Building applications of cold-formed steel shapes

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Abstract

Cold-formed steel shapes are light-weight materials and suitable for building construction owing to their versatility in shapes and sizes, high structural performance and durability. They are widely used as structural and non-structural building products in many parts of the world for the last fifty years. This paper aims to introduce the general use of cold-formed steel shapes in building construction. Details of the steel materials and the manufacturing processes of cold-formed steel shapes are presented. Typical uses of cold-formed steel shapes in roof, wall and floor systems are also described in details. Recent developments of cold-formed steel shapes are also highlighted. Engineers are encouraged to take full advantages offered by cold-formed steel construction technology to build strong and stiff buildings of high buildability and structural economy.

Key words

Cold-formed steel shapes, roof and wall systems, floor systems, steel building products.

1 Introduction

Cold-formed steel shapes are light-weight materials and suitable for building construction owing to their versatility in shapes and sizes, high structural performance and durability [1,2]. They are widely used as structural and non-structural building products [3,4,5] in many parts of the world for the last fifty years. Common applications of cold-formed steel shapes include building envelopes such as roof and wall systems with claddings and sections, and floor systems with decking. Other applications are joists of medium span in floors, studs in wall panels, storage racking in warehouses, and hoarding structures in construction sites. Since 1990, there is a growing trend to use cold-formed steel sections as primary structural members in building construction, such as low to medium rise residential houses and portal frames of modest span.

This paper aims to introduce the general use of cold-formed steel shapes in building construction. Details of the steel materials and the manufacturing processes of cold-formed steel shapes are presented. Typical uses of cold-formed steel shapes in roof, wall and floor systems are also described in details. Recent developments of cold-formed steel shapes are also highlighted.

2 Cold-formed steel shapes

Structural cold-formed steel shapes are produced from thin quality steel strips, such as Grade S280 and S350 steel strips which have guaranteed minimum yield strengths of 280 and
350 N/mm\(^2\) respectively. Both steel grades are the most commonly specified grades in cold-formed steel shapes, although it is often found that the actual yield strength is considerably higher than the specified minimum values. Steels with non-guaranteed yield strengths may be used in some applications, provided that the strengths of the materials are determined with standard coupon tests. The thicknesses of cold-formed steel claddings and deckings typically range from 0.6 to 1.5 mm while those of cold-formed steel sections typically range from 1.0 to 3.5 mm; they are usually supplied pre-galvanized.

Steel strips are produced by cold reducing hot rolled coil steel with further annealing processes to improve the ductility of the materials. During 'cold forming' of a shape, the yield strength of the steel is further increased, due to cold working by the process of "strain hardening", as illustrated in Figure 1. The increase in yield strength by cold working is often expected to be significant, and it is typically in the range of 10% to 30%, especially in highly stiffened sections with many bends. It should be noted in cold-formed steel shapes that the yield point is not a clearly defined transition point, as it is for hot rolled steels, and thus, the proof strength at 0.2% strain is often used as an effective yield value. Moreover, ductility always reduces with cold working, and cold working reduces the ratio of the ultimate to the yield strength of the material.

2.1 Methods of forming

Strip steels in coils are normally supplied with a cover width of 1 to 1.25 m, and the steels are then cut (slit) longitudinally to the correct width for the shapes being produced and then fed into a series of roll formers [3,4], as shown in Figure 2. These rolls are set in pairs moving in an opposite direction so that the sheets are drawn through and their shapes are gradually modified along the line of rolls. The number of rolls needed to form the finished shapes depends on the complexity of the shapes, and the overall length of the roll forming machinery may be over 30 m.

In general, setting-up costs are high if special rolls are needed, and adjustable rolls are used as far as possible which permit a rapid change of section depth or width. Roll forming is therefore most economic where large quantities of the same section produced at one time. The lengths of the shapes may be pre-programmed and cut accurately. Holes for attachments and services can also be punched either before or after forming.

