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NUMERICAL MODELING OF TOP AND SEAT ANGLE CONNECTIONS WITH DOUBLE WEB ANGLES

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ABSTRACT

In this study, the moment-rotation behavior of bolted top and seat angle with double web angle connections under monotonic loading are studied. Several 3D parametric finite element models are presented where the geometrical and mechanical properties of connections are considered parameters. The effect of all component interactions, such as slippage of bolts, bolts pretension and friction forces, are modeled using gap elements. To confirm the moment–rotation relationship, numerical results are compared with test results using different data and properties of experimental work that has been done by other researchers. In addition, the results are compared with a mathematical formulation suggested by other researchers. The results of the numerical modeling show good agreement with the test results. Also, the effect of the beam length on connection behavior is studied and by analyzing models with different beam lengths, an increase in connection stiffness and moment capacity with a reduction beam length is shown. The study is further extended by investigating the effect of these flexible connections on global behavior of the moment resisting frame. For this purpose, the moment resisting frame uses this type of connection instead of a rigid connection that was designed. In this frame, all connections are modeled as joint elements with moment-rotation relationships that are derived from numerical results. To study the dynamic behavior of this type of structure, three earthquake excitations were selected and the designed frame was subjected to these records. The global behavior of this frame is compared to that behavior of the special moment resisting frame. In this comparison, the capacity and global ductility of these two types of structures are presented and discussed.

Introduction

Due to the Northridge earthquake, sever damage in welded moment connections of steel frames occurred; since at the time, the many alternative types of connections suggested by researcher were bolted top and seat angle connections. This type of connection is categorized as a semi-rigid connection and it does not have the brittle fracture behavior of corresponding welded connections. On the other hand, it has the advantages of deformable failure patterns, relatively large energy dissipation capacity, and relatively easy erection.

Analyses and design of a semi-rigid frame needs a clear understanding of moment-rotation relative of its connections. Many studies have been preformed all over the world to estimate moment-rotation behavior of bolted top and seat angle connection. Azizinamini et al (1985) has experimentally studied the behavior of such connections under monotonic and cyclic loads, and the results of his experiments are a vital

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reference used by later investigators to verify their proposed methods. In the last few years, numerical modeling, especially the finite element method, is used to investigate the behavior of this type of connection. Citipitioglu et al (2002) studied the effect of bolt pretension and friction coefficient of adjacent surfaces on the behavior of such connections in details. In their models, for similarity and to over come the solution convergence difficulties, bolt shanks were elastically modeled so their models had a good agreement in the elastic range. Kishi et al (2001) studied the behavior of this type of connection using the finite element method and evaluated the applicability of the three parameter relation proposed by Kishi and Chen to estimate the behavior of semi rigid connections. Their FE models included the material nonlinearity of all components and the value of 0.1 was used for the friction coefficient. Ahmed et al (2001) studied the prying action of the bolts in the top and seat angle connections using FE. Their study showed prying force is related to bolt diameter, gage distance, and top and seat angle thickness. Their study showed also that the bolt pretension increases the initial stiffness of the connection. Danesh (1996) proposed a bilinear formulation to estimate the behavior of bolted top-and seat angle connections based on plastic hinges made in the top angle and considering the shear deformations effect on the capacity of the top angle leg. Pirmoz (2006) evaluated the effect of beam dimensions and friction coefficients of connection components on moment-rotation behavior of bolted angle connections under monotonic and cyclic loads and the applicability of the FE method in studying the connection behavior and dynamic parameters of semi-rigid frames. In this study, decay of frictional surfaces is considered. Results of this study showed that, in spite of the flexibility of the FE method to evaluate behavior of bolted connections under cyclic loads, the method is very time consuming.

The purpose of this study is to investigate the effect of beam dimensions on moment-rotation behavior of top and seat angle connections with double web angles and the applicability of the results. For this purpose, a parametric FE model is created and verified with test results from available research. The effect of beam length on the connection behavior is studied by some models with variable beam length/depth ratio and the results used in modeling and analyzing of a semi-rigid frame subjected to ground motion.

