An overview of analysis of Cold-formed steel stud wall subjected to blast loading

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Abstract. This paper is aimed at presenting an overview of research performed worldwide related to analysis of Cold-formed steel (CFS) wall subjected to blast loading. The basics regarding definition of blast, the merits and demerits of using CFS for blast resistant structures, connection details, the methods of improving blast resistance of structures are included in this paper. The overview presented in this paper based on the earlier research works published in journal provide an insight into the topic and the research needs are also highlighted.

Keywords: cold-formed steel; blast resistance; stud wall, connections

1. Introduction
Cold-formed steel (CFS) structures are structures made from sections formed by folding thin sheets of steel at ambient temperature without any heating. Blast is a destructive wave of highly compressed air spreading outwards from an explosive. Due to the recent increase in terrorist attacks, people are becoming aware of the hazards caused if the structure is not designed as blast resistant. For the construction of blast resistant structures, stud walls fabricated by CFS sections are preferred than hot rolled steel sections due to their better blast resistant properties. They possess good strength, ductility and energy absorption capacity. The stud wall component details are provided [2], [1]. From the available literature, it has been identified that the software best suitable for creating an analytical model of CFS stud walls and generating blast loading is ABAQUS. Some of the studies reported in literature are [4], [17] and [20]. Stiffeners help in increasing the strength of the CFS stud wall and so is sheathing material. The properties of welded stiffener are also explained [17]. The different types of sheathing material reported in literature are Oriented strand board(OSB), gypsum, Carbon nanotubes etc., [18-23].

2. Blast resistant design of CFS stud wall
This section includes some of the basics related to blast, usage of CFS for blast resistant structures, connection details, blast resistant materials, the ways to improve blast resistance of stud walls.

2.1. Blast
Blast is a strong gust of wind or air caused due to an explosion. There are several research works reported in the past which deal with the properties and types of blast including the different methods of calculation of blast load and defining the blasts wave. It is found that maximum vertical deformation due to blast loading can be obtained by using static one dimensional approach with the properties of geo materials [15]. The strain in loading and unloading condition is also explained in this paper and the corresponding equations are derived for it. The proposed closed-form solution is validated with the experiments conducted with an air-overpressure record taken from measurements made at a distance of 198.12m from ground zero for a nuclear detonation of 37 kt yield at height of burst of 213.36 m. The overpressure time-history obtained is shown in figure 1. The solution accounts
for the difference between P-wave velocity and ground shock propagation velocity due to plastic wave propagation at high blast overpressures. The proposed model is further applied to estimate ground displacement in one of the nuclear tests conducted at Nevada Proving Grounds. It was concluded that the proposed solution predicts the ground displacement if proper engineering judgment is applied in selecting geotechnical parameters. An overview of effects of explosion on structures is presented [16]. The different methods to estimate blast loads with the structural response are introduced. The blast wave pressure versus time history is plotted as shown in figure 2.

The solution accounts for the difference between P-wave velocity and ground shock propagation velocity due to plastic wave propagation at high blast overpressures. The proposed model is further applied to estimate ground displacement in one of the nuclear tests conducted at Nevada Proving Grounds. The scaling law is explained and the equation for prediction of peak reflected overpressure for a given distance \( R \) and weight of charge (W) is proposed. The results are given in Table 1.

![Figure 1. Overpressure-time history[15]](image1.png)

![Figure 2. Blast wave pressure-time history [16]](image2.png)

**Table 1.** Peak reflected overpressures (in MPa) with different W-R combinations

| R/W | 500 kg TNT | 1000 kg TNT | 2000 kg TNT |
|-----|------------|-------------|-------------|
| 1m  | 354.5      | 464.5       | 602.9       |
| 5m  | 24.8       | 39.5        | 60.19       |
| 15m | 1.25       | 2.53        | 5.01        |
| 25m | 0.29       | 0.55        | 1.08        |

The strain rates in \( s^{-1} \) of different types of loading is explained which starts from \( 10^{-6} \) in quasi static to \( 10^2 \) in earthquake loading and highest of \( 10^3 \) in blast loading. The computer programs which are used to simulate blast effects and structural response is given. The global and local responses with different failure modes are also explained. BLASTX, FEFLO, FOIL, SHARC are software used for blast prediction purpose and CFD for code type of analysis. CONWEP for blast prediction (empirical) and AUODYN, ABAQUS for structural response. The same kind of approach is explained [17]. The information related to blast wave, scaling law, methods of calculation of blast load and blast pressure are explained.

