumn
                                     242
                                         423 522 $Abeam_234 $Ec
                                                                     $Ibeam_234mod
           $LinearTransf;
715
716
       # Beams Story 2
       element elasticBeamColumn
                                          133 232 $Abeam_234 $Ec
                                                                     $Ibeam_234mod
717
                                     213
           $LinearTransf:
718
       element elasticBeamColumn
                                     223
                                          233 332 $Abeam_234 $Ec
                                                                     $Ibeam_234mod
           $LinearTransf;
719
       element elasticBeamColumn
                                          333 432 $Abeam_234 $Ec
                                                                     $Ibeam_234mod
                                     233
           $LinearTransf;
720
       element elasticBeamColumn
                                     243
                                          433 532 $Abeam 234 $Ec
                                                                     $Ibeam 234mod
           $LinearTransf;
721
722
       # Beams Story 3
723
       element elasticBeamColumn
                                     214
                                          143 242 $Abeam_234 $Ec $Ibeam_234mod
           $LinearTransf:
724
       element elasticBeamColumn
                                     224
                                          243 342 $Abeam_234 $Ec $Ibeam_234mod
           $LinearTransf;
725
       element elasticBeamColumn
                                     234
                                          343 442 $Abeam_234 $Ec $Ibeam_234mod
           $LinearTransf;
726
       element elasticBeamColumn
                                     244 443 542 $Abeam_234 $Ec $Ibeam_234mod
           $LinearTransf;
```

727 728 # Beams Story 4 element elasticBeamColumn 215 153 252 \$Abeam\_567 \$Ec \$Ibeam\_567mod \$LinearTransf 729 730element elasticBeamColumn 225253 352 \$Abeam\_567 \$Ec \$Ibeam\_567mod \$LinearTransf : element elasticBeamColumn 235 353 452 \$Abeam\_567 \$Ec \$Ibeam\_567mod \$LinearTransf 731 element elasticBeamColumn 245 453 552 \$Abeam\_567 \$Ec \$Ibeam\_567mod \$LinearTransf 732 ; 733 734 735 736 737 738 739# General input values for Beam Springs 740 set LS13 64.0; # basic strength deterioration (a very large # = no cyclic 741 deterioration) set LK13 0.0; # unloading stiffness deterioration (a very large # = no cyclic 742 deterioration) set LA13 0.0; # accelerated reloading stiffness deterioration (a very large # = no743cyclic deterioration) 744 set LD13 64.0; # post-capping strength deterioration (a very large # = no deterioration) 745 set LS14 64.0; # basic strength deterioration (a very large # = no cyclic 746 deterioration) set LK14 0.0; # unloading stiffness deterioration (a very large # = no cyclic 747 deterioration) set LA14 0.0; # accelerated reloading stiffness deterioration (a very large # = no 748cyclic deterioration) 749 set LD14 64.0; # post-capping strength deterioration (a very large # = no deterioration) 750751752753754set cS 1.0; # exponent for basic strength deterioration (c = 1.0 for no deterioration) 755 set cK 1.0; # exponent for unloading stiffness deterioration (c = 1.0 for no deterioration) set cA 1.0; # exponent for accelerated reloading stiffness deterioration (c = 1.0756for no deterioration) 757 set cD 1.0; # exponent for post-capping strength deterioration (c = 1.0 for