Connection Model

The connection models selected for this study and for verifying the numerical modeling are taken from experiments of Azizinamini (1985). The objective of these tests is to investigate the effects of different geometric properties of connection such as, top and web angles dimensions and bolt spacing on connection behavior. The test setup includes two beam segments with equal lengths, which are symmetrically bolted to a stub column. Beam ends are simply supported, the stub column can move vertically and the applied load on the center of the stub column applies a moment to the connection. Fig. 1 shows the test setup configuration.

Geometries of connection models

Azizinamini's (1985) experiments include 18 test specimens of bolted top and seat angle connections with web angles. Among them, 14S1 and 14S2 specimens are selected to modify numerical models.

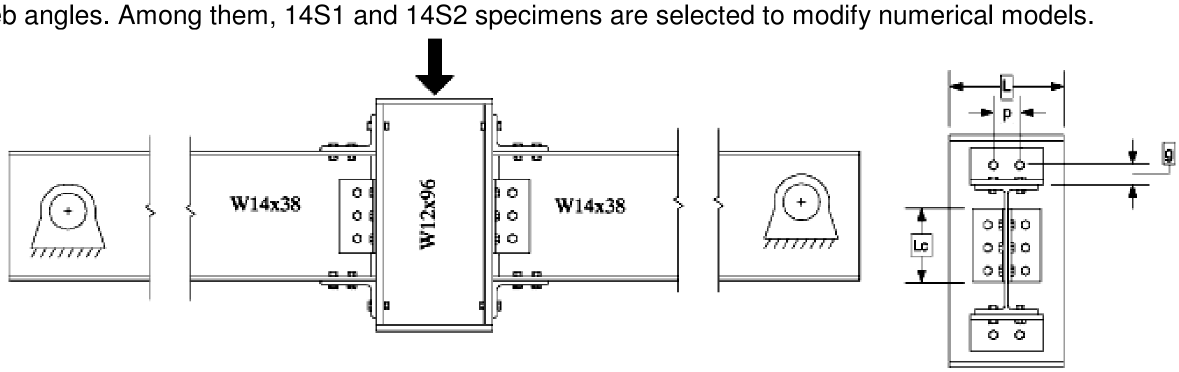


Figure 1. Test setup configuration and Connection parameters of 14SX specimens (Citipitioglu et al,. 2002).

Finite element modeling

Numerical modeling of the connection involves the following considerations: all components of the connection such as beam, column, angles and bolts are modeled using eight node first order solid elements and all are 3D and bolts holes are 1.6 mm larger than bolt diameter. Just half of the connection is modeled because of the symmetry about web plane. The effect of adjacent surfaces interaction, including angle-beam flange, angle/beam flange-bolt head/nut, bolt hole-bolt shank, and effect of friction, modeled using gap elements. To consider the frictional forces, Coulomb's coefficient is assumed as 0.25. Fig. 2 shows the FE model and mesh pattern of connection.

