STRUCTURAL EFFECTIVENESS OF CARON FIBRE REINFORCED PLASTIC (CFRP) CASSETTE WALL PANELS SUBJECT TO IN-PLANE SHEAR LOAD

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ABSTRACT

This paper discusses the structural effectiveness Carbon Fiber Reinforced Plastic (CFRP) used in the structural sections of a wall. The cassette wall was assumed pinned at the edges and uniformly loaded on one side with an in plane shear load as well as an axial load from the top of the wall; the loading was based on the maximum bending moment. Finite Element Analysis modes were performed on the cassette wall panels using ABAQUS/CAE 6.10.1(FEA software). The non-linear finite element analysis results shows that, cassette walls subjected to in-plane shear loading can sustain axial loads of 5kN/m^2 up to 20kN/m^2 without suffering major deformation damage due to reaction forces. However, considering loading as a result of both axial as well as in-plane shear load on the cassette wall, it indicates some stress deformation failure although visible but since the maximum stress values obtained under loading (7.424N/mm^2) is lower than the ultimate tensile strength of the cassette wall (22.50N/mm^2) from the material properties used. This is an indication that CFRP cassette walls can adequately transmit load safely to the adjoining structural member.

Keywords: Cassette Walls, CFRP

1. INTRODUCTION

In the last decade, experiments have been conducted to investigate the application of CFRP in civil engineering structures. Carbon Fiber Reinforced Plastic (CFRP) has been identified as one of the materials that possesses numerous benefits in the field of construction such as; its ability to enhance shear strength and compressive strength of reinforced concrete, high strength-to-weight ratios, corrosion resistance, high stiffness-to-weight ratio, chemically inert, non-magnetic behavior, high durability potential, good rigidity, etc.(Dai, 2013). This paper presents the structural effectiveness of CFRP cassette walls subject to in-plane shear load which in-turn measures its performance under; wind induced diaphragm action and earthquake loads. In construction industries, the use of CFRP is dominant in retrofitting (strengthening an existing structure) and as a pre-stressing material in place of steel (Dai, 2013). Applied to reinforced concrete structures for flexure, CFRP typically has a large impact on strength (doubling or more the strength of the section is not uncommon), but only a moderate increase in stiffness (perhaps a 10% increase). This is because the material used in this application is typically very strong (for example, 3,000 MPa ultimate tensile strength, more than 10 times mild steel) but not particularly stiff (150 to 250 GPa, a little less than steel, is typical) (Micheal, 2006).

Walls are solid structures that define and sometimes protect an area, but in most occurrences, a wall; delineates a building and supports its superstructures, separates space in buildings into rooms, or protects or delineates a space in the open air. The balance between shear and flexure loading has a very significant role in overall deformation and strength characteristics. In engineering practice, the main loads applied to a structural wall system may be vertical compressive load (from the storey's above), horizontal bending load about the minor axis (from wind pressure and suction) and in-plane shear load (from earthquake or wind-induced diaphragm action) (Dai, 2013). In the past, the study of cassette wall panels was mainly focused on the buckling behavior of individual components under axial loads due to their thin-walled feature. It is also very important to consider the behavior of the overall wall when the panel system is subjected to in-plane shear loads, such as; earthquake load and wind-induced diaphragm action. Although, previous researches have indicated that connections are extremely important for shear wall panels (Dai, 2013). The connectors dominate the in-plane shear stiffness and ultimate load capacity of the wall panel.

