The Egyptian International Journal of Engineering Sciences and Technology

Vol. 32 (2020) 25–31

https://eijest.journals.ekb.eg/

EIJEST
ISSN:1687-1006

Review of Steel Stud Wall Systems Behavior under Blast Loads

Mahmoud T. Nawar[a], Mohamed A. Abo-Elfotouh[b]* and Atef E. Amin[c]

[a] *Lecturer at Structural Engineering Dept, Faculty of Engineering, Zagazig University, Zagazig, Egypt*
[b] *Structural engineer, Faculty of engineering, Zagazig university, Egypt*
[c] *Professor of structural Analysis and Mechanics, Faculty of engineering, Zagazig university, Egypt*

ARTICLE INFO

Keywords:

1st steel stud walls
2nd blast loads
3rd static resistance function
4th dynamic analysis

ABSTRACT

Blast threatening and blast event hazards increased dramatically on both scales of artificial and even those occurring unintentionally like accidents in sites highly exposed to such events like petrochemical facilities. Hence designing blast-proof structures to save lives of the occupants of these structures undergoing blast events became an important criterion. One side for achieving this purpose is designing resisting structures to such events. One of the most common types of structures that are widely used is steel stud wall panels. Steel stud wall systems (SSWSs) are a preferable alternative due to the structural and architectural merits of this system. Despite they are steel structures; they still have the advantages of light weight structures. Especially that the main structural members of the system, are usually made from cold formed steel with small sheet thicknesses. This research is fundamentally focused in providing literature view pertaining to previous works done to this point as research. At the end of the paper a conclusion is withdrawn that indicates some fields about the design of SSWSs that are not discussed yet nor investigated before and that are still valid for future works.

1. Introduction

1.1. Blast on various types of structures

The blast design of structures made from different materials is coming recently into priority due to the dramatically increasing hazards of such events. Since using different materials in construction is a must, different types of structures were in the focus of interest of scientific research from blast analysis and design [1]. As a material, concrete was studied to include the failure of material due to such destructive case of loading [2–5]. Also, in the field of concrete blast proof structures experimental in addition to numerical modelling work was performed to estimate different damage levels in RC structural members and the phenomenon pertaining to responses of these members [6–12]. Beam columns and the pertaining Pressure-Impulse diagrams extensively studied [13]. Concrete-steel composite columns were numerically studied for blast cases [14]. An overview to damage criteria and failure modes on RC structures was additionally introduced [15]. Progressive collapse of RC structures was also introduced [16]. Cable stayed bridges and their performance when loaded in blast was discussed as well [17,18]. Bridges on girders and piers supporting systems were also light spotted [19]. RC piers systems with carbon fiber reinforced polymers (CFRP) where experimentally tested and explored for finding protective measures for blast proofing of the axially loaded piers to protect bridges [20]. Bridge columns have their share of blast interest and study [21]. Similar type of work was experimentally and

---

* Corresponding author. Tel.: +02 01140013135
E-mail address: m_motaal_design@yahoo.com

numerically done to steel columns [22–27]. Also experimentally Aluminum foam panels were studied for close range explosions [28]. Another similar research was done by testing timber stud wall panels [29]. Also architectural glazing and glass panels were studied under the blast loads [30,31]. Masonry walls had also an scope of interest in this field on both experimental and numerical scales [32–34]. Web steel joists were also examined and numerically modelled [35]. Beams in general, and castellated steel beams were also studied from point of view of blast hazards and loading [36,37].

1.2. Blast on steel stud walls panels

The importance of blast proof design for SSWSs structures has urged researchers to find economic engineering solutions and has put this aspect to a priority of the scientific research. Accordingly, different types of structures are in the focus of research studies such as reinforced concrete, reinforced masonry, steel frames, wood and timber stud walls in addition to many other types of structural systems and structures of various material-based categories. One of these recent wide range used structures are steel stud wall systems (SSWS). SSWS has numerable advantages that gives the option of using them a preferable priority. Some of these advantages are material of construction which is light weight cold formed steel sections, fast erection process which is counted for the excellent merit of this type of structures, meeting the architectural needs using various types of sheathing and cladding and the ease of providing and passing power supplies from MEP point of view as well.

