SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V7I4P102

Volume 7 Issue 4, 5-13, April 2020

Cold-formed Steel Cassette Wall System for Building Construction

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Received Date:29 February 2020
Revised Date: 06 April 2020
Accepted Date: 11 April 2020

Abstract *Cold-formed steel cassette wall construction is a relatively new modern technology but fast gaining in popularity in the steel construction industry. Steel cassettes are modern cold-formed steel profiles used for load-bearing wall panels in low-rise buildings. This paper reviews the major developments in the theory and practice of steel cassette wall construction. After series of research efforts, coupled with the testimonies of industry practitioners, the steel cassette wall system was developed as a good alternative to the use of the traditional wall studs in light gauge steel framed buildings. Wall studs are old-fashioned and cumbersome to handle whereas steel cassettes are light, durable and aesthetically appealing. This paper also acknowledges the deficiencies in the existing design approach of the cassette wall systems and what the research community is doing to address this challenge.*

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Keywords *Steel cassettes, cold-formed, light gauge, wall studs, low-rise, building construction.*

I. INTRODUCTION

The emergence of steel cassette profiles as construction material in the steel construction industry dates back to the 19th century. The concept of cassette wall construction emanated from the works of Baehre in Stockholm in the late 1960s. However, the practical application began to manifest in the late 1990s to 2000. The use of cold-formed steel cassette walls in building construction is a relatively new technology in the steel construction industry. The technology is suitable for low-rise building projects and related construction works. This is a perfect alternative to the use of the traditional wall studs for delivering low and medium-rise buildings.

Steel cassettes are cold-formed, usually C-shaped sections with integral folds (stiffeners). Generally cassettes have relatively narrow (lipped or unlipped) webs and wide flanges. In general, the dimension of the wide flange ranges from 300 – 600 mm, and the thickness of section material ranges from 0.75 to 1.5 mm following the governing code of practice [1]. Cassettes can be manufactured as plain section members or in perforated form depending on functional, technical and architectural demands. They derive part of their advantages (over the alternative materials) from their relative thinness, lightness, shear stiffness and attractive appearance. The major function of the steel cassette member is to carry the load. Thus, strength and stiffness are the major governing design criteria. The stressed-skin design principle is given prime consideration in the design methodology for cassette wall systems because of the required resistance to the in-plane lateral forces often generally imposed by wind or seismic forces. Lateral loads can also arise from mining subsidence.

The cassette wall typically comprises of the steel cassettes themselves, the longitudinal and transverse framing members, fasteners or connectors which are often referred to as self-drilling or self-tapping screws, spot welds or clinches, and holding down bolts. The wall may also include lining boards or infill foam materials for thermal and acoustic insulations. Cassette walls have the advantage of providing a weatherproof wall as well as a structural frame and avoid many of the stability problems of stud wall construction. They also act as a shear diaphragm concerning horizontal (wind) load and thus avoid the necessity of providing bracing systems in the plane of the walls. The conventional diaphragm design methods can equally be used for the design of cassette diaphragms [2]. This can even enhance simpler and more flexible detailing and speedy construction.

Components of cassette wall assembly are often connected using fasteners. Fasteners come in different forms, shapes and sizes. The strength, stiffness and stability of the cassette wall diaphragm depend largely on the quality and adequacy of the interconnection of members by fasteners. Although basic fastener types such as bolts, screws, welds, and rivets may be used, experience has shown that unless special and skilled techniques are employed, welding of thin metal sheets may not produce good results because of the likelihood of damage to the protective coating, susceptibility to bimetallic corrosion and resultant impairment of water-tightness. Rivets should also be used with caution because of their vulnerability to brittle mechanisms of fracture. For instance, aluminum blind rivets are unsuitable. In the same vein, clips and hook bolts, or other fasteners that transmit shear forces by friction, are generally unsuitable in this regard [3].

The forces induced in the fasteners by stressed skin action are essentially shear forces and it is the shear strength and shear flexibility (slip) of these fasteners that are important in stressed skin design. However, certain fasteners such as sheet to purlin fasteners in roof diaphragms are subjected to additional tensile (uplift) forces from wind suction. Since the critical fasteners are usually the seam fasteners, combined loading is not significant. Also, fasteners should be able to transfer forces to the diaphragm in such a way that shear panel results in a state of pure shear. Comprehensive standard specifications of different forms of fasteners are available in the literature [4-6] and some specific information can be obtained directly from the manufacturers. Some basic requirements of mechanical fasteners include nominal size, minimum pitch, minimum end and edge distances, and use of washers to enhance shear strength and ensure water-tightness.