2. BACKGROUND OF STUDY

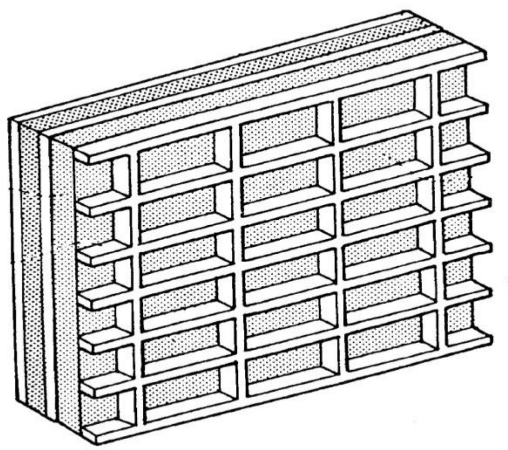
The idea of cassette wall construction was first developed by Rolf Baehre in the late 1960’s. He published several papers, which presented the results of experimental and theoretical studies and were used as the basis of the design rules in ENV 1993-1-3: 1996 (Eurocode 3: Part 1.3). Baehre’s results were published in the German journal Stahlbau between 1986 and 1988 (Kaitila, 2004).

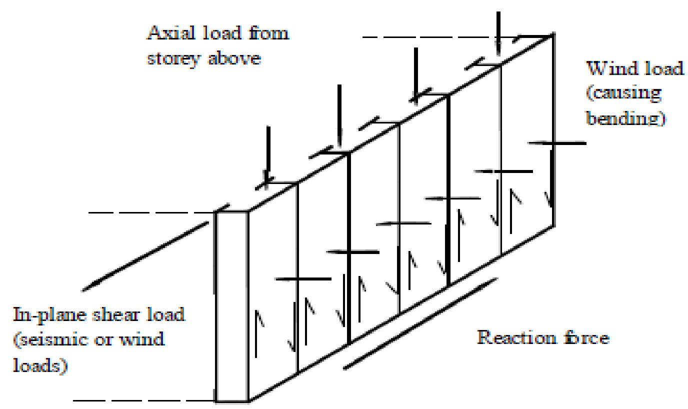
a) Cassette Walls

Cassette wall structures provide an alternative to the more common type of light-weight steel wall framing based on individual stub columns connected to each other at both flanges with the help of gypsum wall boards (Kaitila, 2004).

A wall cassette is a perfect material for quick wall development, mainly for industrial buildings and warehouses. Their biggest advantage is an easy assembly, multifunctional use and high durability of elements. A building can be easily insulated which allows for the use of comprehensive solutions for light building development. The whole construction is characterized by high rigidity, leak-tightness and low specific gravity of sheets. High aesthetic value of elevation and resistance to mechanical damages is an additional asset (Lawal, 2014).

Figure 1 shows a typical cross section of a cassette wall (Dai, 2013)





(a) typical cross-section of a CFRP cassette wall (b) the typical loading modes

Cassettes are large U- or C-shaped cross-sections that have two webs connected with a wide flange and a lip-stiffened narrow flange on the other side, as shown in Figure 2.2. Different types of stiffeners can be used also along the wider flange and in the webs in order to increase the effective width of section parts in compression. Cassettes are installed as wall structures so that they span either vertically or horizontally. They have also been used as roof structures. They are fastened using screws to columns and beams or purlins (Kaitila, 2004).

