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Experimental and analytical investigations of T-joint piping systems for various different pipe sizes

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ABSTRACT

In the critical facilities typically hospitals and school buildings, the structural and nonstructural components must remain operational or functional after an earthquake. Nonstructural components for maintaining the operation of the buildings are defined as architectural components, piping systems, mechanical and electrical equipments, and building contents. In recent years, the economic loss due to failures of nonstructural components has been much more considerable than that due to failure of structural systems in most seismic events. Previous studies reported that the widespread failure of nonstructural components like sprinkler piping systems from 1974 San Fernando and 1994 Northridge earthquakes. The failure of piping systems led to leakage of water and subsequent shutting down of hospitals immediately after the event. Therefore, a reduction in the damage to nonstructural components or an improvement the performance of nonstructural components has emerged as a key area of research in recent years. The primary objective of this study is to understand the performance of complex T-joint piping systems conducted at University of Buffalo (UB) and it is also targeted on the development of nonlinear Finite Element (FE) model specified by moment-rotation relationships based on experimental tests. Finally, this study focuses on reconciliation of experimental and analytical results of T-joint piping system for various different pipe sizes subjected to cyclic loading. As a result, the findings from current study are in agreement with the analytical results of T-joint FE models using the *OpenSees* platform.

1. INTRODUCTION

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Nonstructural components in a building include partition walls, ceilings, piping systems, and mechanical and electrical equipment. Damage to critical component-systems in seismic events, such as the fire protection piping system, heating, ventilating, and air conditioning (HVAC), and water piping systems can cause direct economic loss and/or indirect loss of life. FEMA (2007) emphasizes that the potential disruption of hospital operations due to damage to nonstructural systems can be significant during and after an earthquake. For example, the Mount Olive View hospital was shut down for many weeks due to failure of fire sprinkler piping system during the 1994 Northridge earthquake (Ayres and Phillips, 1998).
Many researchers have recognized the importance of nonstructural components in the critical facilities. Therefore, many attempts were made to remain operational and functional without leakage by reinforcing non-structural components during and after the earthquake. Antaki and Guzy (1998) conducted static and dynamic tests on piping components of the fire protection piping systems. Their fire protection piping systems were designed in accordance with National Fire Protection Association (NFPA). They reported the failure types of piping connections for grooved couplings and threaded joints, in terms of the leakage and the rupture limits. Threaded joint connections for piping systems have been used in a wide variety of industrial applications. Therefore, the primary objective of this study was to develop the Finite Element (FE) model of the T-joint connections for the various different pipe sizes based on the experimental tests conducted by University at Buffalo (UB). In particular, the FE models of the threaded T-joint piping systems were described by two nonlinear rotational springs on either side each specified by the experimental moment-rotation curves.

2. DESCRIPTION OF EXPERIMENTAL TESTS FOR VARIOUS DIFFERENT PIPE SIZES

In order to avoid the computational effort and dense mash in FE analysis, FE model for connecting two different systems often used in the nonlinear moment-rotational springs based on the experimental tests. Laboratory tests were conducted by the University at Buffalo, State University of New York (Dow (2010); Tian (2011)). Various types of piping material like black iron and chlorinated polyvinyl chloride (CPVC) and connections such as threaded, grooved fit, and cement joint connections were selected for the experiments. In this study, three different types of pipe sizes, 1 in, 2 in, and 4 in, were described for characterizing the behavior of the complex T-joint connections of the Black Iron Schedule 40 piping systems.

2.1 Test Setup Layout

According to Dow (2010), in-plane loading was applied from the bottom of the T-shaped component, which was connected to an actuator with a 6- inch stroke, as shown in Fig.1. Each directions of the loading were as followings: forward for the monotonic test; forward and reverse for the cyclic test; and the axis perpendicular to the center of the T-joint. The tests were performed with a constant loading rate of 0.01 in/sec for the monotonic test, and it gradually increased with each cycle up to the maximum rate of 0.2 in/sec for the cyclic test. City water pressure was applied into the piping component to detect water leakage during the test. The leakages occurred at the

T-joint connections due to slippage and rupture of the joints. Table 1 showed the detected “leakage" points during monotonic and cyclic tests.

Table 1 The First Leakage Points for the Various Piping Systems Conducted by UB

Sizes	The First Leakages	
	Monotonic Test (rad)	Cyclic Test (rad)
1-inch	0.1157	0.039
2-inch	0.0804	0.015
4-inch	0.0449	0.011

Fig. 1 T-joint Test Setup (Tian, 2011)

3. VALIDATION OF EXPERIMENTAL RESULTS OF THE T-JOINT SYSTEMS

The results from such tests were used to develop the FE model and to understand the seismic response of the connections in the complex piping systems. Ju *et al.* (2011) developed the modeling technique of the threaded T-joint connection of the 2-inch Black Iron piping system. The FE models for the different sizes and loading tests were conducted according to Ju *et al.* (2011), and it is described in the next two sections.

