Experimental Investigation of Innovative Self-Centering Polyurethane Piston Based Bracing

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ABSTRACT

In braced frames, the response of a structure after an earthquake can be affected by the strength and properties of the bracing system. Concentric Braced Frames (CBFs) are mostly used in order to resist seismic load. However, traditional tension-compression bracing system may not perform well under earthquake loads because of buckling in compression. In order to solve this problem, other bracing systems such as Buckling Restrained Bracing (BRBs) and Self Centering Energy Dissipation Device (SCED) are being used. Buckling restrained braces are one of the effective systems to resist seismic loads. However, they cannot prevent permanent deformation in the building. In order to overcome the shortcomings of the developed system, a new Polyurethane Piston Based Bracing (PPBB) system has been developed and fabricated in the University of British Columbia. This device consists of a brace system that is able to take a large tension and compression force. The system is a cylinder-piston assembly in which polyurethane and steel are utilized. This specimen consists of five main parts; two halves of steel tubes, two polyurethane cylinders and a shaft. Quasi-static experimental testing was performed on the device where very good self-centering behaviour was achieved using this relatively cheap and light material. This was achieved by analysing the Displacement versus Force graph and finding the energy dissipation for this system.

KEYWORDS: *Bracing system, Polyurethane, Self-centering*

1 INTRODUCTION

Strong earthquakes can cause extensive damages to buildings and result in human and huge financial losses. According to the Insurance Bureau of Canada, the total economic cost of a major earthquake in the West Coast is $127.5 billion. (Talmazan, 2016). One way to resist earthquakes is by using base isolation system which is done by using elements with low stiffness to isolate the structure from the foundation. However, it is expensive to construct buildings with this ability to resist an earthquake. Therefore, self-centering devices are used to resist seismic load, in order to reduce the deformation of structures. Different studies have been conducted on various types of bracings in order to improve their resistance to earthquake loads. As the response of a structure after an earthquake can be affected due to the degradation in the strength and stiffness of the bracing systems. Concentric Braced Frames (CBFs) are mostly used in order to resist seismic load. However, traditional tension-compression bracing system may not perform well under earthquake loads (Issa and Alam, 2019) Other systems such as Buckling Restrained Bracing (BRBs) and Self Centering Energy Dissipation Device (SCED) are being used. BRBs are one of the effective systems to resist seismic loads. However, they cannot prevent permanent deformation in the building.

In order to overcome the shortcomings of the previously developed bracing systems, a Self-Centering Polyurethane Piston Based Bracing system has been developed and fabricated in the Applied Laboratory for Advanced Materials and Structures (ALAMS) at the University of British Columbia. This device can take large tension and compression forces. The system is a cylinder-piston assembly in which polyurethane and steel are utilized. The polyurethane cylinders provided by Redwood Plastics and Rubber which can carry the compression forces and generate a hysteresis behaviour. Experimental testing has been carried out to characterize the system's performance. This system has various advantages compared to others that are being used nowadays. Issues related to manufacturing, the cost, as well as the functionality and efficiency of the system and a structure, in general, have been improved. Therefore, the focus of this study is to develop a reliable self-centering bracing system by decreasing the cost of production and the weight of the device.

2 MATERIAL

As the purpose of this project is to improve the performance of a multi storey frame building, it is important to develop buckling restrained bracing systems. In order to optimize the performance of the bracing system, different factors including the material chosen were considered. In general, different materials are usually used in bracing systems such as steel, wood or a combination of these. However, factors such as weight, strength and sustainability should be considered when choosing the systems' materials. The design of this PPBB device has been done by using polyurethane and steel. Utilizing these two materials have resulted in designing a product that has high efficiency and strength as well as being financially beneficial.

