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Seismic Behavior of Welded Hospital Piping Systems

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Summary

This paper presents findings from shake table experiments on cable-braced and unbraced welded hospital piping systems. The research identifies the capacity characteristics of a hospital piping system with and without bracings as well as the system's weak points. The system was tested to the ICBO AC156 acceptance criteria for nonstructural components. The input motion of 1g was amplified to almost 2.6g at the top of the braced and unbraced piping systems. There was no significant damage to the piping system due to the high displacements and accelerations. Two of the eleven braces failed at the highest input excitation, the 2½" diameter vertical hanger rods failed during the unbraced tests, and a flanged connection began to leak during a pushover test. Preliminary results show that the braces limited the displacements, but they did not significantly reduce the accelerations of the system.

Background

The functioning of an essential facility, such as a hospital, after an earthquake relies heavily on proper functioning of its nonstructural components such as fire suppression and water distribution systems, elevators and medical equipment. In recent earthquakes, nonstructural components in hospitals and medical buildings have suffered a large amount of damage, which resulted in a significant reduction of the functionality of the facilities. The 1971 San Fernando Earthquake caused severe damage to many hospitals and medical facilities. As a result of that damage, four of the 11 damaged medical facilities in the area had to be evacuated (Wasilewski 1998). Due to this unacceptable performance, the State of California passed the Hospital Seismic Safety Act, which required that medical facilities be designed and built to remain operational after an earthquake event (Ayres and Phillips, 1998). The California Office of Statewide Health Planning and Development (OSHPD) was charged with certifying that bracing components installed in California hospitals met a certain level of strength.

Test Specimen

In consultation with OSHPD engineers, the experimental hospital piping system was modeled after a system in the University of California, Davis hospital. The system was modified slightly to accommodate the dimensions and geometry restrictions of the testing facility. The system is made up of approximately 100' of 3" and 4" diameter schedule 40 ASTM grade A-53 black steel pipe. The system includes two water heaters, one simulated heat exchanger, one y-strainer, two check valves and one gate valve. The water heaters and the heat exchanger were anchored to the shake table, while the pipes were braced and hung from a stationary frame, which rested on the lab floor. The fixed frame permitted direct measurement of relative displacements.

Figures 1 and 2 illustrate the plan and elevation views of the system. The water heaters were braced on the table to avoid premature failure of the piping system due to excessive rigid body motion of the water heaters. The water heaters were connected to the system through a four bolt flanged connection. The heat exchanger and all of the valves were connected to the pipes through an eight bolt flanged connection. All of the elbow to pipe connections were welded using a shielded metal arc welding process.

The bracings used were cable style braces. There were seven brace points and four hanger points in which there were vertical supports only. The cables were made of ⅛" diameter prestretched galvanized 7x19 aircraft grade steel. The vertical hanger rods were of two sizes: ⅝" diameter all-thread rod for supporting the 4" diameter pipe and ½" diameter all-thread rod for supporting the 3" diameter pipe. The vertical hanger rods were braced continuously along their length with 1⅝" square, 12 gauge strut. The system was white washed so that any leaks would be noticeable.

Two systems, one braced and one unbraced, were tested in the experimental program. The unbraced system was the same piping system as the braced one, except that the cable braces, the strut bracing the all-thread vertical rod and the clevis cross braces were removed, reflecting actual field unbraced conditions.