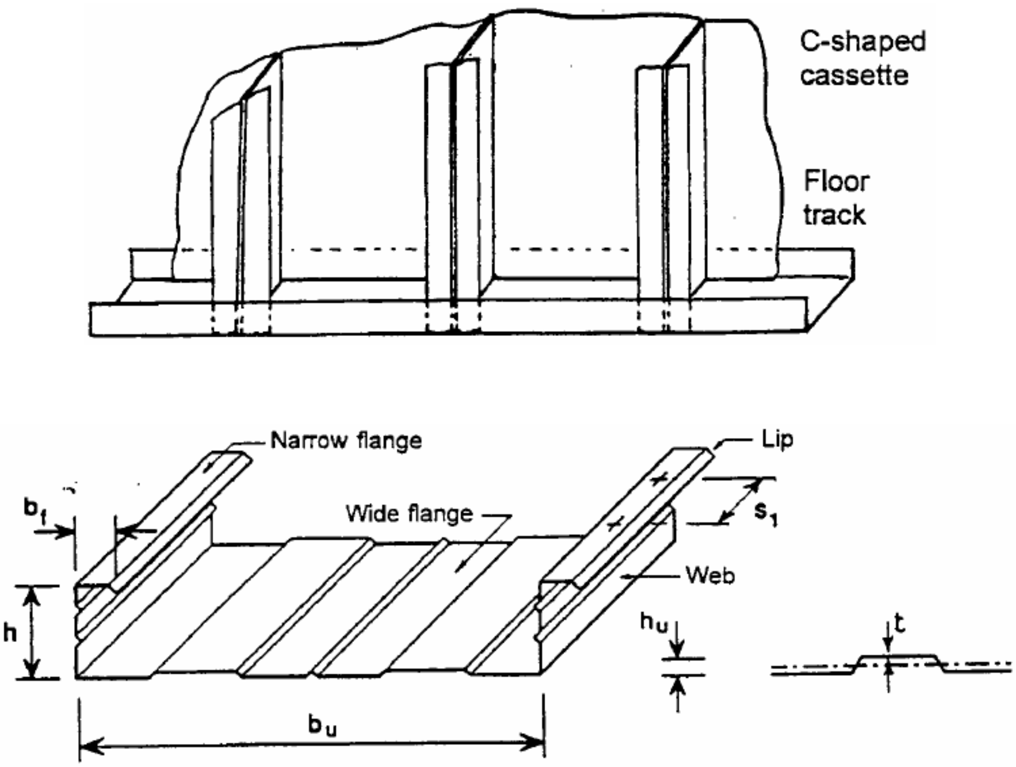


Figure 2.2: Cassette wall construction (Kaitila, 2004).

Where; b_f = width of flange, h = height of web, s_1 = slant height, h_u = web height between the middles of the flanges, t = thickness of the steel sheet, b_u = width of the wider flange

b) Shear Design Philosophy

The design of CFRP shear reinforcement is based on the strength design method. The strength reduction factor of 0.75 given by ACI 318 – 05 for reducing nominal shear capacity of steel reinforced concrete members should also be used for CFRP reinforcement. The factored shear strength ϕV_n must be larger than the factored shear force V_u at the section considered. Computation of the maximum shear force V_u at beam supports can be attained following ACI 318 – 05 provisions (Nagasaka *et al.*, 1993). Also, the provisions of EC2 (2008) should be diligently considered such that its shear recommendations can be satisfied.

c) In-Plane Shear of Cassette Walls

Cassettes have commonly been designed as single-span structures. In this case, the sagging bending moment is usually critical in design and vertical shear forces and transverse forces at supports can often be ignored. The bending moment resistance is critical for instance when the structure is submitted to a large wind load (Kaitila, 2004). When cassettes are designed to have two or more spans, the structural behavior at the interior support has to be studied carefully. The resistance against the combined actions of hogging bending moment and local transverse forces has to be verified (Kaitila, 2004).

When the cassette is under bending action, the wider flange tends to deflect towards the neutral axis of the cross-section. This phenomenon is known as flange curling and has the effect of reducing the bending capacity as the distance of the flange from the neutral axis is reduced.

According to the ECCS (1995), the maximum shear capacity (ignore the buckling) at the ultimate limit state of a steel cassette wall panel without opening and without lining board can be determined by the fasteners in the webs (P_{max}) of the cassettes as shown in Equation 2.1 (Dai, 2013);

$$P_{max} = \left(\frac{a}{b}\right)\left(n_s F_s + \beta_1 F_p\right)$$
(2.1)

Where; a = width of cassette wall panel, b = height of cassette wall panel, P_{max} = design shear capacity, n_s = number of seam fasteners (fasteners in the webs) per seam, F_s = design strength of an individual seam fastener, β_1 = factor to allow for the number of cassette to longitudinal member fasteners per cassette values are given.