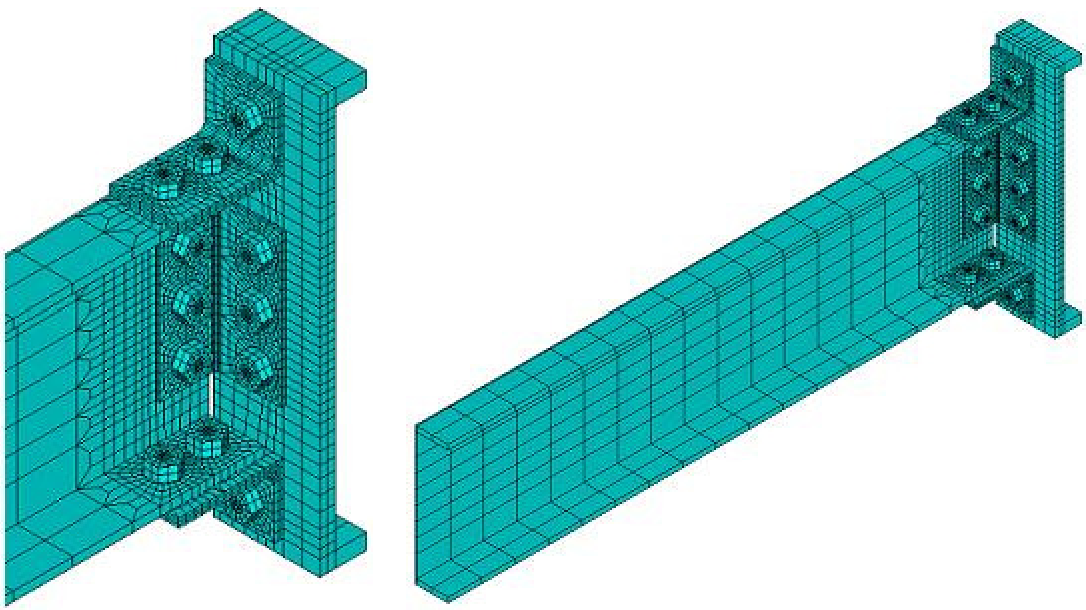


Figure 2. FE modeling of connection.

Boundary conditions and applied loads

To satisfy symmetry conditions, all nodes of the web plane are restrained against out of plane motion. Bolt pretension is applied as the first load case, for this purpose a thermal gradient is applied on the bolt shank such an equivalent pretension force yields. 178 KN pretension force is applied to 22.3 mm bolt diameter and 133KN for 19.1 mm. The vertical load is applied on the nodes of the beam end to impose the moment on connection, the resulting moment is evaluated by $M = P.L$ and relative rotation of connection is evaluated using $R = \frac{\varepsilon_1 - \varepsilon_2}{h}$ equations. Where M is moment, P is the applied load on beam end; L corresponds to beam length, R is relative rotation of connection, h is beam depth, ε_1 and ε_2 are relatively top and bottom flange horizontal displacements.

Material properties

The stress-strain relation for all connection components, except bolts, is represented using a three-linear constitutive model. Isotropic hardening rule with Von Mises yielding criterion is applied to simulate plastic deformations of the connection components. The mechanical properties of the beam, column and angle materials are taken from the numerical study by Citipitioglu et al (2002). Bolt materials modeled bilinear with 634.3 MPa yield stress and ultimate stress of 930 MPa at 8% strain. Modulus of elasticity and Poisson's ratio is considered 210 GPa and 0.3 respectively. Fig. 3 shows the mechanical properties of beam and angle material.

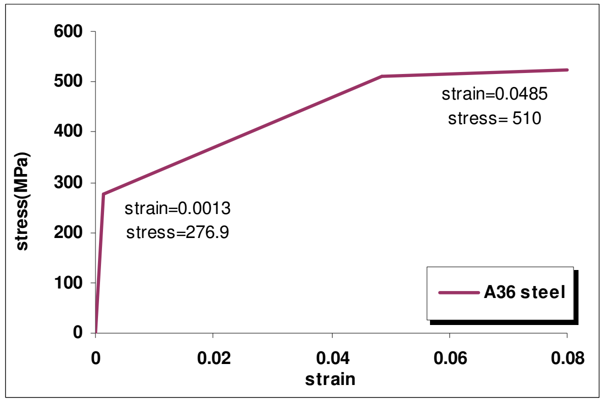


Figure 3. Material properties of connection components (Citipitioglu et al,. 2002).

Verification of Finite Element Models

To evaluate the accuracy of the finite element modeling approach, 17 finite element models are created according to Azizinamini's (1985) tests and the results are compared with test results. Just three of them are presented in this study for verification. Fig. 4 shows a comparison of moment-rotation relations for numerical modeling proposed by Danesh (1996) and test data from Azizinamini (1985). From this figure, results obtained from finite element models show good agreement with test data. Differences between numerical simulation and test results may be due to several reasons, such as; numerical modeling simplification, test specimen defects, residual stress, using uniaxial stress-strain relation, bolts pretension and friction coefficient of adjacent surfaces and their roughness. Citipitioglu et al (2002) studied the effect of bolt pretension and friction coefficient of adjacent surfaces on the behavior of such connections in detail. Figs. 5 and 6 show the deformed shape and stress distribution of connection components.