An alternative method of cold forming is by press-braking. This is normally only practicable for short lengths up to 0.6 m, depending on the size of the machines available, and for relatively simple shapes. This method can be advantageous for small production runs, because of its low setting-up costs.

2.2 Methods of protection

Hot dip galvanizing, or zinc coating, of preformed strip steels offers protection by sacrificial loss of the zinc surface which occurs preferentially to corrosion of the steel. A zinc coating of 275 g/m\(^2\), or G275, is the standard specification for internal environments [2], and corresponds to a total zinc thickness of about 0.04 mm on both faces, i.e. 0.02 mm per face. It should be noted that the specified sheet thickness includes galvanizing. G100 to G600 coatings may be obtained but these are non-standard. Thick coatings are used in applications where moisture may be present over a prolonged period. Zinc coatings can also be applied by hot dipping of the shapes after cold-rolling or press-braking.
Galvanized steels have good durability [4] because, unlike paint, scratches do not initiate local corrosion of the steels. Similarly, cut ends do not corrode, except where the rate of zinc loss on the adjacent surfaces is high. In some applications, it may be necessary to apply zinc-rich paint to the exposed steels. 'White rust' or wet storage stains may occur if galvanized shapes are stored in bundles in moist conditions, but this does not normally affect their long term performance. Correct storage of bundles of shapes is therefore important.

Galvanizing gives adequate protection for internal members, including those adjacent to the boundaries of building envelopes, such as purlins. The expected design life of galvanized products in this environment exceeds 60 years. Moreover, a recent SCI publication entitled ‘Durability of light steel framing in residential building’ [6] shows that the design life of galvanized steel in 'warm frame' applications is at least 200 years, provided that the external envelope is properly maintained.

Zinc-aluminium coatings also have high corrosion resistance and are sometimes used in cladding applications, but rarely on sections; organic coatings are not used for sections at all. Powder paint coatings, in addition to galvanizing, are often used for specialist products such as lintels.

2.3 Common shapes

Cold-formed shapes are used in many industries and are often specially shaped to suit particular applications. In building applications [5], the most common sections are C and Z sections while trapezoidal and re-entrant shapes are common in claddings and deckings, as shown in Figure 3. There are a wide range of variants of these basic shapes, including those with edge lips, internal stiffeners and bends in the webs. The reason for edge lips and internal stiffeners is because unstiffened wide and thin plates are not able to resist significant compression, and consequently the sections are structurally inefficient. However, a highly stiffened shape is less easy to form and is often less practicable from the point of view of connection to other members. Therefore, a compromise between structural efficiency and practicability is often necessary. Other shapes are the 'top-hat' section and the modified I section, and some sections may also be joined together back to back or toe to toe to form compound sections, as necessary.

2.4 Common applications

Cold-formed steel shapes are widely used in building applications. Profiled cold-formed steel decking is widely used in composite floors, and in flat roofs. Roof and wall cladding are well established and are generally supplied as colour-coated cladding with various forms of organic surface coatings [3].

Main advantages of using cold-formed steel shapes are:

- dimensional accuracy, and capability to be formed to a particular shape for specific applications
- lightness, which is particularly important for buildings in poor ground conditions
- long term durability in internal environments, and freedom from long term creep and shrinkage
- no wet trades, as a 'dry envelope' is quickly achieved using light steel framing
- connections are strong and easily made in factory or on site
ease of construction, as they are delivered to site cut to length and with pre-punched holes, requiring no further fabrication.

Examples of the structural use of cold-formed shapes are as follows:

- roof purlins and wall side rails
- roof and wall claddings
- profiled steel decking in composite slabs
- lintels, floor joists, roof trusses, and space trusses
- separating walls and partitions
- in-fill walling and over-cladding
- storage racking
- prefabricated modular buildings

Applications in general civil engineering include:

- Lighting and transmission towers
  These towers are often made from thin tubular or angle sections that are cold-formed.

