Pre-Engineered Buildings
Selection of Framing System, Roofing & Wall Materials

Dr. N. Subramanian
Computer Design Consultants
Gaithersburg, MD 20878, USA

Introduction

High-rise steel buildings account for a very small percentage of the total number of structures that are built around the world. The majority of steel structures being built are only low-rise buildings, which are generally of one storey only. Industrial buildings, a sub-set of low-rise buildings are normally used for steel plants, automobile industries, light, utility and process industries, thermal power stations, warehouses, assembly plants, storage, garages, small scale industries, etc. These buildings require large column free areas. Hence interior columns, walls and partitions are often eliminated or kept to a minimum. Most of these buildings may require adequate headroom for use of an overhead traveling crane. The planning and design of these units require the knowledge of the following items (Fisher 1984).

➤ Site information ➤ Soil conditions. ➤ Plant layout and work flow ➤ Preferred bay sizes ➤ Future expansion plans ➤ Loading docks ➤ Crane types and capacity ➤ Roofing, side cladding and wall material preferences ➤ Heating, ventilation and air-conditioning (HVAC) equipments loads ➤ Availability of raw materials ➤ Availability of waste disposal and sanitary facilities ➤ Parking facilities ➤ Preferred fabricators/contractors ➤ Budget and project schedule.

The structural engineer has to consider the following points (Fisher, 1984).

1) Selection of roofing and wall material 2) Selection of bay width 3) Selection of structural framing system 4) Roof trusses 5) Purlins, girts and sag rods. 6) Bracing systems to resist lateral loads 7) Gantry girders, columns, base plates and foundations

We shall confine our attention to the selection of framing system and selection of roofing and wall material in this article. Details about other points may be found in Subramanian (2008).

Structural Framing

For the purpose of structural analysis and design, industrial buildings are classified as

➤ Braced frames ➤ Unbraced frames.

In *braced buildings*, the trusses rest on columns with hinge type of connections and the stability is provided by the following bracings in the three mutually perpendicular planes:

(a) bracings in vertical plane in the end bays in the longitudinal direction

(b) bracings in horizontal plane at bottom chord level of roof truss

(c) bracings in the plane of upper chords of roof truss

(d) bracings in vertical plane in the end cross sections usually at the gable ends.

The function of bracing is to transfer horizontal loads from the frames (such as those due to wind or earthquake or horizontal surge due to acceleration and breaking of traveling cranes) to the foundation. The longitudinal bracing on each longitudinal ends provide stability in the longitudinal direction. The gable bracings provide stability in the lateral direction. The tie bracings at the bottom chord level transfer lateral loads (due to wind or earthquake) of trusses to the end gable bracings.

Similarly stability in the horizontal plane is provided by

➤ rafter bracing in the end bays which provide stability to trusses in their planes ➤ A bracing system in the level of bottom chords of trusses, which provide stability to the bottom chords of the trusses.

Braced frames are efficient in resisting the loads and do not sway. However, the braces introduce obstructions in some bays and may cause higher forces or uplift forces in some places. Hence unbraced frames are now-a-days preferred. Such unbraced frames are often designed, prefabricated, and supplied and erected at site by firms and are called pre-engineered buildings or metal building systems. Many companies are there India through whom we can order these buildings

Pre-Engineered Buildings

Unbraced frames are in the form of *portal* frames

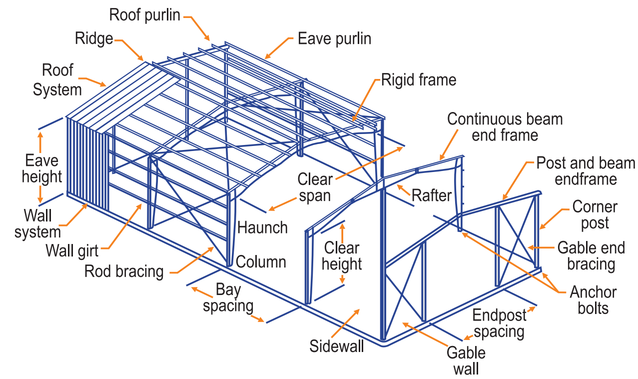

Fig 1. Typical Pre-engineered Building Construction

and are distinguished by their simplicity, clean lines and economy. The frames can provide large column free areas, offering maximum adaptability of the space inside the building. Such large span buildings require less foundation, and eliminate internal columns, valley gutters and internal drainage. Portal frame buildings offer many advantage such as more effective use of steel than in simple beams, easy extension at any time in the future and ability to support heavy concentrated loads. The disadvantages include relatively high material unit cost and susceptibility to differential settlement and temperature stresses. In addition, these frames produce horizontal reaction on the foundation, which may be resisted by providing a long tie beam or by designing the foundation for this horizontal reaction.

