International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:11, No:7, 2017

A Methodology of Testing Beam to Column Connection under Lateral Impact Load

A. Al-Rifaie, Z. W. Guan, S. W. Jones

Abstract**—**Beam to column connection can be considered as the most important structural part that affects the response of buildings to progressive collapse. However, many studies were conducted to investigate the beam to column connection under accidental loads such as fire, blast and impact load to investigate the connection response. The study is a part of a PhD plan to investigate different types of connections under lateral impact load. The conventional test setups, such as cruciform setup, were designed to apply shear forces and bending moment on the connection, whilst, in the lateral impact case, the connection is subjected to combined tension and moment. Hence, a review is presented to introduce the previous test setup that is used to investigate the connection behaviour. Then, the design and fabrication of the novel test setup is presented. Finally, some trial test results to investigate the efficiency of the proposed setup are discussed. The final results indicate that the setup was efficient in terms of the simplicity and strength.

Keywords**—**Connections, impact load, drop hammer, testing methods.

I. Introduction

THE design of buildings due to gravitational loads represent the major part comparing with lateral loads. The lateral loads may be produced due to wind load or accidental loads such as vehicle impact, explosions, and terrorists attack. The design of structural frame under wind load is available in many design codes, while the requirements to design structural members under accidental loads are still incomplete. However, many studies were conducted to investigate the response of columns as one of the important parts of the structural frames under impact loads [1]-[5], while limited studies were conducted to investigate the connection behaviour under impact loads [6]-[8].

The beam-to-column connection test specimen could be considered one of the more complicated specimens if compared with other structural members. That is because an assembly of three structural members representing by beam, column in addition to their connection should be fabricated and assembled before testing; whilst, test specimen of other structural members such as beam, column or slab does not require such that assembly in connections. Hence, designing the selected test specimen should consider these difficulties into account. Also, the selected specimen design should be simple as much as possible provided that it achieves the aim of the study.

The most common test setup used by the previous research called cruciform test setup [7], [9], [10] is shown in Fig. 1. In this setup, a combined shear-moment stresses are produced on the connection due to the external applied load (P).

Applying this setup to investigate the lateral impact response needs complicated modifications to be done particularly if the impact load applied using vertical drop hammer. Also, even with the possibility of providing lateral impact load (P is applied on column laterally) using this setup, strong supports should be fabricated. Moreover, using two beams with two connections increases the time and cost of sample fabrications. However, adopting another test setup is valuable if it takes into account the avoidance of these difficulties.

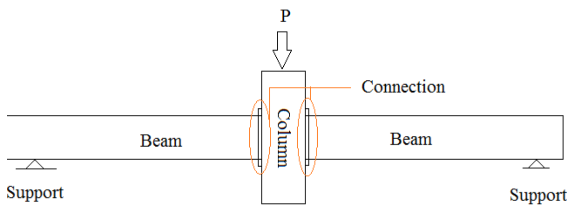

Fig. 1 Cruciform test setup

II. Proposed Test Setup

Corresponding to cruciform test setup the possibility of using one column connected to two beams by two connections could be adopted as a first proposal of test specimen as shown in Fig. 2.

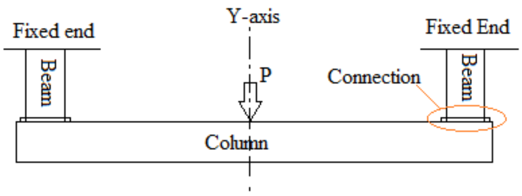

Fig. 2 First proposal of test setup

It should be mentioned that there was no option to apply the impact load horizontally using drop hammer. Thus, the column should be located in the horizontal direction perpendicular to the beams. Since most of structural frames are braced, the beams could be fixed and small portion of it could be used to save the cost. With this test setup, each connection would be subjected to dynamic tensile force and dynamic bending moment. Moreover, due to symmetry, the response of both connections should be similar in terms of resistance and failure mode. Considerable disadvantages could