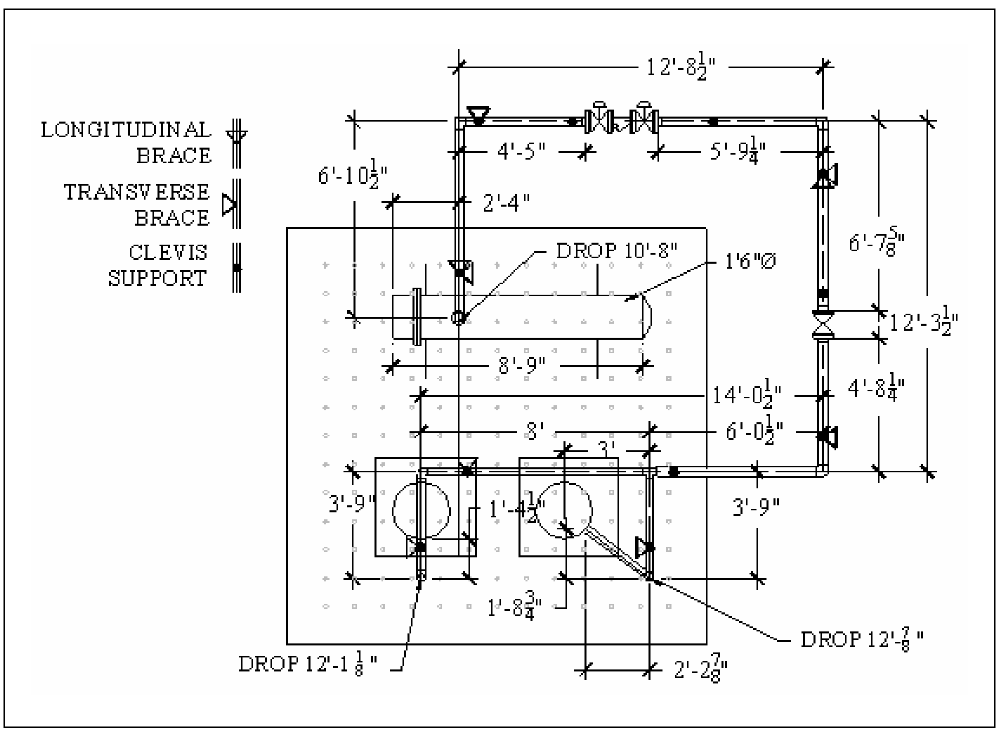


Figure 1. Plan view of experimental setup

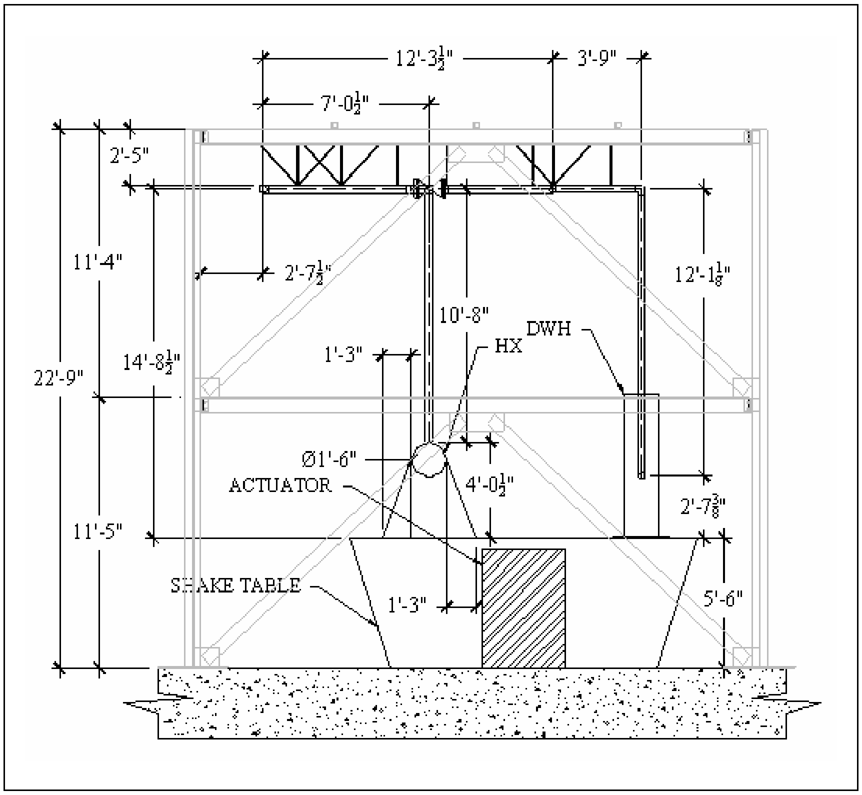


Figure 2. Elevation view of experimental setup

Testing Criteria

The piping system was tested to meet the ICBO AC156 Acceptance Criteria for Seismic Qualification Testing of Nonstructural Components (ICBO Evaluation Service, Inc., 2000). AC156 requires that the nonstructural component be subjected to a synthetic input motion that meets a response spectra where the maximum spectral acceleration is determined according to the formula:

$$A = 2.5C_a\left(1 + 3\frac{h_x}{h_r}\right) < 4C_a \qquad (1)$$

where:
C_a = seismic coefficient (UBC Table 16-Q)
h_x = element or component attachment elevation with respect to grade
h_r = structure roof elevation with respect to grade