Studying the behavior of SSWSs under blast loads is an important point in designing this type of structures. When a blast load event occurs, the load is applied at a very short time period to the structural members subjected to the load. This very short duration of loading gives the blast load special characteristics that do not exist in other types of loading from all point of views. Such as environmental point of view which is concerned with how to put empirical relations to measure in an engineering way the damage an explosion may cause to the surroundings [30]. From structural dynamics point of view, the extremely short duration of load application may be much lesser than natural time period of the structural systems especially that it does not long more than a period measured in milliseconds [31]. This means that the structural system does not have sufficient time to respond to the subjected blast loads. Also, from point of view of engineering material science, the structural system must have the ability to adequately behave under the shed of plastic range to dissipate the enormous amount of energy sourcing from the explosion epicenter. Thus, the latest point of view turns into a fact; that is a structural engineer has to keep in consideration to hold the structure lasting as long as possible. That means that the structure has to sustain the applied loads and last until the civil defense and safety directories can arrange for the emergency. Thus, satisfying the safety engineering requirements which is counted as an additional important point of view. Since it’s a fertile field of study, SSWSs still carry a lot to be found out about the behavior of such structures under various types of loading and different ways of fabrication.

To achieve the required response of the structure a spot of light should first be focused on the behavior of steel studs under the plastic region to pave the way to understand how the structure responds to loads and how to make full use of the structural system. To study the effect of blast load the problem should be expressed first as a mathematical model. To create a suitable dynamic mathematical model to the main element in the structural system -which is the cold formed studs- the stud is to be dealt with as a single degree of freedom system that consists of a mass M subjected to a spring of which has a force to displacement relationship or stiffness constant k_e. The later constant is not sufficient to describe the behavior and response of the stud after the elastic limit so; it will be replaced with the resistance function as will be discussed later on.

2. Steel stud wall components and structure

Steel stud wall applications as previously mentioned in the head of this research are becoming more and more interesting alternative for various construction purposes such as being used generally in building exterior and interior partitions in addition to outward fencing due to their merits from several points such as economy, time of construction and flexibility in handling different utilities supplies. These strength points urged the researchers not only to try to use SSWS for general use but to study the extent of their efficiency in further engineering applications, seismic resistant buildings and buildings subjected to moderate blast events are examples. SSWS as structural elements consists of three main parts. They are from top and downwards: upper track, studs and lower track. A fourth item is often to be added for preventing buckling of the studs if needed. These components of the system are as shown in Fig.1. Two studies on the connection with extensive work, were generally aiming at studying the system to determine the modes of failure taking place within the connection [9,38]. Both studies have focused on the point of how to increase the load-displacement curve known as "resistance function" due to static load. Especially that toughness of the system (area under resistance function curve), is a good indicator to the capability of the system to sustain blast loading.

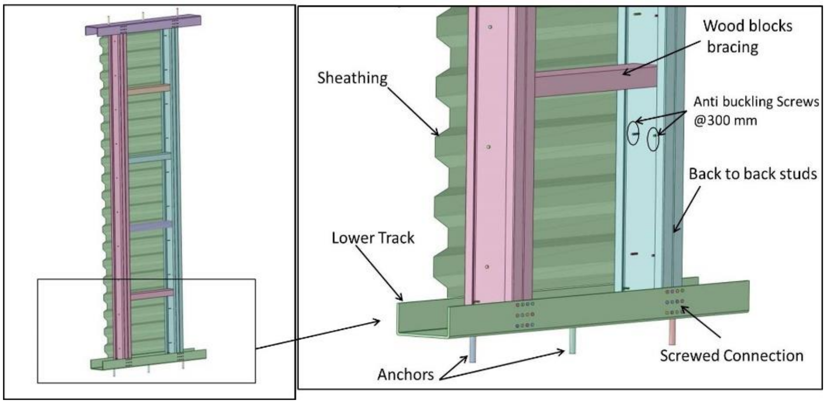

Fig. 1. Components of stud wall system (front sheathing removed).

3. Connection and detailing

Experimentally, studs have been successfully forced to approach greater capacity using very stiff connections which was impractical for general purposes from both sides of time and costs of construction alike [39]. The main gain of creating such stiff connections was as mentioned to help the stud reach a limit far beyond yielding and make it undergoes through the tension membrane behavior discussed later on. Hence the need for efficient and economic connections arose to meet both ends.