A. Al-Rifaie, Z. W. Guan, and S. W. Jones are with the Civil Engineering and Industrial Design Department, University of Liverpool, L69 3GQ UK (e-mail: a.k.i.al-rifaie@liv.ac.uk, zguan@liv.ac.uk, swjones@liv.ac.uk).

be concluded if this proposal is adopted. The first one was the complexity of the specimen that leads to high cost and effort to fabricate them. Therefore, it was found that the symmetry in y-axis could be used to facilitate the test specimen and to make it more practical and economical. Hence, the second proposal was suggested to eliminate the setup to contain one beam, one column, and one connection using the symmetry in y-axis as shown in Fig. 3.

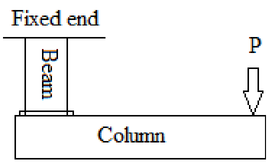

Fig. 3 Second proposal of test setup

Many advantages could be obtained using the second proposal. Firstly, the connection is still subjected to dynamic tensile force and dynamic bending moment as planned before but with eliminating the amount and cost of material to 50% and saving the effort and time. Secondly, using the first proposal may not lead to obtain high deformation in the connection because the applied energy was resisted by two connections. Whilst, the second proposal increases the possibility of deforming the connection significantly as one connection only was provided particularly with the limitation of the maximum impact energy can be applied by the drop hammer. It is important to obtain considerable deformation to investigate the maximum connection capacity and to use the deformed shape of the connection during the process of the validation of the FEA models. Moreover, a stiff mounting system should be designed and fabricated to achieve the requirements of providing fixed end in the beam as is discussed in section followed. Using the second proposal needs one stiff frame to be fabricated which is the better option if compared with the first proposal that needs two of them. This would also save the time and cost of the project. Finally, it could be concluded that the second proposal is the best option of the test specimen and can be to be used in this study due to the aforementioned reasonable reasons.

III. Mounting Stiff Frame

The specimens to be tested require a stiff reaction frame to support them under impact loads. This frame should be stiff enough to minimize any movement during the test that may affect the results. The frame was designed and fabricated at the University of Liverpool and some trial tests were carried out to examine its suitability.

Fig. 4 shows the schematic diagram of the test setup and the real test setup containing the details of the frame, in which the frame contains three parts, i.e. floor mounted rails, moveable sub-assembly in addition to bracers. The rails provided a fixed location for the drop hammer operator. Also, holes in the rails were provided to allow the movable sub-assembly for variable impact locations. Two vertically mounted supports fabricated were bolted to the rails to provide a stiff base. The cross members with a detachable clamping setup provided a method to rigidly clamp the specimens. Three rigid bracers were fabricated to connect the rails to both ends of the sub-assembly frame and the detachable clamping setup to minimize the rotational movement of the sub-assembly frame.

The rigidity of the reaction frame was examined prior to test the specimens. Hence, three trial specimens with a connection stronger than those to be tested in this study were tested under impact load. The translational and rotational movements of the reaction frame at the detachable clamping where the specimen is connected to the stiff frame were recorded using high speed camera. The maximum rotational angle and the maximum downward translation of the detachable clamp for all trials measured were 0.61° and 1.7 mm, respectively. However, it is expected that this error is to be minimized using weaker connections.