no deterioration) 758759set th\_pc13P 0.076; # post-capping rot capacity for pos loading set th\_pc13N 0.076; # post-capping rot capacity for neg loading 760761762 set th\_pc14P 0.076; # post-capping rot capacity for pos loading set th\_pc14N 0.076; # post-capping rot capacity for neg loading 763 764765766 set ResP 0.10; # residual strength ratio for pos loading set ResN 0.10; # residual strength ratio for neg loading 767 768 769set th\_uP 0.20;"# ultimate rot capacity for pos loading 770set th\_uN 0.20; # ultimate rot capacity for neg loading 771772 set DP 1.0; # rate of cyclic deterioration for pos loading 773 set DN 1.0; # rate of cyclic deterioration for neg loading 774775 set McMv13 1.20 776 777 set McMy14 1.20 set th\_p13P 0.049; 778 set th\_p13N 0.043; 779 780 781set th\_p14P 0.046; 782set th\_p14N 0.046;

- 783 set My\_bP 3550. 784785 set My\_bN [expr -5750.] 786 787 #Story 1 788 #Defining Rotational Springs 789 #beam springs at Floor 2 790 rotSpring2DModIKModel 4121 9123 123 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 791 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4122 9222 222 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 792\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4221 9223 223 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 793 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP  $ResN th_uP th_uN DP DN;$ 794rotSpring2DModIKModel 4222 9322 322 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 795 rotSpring2DModIKModel 4321 9323 323 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4322 9422 422 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 796 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 797 rotSpring2DModIKModel 4421 9423 423 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4422 9522 522 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 798 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 799 # Story 2 800 801 #beam springs at Floor 3 rotSpring2DModIKModel 4131 9133 133 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 802 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 803 rotSpring2DModIKModel 4132 9232 232 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 804 rotSpring2DModIKModel 4231 9233 233 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 805rotSpring2DModIKModel 4232 9332 332 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4331 9333 333 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 806\$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4332 9432 432 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 807 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; rotSpring2DModIKModel 4431 9433 433 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 808 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; rotSpring2DModIKModel 4432 9532 532 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 809 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP; 810 811 # Story 3 #beam springs at Floor 4 812 813 rotSpring2DModIKModel 4141 9143 143 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN; 814 rotSpring2DModIKModel 4142 9242 242 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP
  - \$th\_uN \$th\_uP \$DN \$DP;