II. Steel cassettes and cassette wall systems

The apparent lack of sufficient published literature in this research area is attributable to the relative newness of the cassette wall technology, inadequate public awareness, poor patronage from the stakeholders, and the slow pace of research efforts generally. However, significant contributions have been made to advance the course of this research area by researchers such as Rolfe Baerhe of Stockholm and his team and JM Davies of the UK and his team, and a host of others.

A. Steel cassettes as cold-formed members

Steel cassettes are cold-formed steel products manufactured by cold-forming processes such as roll-forming, folding and press-braking operations. Cold-formed steel members are of different types and applications depending on their weights, shapes, and dimensions. The different categories include framing members (open, closed, and tubular sections) and panels (cassettes and profiled sheets). A lot of research works have been done in cold-formed steel design and construction culminating in definitive and authoritative publications [1], [7-11]. These include their properties, structural behavior, design approach, and applications. Unlike the hot-rolled steel sections which are generally thicker and heavier and are more suited for carrying heavier loads, especially over longer spans, cold-formed steel sections are mostly thinner in cross-section and lighter and generally suited for carrying relatively light loads over relatively shorter spans. Also, while hot-rolled steel sections have applications in tall multi-story buildings as primary framing members, cold-formed steel members are suitable for building components such as purlins, light-weight beams, and columns in low-rise building developments [7]. Nonetheless, the two categories of steel sections can complement each other in multi-story buildings whereby hot-rolled sections function as primary members and cold-formed sections act as secondary members (especially as joists, decks or panels). However, due to improvement in research, manufacturing processes, marketing and construction environments, cold-formed steel sections have been used effectively as primary framing members [12].

B. Steel cassette profiles

Steel cassette profiles (otherwise referred to as Structural Liner Tray [1] are C-shaped sections usually with integral stiffeners and with relatively narrow (lipped) webs and wide flanges. They may be plain (empty) or filled with rigid foam or mineral fiber insulation bonded to the metal for thermal and0 acoustical performance as well as for the improvement of strength, stiffness, durability, and resistance to impact and accidental damage. The elements of a typical cassette profile comprise of a wide flange, two webs, two narrow flanges, two lips, and integral bends or folds (stiffeners) as shown in figure 1 while figure 2 depicts a class of cassette profile used in practice, which is referred to as CIBBAP model.

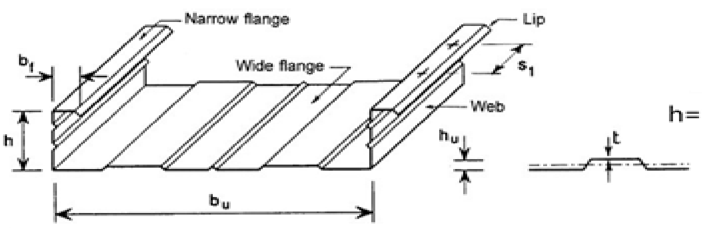

Figure 1: Steel cassette profile [1]

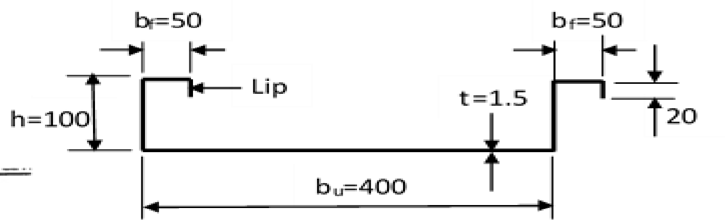

Figure 2: Steel cassette profile (CIBBAP model)

The range of validity of the cassette profile as

0.75 mm	≤	t_{nom}	≤	1.5 mm	(Nominal thickness of cssette section)
30 mm	≤	b_f	≤	60 mm	(Width of the narrow flange)
60 mm	≤	h	≤	200 mm	(Overall depth of the cassette)
300 mm	≤	b_u	≤	600 mm	(Overall width of the wide flange)