Basically, a portal frame is a rigid jointed plane frame made from hot-rolled or cold-rolled sections, supporting the roofing and side cladding via hot rolled or cold-formed purlins and sheeting rails (See Fig. 1). The basic structural form of portal frames was developed during the Second World War. The typical span of portal frames is in the range of 30-40 m, though they have been used in 15 to 80m, spans. However, it is worthwhile considering the use of multi-bay structures beyond 40 m span. The bay spacing of portal frame may vary from 4.5 to 10 m (typical bay spacing is 6 m). The eave height in normal industrial building is about 4.5 m to 6.0 m (which corresponds to the maximum height of one level of sprinklers for fire protection). The ideal slope for portal frame roofs probably lies between 19 and 30°, depending on the dimensions of the building and wind permeability. The slope may be varied in design to obtain minimum loading depending on the wind permeability of the building sides and roofs.

Recent portal frames have a roof slope of from 6 to 12°, mainly chosen because of the smaller volume of air involved in heating/cooling the building. But in such cases, frame horizontal deflections must be carefully checked and proper foundations should be provided to take care of the large horizontal thrust. Usually, the portal frames

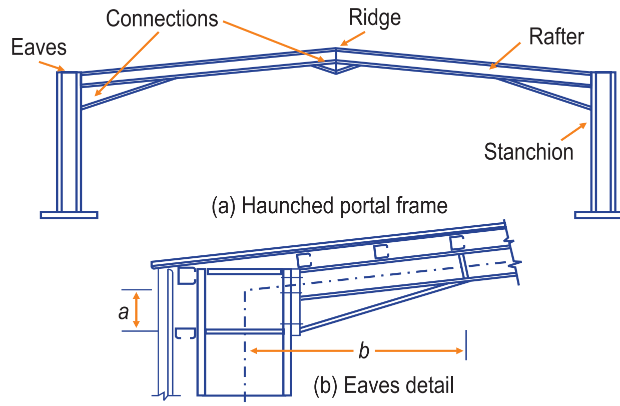

Fig.2 Typical Haunched Portal Frame

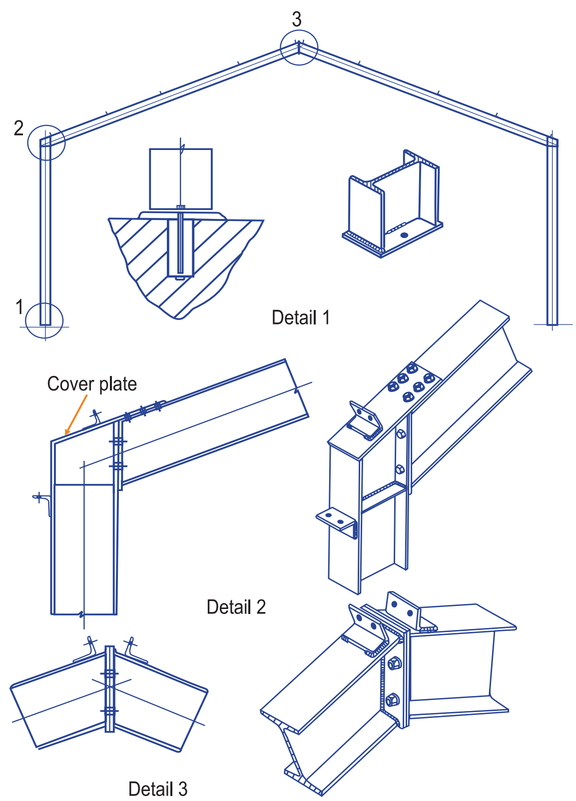

Fig.3 Simple unhaunched portal frame

(a) Connecting the columns to Foundation

(b) Typical connection at Ridge

(c) Typical connection at Rafter-Purlin junction

(d) Typical Column-Rafter connection

Fig. 4 Typical Details and Erection of Pre-Engineered Buildings (Source: http://www.excelbuildings.com/site/790508/page/905273)