As work continues on this point, several experimental tests were carried out to maintain static resistance function [9,40,41]. During this work the connection effect on the behavior of the loaded stud was investigated including various configuration of connecting the stud from top and bottom. The experimental work was not only on the static behavior but extended further to shock tube and furthermore to live field explosion tests.

One type of these connections is the clipped and bent flange connection. It is formed by cutting a portion of the web at both ends of the stud and bending it into an angle of 90 degrees to form a leg which is in its turn holed to accommodate the anchor to fix the stud from top and bottom [42]. However this connection type did not enhance the behavior of the stud. Also a special type of connection described as "Academic hinge" was verified numerically using FEA ABAQUS software [43].

Another study had been conducted an experimental work on short length studs (4-feet) to magnify the effect of the shearing force to make a closer look at the behavior of the connection when shear becomes the dominant type of force acting on the connection [9]. The author worked on full length studs side by side to the short ones. The effect of increasing number of screws on enhancing the static capacity of the SSWS was extensively and generally studied. Generally the author concentrated on main parameters that may increase the capacity such as: a) Gauge of studs, b) Gauge of tracks, c) Flange length of the track, d) No. of screws, and e) Size of screws.

The author concluded that adding screws is economically the most efficient way of increasing strength of studs and subsequently their toughness. The angles of rotation of studs was enhanced from 8.9 to 17.1 degrees when using single screw per flange and six screws respectively. Also the author stated that adding one more screw per flange has increased the toughness by 89%, and using four screws also instead of the single screw connection enhanced the toughness by 111%. It is reported also in [9] that increasing number of screws up to four and six screws per flange is increasing the toughness of the studs by 173% and 185% respectively when compared to a connection hold with only two screws per flange. The author also mentioned that the heavier gauges are more energy dissipating and that this option is the most expensive alternative. According to the author this option has also some limitations to the shear capacity of the screws themselves since in the case of heavier stud thicknesses (2.46 mm and above), the screws have weaker sections to resist the developed shear and the failure mode turns into screws shearing.

Thus, the author worked on the general keys controlling the connection behavior and hence paved the way for deeper study for other details. The author also manifested and classified the modes of failure that may take place within the connection into four main groups: a) Web crippling, b) Lateral torsional buckling, c) Screw pullout, d) Shear of stud, e) Screw tilting and bearing, and f) Screw pullover.

4. Response of SSWSs to blast loads

4.1. Static response

Static response is a very important index to which degree is the system capable of dissipating an amount of energy exerted by external load to the system. The area under load displacement curve is referred to as the toughness of the system. The further we can stretch this area, the better the system becomes as energy dissipation means. From this approach, studying the system resistance curve under static lateral load becomes important [34].

Resistance function can be defined in general as the internal force because of which the system tries to remain in its initial displacement state before being loaded. The load-displacement curve of a system and the stages it undergoes during quasi static loading have been classified into three main zones of stiffness [44]:

- Zone A: The elastic zone in which stiffness is expressed in a scalar number with magnitude $k_1= k_e$.
- Zone B: The zone of plastic deformation and bears stiffness equal to zero k_e. This zone sometimes is not clearly defined in experimental work results that means that the system under testing has bypassed this zone to the third one directly [40].
- Zone C: The zone at the end of which the ductility limit is reached and the system failure occurs and has a slope of k_3 and this region is called the tension membrane region.

These three regions can be described graphically via tri-linear curve as shown in Fig. 2 in which R_m Is the maximum elastic load before logging into plastic behavior and, y_{el} is the maximum elastic displacement and y_m is maximum displacement before region 3 as will be discussed later sections.

A brief description is given to each characteristics line of the three zones in the next sections.

4.1.1 *Elastic region*

It's the zone in which the curve of load displacement relationship begins and continues linearly until the point with the coordinates (y_{el}, R_m). This point can be simply calculated from structural mechanics

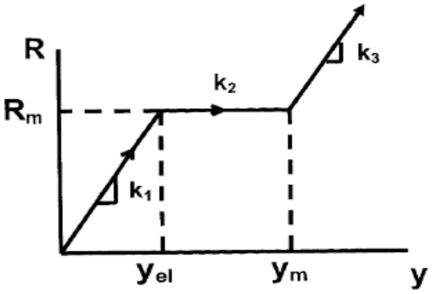

Fig. 2. Tri-linear representation of resistance function.