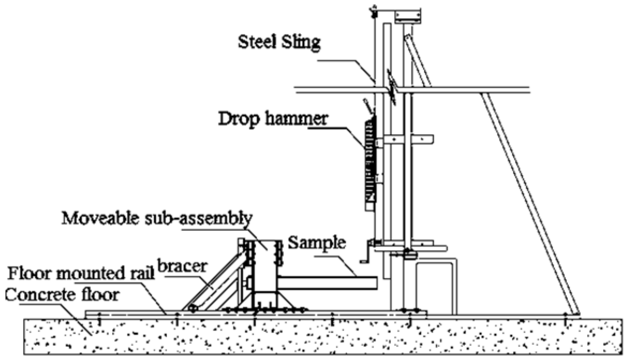

Fig. 4 (a) Schematic proposed test setup

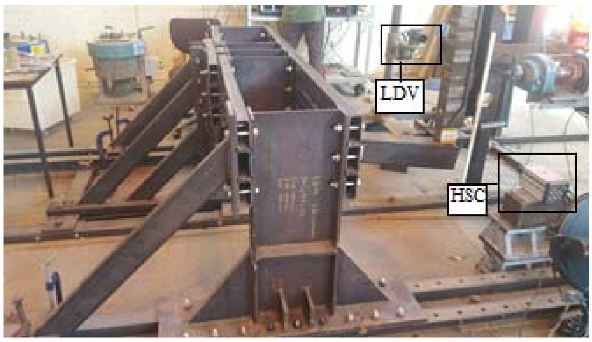

Fig. 4 (b) Real test setup

IV. Instrumentations

A laser Doppler velocimeter (LDV) system was employed as shown in Fig. 4 (b) to acquire the velocity time history using a target placed on the projectile during the impact event. To manage the operating, the system was connected to a computer via an interface card and fiber optic cable software. The processing of the LDV signals was accomplished to minimize the noise using software named imPRESSion 6 [11]. Different values of cut off frequency were tested and compared with the experimental results, and a value of frequency of 1000 Hz was so correlated to the experimental results. Three stages in the velocity-time history curves were specified during the impact event as shown in Fig. 5. The first stage occurred as the impactor hits the column with its maximum velocity which is about 7.5 m/s. In the second stage, the projectile and the column move downward together up to the maximum displacement of the column. In this stage, the velocity of the projectile decreases corresponding to an increase in the displacement of the projectile and the column up to the maximum displacement of them. The third stage includes the bouncing back of both the column and the projectile due the elastic energy. It should be mentioned that the use of LDV technique would save the cost of using dynamic load-cell which may break due to high impact load. The impact force can be obtained using Newton Second Law by multiplying the mass of the drop-hammer by the acceleration which was calculated from the differentiation of the impact velocity with respect to time.