For the seam connections (including fasteners joining cassette and cassette, cassette and vertical cold formed steel edge stiffeners), the ultimate (design) strength is determined by Equation 2.2;

$$F_u = 2.9(t/d_n)^{1/2} * f_u d_n t$$
(2.2)

Where; F_u = ultimate (design) strength, t = net sheet thickness (mm), d_n = the nominal diameter of the fastener (mm), f_u = the specified ultimate tensile strength of the connected steel sheet (kN/mm^2) (Dai, 2013).

3. METHODOLOGY

a) Finite-Element Method

This approach discretizes the structure into small divisions (elements) where each element is defined by a specified number of nodes. The behavior of each element (and ultimately the structure) is assumed to be a function of its nodal quantities (displacements and/or stresses), that serve as the primary unknowns in this formulation. This is one of the most general and accurate methods to use, because it does not put any limitation on the geometry, loads, or boundary conditions, and can be applied to open/closed girders and static/dynamic analysis. Additionally, the structure's response can always be improved by refining the mesh and increasing the number of nodes (or degrees of freedom) for each element. However, the rather involved modeling and analysis efforts required by this method may in some cases make it impractical for preliminary analysis (Beneditti and Tralli, 1989).

b) Finite Element Modeling using Simulia ABAQUS

Finite Element modeling method has been successfully used in the analysis of light gauge steel wall panels (Dai, 2013). The non-linear finite element package ABAQUS software will be employed in the simulation of the structural effectiveness of cassette wall panels subject to in-plane shear load. The cassette walls were designed using ABAQUS/CAE through the following procedures: Creating Part, Creating Material, Defining and Assigning Section Properties, Configuring Analysis, Creating Linear Perturbation Step, Applying Boundary Conditions and Loads

Table 1: The ABAQUS material properties as used in this paper.

Materials	Young Modulus	Poison Ratio	Density(KN/m^3)	Yield Stress	Strain
CFRP	310000Mpa	0.34	1400	2250Mpa	0.019

4. RESULTS AND DISCUSSION

The CFRP cassette wall was analyzed using Simulia ABAQUS CAE 6.10.1. The cassette wall was subjected to in-plane shear loading as well as axial load from the top of the wall when in service. Finite Element Analysis was carried out on the modeled cassette wall when uniformly distributed load of $5kN/m^2$ was applied up to a maximum of $20kN/m^2$ considering a linear perturbation step axial load yielded a deformation scale factor of 1.00E0 at 1 second

a) Von Mises stress deformation at $5kN/m^2$

The non-linear finite element stress analysis resulted to a Von Mises minimum stress value of 2.124E25 and maximum stress value of 2.423E27 and a full analysis loading comprising both axial load as well as in-plane shear load yielded a stress deformation scale factor of 6.307E6 at 1 second, resulting to a maximum Von Mises stress values of 1.896E3 and minimum value of 2.061E2 as shown in Plates 1 and 2.

b) Von Mises Stress Deformation at $10kN/m^2$

The non-linear finite element stress analysis result to a Von Mises minimum stress value of 2.124E25 and maximum stress value of 2.423E27 and a full analysis loading comprising both axial load as well as in-plane shear load yielded a stress deformation scale factor of 3.154E6 at 1 second, resulting to a maximum Von Mises stress values of 3.712E3 and minimum value of 4.120E2 as shown in Plate 3 and 4.

c) Von Mises Stress Deformation at 15kN/m^2

The cassette wall diagram below did not suffer any stress deformation failure due to the stiffness of the material property of the cassette wall; the non-linear finite element stress analysis considering a linear perturbation step axial load yielded a deformation scale factor of 1.00E0 at 1 second, resulting to a Von Mises minimum stress value of 6.372E25 and maximum stress value of 7.269E27 and Considering a full analysis loading comprising both axial load as well as in-plane shear load yielded a stress deformation scale factor of 2.102E6 at 1 second, resulting to a maximum Von Mises stress values of 5.568E3 and minimum value of 6.182E2 as shown in Plate 5 and 6.