4.1.2 Softening region

It's the region that directly follows the linear elastic region and starts from the point of first buckling yield. Any exceedance in loading on a structure to the first yield point has to pass through this region [45]. As shown in Fig. 1, this stage of loading is characterized by zero stiffness. Yet the amount of displacement or rotation during this region is not completely defined according to experimental results [38].

4.1.3 Tension membrane region

The region immediately following the softening region. During this region the stud tends to consume large amount of load. The importance of this region lies in being the most dissipative region of the curve for energy. For this reason the connections must be stiff enough to hold the stud until it reaches the ultimate response in the tension membrane region. When a stud undergoes this region it may follow one of two types of behavior:

Catenary action behavior: This mode of behavior takes place when the upper response limit mentioned in the previous section is being achieved. This region is characterized with the shape the stud takes which tends to seem like an arch. The major stresses experienced by the stud during this stage are tension and bending stresses.

Pure tension behavior: The naming of this type of behavior expresses the dominant type of stresses which the stud suffer from during the tension membrane region but not meaning that the stud is subjected to tensile force. The slopes of response curves for both behaviors are approximately the same, the major difference is the point at which the softening region ends and tension membrane region starts [38].

4.2. Dynamic response

Several researchers worked on experimental live explosions in open field on different structural systems. For example, authors worked on studying the live blast on hot rolled column sections W360x347 with net height of 5.73 m and an equivalent to TNT detonator of ANFO material that was of charge weight 1818 kg from a stand-off distance of 4.75 m [46]. A further experimental work on studying a set of wide flange column sections under live explosives was conducted [47]. SDOF models were used to verify the experimental work. The standing off distances ranges from 7.0 m to 10.30 m and charges of ANFO detonators of weights that range from 50 kg to 250 kg. The experimental work performed in [47] has been also validated using the LS-DYNA FEA software [48]. A series of testing was performed on several specimens of steel/vanadium alloy stud wall systems using artificial blast simulating machine and the experimental work was verified numerically [49].

Using Steel Stud Wall Analysis Code (SSWAC) software which is developed by university of Missouri-Colombia analysis of SSWS was carried out to calculate the dynamic response using SDOF approach [38]. A finite element model that used LS-DYNA software to simulate the blast loading on the slip-track connection or non-load bearing type connection was also introduced [50]. This system that have one of two forms at the upper end connection of the track to stud connection was statically studied [39]. The system connections are as shown in Fig. 3.

After dynamic modelling using LS-DYNA the author withdrawn three important recommendations. The first recommendation was that adding screws to the stud-to-track connection has a significant effect on enhancing the connection. In this point the author agrees with earlier static studies recommendations [9].

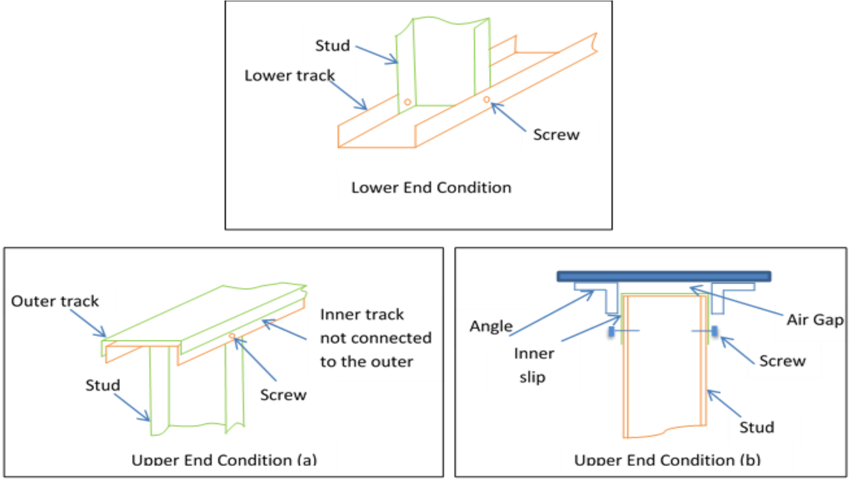

Fig. 3. Stud to track connection with top slip track.

The second recommendation was related to the first one and it was about providing enough room in the track flange and raise it to be 72.6 mm to accommodate the increased number of screws. While the third recommendation was about the slip- track connection which had negative effect on the structural system and the author recommended to avoid this type of connection if possible. In this LS_DYNA model all screws and fasteners were dealt with as beam elements.

