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Impact shear resistance of double skin profiled composite wall

Shahryar Rafiei [a], Khandaker M.A. Hossain [a,*], Mohamed Lachemi [a], Kamran Behdinan [b]

[a] Department of Civil Engineering, Ryerson University, 350 Victoria Street, Toronto, Ontario M5B 2K3, Canada
[b] Department of Mechanical and Industrial Engineering, University of Toronto, 5 King's College Road, Toronto, Ontario, Canada

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ABSTRACT

This paper presents the behavior of a new form of composite walling system consisting of two skins of profiled steel sheeting and an infill of concrete subjected to in-plane impact loading. Composite wall specimens with overall dimensions of 1626 mm high by 720 mm wide were tested under impact shear loading in two phases, namely Phase I and Phase II (in addition to ones tested under in-plane monotonic shear). In Phase I, impact energy of the projectile was kept low intentionally to capture dynamic characteristics of wall. In Phase II, the impact test was performed with maximum speed of the projectile, which the impact apparatus could produce. The performance of composite walls was judged based on the development of acceleration and top displacement during impact as well as post-impact shear-displacement response, strength/stiffness, energy absorbing capacity, stress development and failure modes. The post-impact shear strength of walls was found to be not reduced (compared to control wall tested under static monotonic loading without impact) after the application of impact energy. The stiffness degradation of the wall after impact was around 8% compared to the control wall. This was an indication of better strength/stiffness retaining capacity of the walls after subjected to impact. Theoretically predicted maximum displacement at the top of the wall at impact was also found to be in good agreement with those obtained from experiments. This research confirmed the suitability of proposed profiled double skin composite wall (DSCW) to be used as impact shear resisting element in framed buildings.

1. Introduction

The behavior under impact loading is important due to the possibility of impact during the service life of a structure. For building structures, impact loading can be accidental explosions, hitting objects by hurricane, striking airplanes, impact vehicles, etc. In recent time, impact resistant design of building structures has become a new focus of attention in the world. When a projectile impacts a structural element, it will absorb energy until the material deforms elastically up to its yield strength and will undergo plastic deformation after yielding. Strain rate is the change in strain (deformation) of a material with respect to time and describes the rapidness of deformation processes [1]. The strength properties of both steel and concrete usually change with the speed of applied load [2]. Generally, both the yield and ultimate strengths as well as elongation increase with the speed of loading (or with the increase of strain rate). The ratio of yield strength to ultimate strength varies from 0.5 (for static loading) to 1 (for very high strain rate) for the mild steel. The Dynamic Increase Factor (DIF), a coefficient that magnifies the tensile strength of concrete based on different strain rates, has a value of 1 (for very low strain rate -static loading) and up to 8 (for high strain rate). The strain rate sensitivity of concrete in compression is less than concrete in tension [3,4].

Many experimental testing and numerical impact analyses have been performed on reinforced concrete slabs [5–7] and on reinforced concrete beams [8–10] to investigate the behavior of the structure and different type of concrete under striking dropping weight. Zineddin and Krauthammer [5] studied the dynamic response of reinforced concrete slabs having different types of reinforcements subjected to varying impact loads. Miyamoto et al. [6] used a nonlinear dynamic layered finite element method to predict the failure modes of reinforced concrete slabs associated with soft impulsive loads. The failure modes were found to be affected by the loading rates. Dancygier et al. [7] experimentally studied the response of high performance concrete plate specimens subjected to the impact of non-deforming steel projectiles. The influence of concrete mix ingredients (such as: types/size of aggregates and steel fibers) and reinforcement details were studied. Banthia et al. [8] presented calibration, the inertial loading correction and the dynamic analysis of beam specimens (made of plain concrete, fiber-reinforced concrete and conventionally

* Corresponding author.
E-mail address: ahossain@ryerson.ca (K.M.A. Hossain).

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Nomenclature

Notations

- σ_{p1} and σ_{p2} maximum and minimum principal stresses, respectively
- ε_{p1} and ε_{p2} maximum and minimum principal strains, respectively
- E_s, f_y and ν_s modulus of elasticity, yield stress and Poisson's ratio of steel plate, respectively
- γ_{max} and τ_{max} the maximum shear strain and maximum shear stress, respectively
- $x(t)$ displacement response in time (t) domain
- m, k, f and ω mass, stiffness, natural circular frequency and angular velocity of the SDOF structure, respectively
- $F(t)$ and F_0 impact load and constant pulse load, respectively
- T natural period of the structure
- $M_{Projectile}$ mass of the projectile
- $V_{Initial}$ and V_{Final} velocity of the projectile before and after the impact, respectively
- x_{max} maximum displacement at the top of the wall
- a_g maximum acceleration

reinforced concrete) subjected to three-point impact flexural loading. Hughes and Beeby [9] tested 92 concrete beams with different support conditions by dropping rigid weight on mid span and described the behaviour based on impact force history and maximum and residual displacements. Fujikake et al. [10] examined the impact responses of reinforced concrete beams through an experimental study (under varying drop height and amount of longitudinal steel reinforcement) and developed an analytical two-degree-of-freedom mass-spring-damper system model to predict the maximum mid span deflection and maximum impact load.