For this research, the following assumptions were made:
$C_a = 0.44N_a$
Z = 0.4, seismic zone factor (UBC Figure 16-2)
S_D soil type
N_a = near source factor (UBC Table 16-S)
$C_a = 0.66$
$h_x = h_r$

Formula (1) is derived from Equation 16-32-2 of the 1997 UBC, Formula (2) in this paper. By using Formula (1), the maximum spectral acceleration was found to be 2.64g. Figure 3 shows the required response spectra (RRS), the envelope that the AC156 requires the synthetic motion response spectra fall between (bold lines), and the response spectra of the generated motions. The AC156 requires that the input motion have a build, hold and decay curve of 5, 15 and 10 seconds, respectively.

The program SIMQKE (Gasparini and Vanmarcke, 1976) was used to generate a synthetic input motion that conforms to the AC156, as shown in Figure 4. The program required the following items to generate a motion:

- Points describing the required response spectra
- Build, hold and decay envelope
- A maximum input acceleration

A maximum acceleration of 1 g was chosen as the SIMQKE input. An additional synthetic motion using the program RSCTH (Halldorsson et al., 2002) was also generated. The RSCTH motion met the response spectra as seen in Figure 6, but did not meet AC156 due to the fact that it could not produce a motion that had a build, hold and decay envelope. Using the maximum displacement input of the SIMQKE motion of 8.32" and considering 16.5' as a story height, the story drift ratio that was achieved with the SIMQKE motion was 4.18%.