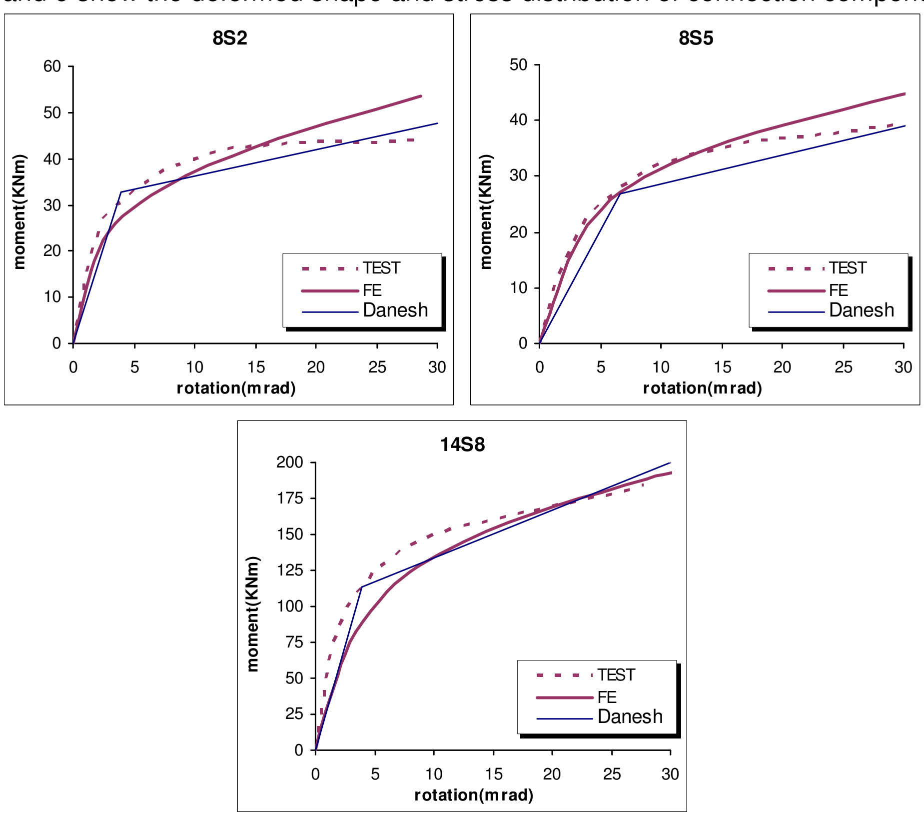


Figure 4. Comparison between numerical method, test results and proposed model by Danesh (1996).

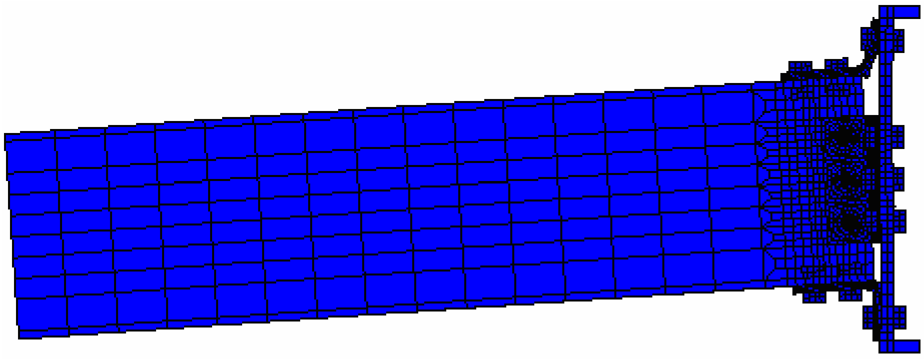
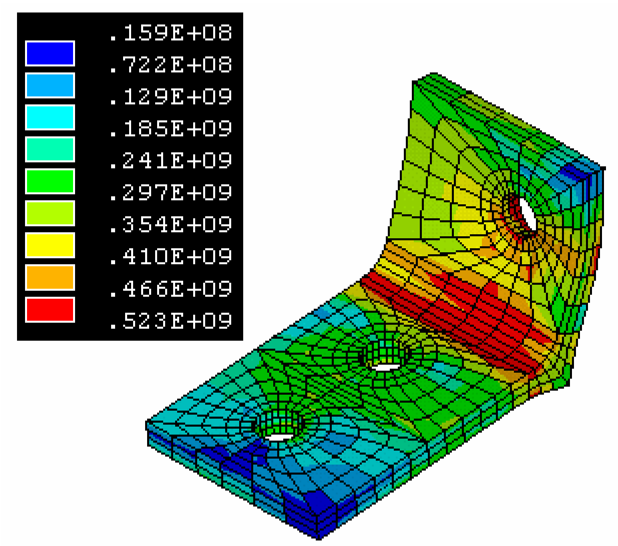
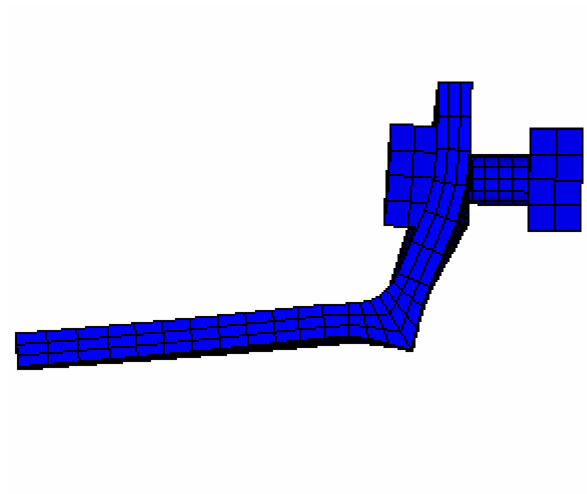