2.2 Cold-formed steel

The strength and ductility properties of CFS have been discussed [1]. The behaviour of CFS stud wall under compression is explained [12]. The behaviour of CFS stud wall stud with sheathing, subjected to compression is explained [6]. The design methods for CFS stud walls with sheathing as OSB and gypsum is explained [12]. The OSB sheathing is provided at the exterior face and the gypsum at the interior face of CFS stud wall. The impact of sheathing on elastic stability of the stud in local, distortional and global buckling modes is given. This design method is found to yield good results while performing tests by varying predictions for the limit state and the strength of walls for varying conditions such as with sheathing, sheathing on one side only and different sheathing materials on the two stud flanges. Sixteen full scale stud walls are tested experimentally and the impact of various parameters, such as stud section and spacing, sheathing configuration, type and layer of wall panels, and joint details of wall panels on performance of stud walls are analyzed [6]. A
finite element model of CFS walls using ANSYS is developed and examined under axial compression. The entire analysis procedure is described, including element type, applied load, material properties and screw connectors. It is found that the ultimate load of wall with OSB is 27% greater than the stud wall with gypsum board. The performance of CFS hollow sections under high loading rates, and material characteristics like toughness and energy absorption capacity, member behaviour and analysis methods is reviewed [8]. The stiffness are the two transitional stiffness values considered. It provides bracing model with sheathing braced stud walls. A hybrid solution to replace some CFS chord studs with hot-rolled square hollow sections to achieve higher strength is explained [11]. As a result of the experimental studies, the lateral behaviour of a hybrid light-weight steel panel and the need for any further improvements for mid-rise construction is investigated. The stress-strain graph and hysteretic curves are given in figure 3 and figure 4 respectively.

![Figure 3: Material properties [11]](image1)

![Figure 4: Hysteretic envelope curves [11]](image2)

The progressive collapse of CFS framed structures is investigated by using software SAP2000 version 9.0.3 [14]. The removal of exterior is done as per GSA and DoD guidelines. The structure is not collapsed but portion of the structure is vulnerable when the columns are removed. The experimental study on several CFS structural system, including Square Hollow Sections (SHS), Rectangular Hollow Sections (RHS) and Circular Hollow Section (CHS) are performed [13]. The young’s modulus is found to be high (220,000 N/mm²) from stress-strain graphs plotted for ferrite grades. The average value of 195,000 N/mm² is adopted for further studies. Few experiments by heating the test specimens to various elevated temperatures and then cooled down to an ambient temperature is done [9]. Light gauge steel framed walls and floors are used in these tests. The stress-strain curves, elastic modulus, yield and ultimate strengths are determined from the tensile coupon tests. The results showed that the steel grade had an influence on the yield strength and elastic modulus of steel while the steel thickness had no influence on the yield strength and elastic modulus of steel while the steel thickness had no influence on the result. The properties of cold formed steel hollow sections are highlighted [10]. Square and rectangular hollow sections with different thickness and grades are used in the experimental study. It is heated at varying temperatures ranging from 100 to 800°C. Tensile tests of these coupons are conducted and their stress strain curves and the post-fire reduction factors are plotted. The yield and ultimate strengths and elastic modulus are finally obtained. Till 300°C, the loss of yield and ultimate strength is found to be negligible. Some equations are proposed but it is applicable only for hollow sections.

2.3 Blast response of members

The protected spaces and exterior envelopes are discussed [18]. This improves the structural response during blast loading. The weak portion of the building is supported with an exterior envelop. Few new construction techniques like glazing systems and doors; exterior wall systems, such as concrete, masonry and steel wall construction; roof systems; debris mitigating systems, and venting is defined and the requirements for the design of components to resist fragmentation, structures to resist blast loads, the isolation of protected spaces and the design of debris mitigating building envelope are discussed. The experimental study on metal columns by adopting a reflected pressure and time history, is also conducted. The strain versus time graph is plotted and the displacement versus time
graph for each strain is obtained. The different mode of failure in tension membrane action test and bending prying action test is observed [3]. The load deflection curve for two different specimens of steel stud walls are obtained and the better specimen is found to be the sheathed one.

2.4 Connections
The stud to track connections and its behavior is explained [9], [7],[1]. The blast resistance of stud wall under various parameters like screw sizes and layouts is explained [4]. The connection of stiffener to the wall will mostly be welding as in the analysis and simulation of welded stiffener plates subjected to localised blast loading [17]. The connection of conventional steel stud wall which is then referred in several other journals for connection detailing of CFS stud wall is explained [8]. Some of the research work addresses the use of traditional screws for connection [3].

