A Study on Suspended Fire Protection Sprinkler Piping Systems in Buildings

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Abstract

In Taiwan, hospital, emergency and rescue command centers are important and should be operational after an earthquake. However, in 1999 Chi-Chi earthquake and 2010 Jia-Xian earthquake, lots of suspended hospital piping systems were broken at hanger, connecters, and sprinkler head and ceiling hit each other. These situations caused water leakage, machine shut down, and reduce the first aid operation. It is an urgent issue to improve the seismic capacity of suspension piping systems in hospitals with existing codes.

This research program is jointly conducted by Japanese and Taiwanese researcher. The differences in piping systems designed in NFPA13, ASHRAE and GB were first analyzed. NFPA13 was chosen for the bracing design baseline reference for future improvement. Full-scale shaking table tests in E-DEFENSE Lab and NCREE Lab were conducted. We not only analyzed the dynamic characteristics, but also observed the motion and displacement in earthquakes for different level of bracing installation with white noise and Kobe earthquake time history shaking table tests. With these results, a reasonable computer model can be established to be a foundation for establishing a strengthened suspended piping systems in buildings.

Keywords: non-structure component, suspended piping system, shaking table tests, numerical analysis

1. Introduction

There are various piping systems in a hospital, the most vulnerable one is sprinkler piping systems. During the 1999 Chi-Chi earthquake and 2010 Jia-Xian earthquake in Taiwan, many sprinkler piping systems had large displacement and suffered collision with other building elements overhead. This led to leakage, medical equipment damaged with water, and ceiling absorbing water to collapse in large area. Under these situations, hospitals could not continue first-aid operation immediately and the post-EQ resilience was reduced. If the sprinkler piping systems can be strengthened to increase the seismic capability, to decrease the broken probability with an effect method, the emergency resilience would be maximized in time for hospitals. This study intends to: (1) compare the existing sprinkler piping codes. (2) Referencing to NFPA13, suspended sprinkler piping systems of different bracing types were designed and tested on shaking table.

2. Code Comparison

According to Taiwan's fire code, architects always decide the pipeline direction and sprinkler head locations for the fire piping system at the design phase. Suspended sprinkler piping systems are composed of feed main, cross main, and branch. When the fire alarm system was switched on, the feed main would transport water to cross main and to branch, and the sprinkler could spray water to extinguish fire. Normal suspended sprinkler piping systems were suspended by expansion bolts, 3/8" threaded rod and hangers on RC floor above. In some particular locale such as high-tech factory and hospitals, the suspended sprinkler piping systems may be strengthened by following fire code to reduce the probability of failure in earthquake. Huang [1] probed and compared the differences of seismic restraint design for existing fire codes: NFPA13 (2009) [2], ASERAE (2012) [3] and GB [4]. The main parameters project including hanger, slenderness of bracing and angle, bracing, piping direction changing and restraint of branch.

3. Piping Systems Preliminary Numerical Analysis

Comparing differences of NFPA13, AHERAE and GB, Huang [1] adopted the bracing configuration for an existing suspended sprinkler piping analysis in NCKU. By numerical software SAP2000, the displacement of different bracing configurations case was analyzed under the same designed acceleration. Shown as Fig. 1, the diameter of feed main was 4", the cross main was 2" and the branch was 1". In this case, the suspended length was 60cm and the scale was 52.88m*7.5m. Under different codes, the seismic bracing configurations were shown in Fig. 2 to Fig. 4. The "T" represents for "transverse brace", "L" for "longitudinal brace". In the NFPA13 case, a circle dot is marked for the restraint at end of branch.

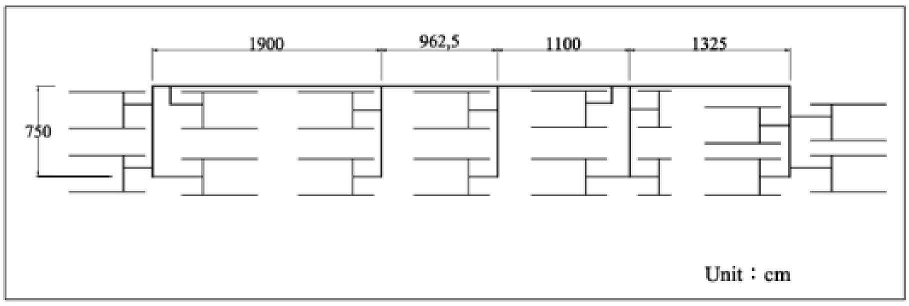


Fig. 1 – Case study dimension.