Figure 5. Deformed shape of 14S2 connection at 0.03 rad, scaled with factor of 2.



a) Von-Mises stress distribution in top angle (MPa).

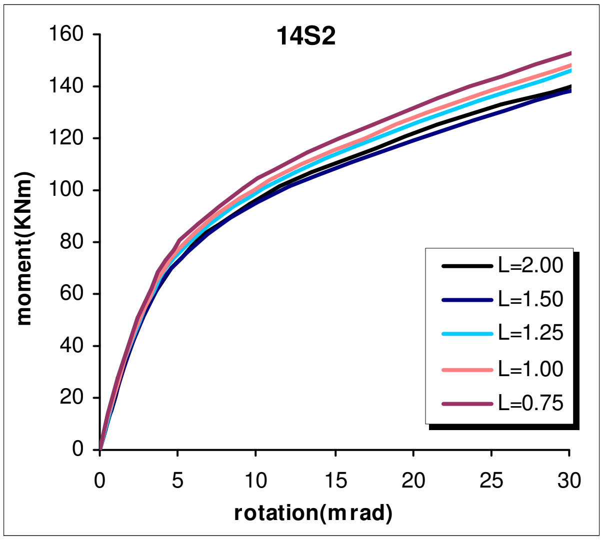


b) Top bolt-angle interaction and deformed shape.

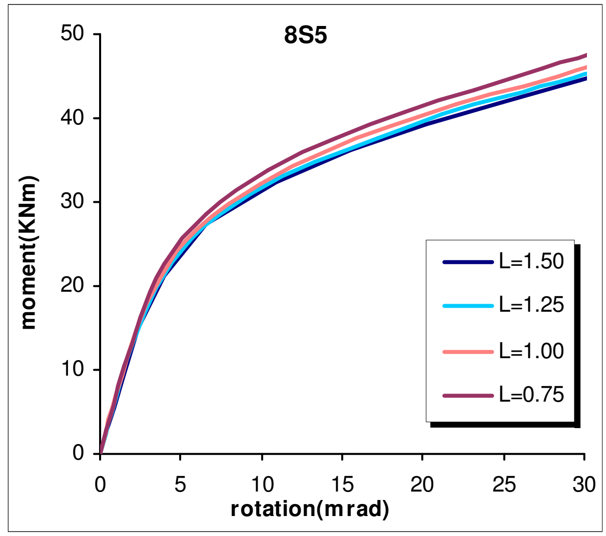
Figure 6. Angle and bolt of connection 14S2 at 0.03 rad, scaled with factor 2.

Effect of Beam Length on Connection Behavior

To evaluate the effect of beam length or depth/length ratio of the beam on the moment-rotation behavior of the bolted angle connections with web angles, the beam length of connection was varied from 0.75m up to 2m for 14S2 and up to 1.5m for 8S5 specimen. The moment-rotation curves are compared in Figs. 7a and 7b.



a) 14S2 specimen for different beam lengths.



b) 8S5 specimen for different beam lengths.

Figure 7. Comparison of moment-rotation behavior of connections with different length ratios.