5. Conclusions

From the review mentioned above about SSWSs, it is concluded that increasing screws number is an efficient method to enhance the static resistance and toughness of SSWS which by its turn is used as an important indicator for better response under the case of blast loading. Increasing number of screws from one to two, and from one to four screws per flange has led to an increase in toughness by 89% and 111% when compared to the single screw. In addition to an increase of 173% and 185% for four screws and six screws per flange when compared to a connection that has only two screws per flange at the same gauge of studs and tracks. Providing extra room is recommended to accommodate the increase in screws number. Another important additional conclusion, is that some connections are either of non-significant enhancement to the performance of studs such as the clipped-and-bent flanges connections or even not recommended for blast design like slip track connections.

It is clear that research in this point is a fertile field that still needs more investigation. After successful numerical verifications were done to the static experiments, comprehensive parametric studies to investigate more about different sections and their capacities in addition to optimizing the material to the traditional system become a new field of interest. Also on the dynamic scale, studying SSWSs through FE modelling is another field that would reduce the costs of experimental work required to find the response under blast loading. FE will provide a good method of getting rather more data especially that finite element packages and tools allows the user to study various complicated scenarios and conditions of blast events.

References

[1] G. Mays, P.D. Smith, P.D. Smith, Blast effects on buildings: Design of buildings to optimize resistance to blast loading, Thomas Telford, 1995.

[2] H. Hao, X.Q. Zhou, Concrete material model for high rate dynamic analysis, in: Proceedings, 2007: pp. 753–768.

[3] Y. Hao, H. Hao, X. Zhang, Numerical analysis of concrete material properties at high strain rate under direct tension, Int. J. Impact Eng. 39 (2012) 51–62.

[4] Y. Hao, H. Hao, G.P. Jiang, Y. Zhou, Experimental confirmation of some factors influencing dynamic concrete compressive strengths in high-speed impact tests, Cem. Concr. Res. 52 (2013) 63–70.

[5] J. Ožbolt, A. Sharma, B. İrhan, E. Sola, Tensile behavior of concrete under high loading rates, Int. J. Impact Eng. 69 (2014) 55–68. https://doi.org/10.1016/J.IJIMPENG.2014.02.005.

[6] Y. Shi, H. Hao, Z.-X. Li, Numerical derivation of pressure–impulse diagrams for prediction of RC column damage to blast loads, Int. J. Impact Eng. 35 (2008) 1213–1227.

[7] D. Kelliher, K. Sutton-Swaby, Stochastic representation of blast load damage in a reinforced concrete building, Struct. Saf. 34 (2012) 407–417. https://doi.org/10.1016/J.STRUSAFE.2011.08.001.

[8] X. Bao, B. Li, Residual Strength of Blast Damaged Reinforced Concrete Columns, Int. J. Impact Eng. 37 (2010) 295–308. https://doi.org/10.1016/J.IJIMPENG.2009.04.003.

[9] B.M. Agee, Upgrading conventional cold-formed steel connections to protect against moderate blast events, (2010).

[10] Y. Shi, M.G. Stewart, Spatial reliability analysis of explosive blast load damage to reinforced concrete columns, Struct. Saf. 53 (2015) 13–25. https://doi.org/10.1016/J.STRUSAFE.2014.07.003.

[11] J. Li, H. Hao, Development of a simplified numerical method for structural response analysis to blast load, Procedia Eng. 14 (2011) 2558–2566. https://doi.org/10.1016/J.PROENG.2011.07.322.

[12] W. Wang, D. Zhang, F. Lu, S.-C. Wang, F. Tang, Experimental study on scaling the explosion resistance of a one-way square reinforced concrete slab under a close-in blast loading, Int. J. Impact Eng. 49 (2012) 158–164. https://doi.org/10.1016/J.IJIMPENG.2012.03.010.

[13] R. Yu, D. Zhang, L. Chen, H. Yan, Non-dimensional pressure–impulse diagrams for blast-loaded reinforced concrete beam columns referred to different failure modes:, Adv. Struct. Eng. 21 (2018) 2114–2129. https://doi.org/10.1177/1369433218768085.