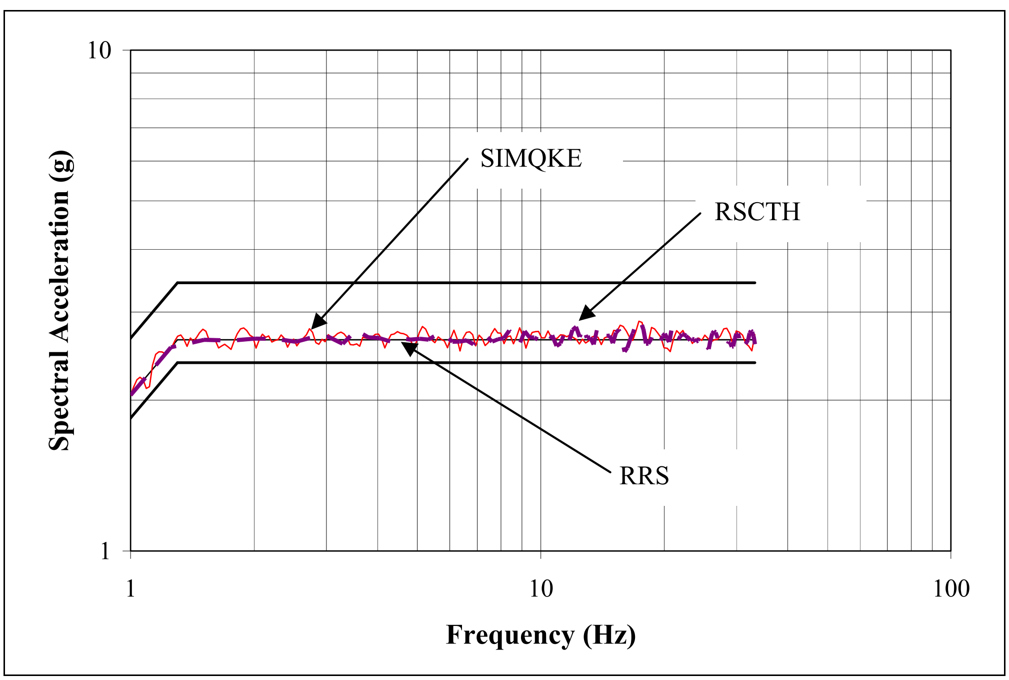


Figure 3. Required and generated response spectra

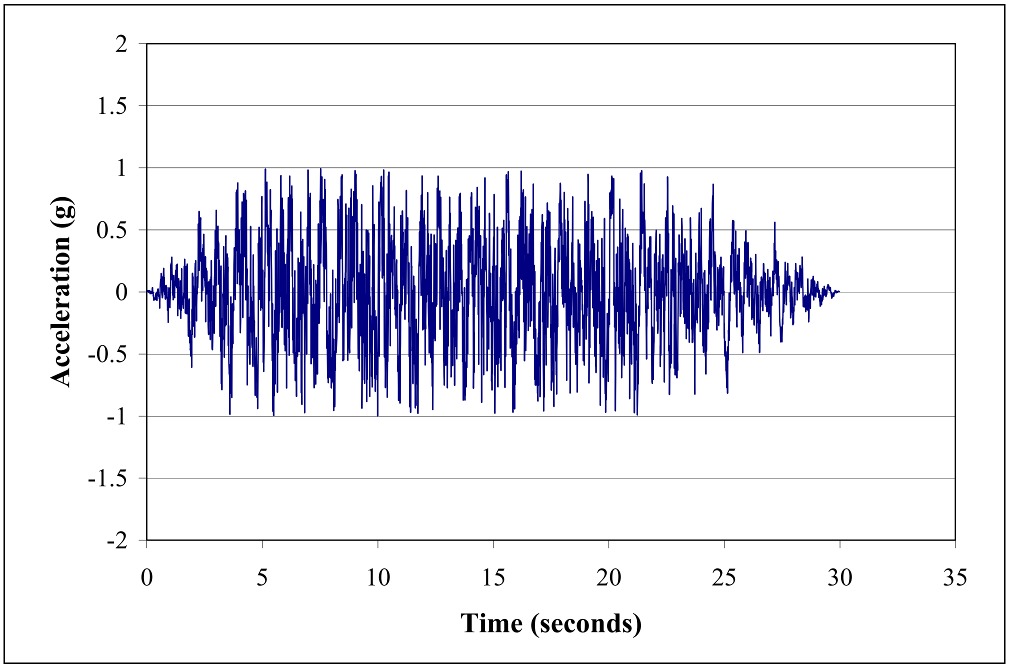


Figure 4. SIMQKE generated input motion

Test Protocol

A test protocol was developed that subjected the braced and unbraced systems to varying intensities of the SIMQKE and RSCTH motions in both principle axes as well as a biaxial excitation at 45° with respect to the principle axes. Both systems were subjected to a varying frequency sinusoidal sweep with a constant amplitude of 0.8." The braced system was also subjected to a dynamic pushover. Overall, each system was subject to 61 runs.

Experimental Results

During the braced E-W 100% SIMQKE input motion, two of the braces bracing the 4" pipe failed. The flanged connection joining the heat exchanger to the pipe began to leak during the braced 10" dynamic pushover. White washing the surface of the pipes not only aided in identifying leaks, but also illustrated the permanent relative displacement of the braces to the piping system. The clevis hangers scraped off the whitewash in the places it had touched the pipe during the excitation. Every brace point had at least 1" of permanent displacement after the testing of the braced system and one brace moved permanently 4." During the unbraced biaxial input motions, the only 2½" diameter rods failed. None of the ⅝" diameter rods failed.

Figure 5 shows a comparison of the braced and unbraced displacement response of instrument nv26. Figure 6 shows the braced and unbraced acceleration response of instrument nv17. As seen in these graphs, the braces significantly reduced the displacement response but did not have a major effect on the acceleration response of the system. The maximum acceleration responses for the braced and the unbraced cases were 2.62 g and 2.58 g, respectively. Similar behavior was observed with the response of other instruments.