3.1 The FE Models for Monotonic Tests

In order to validate the T-joint systems, the piping systems were modeled in Open System for Earthquake Engineering Simulation (OpenSees), which was finite element structural analysis package by Tcl/Tk interpreter extension (Mazzoni *et al.*, 2006). Fig. 2 showed the schematic design of the T-joint connection. The piping system was designed by linear elastic frame elements, and was supported by hinge systems at the end of the piping system. In addition, the T-joint connection was specified by two nonlinear rotational springs on either side, in which inelasticity was confined to the threaded connection. A “Parallel” material was applied in this study in order to validate the monotonic tests and it is shown in Fig. 3. The stiffness of “parallel” material was composed of multi-linear models (i.e., individual "ElasticPPGap" material properties in OpenSees). The monotonic loading was applied as axial displacements at the bottom of the T-joints. Fig. 4(a) to 4(c) compared the moment-rotation relationships between experimental and analytical results from the FE model at the location of the rotational springs. As seen in the figures, the moment-rotation curves for 1-in, 2-in, and 4-in T-joint connections using OpenSees were identical till the first leakage point based on the experimental tests.

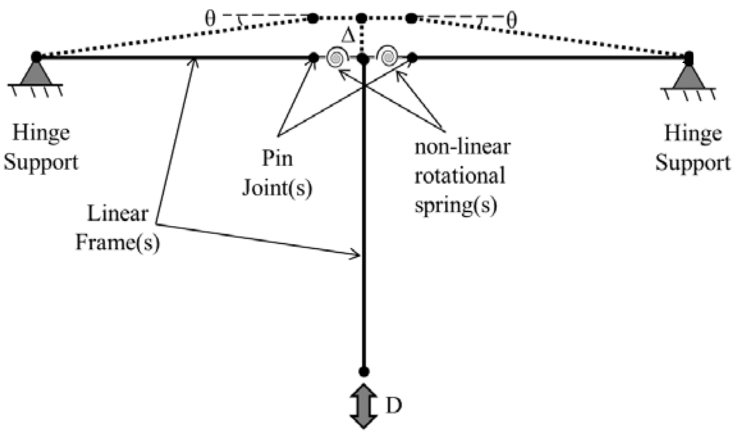


Fig. 2 The FE Model of T-joint System

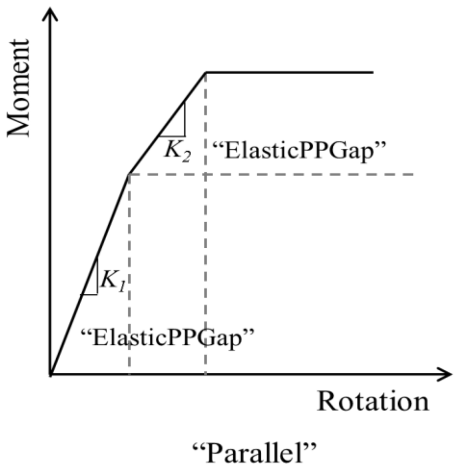
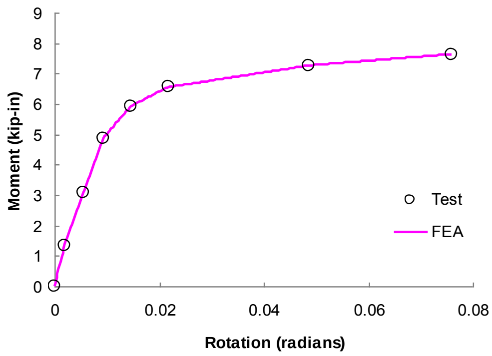
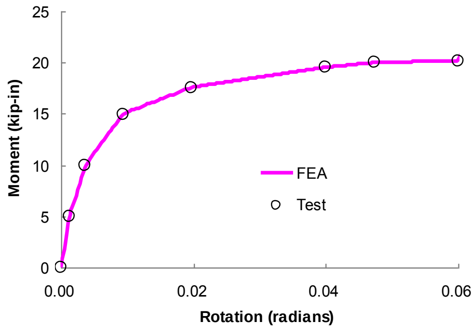