[14] R. Jayasooriya, D.P. Thambiratnam, N.J. Perera, Blast response and safety evaluation of a composite column for use as key element in structural systems, Eng. Struct. 61 (2014) 31–43. https://doi.org/10.1016/J.ENGSTRUCT.2014.01.007.

[15] M. Abedini, A.A. Mutalib, Investigation into Damage Criterion and Failure Modes of RC Structures When Subjected to Extreme Dynamic Loads, Arch. Comput. Methods Eng. 27 (2020) 501–515. https://doi.org/10.1007/S11831-019-09317-Z.

[16] Y.A. Al-Salloum, T.H. Almusallam, M.Y. Khawaji, T. Ngo, H.M. Elsanadedy, H. Abbas, Progressive collapse analysis of RC buildings against internal blast, Adv. Struct. Eng. 18 (2015) 2181–2192.

[17] J. Son, H.-J. Lee, Performance of cable-stayed bridge pylons subjected to blast loading, Eng. Struct. 33 (2011) 1133–1148. https://doi.org/10.1016/J.ENGSTRUCT.2010.12.031.

[18] G. Gholipour, C. Zhang, A.A. Mousavi, Nonlinear numerical analysis and progressive damage assessment of a cable-stayed bridge pier subjected to ship collision, Mar. Struct. 69 (2020). https://doi.org/10.1016/J.MARSTRUC.2019.102662.

[19] G. Gholipour, C. Zhang, A.A. Mousavi, Analysis of girder bridge pier subjected to barge collision considering the superstructure interactions: the case study of a multiple-pier bridge system, Struct. Infrastruct. Eng. 15 (2019) 392–412. https://doi.org/10.1080/15732479.2018.1543710.

[20] L. Liu, Z. Zong, C. Gao, S. Yuan, F. Lou, Experimental and numerical study of CFRP protective RC piers under contact explosion, Compos. Struct. 234 (2020). https://doi.org/10.1016/J.COMPSTRUCT.2019.111658.

[21] S. Yuan, H. Hao, Z. Zong, J. Li, A study of RC bridge columns under contact explosion, Int. J. Impact Eng. 109 (2017) 378–390. https://doi.org/10.1016/J.IJIMPENG.2017.07.017.

[22] L. Figuli, C. Bedon, Z. Zvaková, Š. Jangl, V. Kavický, Dynamic analysis of a blast loaded steel structure, Procedia Eng. 199 (2017) 2463–2469. https://doi.org/10.1016/J.PROENG.2017.09.388.

[23] M.A. Hadianfard, A. Farahani, A. Bahadori-Jahromi, On the effect of steel columns cross sectional properties on the behaviours when subjected to blast loading, Struct. Eng. Mech. 44 (2012) 449–463. https://doi.org/10.12989/SEM.2012.44.4.449.

[24] A.A. Nassr, A.G. Razaqpur, M.J. Tait, M. Campidelli, S. Foo, Single and multi degree of freedom analysis of steel beams under blast loading, Nucl. Eng. Des. 242 (2012) 63–77. https://doi.org/10.1016/J.NUCENGDES.2011.10.020.

[25] A.A. Nassr, A.G. Razaqpur, M.J. Tait, M. Campidelli, S. Foo, Dynamic Response of Steel Columns Subjected to Blast Loading, J. Struct. Eng. Asce. 140 (2014). https://doi.org/10.1061/(ASCE)ST.1943-541X.0000920.

[26] A.A. Fekry, A.A. Nassr, A.M. Ismail, E.M. Soliman, A. Gamal, BEHAVIOR OF STEEL HOLLOW SECTIONS UNDER BLAST LOAD, 39 (2020) 121–134. https://doi.org/10.21608/JAET.2020.96450.

[27] H. Al-Thairy, A modified single degree of freedom method for the analysis of building steel columns subjected to explosion induced blast load, Int. J. Impact Eng. 94 (2016) 120–133. https://doi.org/10.1016/J.IJIMPENG.2016.04.007.

[28] A.G. Hanssen, L. Olovsson, T. Børvik, M. Langseth, Close-range blast loading of aluminium foam panels: A numerical study, in: IUTAM Symp. Mech. Prop. Cell. Mater., Springer, 2009: pp. 169–180.