Rezai et al. [11] conducted vibration/impact tests on a 30% scale one bay, four storey steel frame with flat steel plate infill shear panels to detect and characterize structural damages. The natural frequencies of the structure are proportional to the square root of generalized stiffness and any decreases in natural frequencies represent the structural stiffness degradation. It was observed from the study that a 3% reduction in the first longitudinal natural frequency of the structure represented about 6% structural degradation. The effect of impact on a structure can be considered in two different ways: the dynamic behavior of the structure as a whole and the shock wave propagation in the structure. The shock wave (stress wave) propagation must be considered when loads are applied to the structure for short time durations and measurements are made in very small intervals of time after the application of impact load [12].

Novel double skin composite wall (DSCW) is a new form of walling systems which have applications in steel framed building as shear elements to resist lateral loads. A steel-concrete composite wall can have the benefits of both steel and reinforced concrete shear walls and yields the best traits of concrete and steel [13]. New form of DSCW (investigated in this study) comprises of two skins of profiled steel sheeting and an infill of concrete (Fig. 1). The concept of this type of wall was originated from the floor structure using profiled steel deck and concrete [14,15]. Composite walling as shear or core walls in steel frame buildings has many advantages. In building construction stage, profiled steel sheeting can act as a bracing system to the steel frame against lateral loads and also can act as a permanent formwork for infill concrete. During the in-service stage, profiled steel sheets and infill concrete work together to resist lateral loads. The interaction between the profiled steel sheet and concrete has an important role in the composite action of the system.

In order to increase the load resistance of the composite wall, the global buckling of the profiled steel sheets is prevented by using adequate intermediate fasteners (sheet-concrete interface connection). The reason for preventing the global buckling of the sheets is to ensure that the profiled steel sheet reaches almost its yield stress under shear loading. This can be achieved in composite wall due to the fact that the concrete core provides bracing to the profiled steel sheet and hence, prevents its buckling prior to reaching yielding. The design criteria associated with the DSCW system includes its resistance against axial and lateral loading. Structural behavior of such walls under axial and in-plane monotonic/cyclic shear has been investigated in previous research studies based on experimental and theoretical investigations [14–17]. The influence of steel-concrete interface connections, in-fill concrete types (normal concrete, lightweight concrete and highly ductile engineered concrete), size of opening (for doors and windows in walls), wall slenderness, types of strength enhancement devices around openings and types of wall-frame connections were investigated [17–19]. The performance of the walls were described based on load-deformation response, stiffness degradation, energy absorbing capacity and failure modes. Design equations for predicting axial and shear strength of such walls were developed with recommendations for steel-concrete interface connector spacing and effectiveness of various strength enhancement devices around openings and wall boundaries). Previous research confirmed the viability of using DSCW as an effective structural system for building construction in terms of enhanced strength, ductility and energy absorbing capacity [17–19]. The practical use of DSCWs in conjunction with a building frame is to increase the shear resistance of the frame. In such a case, the frame failure (which may lead to the total collapse of the building) is not desired and the failure of the infill wall should govern the design.

Few research studies on impact resistance of composite walls/panels were conducted. Mizuno et al. [20] carried out experimental, analytical and numerical studies on the impact resistance of composite steel plate reinforced concrete (SC) walls and slabs SC (rebars of reinforced concrete are replaced by steel plates). Such steel plate reinforced concrete structures are more attractive struc-

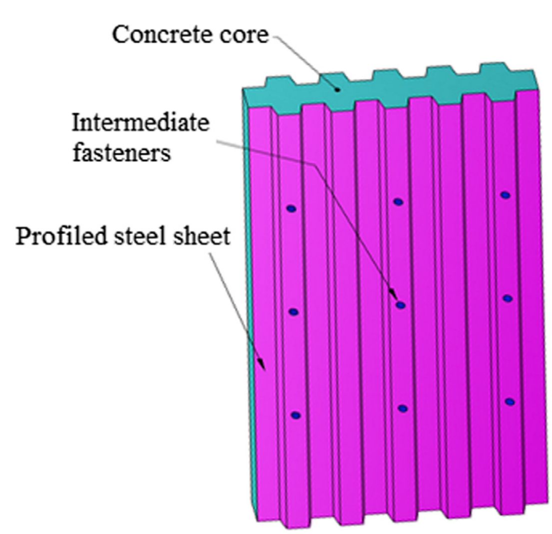

Fig. 1. Schematic diagram of a double skin composite wall.