I_a/b_u ≤ 10 mm^4/mm (Ia = The second moment of inertia of cassette section)

h_u ≤ h/8 and s_1 ≤ 1000 mm (hu = Depth of corrugations of wide flange)

(s_1 = Longitudinal spacing of fasteners providing lateral restraint to narrow flanges)

given by the code [1] is given above

Typical CIBBAP steel cassette sections measuring 400 mm flange width by 100 mm web depth and 0.75-1.5 mm uniform nominal thickness were in use. This formed the basis of the paper by [13] which was also referred to in [2]. After CIBBAP, steel cassette profiles and a wide range of similar products are being manufactured in Europe by companies such as ArcelorMittal Steel (EU zone - France, Germany) Munker Metallprofile GmBH, in Germany; Kovove Profile in Czech and Slovak republics; Tata Steel in the U.K, etc. Their range of products includes steel cassette profiles; trapezoidal steel profiles, corrugated or sinusoidal profiles; sandwich panels; transparent panels, flashings, and accessories (pads, fasteners – bolts and screws). These products are either in plain or perforated form depending on functional and architectural demands. In the previous research works involving steel cassette profiles, the use of a 400 mm wide flange size (bu) was common [14-15]. However, based on advancement in research and technology, the 400 mm wide flange size (bu) hitherto peculiar to CIBBAP cassette has been increased to 500 and 600 mm by some manufacturers such as Munker and Kovove companies, with a corresponding increase in the web depth. This increment in cassette size appears to pose no design and stability problems because it falls within the range of validity specified by [1], i.e. the wide flange size (bu) should be between 300 and 600 mm. This also explains why, so far, no manufacturer has produced cassette profiles with the wide flange size outside the allowable limits. The cassettes may be delivered plain or with perforations and are generally galvanized or coated with polyester or zinc, in thickness typically ranging from 15 to 40 microns (μm) [16]. The cassettes may also be delivered in aluzinc or stainless steel.

C. Shear strength of steel cassettes

The peculiar lightness and thinness of cold-formed steel members make them prone to all manner of buckling problems. It is normal practice to take the effect of local and distortional buckling modes of failure and their interactions into account in

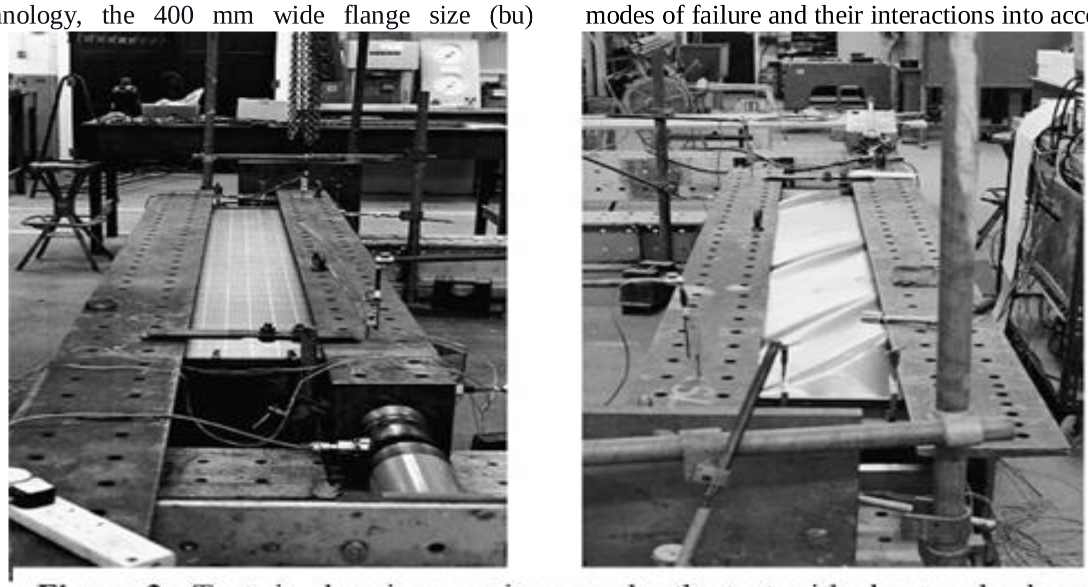

Figure 3: Test rig showing specimen under the test with short ends clamped

the design (determination of strength, stability, and stiffness) of cold formed steel members. The Local buckling behavior, in shear, for both empty (plain) cassettes as well as cassettes filled with rigid insulation was investigated [17-18] using testing and finite element analysis methods. Full-scale laboratory tests with standard cassette trays were conducted based on apparatus in the previous experiment [19] as shown in figure 3.