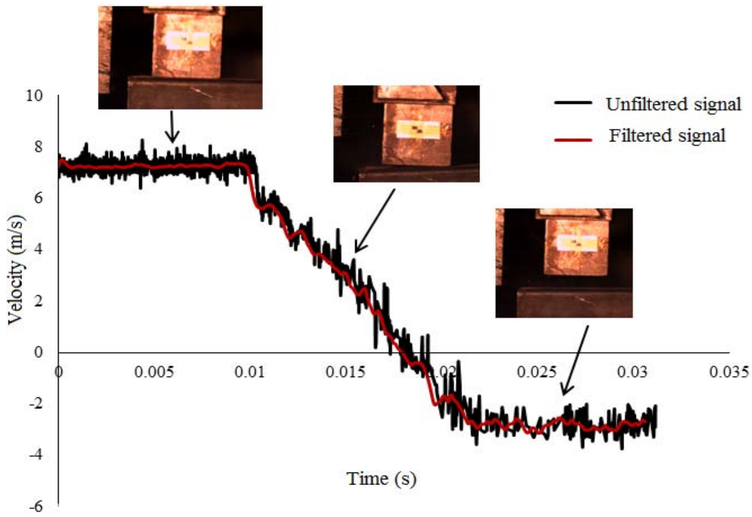

Fig. 5 Filtering of typical impact signal

In order to capture the displacement time history of the projectile, a high speed camera (HSC) was employed as shown in Fig. 4 (b) supported with one high voltage light to increase the clarity of the target placed on the projectile. ProAnalyist motion analysis software was used to convert the frames captured by the HSC to displacement time histories. In addition to the LDV and HSC, four multipurpose strain gauges were attached to each specimen at different locations to capture the strain time history. Two of them were placed on the connection zone, while the other two were located on the column beam. The strain gauges were wired and connected to a conditioning unit which completes a full bridge and amplifies the bridge output. The output of the signal conditioner was also connected to four channels Tektronix TDS2024C oscilloscope of 2 Gs/s sampling rate. The system was designed to capture 10000 με, and a calibration equation of 5 volt = 10000 με was used to convert the voltage time history provided by the oscilloscope to strain time history. Besides, the developed system was examined before testing using small steel cantilever beam loaded at its end with different known masses. A strain gauge was placed at the top fiber of the beam near the fixed end. The theoretical stress at the location of strain gauge was calculated then multiplied by the modulus of elasticity € of steel to obtain the strain. The calculated strain then was compared with the measured strain for different masses and the results showed excellent agreement. It should be mentioned that strain rate effect is important to be investigated with studies concerning impact load. Therefore, the experimental strain time histories could be used to estimate the strain rate in any selected location in the specimen. This could be performed by calculating the slope of the strain time history to represent the strain rate.

V. Conclusions

The test setup proposed succeeded to sustain impact energy of about 3000 J corresponding to a mass of 107.5 kg hit the specimens from a height of 2.9 m. Also, the force time histories using LDV were acquired successfully in addition to displacement and strain time histories. The cost and time of fabrication of the tested specimens were eliminated to about 50% as one part of each connection members (beam, column and connection) is needed.

Acknowledgment

The work presented in this paper was supported by the Ministry of Higher Education and Scientific Research in Iraq, which is gratefully appreciated. The authors would like to thank Mr A. Al-Husainy for his help with the data processing. The authors also wish to thank Mr. M. Bratley and Mr. D. Neary for their assistance in the fabrication of specimens and designing a system to obtain strain time history using Oscilloscope.

References

[1] Yu. J. and Jones N., Numerical simulation of a clamped beam under impact loading. computers and Structures, 1989. 32, No. 2: p. 281-293.

[2] Shakir A. S., Guan Z. W., and Jones S. W., Lateral impact response of the concrete filled steel tube columns with and without CFRP strengthening. Engineering Structures, 2016. 116: p. 148-162.
[3] Zeinoddini M., Parke G. A. R., and Harding J. E., *Axially pre-loaded steel tubes subjected to lateral impacts- an experimental study.* International Journal of Impact Engineering, 2002. 27: p. 669-690.
[4] Zeinoddini M., Harding J. E., and Parke G. A. R., *Axially pre-loaded steel tubes subjected to lateral impacts (a numerical simulation).* International Journal of Impact Engineering, 2008. 35(11): p. 1267-1279.
[5] Al-Thairy H., Behaviour and design of steel column subjected to vehicle impact, in School of Mechanical, Aerospace and Civil Engineering. 2012, University of Manchester.
[6] Rahbari R., Tyas A., Buick Davison J., and Stoddart E. P., Web shear failure of angle-cleat connections loaded at high rates. Journal of Constructional Steel Research, 2014. 103: p. 37-48.
[7] Grimsmo E. L., Clausen A. H., Langseth M., and Aalberg A., *An experimental study of static and dynamic behaviour of bolted end-plate joints of steel.* International Journal of Impact Engineering, 2015. 85: p. 132-145.
[8] Ribeiro J., Santiago A., Rigueiro C., Barata P., and Veljkovic M., *Numerical assessment of T-stub component subjected to impact loading.* Engineering Structures, 2016. 106: p. 450-460.
[9] Sheet I. S., Gunasekaran U., and MacRae G. A., *Experimental investigation of CFT column to steel beam connections under cyclic loading.* Journal of Constructional Steel Research, 2013. 86: p. 167-182.
[10] Yang B. and Tan K. H., Experimental tests of different types of bolted steel beam–column joints under a central-column-removal scenario. Engineering Structures, 2013. 54: p. 112-130.
[11] *ImPREESSion 6. NecoletTecnonlgies. Germany: Weisang GmbH & Co. KG.; 2002.*