- Motorway crash barriers
  These relatively thin steel shapes are primarily designed for strength, but also have properties of energy absorption under impact by permitting gross deformation.

- Silos for agricultural use
  Silo walls are often stiffened and supported by cold-formed steel shapes.

- Culverts
  Curved profiled claddings are often used as culverts and storm pipes.

Other major non-structural applications in building include such diverse uses as dry walls and partitions, garage doors, and ducting for heating and ventilating systems.

3 Roof and wall systems using cold-formed steel claddings and sections

In building construction, both roof and wall systems [3] are considered to be the building envelope of a building which provide an internal environment for normal indoor activities protected from weather, as shown in Figure 4. Moreover, architecturally, the building envelope complements and accentuates the colour and texture of the building, and plays a major role in establishing its character and appearance. Structurally, it resists wind and live loads, and also provide lateral restraint to structural members such as purlins. Functionally, water-tightness is the most important feature to the client or the end-user of the building as water leakage is always a nuisance which interrupts normal activities, and often expensive to repair. Large amount of research and development efforts is made to produce watertight roofs and walls with simple installation efforts and minimum maintenance. Other features are also required:

- acoustic insulation
- thermal insulation
- air-tightness
- control of condensation
In general, the structural behaviour of cold-formed steel claddings and sections is covered by various parts of the British steel code BS5950 [2]. The thicknesses of cold-formed steel claddings are typically 0.6 to 1.0 mm while the depths typically range from 15 to 35 mm with a cover width of 600 to 900 mm. Typical spans of claddings ranges from 0.9 to 2.1 m under normal loading and support conditions.

3.1 Typical use of cold-formed steel claddings

Although there is a large variety of roof and wall claddings available in the market, they may be classified as follows:

**Single skin construction**

A single skin roof or wall consists of

a) an outer profiled cladding, and  
b) an internal insulation layer

As shown in Figure 5, the outer profiled cladding supports all external and internal loads, transferring them directly to the mainframe of the building through purlins. The insulation layer is supported by local attachment to the outer profiled cladding.

**Double skin construction**

Double skin roof or wall consists of

a) an outer profiled cladding  
b) an internal insulation layer, and  
c) a lightly profiled internal liner tray

As shown in Figure 5, the outer profiled cladding supports all external loads and transfers them direct to the mainframe of the building through purlins, and in general, it acts independently of the liner tray. The liner tray supports the insulation layer and a vapour control layer (if present), resists internal wind suction and provides some lateral restraint to the purlins.

It is important to note that there are two different fixing systems commonly adopted in roof and wall construction as follows, as shown in Figure 6:

**Through or screw fastened claddings**

Through-fastened claddings are directly attached to the supporting purlins with self-drilling self-tapping screws. The installation is simple and effective, and full restraint is readily provided to the supporting purlins. However, thermal movement of the attached claddings may enlarge the screw holes, resulting in leakage in time. In order to improve water tightness, long screws may be used for crown fixing.

**Standing seam claddings**

Standing seam claddings provide a virtually penetration-free surface resulting in a watertight roof. Except at the building eave or ridge, standing seam claddings are attached to the supporting purlins with concealed clips which are screw-fastened to
the supporting purlin flange. There are two basic clip types: fixed or sliding clips. In fixed clips, thermal movement is allowed for in the design of the clips, and thus, more fasteners are required. In sliding clips, as thermal movement is accommodated between the clips and the claddings, the installation is simple but the clips are more sophisticated. It should be noted that the restraint provided by standing seam claddings and clips is highly dependent on the profile of the claddings and the clip details.