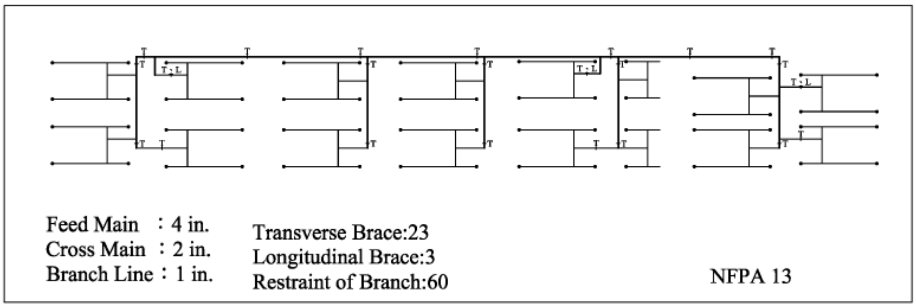


Fig. 2 – Configuration for NFPA13.

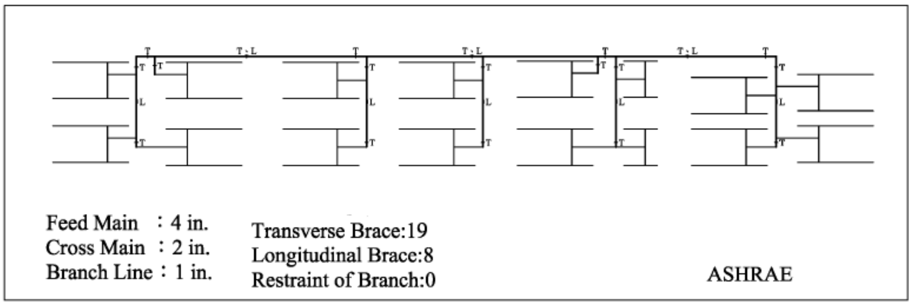


Fig. 3 – Configuration for ASHRAE.

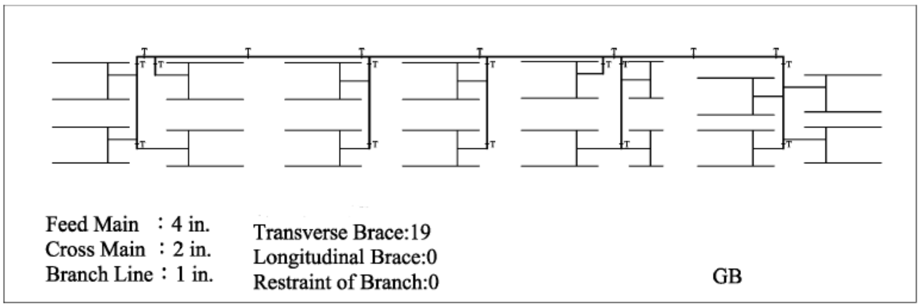


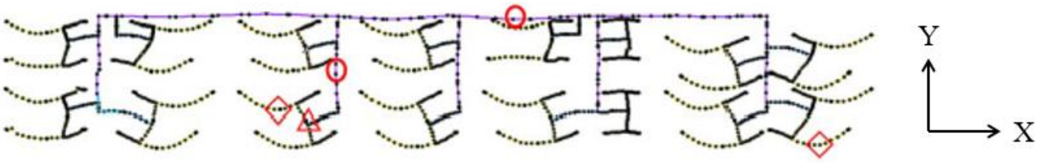
Fig. 4 – Configuration for GB.