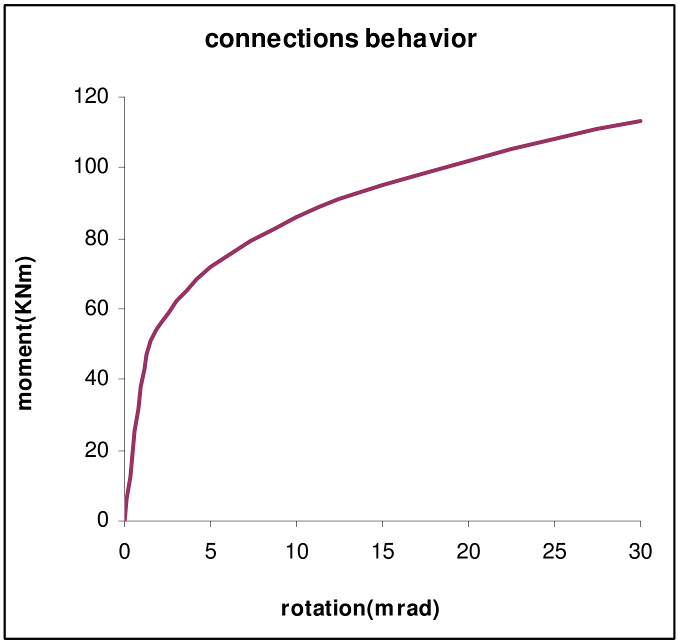
Fig. 7a shows an increase in the connection stiffness and ultimate moment capacity with decreasing beam length. In rotation 30 mrad, the moment capacity of connection 14S2 is almost 140 KNm for 1.5m beam length and 159.6 KNm for 0.75m beam length. Therefore, reducing the beam length increases the ultimate moment capacity of connection by up to 13.8% for 14S2 specimen. There is also a 2.6% increase in the inelastic stiffness of specimen 8S5.

Application of FE Modeling of Connection in Frame Analyzing

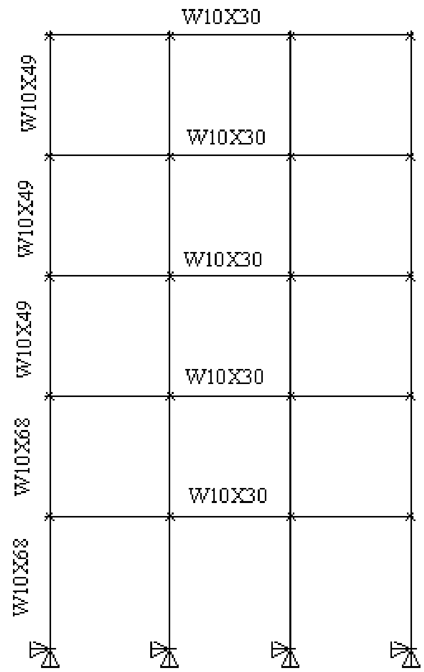
Selection of frame

To evaluate the seismic performance of structures with top and seat angle connections with double web angles, which are assumed to be semi-rigid frames, a two dimensional five story frame with three bays is designed and subjected to three ground excitations to study the overall behavior of the structure. Fig. 8 shows the geometry of this frame. Both the story height and bay width are 3m. A uniform 3500 kg/m dead load and 1000 kg/m live load is applied to the frame beams.

For the analysis and design of the frame, it is considered as a special rigid frame. Seismic loading of the frame is done by UBC provisions and for seismic zone 4, soil type of S_D and designed with AISC-LRFD specifications.



a) Moment rotation behavior of frame connections.



b) Schematic representation of frame.

Figure 8. Structure geometry and frame connection behavior.

After design of the structure and determining the frame sections and design of connection components, the behavior of the connection is determined. For this purpose, a finite element model of connection is made as mentioned previous. Fig. 8a shows the moment-rotation behavior of the frame connections obtained by finite element modeling.

Finite element modeling of the structure

Finite element modeling of the structure is performed using ANSYS 5.4 software. The structure is modeled for two cases: a) rigid frame; b) semi-rigid frame, and the global behavior of the structures are compared. Three types of elements are used for modeling: all beams and columns are modeled with BEAM 23, which can model flexural plastic deformations of beams and columns. Semi-rigid connections are modeled using COMBINE39. This element is a zero length joint element that can define the moment-rotation or force-displacement behavior of a selected element with up to twenty points so the moment rotation relation obtained by finite element analyses and can be used in frame modeling instead of bilinear moment rotation behavior proposed by the author. Story mass is modeled using MASS21. In frame modeling of the panel zone deformations and the effect of the roof slab are neglected.