This is particularly important for single open symmetric cross-sections such as steel cassettes concerning local shear buckling. Due to stressed skin action, in-plane shear stresses are often associated with cassette wall construction, and as such the local buckling of the wide flange usually governs the design process [20]. Further necessary modified tests were carried out by [21] based on parametric studies towards the development of a suitable design model for shear strength. They developed an analytical design model for calculating the local shear buckling of both empty (plain) cassettes and cassettes filled with rigid insulation materials. They discovered that the rigid foam insulant caused a significant increment in the shear buckling strength and that while the initial buckling load is not particularly affected by the boundary condition, the post-buckling load is sensitive to the boundary condition. The objective of these investigations was to address the inherent fundamental deficiencies in the current design code [1] concerning the equations given for calculating the shear strength of plain cassettes. These include the questions of choice of appropriate boundary conditions for plate buckling and whether to consider the plates individually or to consider the section as a whole. Another relevant consideration is whether to neglect the post-buckling strength or to incorporate it into the design equation, as it is usually done in case of plate element in compression. Furthermore, it is necessary to incorporate the beneficial effect of the interaction of the rigid foam and the cassettes into the design equation. In reality, the cassette system is a composite structure and the use of plain cassettes is not normal in practice. Therefore, a realistic, acceptable and efficient design code should take the mutual (in-situ) interaction of the various components of the cassette system into consideration.

Considering their lightweight, thin cross-section and peculiar flange and web conditions, cold-formed sections tend to impose considerable design challenges. Thus their design and construction require careful handling. The relatively small thickness and high ratios of width to thickness may make the individual components of cold formed steel members to buckle at stress values below the yield point if they are subjected to bending, compression, shear, or bearing. Cold-formed steel sections have no precise yield point. The proof strength at 0.5% of the total tensile strain is often used as an effective yield value. Since plastic design requires more stocky steel sections where plastic hinges can be developed. However, the thinness and lightness of cold-formed sections may make the sections not amenable to plastic design. The code [10] allows the increase in yield strength due to cold forming to be taken into consideration by replacing the material yield strength by the average yield strength of the cold-formed element. According to the code, the average yield strength may be determined from the test or calculated from the expression:

$$Y_{sa} = Y_s + \frac{5Nt^2}{A}(U_s - Y_s)$$

, such that $Y_{sa} \le 1.25Y_s$ or U_s (whichever is smaller)

Where N = number of full 90° bends in the section with an internal radius < 5t (fraction of 90° bends should be counted as fractions of N);

t = net thickness of the material in millimetres (mm);

U_s = the minimum ultimate tensile strength in Newton per square millimetre (N/mm^2);

A = the gross area of the cross section in square millimetres (mm^2)

Also, the code gave the values of elastic properties of the steel section to be used in design as:

The Modulus of elasticity E = 205 kN/mm^2
Shear modulus G = 79 kN/mm^2
Poisson ratio,μ = 0.30
Coefficient of linear thermal expansion,
α = 12 x 10^6 per ^{0}C

Other important properties of steel include yield point and yield strength, tensile strength, stress-strain characteristics, tangent modulus, ductility, weldability, fatigue resistance, and toughness.

Kaitila [22] carried out an experimental and numerical investigation of the web crippling strength (resistance) of cold-formed steel cassettes against local transverse forces, using the finite element method. Plain (unstiffened) cassette webs and webs with longitudinal stiffeners situated on only one side of the web mid-line was studied. There was good agreement between numerical results and test results. Thereafter, a parametric study was conducted based on varied cross-sectional parameters on the resistance against local transverse forces of longitudinally stiffened webs. It was shown that the use of a longitudinal stiffener can reduce the web crippling capacity by at least 10% in comparison to a similar cassette with the unstiffened web. A range of reduction factors was proposed for the calculation of the crippling strength of the type of the stiffened web examined. It is interesting to know that in practice, the interconnection of the cassettes and cassette to frame connection in cassette wall construction is done through and along the longitudinal axis of the webs. Research [23] was carried out on the calculation of the distortional buckling strength of cold-formed C-shaped steel column by the Direct Strength Method (DSM), based on consideration of uniform and non-uniform elevated temperatures. The result of the numerical analysis conducted revealed that the equation in [8] based on the DSM is only applicable to uniform temperature conditions. A new distortional buckling curve was proposed for non-uniform temperature conditions.