Under Taiwan's Seismic Design Specifications and Commentary of Buildings (2011) [5], the minimum design horizontal force formula of non-structure is:

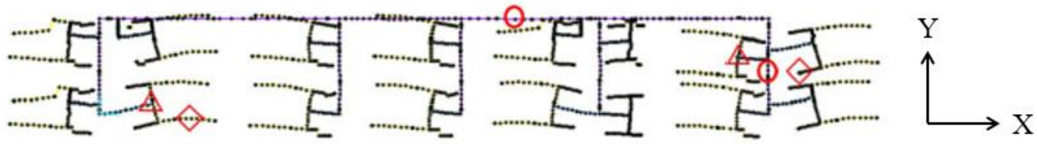
$$F_{ph}=0.4S_{DS}I_p(a_p/R_{pa})(1+2h_x/h_n)W_p \quad (1)$$

Assuming that the equipment is in a building and the amplification factor is 3. From Eq. (1), the minimum design acceleration a_{floor} is 0.96g at NCKU. In comparison, the required seismic design acceleration is 1.0g in ASERAE. In the following analysis, the maximum design acceleration was assumed to be 1.0g, a sine wave frequency at 1.0Hz for time history analysis was chosen for 20 cycle in both X and Y direction.

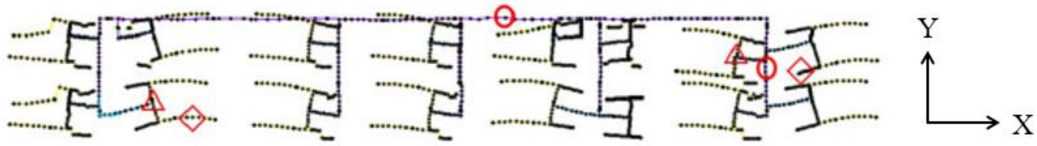
The numerical analysis result is shown in Fig. 5 and Table 1, after time history analysis. The maximum displacement was 1.35cm (NFPA13), 1.4cm (ASHERAE) and 1.6cm (GB) for feed main in transverse; for longitudinal displacement was 4.2cm (NFPA13), 16cm (ASHERAE and GB); the transverse displacement was 6.3cm (NFPA13), 22cm (ASHERAE and GB) for branch. The numerical analysis showed that the vibrations of feed main were alike, about 1.4cm for all three codes. But for cross main and branch the displacement were quite different owing to that only restraint, for cross main and branch were required in NFPA13. However, there were no requirements for cross main and branch in ASERAE and GB.



(a) NFAP13



(b) ASERAE



(c) GB

Fig. 5 – Numerical analysis result for displacement.

Table 1 – Maximum displacement (mm).

	Feed main (transverse)	Cross main (longitudinal)	Branch (transverse)
NFPA13	1.35	4.2	6.3
ASERAE	1.4	16	22
GB	1.6	16	22

From the preliminary numerical analysis results, displacement at the end of branch should be inhibited with restraints. The comparison of three codes shows only NFPA13 has requirement for bracing at cross main and branch and is capable to reduce branch vibration drastically. Hence, NFPA13 was chosen for the follow-up shaking table tests.

4. Shaking Table Tests

This study included two parts of shaking table tests. The first shaking table test was a cooperation between Nagoya University of Japan, National Cheng Kung University (NCKU) of Taiwan and Pusan National University of Korea. The experiments were implemented in E-DEFENSE in January 2019. The second one was done in NCREE in Taiwan (Tainan) in December 2019. The dynamic reactions were analyzed by installing different restraint components.

4.1 E-DEFENSE Tests

Shown in Fig. 6, suspended sprinkler piping system was composed of feed main, cross main and branch. The diameters were 4” and 2” for feed main; 1.5’ for both cross main and branch. The piping unit were 4.7m*5.5m, 60cm for suspended length, total weight was 200kgf without water and installed on 10th floor above (height 27.4m) in a full scale RC structure. There were two parts for this tests. Shown as Fig. 7, Case 1 was strengthened by NFPA13, and installing seismic sway bracings which were certified by FM at feed main and end of branch. The configuration of accelerometers and displacement transducers were shown in Fig. 8.