2.1 Polyurethane

The thermoplastic elastomer polyurethane is being used in new applications nowadays to increase the survivability of structures under loading. Several studies have been done on the mechanical behaviour of thermoplastic polyurethane. It has been shown that an increase in hard segment content increases initial modulus, an increase in ultimate strength and a decrease in elongation to break. (Yi & Boyce & Lee, 2006) As polyurethane is a versatile elastomer, the use of it in this project gives us a unique opportunity to use its mechanical properties to maximize the efficiency of the product. As can be seen in Figure 1, the stress-strain behaviour of polyurethane can be analysed based on various experiments that have been done at MIT. The uniaxial compression stress-strain of polyurethane can be observed during cyclic tests where N represents the cyclic numbers. Polyurethane has a high load-bearing capacity, flexibility and strong bonding properties. It can perform well under heavy loads and return to its original shape after the load is removed due to its high load capacity in both tension and compression. Moreover, it has high tensile and resilience properties, utilizing polyurethane decreases the cost of fabrication and the weight of the device as it is lighter compared to other materials. A wide variety of combinations can be produced by changing the chemical type, molecular weight of the segments and the ratio (Qi & Boyce, 2005). For this research, polyurethane with a hardness of 90A is used which has features including elasticity weather resistance and impact resistance.

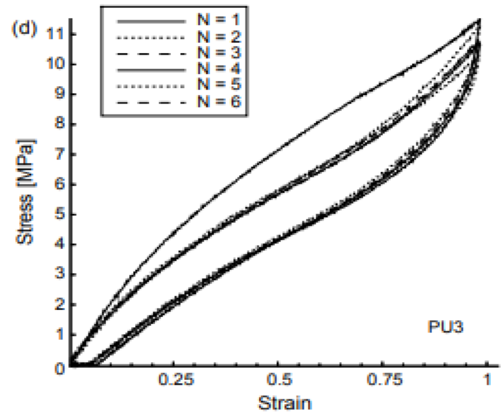

Figure 1: Stress-Strain Analysis of Polyurethane (Adapted from Qi and Boyce (2005)

2.2 Steel

Most of the industrial buildings are constructed using reinforced concrete or steel which increases the weight of the structure. Steel properties such as high strength, ductility and durability are the factors that control the response of a structure when an earthquake occurs. Stainless steel and carbon steel are widely used for bracing systems. The use of steel can improve the performance of the bracing systems due to its strength, stiffness and ductility. (Nakashima & Roeder & Maruoka, 2000) Therefore, in order to optimize this device's performance, a combination of a light weight material like polyurethane and a high strength material such as steel has been utilized. The use of steel on the outer system of this device enables it to hold the polyurethane cylinders and strengthen the device. As the main function of the steel tubes is to provide the strength of the device, the steel will not yield.

3 DETAILS OF THE DEVICE

This specimen consists of five main parts; two halves of steel tubes, two polyurethane cylinders and a shaft. The two polyurethane cylinders have different surface areas as one of them contains a 28mm hole. As the surface areas of the two polyurethane cylinders are not equal, the behaviour will not be completely symmetrical; this will be discussed more in detail in the Results and Discussion section. The cylinders are both 210mm in length and 95mm in diameter. These will be allocated inside the steel tubes, and the piston shaft will be inserted into the first cylinder with the hole and then the next cylinder. When the system is in compression, the shaft slides into the steel tubes compressing the polyurethane cylinders.

Furthermore, when tension is applied, the shaft will slide outward from the cylinders. Figure 2 represents the drawings of the two polyurethane cylinders and Figure 3 presents the steel tubes that were created through Solidworks program. The factors that were considered in fabricating this device were temperature and the loading capacity. The cylinders must be able to take at least 60kN load and function at -10 to 30 degree Celsius. However, chemicals are not a major concern in this design. Tests including the hysteresis behaviour of the system are done on this specimen in order to analyse the performance of the device. The ideal behaviour for our design is to encompass self-centering properties so that the structure can return to its original position after an earthquake to reduce damage to structures. The system was tested on the main stage which includes testing the system assembly on the MTS machine available at UBCO High Head lab. Tension and compression loads were applied, and load-deformation curves were generated and analysed as it can be seen later in this paper.