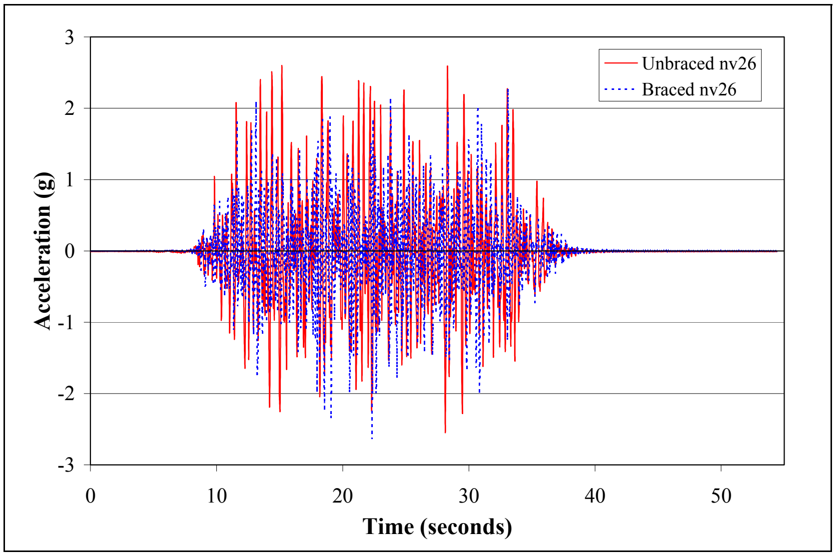
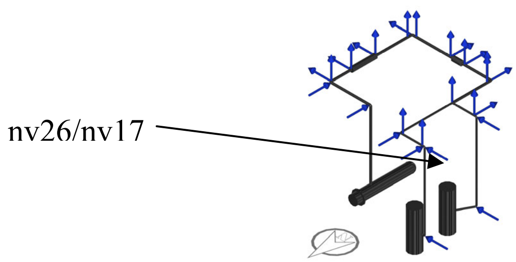


Figure 5. Acceleration response of instrument nv26



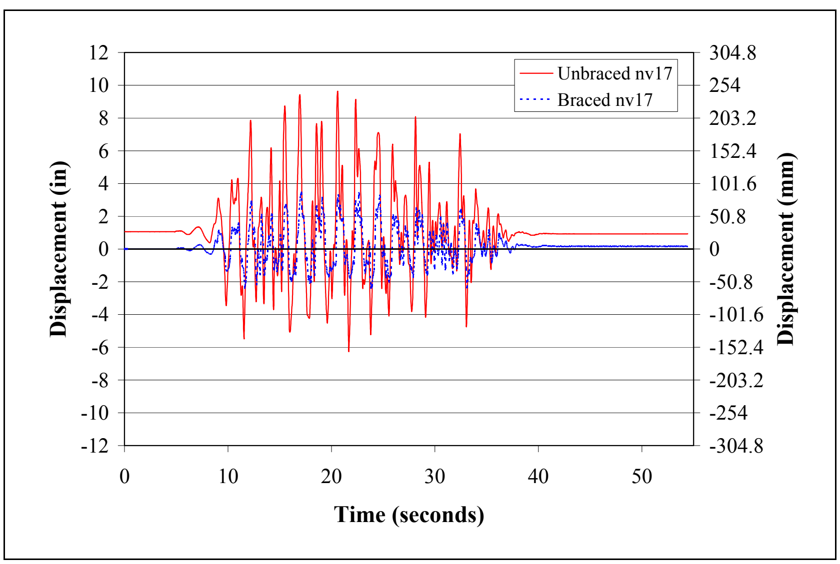


Figure 6. Displacement response of instrument nv17

Concluding Remarks

The system did not have any failure level damage during either the braced or unbraced experiments. The long vertical pipe run into the heat exchanger began to leak during the pushover test, and there were two braces that failed in the cables during the highest SIMQKE input excitation. For the unbraced test, the only damage to the system was the failure of 2½" diameter rods at the highest SIMQKE input excitation. The displacements were significantly reduced by the addition of the braces. However, the accelerations were not significantly affected by the presence of the braces.

Another system will be tested in early winter of 2003/2004. The system will have the same geometry and same brace layout; however, the connections will be threaded instead of welded. In the past, threaded connections have been the source of multiple failures in hospital piping systems, and it is expected that there will be more damage to the threaded system than there was in the welded system.

Acknowledgements

This research was carried out under the supervision of Drs. Emmanuel Maragakis and Ahmad Itani, and primarily supported by the Earthquake Engineering Research Centers Program of the National Science Foundation, under award number EEC-9701471 to the Multidisciplinary Center for Earthquake Engineering Research. Special thanks to William Staehlin and Chris Tokas of the California Office of State Wide Health Planning and Development, David Ainsworth of Stecher-Ainsworth-Miner, Mechanical Engineers, Rich Lloyd of Mason Industries and Pete Rezac from Cooper B-Line.

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