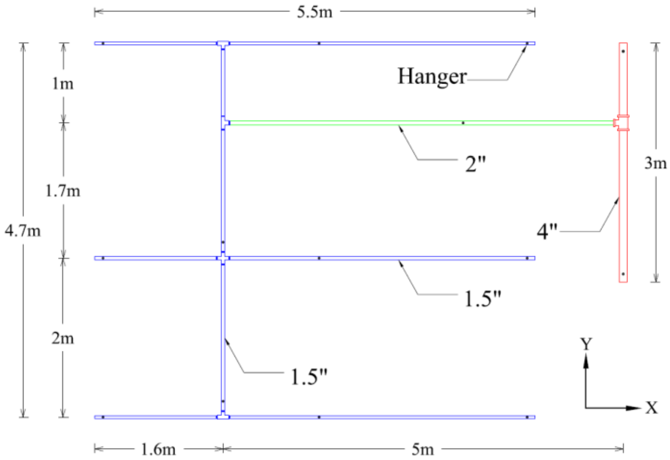


Fig. 6 – Piping system scale for shaking table test.

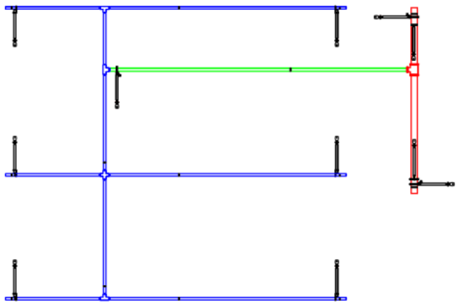


Fig. 7 – Test types.

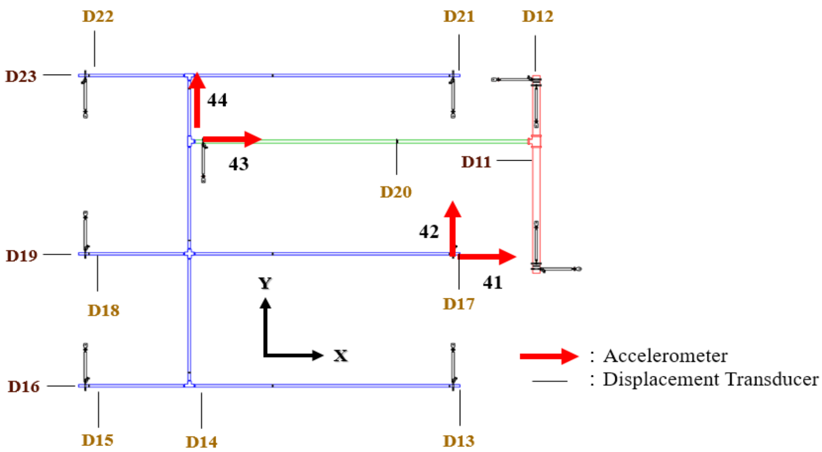


Fig. 8 – Accelerometer and displacement transducer configuration.

In the white noise tests, the signals for floor input and piping systems response were recorded and analyzed for natural frequency from transfer function. For Case 1, the natural frequency is 33Hz in X direction. In Y direction, the natural frequency is 30Hz owing to bracing was installed at end of branch, and 17Hz for cross main in Fig. 9.

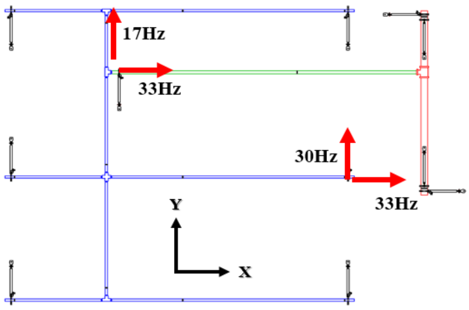


Fig. 9 – Natural Frequency.