- 815 rotSpring2DModIKModel 4241 9243 243 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 816 rotSpring2DModIKModel 4242 9342 342 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 817 rotSpring2DModIKModel 4341 9343 343 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 818 rotSpring2DModIKModel 4342 9442 442 \$Ks\_beam\_2234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 819 rotSpring2DModIKModel 4441 9443 443 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13P \$th\_p13N \$th\_pc13P \$th\_pc13N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 820 rotSpring2DModIKModel 4442 9542 542 \$Ks\_beam\_1234 \$McMy13 \$My\_bP \$My\_bN \$LS13 \$LK13 \$LA13 \$LD13 \$cS \$cK \$cA \$cD \$th\_p13N \$th\_p13P \$th\_pc13N \$th\_pc13P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 821 822 # Story 4
- 823 #beam springs at Floor 5
- 824 rotSpring2DModIKModel 4151 9153 153 \$Ks\_beam\_1567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14P \$th\_p14N \$th\_pc14P \$th\_pc14N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 825 rotSpring2DModIKModel 4152 9252 252 \$Ks\_beam\_1567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14N \$th\_p14P \$th\_pc14N \$th\_pc14P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 826 rotSpring2DModIKModel 4251 9253 253 \$Ks\_beam\_2567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14P \$th\_p14N \$th\_pc14P \$th\_pc14N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 827 rotSpring2DModIKModel 4252 9352 352 \$Ks\_beam\_2567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14N \$th\_p14P \$th\_pc14N \$th\_pc14P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 828 rotSpring2DModIKModel 4351 9353 353 \$Ks\_beam\_2567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14P \$th\_p14N \$th\_pc14P \$th\_pc14N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 829 rotSpring2DModIKModel 4352 9452 452 \$Ks\_beam\_2567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14N \$th\_p14P \$th\_pc14N \$th\_pc14P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
- 830 rotSpring2DModIKModel 4451 9453 453 \$Ks\_beam\_1567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14P \$th\_p14N \$th\_pc14P \$th\_pc14N \$ResP \$ResN \$th\_uP \$th\_uN \$DP \$DN;
- 831 rotSpring2DModIKModel 4452 9552 552 \$Ks\_beam\_1567 \$McMy14 \$My\_bP \$My\_bN \$LS14 \$LK14 \$LA14 \$LD14 \$cS \$cK \$cA \$cD \$th\_p14N \$th\_p14P \$th\_pc14N \$th\_pc14P \$ResN \$ResP \$th\_uN \$th\_uP \$DN \$DP;
   832

833		<del>     </del>
834	∉ Gravity Loads & Gravity Analysis	
835		4##
836	≠ apply gravity loads	
837	#command: pattern PatternType \$PatternID TimeSeriesType	
838	pattern Plain 1010 Constant {	
839		
840	# command: load node Fx Fy Mz	
841		
842	set P_PD1 [expr -\$load_E]; # Pier 1	
843	set P_PD2 [expr -\$load_I]; # Pier 2	
844	set P_PD3 [expr -\$load_I]; # Pier 3	
845	set P_PD4 [expr -\$load_I]; # Pier 4	
846	set P_PD5 [expr -\$load_E]; # Pier 5	
847		
848	load 10127 0.0 \$P_PD1 0.0 ; # Pier 1	
849	load 10227 0.0 \$P_PD2 0.0 ; # Pier 2	
850	load 10327 0.0 \$P_PD3 0.0 ; # Pier 3	
851	load 10427 0.0 \$P_PD4 0.0 ; # Pier 4	
852	load 10527 0.0 \$P_PD5 0.0 ; # Pier 5	
853	, n	
854	load 10137 0.0 \$P_PD1 0.0 ; # Pier 1	

load 10237 0.0  $P_PD2 0.0$ # Pier 2 855 856 load 10337 0.0 \$P\_PD3 0.0 # Pier 3 ; load 10437 0.0  $P_PD4 0.0$ # Pier 4 857 ; 858 load 10537 0.0 \$P\_PD5 0.0 # Pier 5 ; 859 860 load 10147 0.0 \$P\_PD1 0.0 # Pier 1 ; # Pier 2 load 10247 0.0 \$P\_PD2 0.0 861 ; 862 load 10347 0.0 \$P\_PD3 0.0 # Pier 3 ; # Pier 4 863 load 10447 0.0 \$P\_PD4 0.0 ; 864 load 10547 0.0 \$P\_PD5 0.0 # Pier 5 ; 865 866 load 10157 0.0 \$P\_PD1 0.0 # Pier 1 ; 867 load 10257 0.0  $P_PD2 0.0$ # Pier 2 ; # Pier 3 868 load 10357 0.0 \$P\_PD3 0.0 ; # Pier 4 load 10457 0.0 \$P\_PD4 0.0 869 ; load 10557 0.0 \$P\_PD5 0.0 # Pier 5 870 ; 871 } 872 873 874 # define DAMPING 875 876 # apply Rayleigh DAMPING from \$xDamp # D=\$alphaM\*M + \$betaKcurr\*Kcurrent + \$betaKcomm\*KlastCommit + \$betaKinit\*\$Kinitial 877 878 879 set xDamp 0.02; # 2% damping ratio 880 881 set omega1 [expr 6.2832/\$T1\_damp] 882 set omega3 [expr 6.2832/\$T3\_damp] 883 set alpha1 [expr \$xDamp\*2\*\$omega1\*\$omega3/(\$omega1+\$omega3)]; 884 885 set alpha2 [expr 2.