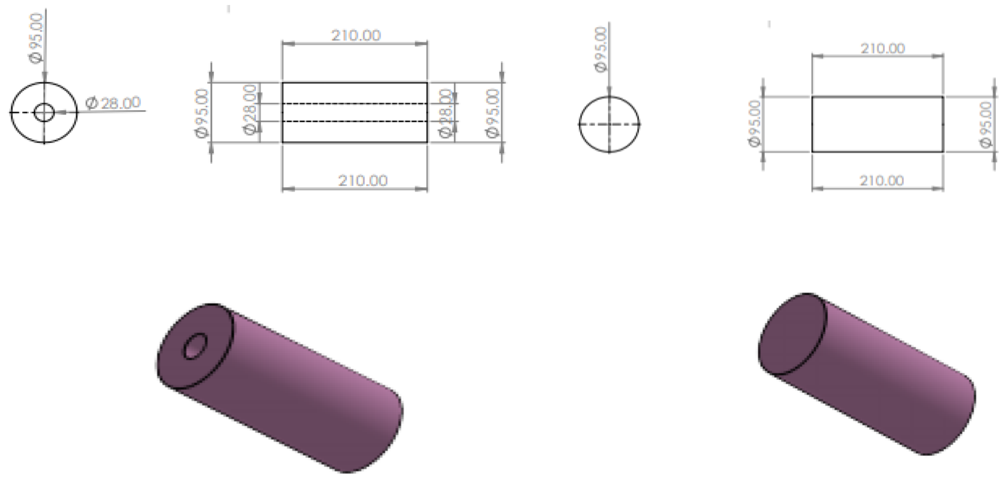

Figure 2: Polyurethane Cylinders (With a 28mm Hole)