3.2 Typical use of cold-formed steel sections

The most common shapes of cold-formed steel purlins are C and Z sections, and the section depths typically range from 100 to 350 mm while the thicknesses range from 1.2 to 3.0 mm. Due to the thinness of cold-formed steel sections, local buckling is a predominant consideration in assessing their section capacities. There are a whole range of variants of these basic shapes, including sections with single and double lips, and sections with internal stiffeners for improved structural efficiency. Common yield strengths are 280 and 350 N/mm$^2$, but recently, steels with high yield strengths up to 450 N/mm$^2$ may be found in some proprietary purlins for improved structural economy. Typical spanning capacities of cold-formed steel purlins range from 4.5 to 12 m, depending on section dimensions, steel grades, connection details and bracing configurations.

As shown in Figure 7, since cold-formed steel sections are very weak against twisting, sag rods or bridgings are often provided during erection to prevent excessive member twisting before installation of roof claddings. Both bolts and self-drilling self-tapping screws are common fasteners while welding is seldom used due to the thinness of cold-formed steel sections and also the presence of galvanized coatings.

3.3 Typical member arrangements of purlins

Four different types of member configurations [5] may be found in practical roof systems with different degrees of continuity:

(i) single span system
(ii) double span system
(iii) the continuous system with sleeves, and
(iv) the continuous system with overlaps

Among all, the continuous system with overlaps is the most widely used system due to simple and effective connection configurations between lapped sections at the purlin-rafter connections. It should be noted that with metal-to-metal positive fixing, modern roof claddings may provide effective partial or full restraints to the supporting purlins, and thus enhance the structural behaviour of roofs and walls significantly.

4 Floor systems with composite slabs using profiled steel decking

Composite slabs with profiled steel decking have been very popular in building construction in many parts of the world for more than 30 years, in particular, in high-rise steel-concrete composite framed buildings. In the recent years, it is becoming more and more popular in Hong Kong not only in commercial high-rise buildings but also in low to medium-rise offices, long span footbridges and building envelopes, as shown in Figure 8. The structural behaviour
of composite slabs with profiled steel decking is covered by various parts of the British steel code BS5950 [2]. One of the major advantages of profiled steel decking [4] in the construction of floor slabs is that neither timber formwork nor temporary support is required as in conventional construction of reinforced concrete slabs. Moreover, the profiled steel decking also provides safe working platforms and effective protection to workers.

The term composite member is generally applied to member having a steel-concrete section, in which the two materials behave compositely as an integral. This action is possible because of inter-connection between the two materials, either continuously, or at discrete points, along the length of the member. In composite slabs with profiled steel decking, inter-connection is achieved by chemical bonds and mechanical interlocking acting on the interfaces between the concrete and the profiled steel decking.

4.1  Typical configurations

Modern profiled steel deckings [1] are in the range of 45 to 80 mm height and 150 to 300 mm trough spacing. Figure 9 illustrates the two common types of deckings: trapezoidal deckings and re-entrant deckings. Galvanized steel strips for this application is typically 0.9 to 1.5 mm thick with design yield strengths at 280, 350 and 550 N/mm$^2$. The most efficient use of composite slabs is for spans between 2.7 and 4.5 m. The typical span to depth ratio of the steel deckings is 50 for simply supported slabs and 60 for continuous slabs.

4.2  Formwork during construction

Profiled steel deckings may be used as permanent formwork to facilitate the construction of reinforced concrete slabs where timber formwork and temporary supports are difficult to be provided. The profiled steel deckings should be able to support the self-weight of the wet concrete and the construction loads together with any other storage loadings as appropriate. The design of profiled steel deckings is covered in BS5950: Parts 4 and 6 where the loading requirements during the construction stage and the section capacities of the profiled steel deckings are given respectively. Moreover, the deflection limit of the profiled steel deckings is normally taken at L / 180 where L is the span of the slab. This limit may be relaxed to L / 130 when ponding effect of wet concrete is being considered during concreting.

In general, both ‘positive’ and ‘negative’ reinforcements should be provided in the slabs according to normal design of reinforced concrete slabs for the in-service stage. No specific requirement on profiled steel deckings against fire resistance is thus required as the profiled steel deckings are considered to be ‘inactive’ after construction, and the fire resistance of the reinforced concrete slabs depends on the provision of suitable concrete cover to reinforcements.