\*\$xDamp/(\$omega1+\$omega3)]; 886 set alphaM [expr \$xDamp\*2\*\$omega1\*\$omega3/(\$omega1+\$omega3)]; # M-prop. damping; D 887 = alphaM\*M 888 set betaKcurr 0.; # K-proportional damping; +beatKcurr\*KCurrent # set betaKcomm [expr 2.\*\$xDamp/(\$omega)]; 889 # K-prop. damping parameter; + betaKcomm\*KlastCommitt # initial-stiffness proportional damping 890 # set betaKinit 0.; +beatKinit\*Kini891 # K-prop. damping parameter; +betaKcomm\*KlastCommitt set betaKcomm 0.: set betaKinit [expr 2.\*\$xDamp/(\$omega1+\$omega3)]; proportional damping +beatKinit\*Kini 892 # initial-stiffness 893 set betaKinit\_mod [expr \$betaKinit\*1.1]; 894 895 # define damping 896 # Beam Regions by Bay 897 898 region 555 -eleRange 212 215 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 899 region 556 -eleRange 222 225 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; region 557 -eleRange 232 235 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 900 901 region 558 -eleRange 242 245 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 902 903# Column Regions by Pier 904 region 560 -eleRange 111 114 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 905 region 561 -eleRange 121 124 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; region 562 -eleRange 131 134 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 906 region 563 -eleRange 141 144 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 907 908 region 564 -eleRange 151 154 -rayleigh 0.0 \$betaKcurr \$betaKinit\_mod \$betaKcomm; 909 910 region 1 -node 10126 9123 10127 9122 -rayleigh \$alphaM 0.0 0.0 0.0; # assign mass 911 proportional damping to structure (assign to nodes with mass) region 2 -node 10136 9133 10137 9132 -rayleigh \$alphaM 0.0 0.0 0.0; 912 913 region 3 -node 10146 9143 10147 9142 -rayleigh \$alphaM 0.0 0.0 0.0; 914region 4 -node 10156 9153 10157 9152 -rayleigh \$alphaM 0.0 0.0 0.0; 915 916 region 8 -node 10226 9223 10227 9222 -rayleigh \$alphaM 0.0 0.0 0.0; 917 region 9 -node 10236 9233 10237 9232 -rayleigh \$alphaM 0.0 0.0 0.0; 918 region 10 -node 10246 9243 10247 9242 -rayleigh \$alphaM 0.0 0.0 0.0; 919 region 11 -node 10256 9253 10257 9252 -rayleigh \$alphaM 0.0 0.0 0.0;

920 region 15 -node 10326 9323 10327 9322 -rayleigh \$alphaM 0.0 0.0 0.0; 921 region 16 -node 10336 9333 10337 9332 -rayleigh \$alphaM 0.0 0.0 0.0; 922 923 region 17 -node 10346 9343 10347 9342 -rayleigh \$alphaM 0.0 0.0 0.0; 924region 18 -node 10356 9353 10357 9352 -rayleigh \$alphaM 0.0 0.0 0.0; 925region 21 -node 10426 9423 10427 9422 -rayleigh \$alphaM 0.0 0.0 0.0; 926 927 region 22 -node 10436 9433 10437 9432 -rayleigh \$alphaM 0.0 0.0 0.0; region 23 -node 10446 9443 10447 9442 -rayleigh \$alphaM 0.0 0.0 0.0; 928 929 region 24 -node 10456 9453 10457 9452 -rayleigh \$alphaM 0.0 0.0 0.0; 930 931region 27 -node 10526 9523 10527 9522 -rayleigh \$alphaM 0.0 0.0 0.0; 932 region 28 -node 10536 9533 10537 9532 -rayleigh \$alphaM 0.0 0.0 0.0; 933 region 29 -node 10546 9543 10547 9542 -rayleigh \$alphaM 0.0 0.0 0.0; region 30 -node 10556 9553 10557 9552 -rayleigh \$alphaM 0.0 0.0 0.0; 934 935 936 937 938DEFINE ANALYSIS OPTIONS, NEEDED LISTS OF STUFF TO RECORD, ETC. 939Define control nodes for monotonic and cyclic pushover - at top of leaning column 940 set poControlNodeNum 15941set poControlNodeNumCyclic 15942 943 # Define a list of element numbers to record - record the columns or primary