[29] M. Poulin, C. Viau, D.N. Lacroix, G. Doudak, Experimental and analytical investigation of cross-laminated timber panels subjected to out-of-plane blast loads, J. Struct. Eng. 144 (2018) 4017197.

[30] M. Nawar, Performance of the laminated glass systems under static and blast pressure loading, (2016).

[31] G. Xuan-neng, STUDY ON BLAST RESISTANT FOR GLASSING CURTAIN WALL CONSTRUCTION UNDER BLAST LOADING, Low Temp. Archit. Technol. (2012).

[32] J.M. Pereira, J. Campos, P.B. Lourenço, Masonry infill walls under blast loading using confined underwater blast wave generators (WBWG), Eng. Struct. 92 (2015) 69–83. https://doi.org/10.1016/J.ENGSTRUCT.2015.02.036.

[33] M. Wang, H. Hao, Y. Ding, Z.-X. Li, Prediction of fragment size and ejection distance of masonry wall under blast load using homogenized masonry material properties, Int. J. Impact Eng. 36 (2009) 808–820. https://doi.org/10.1016/J.IJIMPENG.2008.11.012.

[34] M. Irshidat, A. Al-Ostaz, A.H.-D. Cheng, C. Mullen, Nanoparticle Reinforced Polymer for Blast Protection of Unreinforced Masonry Wall: Laboratory Blast Load Simulation and Design Models, J. Struct. Eng. Asce. 137 (2011) 1193–1204. https://doi.org/10.1061/(ASCE)ST.1943-541X.0000361.

[35] D.H. Bondok, H.A. Salim, M.A. McClendon, Static Resistance of Open Web Steel Joist Roof Trusses for Blast Response Analysis, J. Perform. Constr. Facil. 31 (2017). https://doi.org/10.1061/(ASCE)CF.1943-5509.0001099.

[36] D. Kovačič, Resistance of steel beams with web openings and castellated beams, (2010).

[37] D. Nourzadeh, J. Humar, A. Braimah, Response of roof beams in buildings subject to blast loading: Analytical treatment, Eng. Struct. 138 (2017) 50–62. https://doi.org/10.1016/J.ENGSTRUCT.2017.02.009.

[38] J.W. Lane, Modeling and design of explosion-resistant steel stud wall systems, (2003).

[39] H. Salim, P. Muller, R. Dinan, Response of conventional steel stud wall systems under static and dynamic pressure, J. Perform. Constr. Facil. 19 (2005) 267–276.

[40] H.A. Salim, R. Dinan, S.A. Kigar, P.T. Townsend, J. Shull, Blast-retrofit wall systems using cold-formed steel studs, ARMY ENGINEER RESEARCH AND DEVELOPMENT CENTER VICKSBURG MS INTERNATIONAL …, 2003.

[41] J. Shull, Steel stud retrofit connection development and design, (2002).

[42] L.B. William, P.E. Bounds, Design of blast-resistant building in petrochemical facilities, Am. Soc. Civ. Eng. US. (2010).

[43] D.H. Bondok, H.A. Salim, A.M. Asce, Numerical Modeling of Conventional Steel Stud Walls ’ Static Resistance for Blast Response Predictions, (2014) 1–10. https://doi.org/10.1061/(ASCE)ST.

[44] W.-W. Yu, R.A. LaBoube, Cold-Formed Steel Design, 2010. https://doi.org/10.1002/9780470949825.

[45] J.M. Biggs, Introduction to structural dynamics., McGraw-Hill; 1964, New York., 1964.

[46] J.M. Magallanes, R. Martinez, J.W. Koenig, Experimental results of the AISC full-scale column blast test, Rep. TR-06. 20 (2006).

[47] A.A. Nassr, A.G. Razaqpur, M.J. Tait, M. Campidelli, S. Foo, Strength and stability of steel beam columns under blast load, Int. J. Impact Eng. 55 (2013) 34–48.

[48] M. Momeni, M.A. Hadianfard, C. Bedon, A. Baghlani, Numerical damage evaluation assessment of blast loaded steel columns with similar section properties, in: Structures, Elsevier, 2019: pp. 189–203.

[49] A. Freidenberg, Advancements in blast simulator analysis demonstrated on a prototype wall structure, (2013).

[50] B. Bewick, E. Williamson, Computational modeling of steel stud wall systems for applications to blast-resistant design, J. Struct. Eng. 140 (2014) A4014007.