Testing was carried out to assess the non-linear post-buckling behavior and ultimate strength of a selected number of cold-formed steel channel sections undergoing interactive local-distortional-global (LDG) buckling modes [24]. The test specimens were compressed uniformly between fixed end supports. It was concluded that the failure modes exhibited the simultaneous occurrence of LDG buckling with evidential interaction between the three buckling modes. The ultimate strength data generated can be utilized for the development and calibration of the DSM approach for lipped channel sections experiencing LDG interactions. Using five different design standards including DSM, a comparative study of distortional buckling strength of cold-formed channel sections was conducted by comparing the results obtained from the codes' provisions with the respective experimental results collected from the literature [25]. The result of the comparative analysis showed that the DSM gave flexural strength (moment capacity) closest to the experimental result. The DSM was then chosen for the further parametric study to assess the influence of distortional buckling on the strength of the section by varying the lip depth of the selected sections, which is believed to possess a significant influence on distortional buckling strength. The parametric study was conducted through CUFSM (v3.12), a background analysis software for DSM. It was concluded that all the codes adopted the effective-width-method (EWM) of design as the key provision and that the DSM which gave the closest prediction to the experimental results had the most satisfactory performance.

D. Recent developments

Some researchers have shifted their focus from ordinary coated or galvanized light gauge steel from the rolling mill to that covered, impregnated or reinforced at the flanges or webs with additional material, in a composite fashion. Notable among the materials used in this increasingly attractive modern approach is Carbon Fibre Reinforced Polymers (CFRP). Control of distortional buckling in cold-formed steel members by the use of CFRP has been investigated by several researchers. Compression tests on plain cold-formed steel channel sections and sections strengthened by CFRP were conducted [26]. A total of 36 specimens (i.e. 18 for each of the two categories) was tested in a high capacity hydraulic testing machine using simple lipped channels. Bonding (steel-CFRP interaction) which is commonly problematic with CFRP-related research was adequately addressed. The results of the theoretical calculations carried out by DSM [8] when compared with the experimental results at the ultimate loads, showed that the flexural capacity of the CFRP-strengthened steel section can be predicted within a reasonable accuracy and that the strengthening effect yielded significant increments in axial compressive strength. Similar research efforts involving the investigation of bond characteristics between CFRP and light gauge steel sections include [27] and [28]. This is particularly important and has practical application in the cassette wall and related constructions. Research works have been carried out in this regard. Apart from the improvement of structural performance, the use of rigid in-filling material has the potential of improving thermal performance and resistance to site damage. FRP-strengthened cold-formed lipped channel sections have also been investigated [29].

E. Steel cassette wall system

The cassette wall typically comprises of the steel cassettes themselves, the longitudinal and transverse framing members, fasteners or connectors which are often self-drilling and/or self-tapping screws, spot welds or clinches, holding down bolts, and may include lining boards or infill foam materials for thermal and acoustic insulations. This unique assemblage of different components can produce an integrated structural wall system in the form of a diaphragm, with or without openings. The concept of the cassette wall system originated from Stockholm by Baehre in the late 1960s. However, this idea was not put into use until several years after. Structurally, the cassette wall is subjected to three main load systems as shown in figure 4 [30]. These are the axial compression loads from the stories above, the bending about the minor axis usually from wind pressure and suction, and the shear forces imposed by wind or seismic-induced diaphragm action.