2.5 Cold-formed steel stud wall under blast loading
Several previous studies shows that stud wall using CFS possesses good ductility and blast resistant properties when compared to hot rolled steel. But the finish is not good in the CFS stud wall. An experimental study on CFS stud wall is conducted [1]. The influence of stud design on track screws and track design is discussed. The properties of materials of members used for stud walls are provided in Table 2.

| Component | Yield strength MPa | Ultimate strength MPa | Ductility |
|-----------|--------------------|-----------------------|-----------|
| Stud 600C162-43 | 364 | 498 | 29.5 |
| Track 600T125-43 | 358 | 505 | 28.2 |
| Vetri Clip SL600  | 354 | 535 | 31.0 |
| Buckle Bridge | 407 | 554 | 25.9 |

DYNO AP is used in this experimental study to measure the over pressure impulse. The punch outs are provided and three specimens are tested. The buckling of stud is studied under quasi-static load. TNT weight of 1.306 kg and standoff distance 1.674 m is applied for first specimen, and 1.56 kg and 1.575 m for other two specimens. The performance of CFS stud wall is found to be satisfactory. An experimental and analytical study is conducted on CFS stud walls for moderate blast level protection [4]. Load tree test is conducted in the system by applying quasi-static load condition for several trails by varying size of stud, track and screw. The provision of extra size screws is found to increase resistance and reduce the amount of tilting and bearing on the screws. The deflection and rotation angle is found. Analytical model is also created using ABAQUS/Standard 6.11 to check different failure modes and deflection. The load-deflection response is predicted and compared with the experimental results and it is found to be agreeing well. Additional studies are also performed [5]. Analytical and numerical models for predicting the static resistance of anchored steel studs is studied. The effect of using OSB sheathing and provision of utility holes are the two parameters considered for this investigation. For specimens without utility holes, the OSB sheathing is found to have a positive impact on stud resistance. The developed finite element model is able to predict the resistance of stud specimens provided with / without utility holes that are sheathed / unsheathed.

2.6 Blast resistant sheathing materials
There are varieties of blast resistant sheathing materials available in market. The cheapest and easily available material is OSB sheathing. Gypsum boards are another type of material which give good strength to the structure. The usage of OSB and gypsum board sheathing is explained [18], [20], [22]. Epoxy resins can also be used for obtained higher strength [23]. Recent investigation is done on the performance of Carbon nanotubes which are allotropes of carbon. The property of wood sheathing is also studied [21].

2.7 Methods to improve the blast resistance of stud walls
The simpler technique to improve the blast resistance of the stud wall is by providing stiffeners at the softening regions of the stud [17]. The experimental and numerical investigation performed on a
welded stiffener plate subjected to blast loading is explained. The effect of stiffener height in deflection and tearing is observed. The results obtained for the stress-relieving case versus no stress relieving case is compared. The attempt of increasing stiffener height resulted in lowering the stiffener deflection and tearing threshold which is beneficial. The axial compression strength of CFS stud walls with steel web stiffener and gypsum plaster boards is studied [18]. The configuration of gypsum board and steel sheet is varied for conducting tests. The different wall configuration tested is mentioned in figure 5.

![Wall configurations tested](image)

Six different wall configurations are obtained and six tests are conducted. The failure mode of each wall configuration is observed and the load versus axial and lateral deflection graphs are plotted. As expected, the second one performs better. The damage resistance of 3D textile composites under blast loading is explained [19]. The comparative analysis of performance of 2D woven carbon-epoxy laminate and 3D orthogonal textile carbon-epoxy composites with different volume of z-binder yarns is illustrated. The interlaminar fracture toughness properties of modes I and II for the composites are calculated by using the proposed equations. The strength and stiffness of OSB and gypsum sheathed braced CFS stud walls is investigated [12]. Both experimental and analytical study (by using software ABAQUS) is conducted. Proper bracing is provided by the inclusion of sheathing material. The local fastener deformations and global shear diaphragm behaviour is derived and thereby the local stiffness and diaphragm stiffness. A computational model of CFS is validated for lateral behaviour using full scale test results of 13 different shear walls [22]. Experimental study is conducted on CFS stud panels with gypsum sheathing subjected to out of plane bending. Overall 24 experiments are conducted by varying the parameters like slenderness ratio, sheathing thickness and fastener spacing. The moment versus deflection curve is plotted and the failure modes of the gypsum board is also observed .

3. Research needs
This paper is planned to provide an overview of earlier research works done regarding analysis of cold-formed steel (CFS) stud wall subjected to blast loading. Form this review, it is observed that some of the research areas are yet to be explored. The behaviour of connections used in CFS stud walls, the materials that can be used for enhancing stud resistance, the resistance offered by such materials, the ways of improving them are to be focused.

4. Conclusions
This paper is aimed at presenting an overview of research conducted all over the world related to analysis of Cold-formed steel (CFS) wall subjected to blast loading. The basics related to blast, the advantages of using CFS for blast resistant structures, connection details, the methods of improving blast resistance of structures are presented. The research needs are also highlighted and hence this study provides an insight into the topic .
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