4.3  Composite slabs during in-service stage

In general, the profiled steel deckings may be utilized as positive reinforcements in floor slabs in the in-service stage provided that there are strong chemical bonds and effective mechanical interlocking at the interfaces between the concrete and the profiled steel deckings, i.e. composite slabs with the concrete in compression and the profiled steel deckings in tension. The composite slabs are usually designed as simply supported irrespective of the continuity of the profiled steel deckings over supports, and nominal reinforcements for crack control may be provided over supports.
The composite slabs should be able to support the dead and the imposed loads of the floors at ultimate limit state, and deflection is unlikely to be critical. The design of composite slabs with profiled steel deckings is covered in BS5950: Part 4 [1]. They are usually designed against slippage between the profiled steel deckings and the concrete before the plastic moment resistance of the composite section is reached. This is known as ‘shear bond’ failure, and it is required to execute physical tests to confirm the structural behaviour of the composite slabs, as shown in Figure 10. The composite slabs are first subject to 10,000 cycles of loading variation between 50 and 150% of the intended working load in order to identify any inherent fragility in the concrete-profiled steel deckings interfaces during the in-service stage. The composite slabs are then loaded statically to failure in order to evaluate the shear bond parameters, \( m_r \) and \( k_r \) to design against shear bond failure at ultimate limit state. Figure 11 plots the load-deflection characteristics of a typical composite slab with profiled steel decking undergoing shear bond failure. In general, the load carrying capacities of composite slabs are significantly larger than the loading requirements in typical applications, and thus, the design of continuous composite slabs is usually controlled by strength check of the profiled steel deckings during construction stage.

4.4 Fire resistance during in-service stage

It is common practice [1] to confirm the structural performance of composite slabs with profiled steel deckings in fire through standard fire tests. In general, simply-supported composite slabs with nominal reinforcements rarely exceed a fire resistance period of 30 minutes whereas tests on continuous composite slabs with the same reinforcement can achieve over 60 minutes. Since the release of BS5950: Part 8 [2], it has been widely accepted [7,8] to use the fire engineering approach to assess the load carrying capacities of composite slabs at elevated temperatures, and then to check against the loading requirements with appropriate partial safety factors in fire limit state.

For typical composite slabs with practical dimensions and applications, simplified rules for the fire resistance of composite slabs with normal weight concrete are presented in Table 1 [1]. It should be noted that in typical buildings under normal loading and support conditions, the design of composite slabs is often controlled by strength consideration in the normal or ‘cool’ design rather than the fire resistance requirement.

5 Recent developments of cold-formed steel shapes

Recent developments are presented as follows:

Construction applications

(i) Composite floor slabs using steel fibre reinforced concrete to achieve a fire resistance period of 90 mins without any fire reinforcement in typical loading and support conditions.

(ii) Composite floors using profiled steel decking with deep embedded webs to achieve a fire resistance period of 60 to 120 mins without any positive fire reinforcements under typical loading and support conditions.

(iii) Structural titanium claddings in roofs supported with stainless steel or aluminum purlins for prolonged life without any maintenance.
Research and development

(i) Effects of manufacturing on the structural behaviour of cold-formed steel shapes. Mechanical and geometrical initial imperfections due to hard rolling, galvanization, coiling and uncoiling, cold-rolling, press-braking storage and handling.

(ii) Structural behaviour of bolted connections in cold-formed steel structures. Load distributions within connections, effects of highly localized forces, reduction in strength and stiffness, and innovative jointing methods.

6 Conclusions

Cold-formed steel shapes are light-weight materials and suitable for building construction owing to their high structural performance and durability. Engineers are encouraged to take full advantages offered by cold-formed steel construction technology to build strong and stiff buildings of high buildability and structural economy.

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