The mechanical property of frame components is the same as Fig. 3 and pervious sections. Just the kinematic hardening rule is applied instead of the isotropic hardening rule.

Time history analyses

To perform dynamic analyses of the structure, a macro is created by the programming ability of software, APDL, which imposes ground acceleration to the structure for each time step. Selected ground motions are listed in table (1).

Table 1. General properties of earthquakes.

Earthquake	ML	PGA(%g)	Normalized PGA	Date
Tabas	7.7	0.852	0.59	1978
Kobe	6.9	0.509	1.22	1995
Duzce	7.2	0.822	0.758	1999

Results of nonlinear dynamic analyses

Figs. 9-11 show a comparison between the base shear force of the rigid and semi-rigid frames. From these figures, there is approximately a 35% reduction of frame base shear due to the semi-rigid action of connections. Also, comparison of the lateral drifts of the two frames in Fig. 12 shows that the semi-rigid frame, in spite of a lower base shear, has more lateral deformations than the rigid frame. However, this is acceptable because of the less stiff connections.

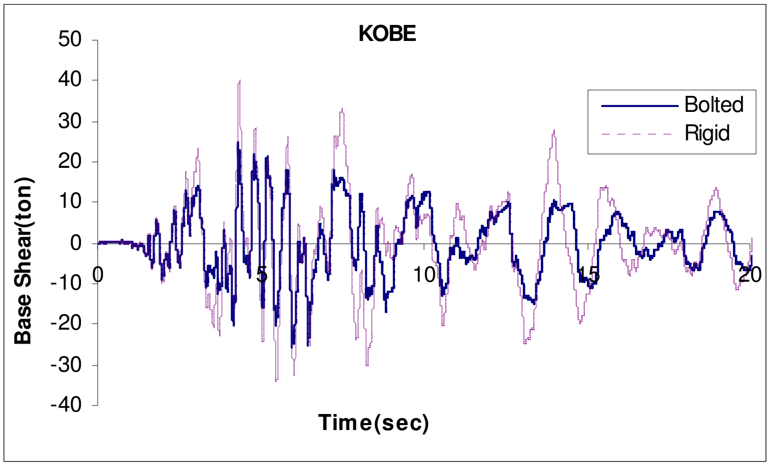


Figure 9. Base shear of structures due to the Kobe earthquake.

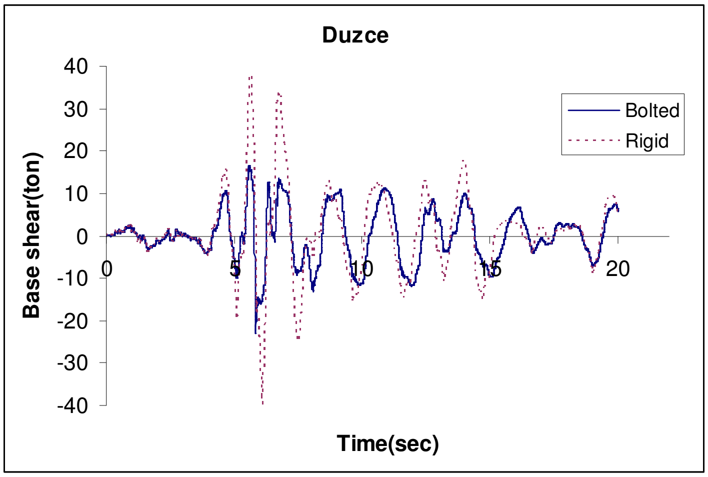


Figure 10. Base shear of structures due to the Duzce earthquake.