frame and leaning column – these are used for computing base shear and story shear set elementNumToRecordLIST { 111 121 112 122 113 123 114 124 } 944945# Define a list of joint numbers to record - all joints of primary frame 946 set jointNumToRecordLIST {} 947 948 # Define a list of node numbers to record - top/bottom node of joint in left column of each floor , leaning column nodes , base spring nodes 949 950 set nodeNumToRecordLIST { 126 226 10126 10226 11 12 13 14 15  $31 \ 32 \ 33 \ 34 \ 35$ set springnodeNumToRecordLIST { 116 126 216 226  $316 \ 326$  $416 \ 426$ 951516 526# Define a list of hinge elements to record - these are the springs at the base of 952the columns (elastic foundation + column PH) set hingeElementsToRecordLIST {} 953954955# Define a list of column numbers at the base of the frame (including the leaning column); this is for base shear calculations 956 set columnNumsAtBaseLIST { 111 121 131 141 151} 957 # Define a list of column numbers at each story (including the leaning column); this 958 is for story shear calculations set columnNumsAtEachStoryLIST { { 111 121 131 141 151 } 959960  $\{ 112 \ 122 \ 132 \ 142 \ 152 \}$ 961  $\{ 113 \ 123 \ 133 \ 143 \ 153 \}$ 962  $\{ 114 \ 124 \ 134 \ 144 \ 154 \} \}$ 963 964 965966 set zerolengthelementNumToRecordLIST { { 3112 3212 3312 3412 3512 }  $\{ 3122 \ 3222 \ 3322 \ 3422 \ 3522 \}$ 967 968  $3132 \ \ 3232 \ \ 3332 \ \ 3432 \ \ 3532$  $\{3142 \ 3242 \ 3342 \ 3442 \ 3542 \}$ 969 970 971 972 973# Define a list of heights of each floor (for computing story drifts) 974set floorHeightsLIST { 0 144 288 432 576} 975 976 # Define a list of the node numbers at each floor (always use node 3 of the joint because it is at the slab level and we measure all height to there) set nodeNumsAtEachFloorLIST {-1 12 13 14 15} 977 978 979980 set nodeNums1stFloorSpringsLIST {12 22 32 42 52}; 981 set nodeNums2ndFloorSpringsLIST {13 23 33 43 53}; 982

```
983
        set nodeNums3rdFloorSpringsLIST {14 24 34 44 54};
984
        set nodeNums4thFloorSpringsLIST {15 25 35 45 55};
985
986
        set springnodeNums1stFloorSpringsLIST {126 226 326 426 526};
       set springnodeNums2ndFloorSpringsLIST {136 236 336 436 536};
set springnodeNums3rdFloorSpringsLIST {146 246 346 446 546};
set springnodeNums4thFloorSpringsLIST {156 256 356 456 556};
987
988
989
990
     991
992
     ##### START NRS
993
994
        set columnRhoLIST { {
995
                                0.00102 0.00102 0.00102 0.00102 0.00102 \}
             0.001020.001020.001020.001020.001020.001020.001020.00102
996
                                                     0.00102
          {
                                                             }
997
                                                    0.00102
998
             0.00102 \quad 0.00102 \quad 0.00102 \quad 0.00102
                                                    0.00102 }
          {
999
        set columnFswLIST { { 17. 17. 17. 17. 17. 17. }
1000
          \{ 17. 17. 17. 17. 17. 17. 17. \}
1001
1002
          \{17. 17. 17. 17. 17. 17. \}
1003
          \{17. 17. 17. 17. 17. 17. \}\}
1004
1005
        set columnWidthLIST { { 18. 18. 18. 18. 18.
           \{ 18. 18. 18. 18. 18. 18. \}
1006
1007
            18. 18. 18. 18. 18.
           \{ 18. 18. 18. 18. 18. 18. \}
1008
1009
1010
        set columnDepthLIST { { 15.5 15.5 15.5 15.5 15.5 }
1011
           \{15.5 \ 15.5 \ 15.5 \ 15.5 \ 15.5 \}
           \{15.5 \ 15.5 \ 15.5 \ 15.5 \ 15.5 \}
1012
           \{15.5 \ 15.5 \ 15.5 \ 15.5 \ 15.5 \ 15.5 \ \}
1013
1014
        set fpc_NRS 4000.
1015
1016
     ##### END NRS
     1017
```