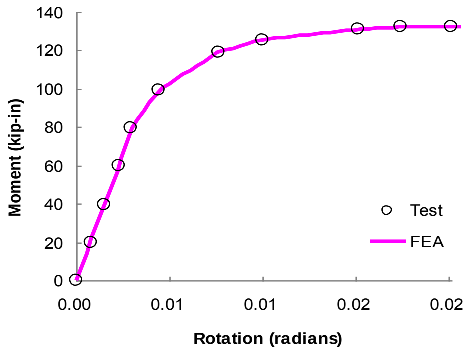
Fig. 3 Multi-Linear Model for Monotonic Loading (Mazzoni and et al., 2006)



(a) 1-inch T-joint System



(b) 2-inch T-joint System



(c) 4-inch T-joint System

Fig. 4 The Validation of FE Models for Monotonic Tests

3.2 The FE Models for Cyclic Tests

For a better understanding of the seismic performance with sufficient accuracy at the complex piping system, it was necessary to validate of the T-joint connections subjected to cyclic loading conditions. The baseline approach for the validation of the cyclic tests followed the same procedure with the monotonic tests. However, “steel02” and “Pinching4” material were selected in order to characterize the hysteretic behavior of T-joint connections. The “steel02” material for 1-in and 2-in T-joint systems can be modelled with yield strength, initial elastic tangent, strain-hardening ratio, and isotropic hardening parameters, as shown in Fig. 5 (Mazzoni and et al., 2006).Also, the “pinched” behavior was described by positive and/or negative response envelope, and each were given 4-points, as given in Fig. 6 (Mazzoni and et al., 2006). The cyclic strength and stiffness degradation properties were determined during unloading and reloading, and from the test data, respectively. Fig. 7(a) to 7(c) compared the results of moment-rotation relationship on the left spring between steel02 and pinching4 model with the experimental tests under the cyclic loading. The relationships from OpenSees were in good agreement with the measured moment-rotation relationships till the first leakage points.

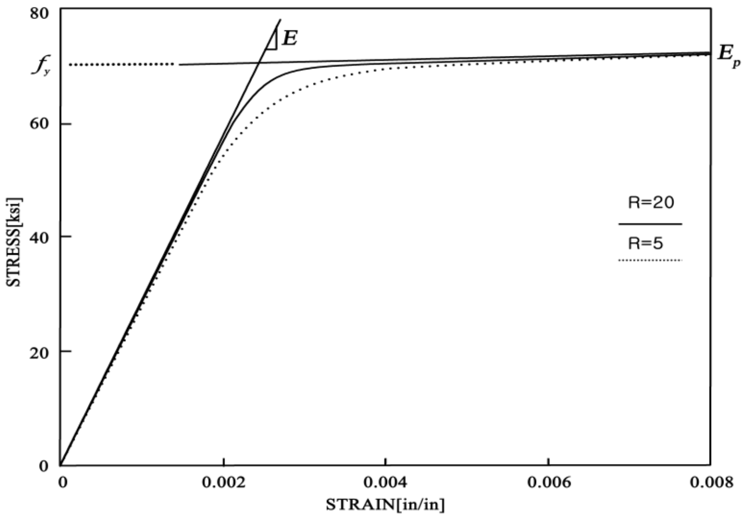


Fig. 5 Steel02 Material in OpenSees (Mazzoni and et al., 2006)

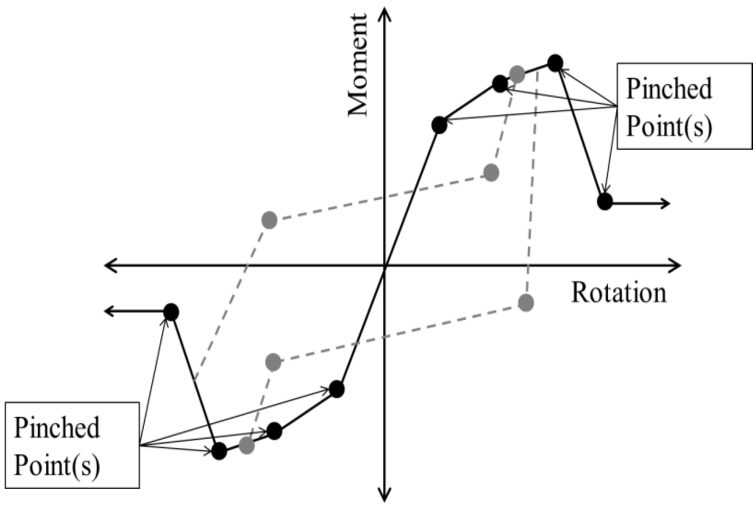
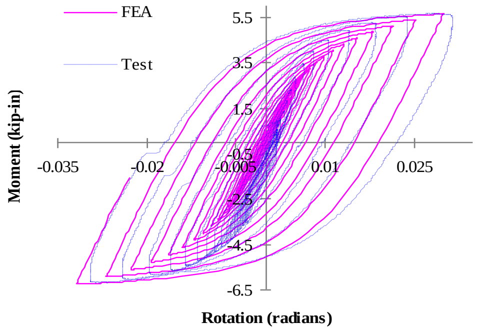
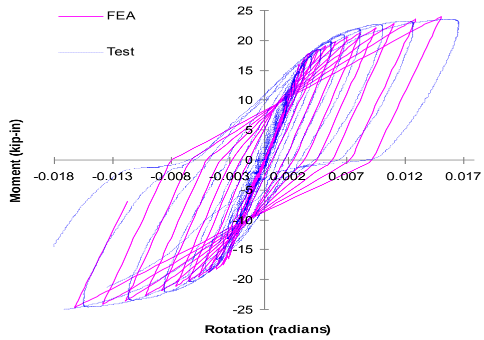