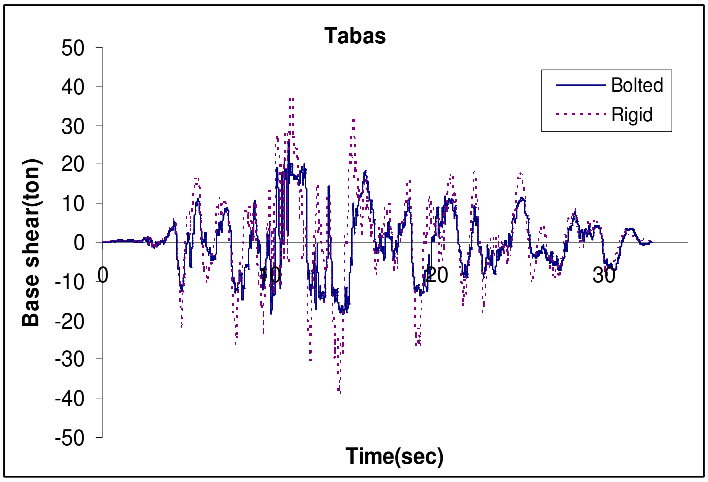


Figure 11. Base shear of structures due to the Tabas earthquake.

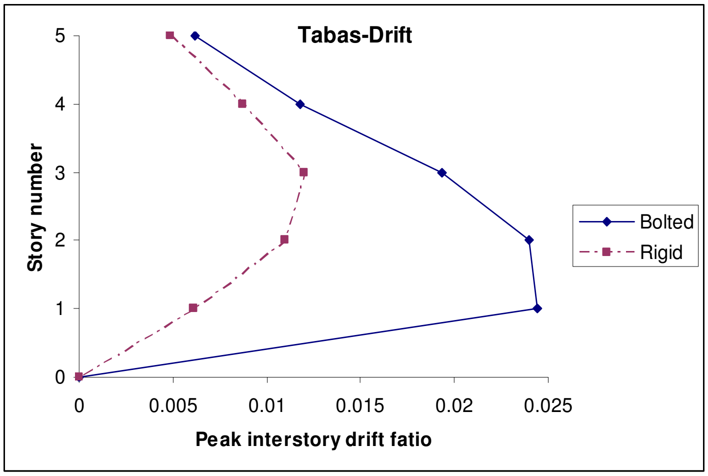


Figure 12. Peak inter story drifts of structures due to the Tabas earthquake.

Conclusions

In this study, a parametric model of bolted top and seat angle connections with double web angles is described, which considers all mechanical and geometrical properties as variable parameters. The effects of adjacent surfaces are modeled with gap elements and small sliding is considered in the finite element models. Results of the finite element models show good agreement with test results. The effects of beam length on the behavior of such connections are studied and an analysis of the models showed an increase in connection stiffness and moment capacity with reducing beam length. This modeling approach, which is used in determining the moment-rotation behavior of a semi-rigid frame, was analyzed and designed as a special moment resisting frame. The moment-rotation behavior of connections used in modeling the frame as a semi-rigid frame and subjected to ground motion excitation and its overall response, is compared with rigid frame response. The analyses showed that semi-rigid connections of the frame reduces the base shear by up to 35%, while the semi rigid frame had more lateral displacement than the corresponding rigid frame.

References

Ahmed, A., N. Kishi, K. Matsuoka and M. Komuro, 2001. Nonlinear Analysis on Prying of Top-and Seat-Angle connections, *International Journal of Applied Mechanics*; 4:227-36.

AISC, 1995. Manual of steel construction-Load and resistance factor design, American Institute of Steel Construction, Chicago, ILL.

ANSYS User's manual.

Azizinamini, A., 1982. “Monotonic response of semi-rigid steel beam to column connections” *MS thesis*, University of South Carolina, Columbia.

Belytschko T., Liu, W. K. and Moran, B., 2001. Nonlinear Finite Elements for Continua and Structures, John Wily & Sons, LTD. 650P.

Citipitioglu, A.M., R.M. Haj-Ali and D.W. Withe, 2002. Refined 3D finite element modeling of partially restrained connections including slip. *Journal of Construcional Steel Research*, 8:995-1013.

Danesh, Nonlinear dynamic analyses of semi-rigid steel frames and comparison with test results, Third International conference of Seismology and Earthquake Engineering; May 1999.

Kishi, N., A. Ahmed and N. Yabuki, 2001. Nonlinear finite element analyses of top and seat-angle with double web-angle connections, *Journal of Structural Engineering and Mechanics*, 12:201-14

Pirmoz, A., 2006. Evaluation of nonlinear behavior of bolted connections under dynamic loads, *MS thesis*, K.N.Toosi University, Tehran, Iran.