There was different scale excitation in JMA Kobe time history. For Case 1, under Kobe 25% (10th floor PFA: X dir. 0.7g, Y dir. 0.67g) excitation, with no bracing installed at the end of branch, the maximum displacement of 9 mm recorded at the branch which was furthest from 2" feed main in X direction. The bracing restricted the transverse vibration of branch which was at end of 2" feed main approaching to cross main. Maximum displacement is 4.7 mm at the center of 2" feed main, in Fig. 10.

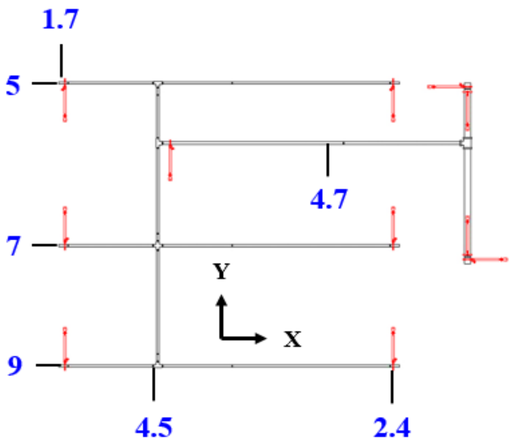
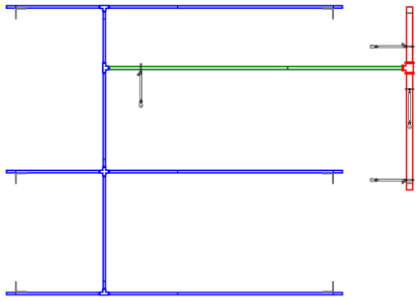


Fig. 10 – Case 1 max. displacement under JMA KOBE25%. (mm)

4.2 NCKU Tests

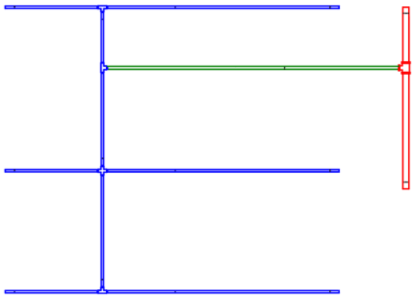
In this test, the dimensions, suspended length, reference code and bracing products were the same with E-DEFENSE tests. The difference between E-DEFENSE tests was the restraint at the end of branch. NCKU tests used vertical steel angle (50mm*50mm, t=3mm) to be the branch-end restraint components, a common practice in Taiwan. This test also had two types, Case A was strengthened by bracing and steel angle in Fig. 11, and Case B only suspended by hangers in Fig. 12. The measurement instrument configuration is shown in Fig. 13.



(a) Case A plane

(b) Bracing retrofit

Fig. 11 – Test type A.



(a) Case B plane

(b) No bracing

Fig. 12 – Test type B.

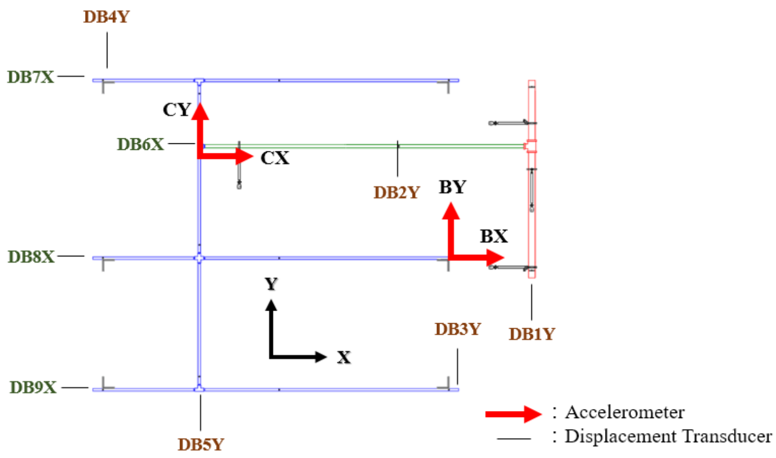
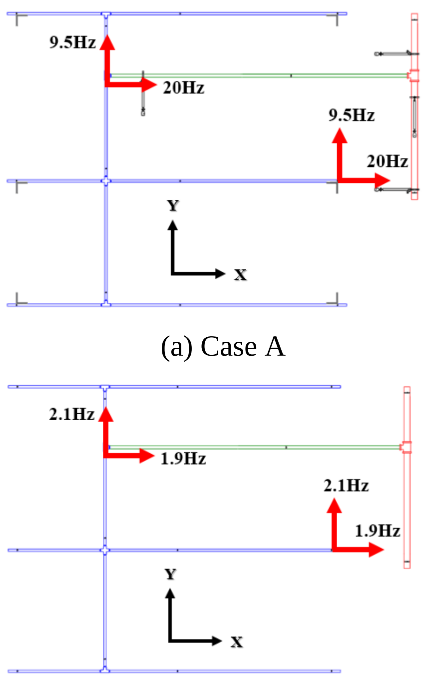