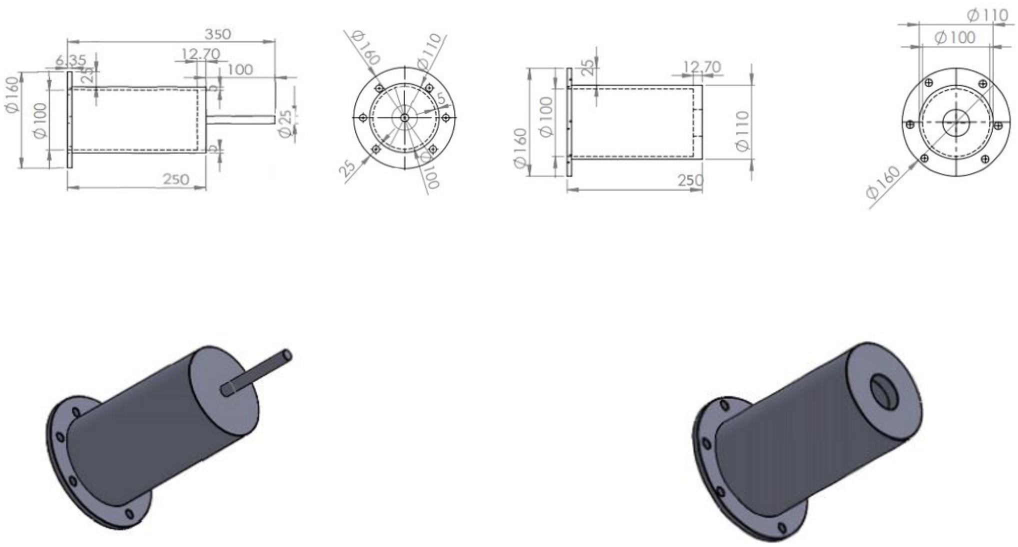

Figure 3: Halves of Steel Tubes

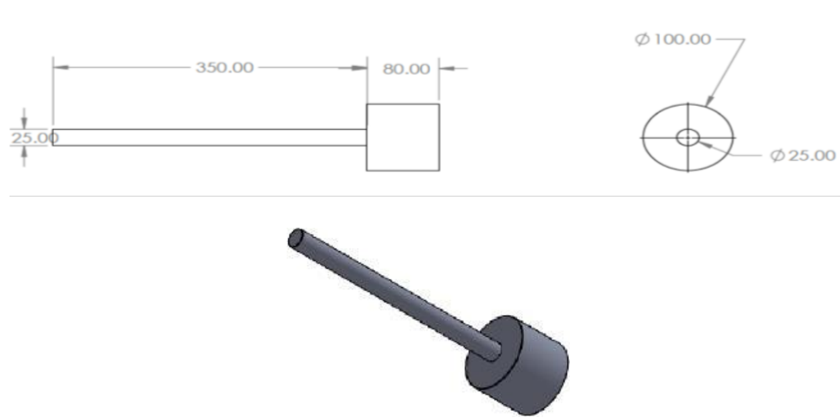

Figure 4: Steel Piston

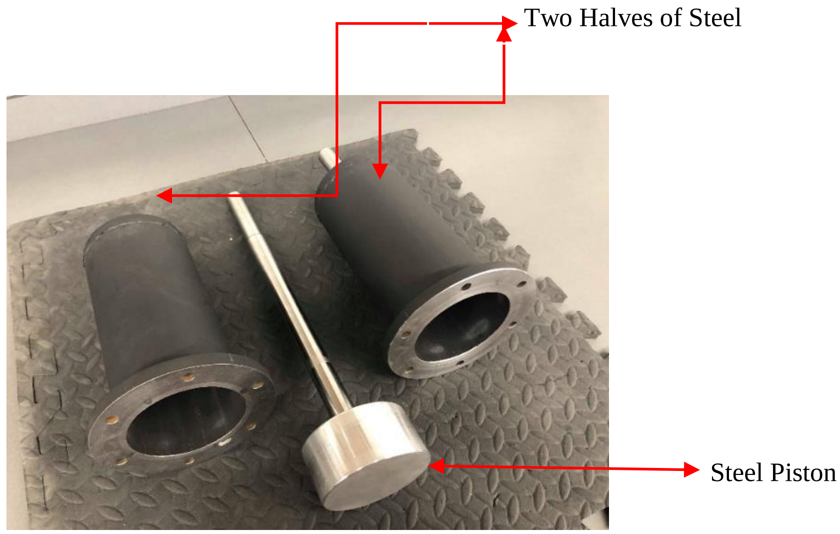

Figure 5: Top View of Parts

4 EXPERIMENTAL RESULTS

The main purpose of this paper is to determine the performance of the self-centring polyurethane piston based bracing system under seismic loading. After fabricating each element, the device was tested in the Applied Laboratory of Advanced Materials and Structures (ALAMS) at the UBC Okanagan under quasi-static loading. The performance of this system under axial was tested in order to determine the hysteric behaviour and load-displacement response. This research will help in understanding the behaviour of different structural elements.

Moreover, it will help to provide an efficient and economically beneficial design which can be used in concrete and steel structures. Figure 5 represents the Force-Displacement graph in which the hysteresis loops can be observed. As it can be seen the tension and compression loops are not identical as the polyurethane cylinders differ in their cross-sectional area. In order to check the deformation capacity of the polyurethane protocol was up to 15mm which is about 6% deformation. The presented results are achieved after a couple of trials to characterize the maximum strain the polyurethane can achieve without failure or any permanent deformations. It was found that this material can take up to 10% and retain its original shape after removing the load. As a maximum deformation of 20mm was applied in the quasi-static loading protocol which results in maximum tension/compression resistance of almost 40 kN as shown in Figure 5. Furthermore, the energy dissipation of the system was found to be 12600 kN.mm by finding the area under the following curve. This is a reasonable number, and it indicates that the device performs well under tension and compression.

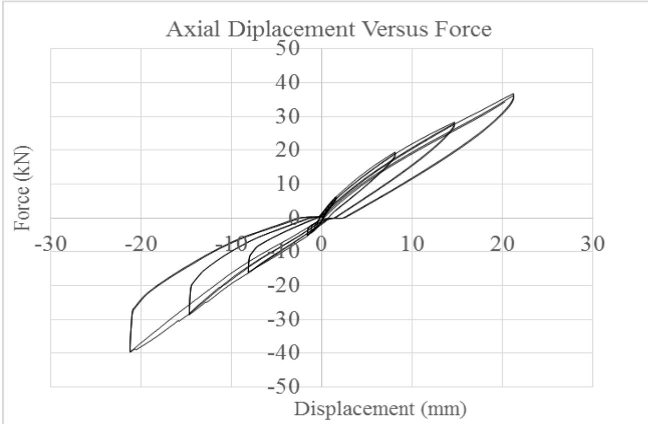

Figure 5: Axial Displacement versus Force

5 CONCLUSION

The purpose of this paper is to analyse and perform experiments on of the new self-centering polyurethane piston braced system. In order to overcome the shortcomings of the previously developed bracing systems, new materials and design have been utilized. According to the results that have been obtained, it can be concluded that force-displacement loops are stable and identical. This device can perform well under both tension and compression. Furthermore, it has a high force and displacement value of 40kN and 20mm respectively. More experiments will be performed on this device in order to further investigate the system's performance in the future in terms of strain rate and dynamic effects.

6 ACKNOWLEDGEMENTS

The support of the School of Engineering at UBC and the Applied Laboratory for Advanced Materials and Structures (ALAMS) is highly acknowledged.

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