Accordingly, three members of Baehre's research

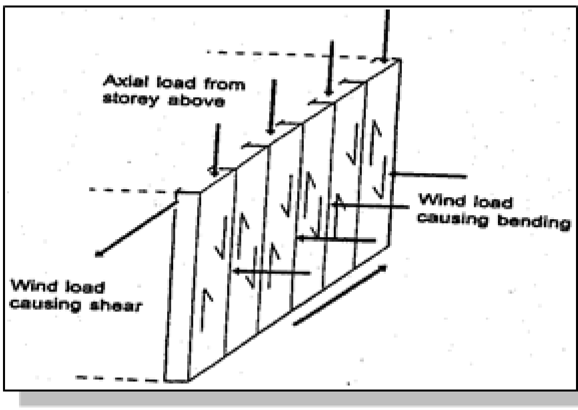

Figure 4: Load systems in a cassette wall

team Thomasson, Konig, and Nyberg researched the structural behavior of steel cassettes under each of these three actions [31]. Within a decade thereafter, Baehre (1986–1996) along with other researchers such as Buca and Egner undertook several research activities on the development of design rules for cassettes (structural liner trays) at the University of “Fridericiana Karlsruhe” in Germany. The empirical design rules for cassettes derived by Baehre and his team are based primarily on testing. This was how the enabling clauses for steel cassette design in the design code [1] came about. Design by calculation gives lower values for the load-bearing capacity of cassettes compared to appropriate tests [21]. Since cassettes are mass-produced products, testing may prove to be a better option. However, modeling a design procedure allows a comparison of different shapes of cassettes and an optimization of the geometry.

For a long time, Baehre’s concept of steel cassettes was not put into practice before the emergence of the “Scanmodule” cassette system [32] when Baerhe’s ideas were first put into use. However, the use of the cassette wall system began in France by the company ‘Produits Acier Batiment’ (PAB) with a trading name ‘CIBBAP’ and has delivered several building projects under the name. Quite a several buildings have been constructed in several countries using the Scanmodule and Cibbap cassette wall construction systems. For instance, the Cibbap system has been applied to a wide range of buildings including housing (single and flat blocks), offices, hospital buildings, and administrative and school premises. These constructions have been carried out in various countries including France (mainland and overseas departments such as Reunion, New Caledonia, and Guadalupe), Spain, United States, and Mauritius and even Thailand [13]. Practical illustrations of the application of cassette wall systems are shown in figures 5 and 6 [15].

Figure 5: Erection of prefabricated cassette wall panels for house construction

The Scanmodule and CIBBAP systems are not only amenable to modular construction techniques; they are also suitable for mass production with relative ease. The same applies to the ease with which they can be fabricated, stacked and transported. The typical case studies given by [31] use press-joining to make the factory connections in the seams between the adjacent cassettes. The corresponding site connections are generally by bolting. Interestingly, they all make extensive use of stressed skin design in the walls, floors and roof so that, with one minor exception, none of these structures include any separate wind bracing. Thus, the connection details are all simple and conventional. In the United Kingdom, the veteran researcher, J. M. Davies and his team investigated the behavior of cassettes in the recent and distant past. Their research concentrated on the shear behavior, the post-buckling behavior, the shear stability of foam-filled cassette sections, the stability generally, and the construction technology. The contribution of Davies and his team of researchers will no doubt enrich the quality of steel cassette construction in Europe and beyond. The cassette walls have the advantage of providing a weatherproof wall as well as a structural frame and avoid many of the stability problems of stud wall construction [31]. They also act as a shear diaphragm concerning horizontal (wind) load and thus avoid the necessity of providing bracing systems in the plane of the walls. The conventional diaphragm design procedures can be equally applied to diaphragms constructed with cassettes (Davies, 2006). This can enhance simpler and more flexible detailing and speedy construction.

The orientation of cassettes in wall construction depends on architectural requirements and construction convenience. Cassettes can be arranged vertically or horizontally to form the load-bearing walls of low or medium-rise buildings such as houses and offices [18]. Typically, cassettes are thin-walled light gauge steel sections with wide flange which seems to characterize the structural behavior under load, which tends to complicate the design process

Figure 6: Houses completed with cassette wall systems

due to curling. Cassettes are fast gaining attraction and acceptability in the areas of wall, floor and roof construction [30]. Experimental models using cassette wall systems without openings have been developed, investigated and analyzed [21]. The results have been validated based on numerical modeling using finite element analysis, which was replicated using cassette wall panels with door and window openings [14-15] and [33-34].