Fig. 13 – Accelerometer and displacement transducer configuration.

After analyzing white noise data in transfer function, the natural frequency is 20Hz in X direction and 9.5Hz in Y direction in Case A, Fig. 14(a). With the same situation, 2.0Hz in X and Y direction in Case B in Fig. 14(b). Under Kobe25% (suspension layer PFA: X dir. 0.78g, Y dir. 0.79g) excitation, due to the restraint of bracing and steel angle in Case A, maximum displacement is 4mm in X direction, and 5.4mm in Y direction at the branch which was the furthest from 2" feed main in Fig. 15. In Case B, the maximum displacement 309mm is happened at the branch which was the nearest from 2" feed main in X direction, and the vibration is much less than far away 2" feed main. Also, 137mm is recorded at the center of 2" feed main in Y direction in Fig. 16.



(a) Case A

(b) Case B

Fig. 14 – Natural frequency.

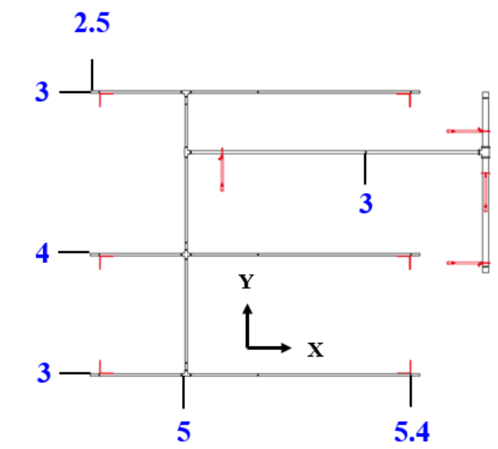


Fig. 15 – Case A max. displacement under JMA KOBE25%. (mm)

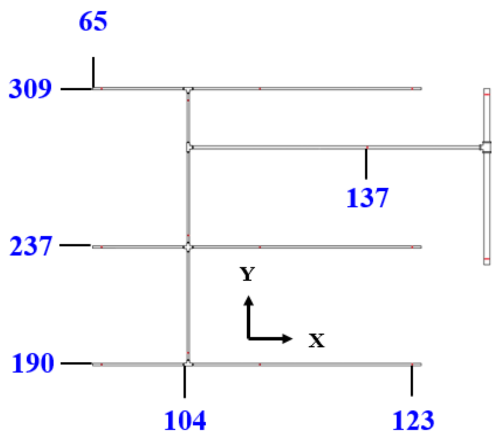


Fig. 16 – Case B max. displacement under JMA KOBE25%. (mm)

5. Conclusion

This study investigated existing codes for suspended sprinkler piping system and compared the response of different configuration of restraints. Studying different codes to establish numerical models and compare the dynamic response were first conducted. We found from the numerical analysis that NFPA13 had the smallest displacement response for a local piping system in NCKU campus. With NFPA13, the vibrations under JMA Kobe25% time history testing are reduced significantly, no matter the restraints are certificated by FM or in restrained suspended sprinkler piping systems. However, if bracing or restraint components want to be installed in hospitals, construction restrictions and cost will be another major consideration. Hence, by using less construction restrictions or easily accessible components to strength suspended sprinkler piping systems would be a better choice.

6. Acknowledgments

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7. References

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