d) Von Mises Stress deformation at 20kN/m^2

The non-linear finite element stress analysis results to a Von Mises minimum stress value of 8.496E25 and maximum stress value of 9.692E27 and a full analysis loading comprising both axial load as well as in-plane shear load yielded a stress deformation scale factor of 1.577E6 at 1 second, resulting to a maximum Von Mises stress values of 7.424E3 and minimum value of 8.242E2 as shown in Plate 7 and 8.

5. CONCLUSION

The results after the analysis shows that cassette walls of the configuration selected and subjected to in-plane shear loading can sustain axial loads of 5kN/m^2 up to 20kN/m^2 without suffering major deformation damage due to reaction forces. However, considering loading as a result of both axial as well as in-plane shear load on the cassette wall indicates some stress deformation failure although visible but since the maximum stress values obtained under loading (7.424N/mm^2) is way lower than the ultimate tensile strength of the cassette wall (22.50N/mm^2) from the material properties used, it therefore implies that the CFRP cassette wall can adequately transmit the load safely to the adjoining structural members without failure in any section.

The use of CFRP cassette walls is a better material substitute for composite concrete wall with steel reinforcement and or timber cassette walls. This result indicates a higher stress carrying capacity of the cassette wall as compared to other conventional walls which may be made from traditional materials like steel, concrete, or timber.

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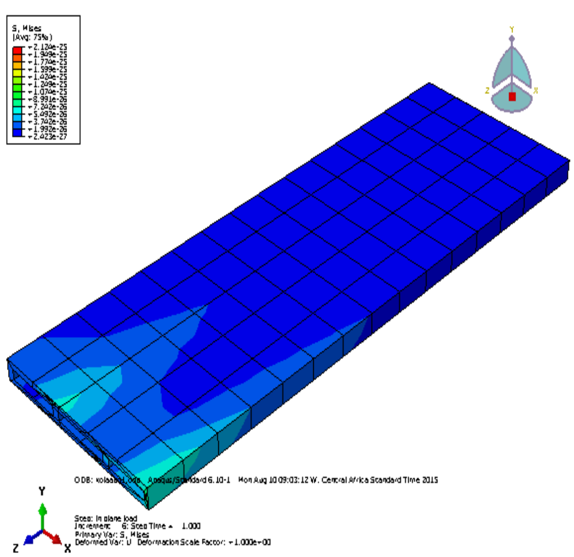

Plate 1: Von Mises axial load stress deformation at $5kN/m^2$

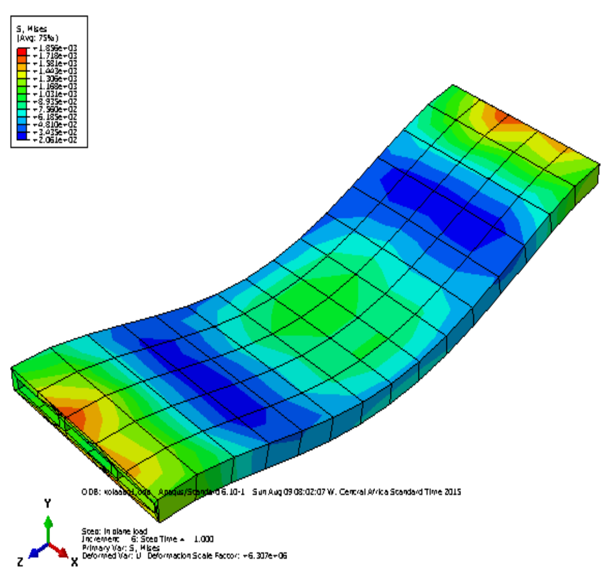

Plate 2: Von Mises axial load and in-plane shear load stress deformation at $5kN/m^2$