Dai [34] carried out numerical modeling of the structural behavior of cold-formed steel cassette wall panels subjected to in-plane shear loads, using the finite element method based on Abaqus software. This investigation involved plain cassette wall panels and wall panels with door and window openings and plasterboards. The maximum shear capacities predicted by the numerical results of the models without openings agreed with the theoretically predicted values by [5]. But no validation attempt was made for models with openings and lining boards because no provision was made for them in the codes. This is in addition to the absence of insulation materials against thermal and acoustic effects. To validate the panels with openings and lining boards, and other related parameters, more work needs to be done. Dai's research was based essentially on linear elastic analysis without consideration for the plastic behavior of the panels. It is no wonder therefore that Dai assumed- that the plastic effect of the cassette material is combined into the non-linear properties (load-slip behavior of fastener) of the connections. This also explains why he used only the elastic (ignoring the plastic) properties of the panel members in his numerical modeling. This is still in line with the traditional diaphragm theory in which the elastic distribution of internal fastener forces governs the design. This approach which is tied to the conventional stressed skin design is conservative, not rational, and unlikely to be economic [30].

F. Stressed skin design of cassette diaphragm

Section 2.5, figure 4 has explained the three main forces acting on the cassette wall system covered in [1-2], and [13]. In design the three loading conditions need to be checked individually and the most critical will govern the design. But the behavior in shear due to the action of in-plane lateral loads in the sheeting and axial forces in the edge members is covered by the conventional principles of steel "diaphragm" or "stressed skin" design. The two are sometimes used interchangeably. Stressed skin design is preferred in Europe [1], [4-6] while diaphragm design is used in America, Canada, Mexico and Australia [9] and [37]. But so far, only one of these codes [1] recognized the existent of steel cassettes. However, this design concept was originally meant for diaphragms composed of trapezoidal steel profiles based on test results and empirical evaluation of the variable parameters tested and the shape factors considered in the enabling optimization process.

The major differences between steel cassettes and the trapezoidal profiles used in roof decking for which the stressed skin design principles were originally developed have been given in [17] and [36]. It is therefore inevitable that certain modifications are necessary before the conventional stressed skin design can be rationally applied to cassette wall diaphragms. A typical necessity for modification is in the application of the well-known Simplified Easley Equation for calculating the shear flow that causes the local shear buckling of the wide flange of the cassette. This equation has long been proved to be valid for the conventional diaphragm theory [36].

$$T_{v,Rd} = \frac{36}{b_u^2} \sqrt[4]{D_x D_y^3} \qquad (1)$$

where Dx = bending stiffness across the wide flange $\approx \frac{EI_a}{b_u}$, Dy = Bending stiffness along the wide flange $= \frac{Et^3}{12\,(1-v^2)} \approx \frac{Et^3}{10.96}$ and I_a= The second moment of area of the wide flange about its centroid

Thus,

$$T_{v,Rd} = \frac{36E}{\sqrt[4]{10.96^3}} \sqrt[4]{\frac{I_a t^9}{b_u^9}} = 6E\sqrt[4]{I_a \left(\frac{t}{b_u}\right)^9} \qquad (2)$$

These are the equations given in the enabling clause 10.3.5 [1], and the code gave the limits of the shear flow due to ultimate limit states design loads as:

$$T_{v,Rd} = 8.43E\sqrt[4]{I_a \left(\frac{t}{b_u}\right)^9} \qquad (3)$$

The shear buckling of the wide thin flange can be based on the Simplified Easley equation, from which the following equation is derived:

$$V_{buc} = \frac{8.43EL}{b_u^2} \sqrt[4]{I_a t^9} \qquad (4)$$

The following four (4) components of shear flexibilities are always to calculate the deflection (shear flexibility) [38]:

c1.2: shear strain

c2.1: flexibility of the sheet end fasteners

c2.2: flexibility of the seam fasteners

c2.3: flexibility of the "shear connector" (longitudinal edge) fasteners.