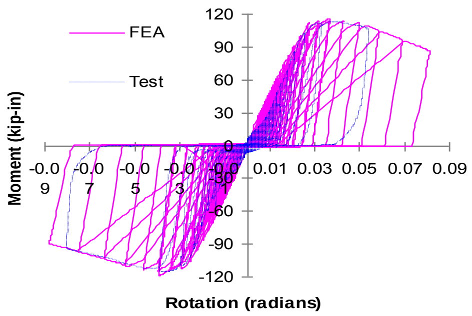
Fig. 6 Pinching4 Material in OpenSees (Mazzoni and et al., 2006)



(a) 1-inch T-joint System



(b) 2-inch T-joint System



(c) 4-inch T-joint System

Fig. 7 The Validation for FE Models of Cyclic Tests

4. Summary and Conclusion

In this paper, a technique to model the piping component with the T-joint connection based on experimental data were presented. The laboratory tests were conducted by the University at Buffalo on T-shaped components using the 1, 2, and 4 inch black iron schedule 40 pipes with threaded joints. The result of current study revealed that the stiffness of larger size of the piping systems was much stiffer than that of smaller size of the piping systems. In another word, as the diameter of pipe sizes decreases, the ductility of the T-joint piping systems increases, respectively. Furthermore, the experimental test data was used to define rotational spring properties for each T-joint connection, which was characterized by “Parallel”, “Steel02”, and “Pinching4” material for the monotonic and hysteretic behavior, respectively. The nonlinear moment-rotation models for threaded T-joints were in agreement with the experimental results for both monotonic and cyclic loading cases. In addition, the rotations of the T-joints subjected to the cyclic loading were more conservative than the values of the T-joints under the monotonic test.

ACKNOWLEDGEMENT

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REFERENCES

Antaki, G. and Guzy, D. (1998), “Seismic Testing of Grooved and Threaded Fire Protection Joints and Correlation with NFPA Seismic Design Provisions”, *ASME, Seismic Engineering,* PVP-Vol. **364**, 69-75

Ayres, J. M. and Phillips, R. J. (1998), “Water Damage in Hospitals Resulting from the Northridge Earthquake”, *American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Transactions Part1B*, Vol. **104**, 1286-1296

Dow, J. (2010), “Testing and Analysis of Iron and Plastic T-joint in Sprinkler Systems”, NEESR-GC: “Simulation of the Seismic Performance of Nonstructural Systems”, Available at http://nees.org/site/oldnees/filedir_2/REU 2009_Dow_Paper.pdf

FEMA 577 (2007), *Risk Management Series Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds*, June 2007

Ju, B.S., Tadinada S. K., and Gupta, A. (2011), “Fragility Analysis of Threaded T-Joint Connections in Hospital Piping Systems”, *ASME 2011 Pressure Vessels and Piping Conference*, Baltimore, Maryland, PVP2011-57958

Mazzoni, S. and et al. (2006), *OpenSees Command Language Manual*, Available at http://opensees. berkeley.edu/

NFPA-13 (2007), *Standard for the installation of Sprinkler System*, National Fire Protection Association, MA, 2007 Edition

OpenSees (2011), *Open System for Earthquake Engineering Simulation*, Available at http://opensees. berkeley.edu/

Tian, Y. (2011), “Progress Report of Sprinkler Piping Subsystems Dynamic Test on NCS”, Progress Report, NEESR-GC: Simulation of the Seismic Performance of Nonstructural Systems, Available at http://www.nees-nonstructural.org/documents/presentations.html