III. Discussion

Cassette wall technology is a relatively new phenomenon in the steel construction industry. It has however, received appreciable attention in developed countries such as the United Kingdom, France, Spain, and the United States. Its ease of construction, relative simplicity and affordability make it a material of choice in the construction of low-rise and medium-rise buildings. Cassette wall technology is a better alternative to the conventional method of constructing light gauge steel framed buildings using wall studs. Cassette wall can be used to comparative advantage in several ways which include: simple design and detailing, rapid construction, robustness, water-tightness, and lightweight. However, despite the promising nature of this technology, there is yet to be an authoritative or definitive standard code or manual for its design. The conservative and wholesale adoption of the conventional diaphragm theory is overly conservative, irrational, may be misleading, and unlikely to be economical. This is so because the theory is based on the linear-elastic distribution of fastener forces without regard to non-linear behavior and plastic distribution of fastener forces at failure. It is also not amenable to ductility requirement and limit states design consideration. However, research efforts have been stepped up in respect of the aforementioned challenges, but more work still needs to be done towards achieving sustainable development of a workable and acceptable design model that can perform satisfactorily at the ultimate limit state and serviceability limit state.

Cassette wall panel as a composite structure presents a substantial amount of structural analysis and design challenges because of the number and types of dissimilar materials involved. This is more so because cassette wall technology has not received widespread acceptance and patronage by major stakeholders in the steel construction industry. Therefore, there are quite several methodical research steps to consider which cannot all be taken in one fell swoop. Apart from the aspect of openings and limit state design consideration, there are other considerations such as the thermal and acoustic performance of the steel cassette walls, coupled with the fact that the walls should be designed as cavity walls (two-skin composite structure). Also, steel cassette profiles are susceptible to buckling phenomena such as local and distortional buckling as well as flange curling. These and other related considerations have not been fully incorporated into the current design manuals for optimal effect. They are subject to subsequent and continuing research and development efforts to take cassette wall construction and development to higher heights.

Practical application of cassette wall technology has been on for several years and quite a good number of projects have been executed using the technology. Cassette wall systems have benefits and advantages over alternative building materials in many ways. Apart from structural, economic and architectural benefits, it is generally cost-effective, fire-resistant and with low risks involved, coupled with attendant low insurance costs. In terms of speed of project execution, cassette wall technology guarantees early or timely project completion, taking advantage of the thinness and lightness of the steel as well as the dry and modular construction opportunities available. Above all, steel cassettes are galvanized cold-formed products with attractive and elegant appearance with the aesthetic appeal on a sustainable basis. This means invariably that it needs little or no renovation requirements, has low maintenance cost and again low insurance cost. It is interesting to note that potential sources of concern to the users of cassette wall systems such as thermal and acoustic problems have been addressed by the provision of mineral wool or polystyrene insulation materials. Though, the activities of the stakeholders in the cassette wall construction industry are somehow low and the research community is seemingly slow, there is no doubt that the industry has come to stay.

4.0 Conclusion

Major developments in the theory and practice of steel cassette wall construction have been reviewed. The emergence of the steel cassette wall system has come as a viable alternative to the use of the traditional wall studs in light steel framing for low and medium-rise buildings such as houses and offices. The deficiencies in the existing design codes and what the research community is doing to address the situation have been discussed. It is not normal in practice to use only plain cassettes without in-filling materials such as mineral wool or polystyrene for improvement of thermal and acoustic performance. Generally, thin-walled metal structures perform better as composite structures when combined with other materials. But the design provisions and specifications in the existing design theories are based on only plain cassettes. However, progress has been made through the design equation developed by Davies and Fragos for the prediction of shear buckling strength of empty and in-filled cassettes. So, members of the research community should strive to sustain the on-going efforts to address this gap. This will help to incorporate efficient design models in the design code that will truly cater to the composite (in-situ) nature of the cassette wall. In the same vein, the existing design standards are based on the conventional diaphragm theory that takes only the linear elastic behavior of cassettes into account without due consideration for the non-linear elasto-plastic and plastic behavior of cassette wall. This is a critical gap that needs to be filled by the research community. The subsisting efforts in this regard should be sustained to achieve this all-important goal.

Acknowledgment

The authors would like to thank the authorities of Ahmadu Bello University, Zaria, Nigeria and Kaduna Polytechnic, Kaduna, Nigeria, for their approval and support to embark on this research study in India. We also express our thanks to Dr. Niraj Shah and Dr. Parag Sanghani for their encouragement throughout the research article. We equally express our thanks to Dr. Deepak Singh Panwar for his assistance in the course of this research study. We also appreciate the opportunity given by P P Savani University, Surat, India, to embark on this research article.

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