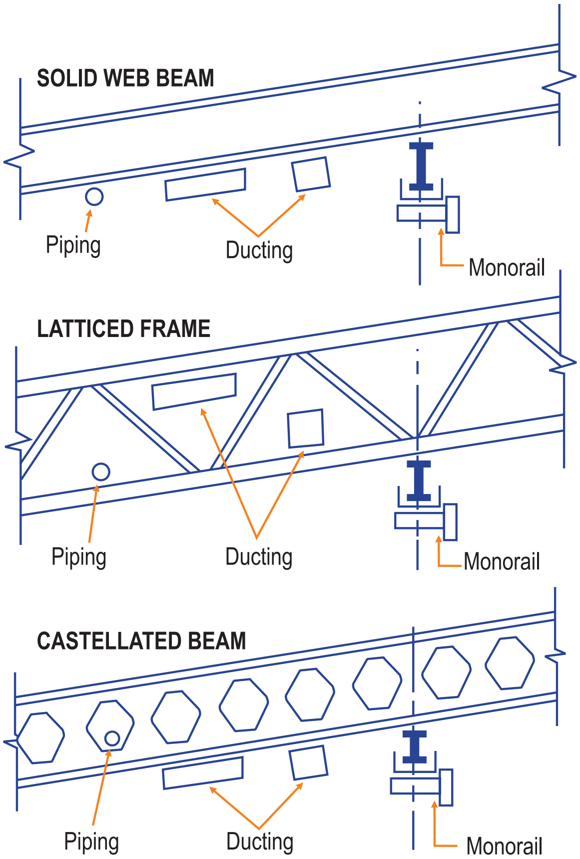

Fig.5 Solid Web, Castellated and lattice Rafters

are composed of tapered stanchions and rafters (See Fig.1) in order to provide an economic solution for single-storey buildings. Portal frames made of lattice members using angles or tubes are also common, especially for covering long spans. The most common form of portal frame used is the pinned-base frame with different rafter and column member size and with haunches at both the eaves and apex connections (see Fig.2). The simple unhaunched portal frame, its connections, and erection are shown in Figs.3 and 4.

Using a solid-web rafter for the portal frame, has the disadvantage of placing pipes and conduits below the bottom flange. This problem may be overcome by adopting castellated or lattice rafters as shown in Fig. 5).

The lateral stability parallel to the portal frame is provided by the frame itself. However, to resist the loads perpendicular to the portal frame, wall and roof bracings have to be provided as shown in Fig. 1. The roof bracings, which may be in the form of diagonal steel rods, are placed below the purlins for simplicity. These diagonal rods and the rafters of the primary portal frames constitute a horizontal truss and is some times termed as roof diaphragm. The secondary framing-wall grits and roof purlins-collects the load from the wall and roof covering and distributes them to the main portal frames and at the same time provides lateral restraint to the members of portal frame.

The end frame or gables of a portal frame can be framed in two different ways. They can be formed using a frame identical to the intermediate portals and then framing the gable or end posts up to the underside of the portal rafter. Suitable arrangements must be made at the post/rafter connections to accommodate vertical movement of the portal rafter (Dowling et al 1988). This method of gable framing may be economical, if the building might be extended in the future. When there is no scope for extension, the gable rafter can be designed as a continuous member, spanning between gable or end posts (as shown in Fig. 1). This form of gable framing has poor sway resistance and hence needs in-plane bracing. The gable posts are generally designed as propped cantilevers. They support the gable sheeting which are subjected to wind loads; they sometimes support secondary steel work for doors, openings, etc.

For buildings without cranes, the choice of column type and orientation depends primarily on building height, the wall system and the lateral load carrying system. In general, wide-flange columns provide most economical choice for exterior columns in the buildings. This is particularly true for rigid frames where rigid frame action is required in one direction and girts are used to brace the weak axis of these columns.

The lateral loads are transmitted along the wall from brace to brace by eave strut. The eave struts are designed for axial compression or for combined axial compression and biaxial bending. The diagonal wall bracing in the form of a rod may be attached to the column through the hillside washer, which is a cast circular element with a vertically slotted hole that allows for variable angles of rod insertion (Newman, 2004). A matching vertically slotted hole is made in the column web (see Fig.6).

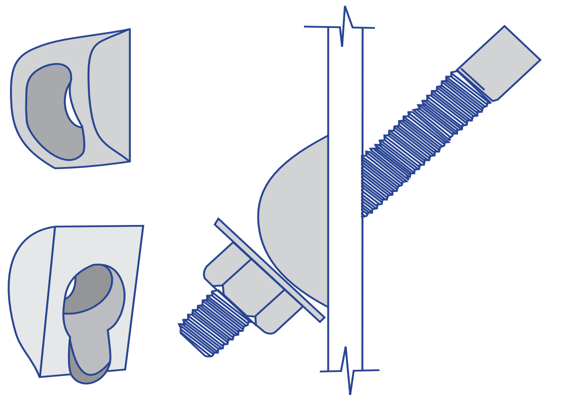

Fig.6 Hillside Washer

Although the steel weight in braced frame buildings is often less than that for a comparable portal frame building, the overall cost is generally higher because of the greater amount of labour involved in fabrication. That is the reason pre-engineered buildings are very popular in countries such as USA where labour is very expensive. building systems.

Though the portal frame is one of the simplest structural arrangements for covering a given area, the designer has to satisfy several structural criteria as applied to more complex structures. In essence, the portal frame is analysed as a rigid plane frame with assumed full continuity at the intersections of the column and rafter members. The normal practice is to assume that the columns are pinned at the bases (see Fig.3 and 4a). It is because the cost of the concrete foundation for fixed bases (owing to the effect of large bending moments), more than offsets the savings in material costs that result from designing the frame with fixed bases. However fixed bases may be necessary when designing tall portal frames, in order to limit horizontal deflections within code prescribed limits.

Since the mid 1950's, portal frames especially in the United Kingdom, are designed using the plastic methods of analysis, as it allows the engineer to analyze frame easily and design it economically. By taking advantage of the ductility of steel, plastic design produces lighter and more slender structural members than similar rigid frames designed by elastic theory. Complete design of a single storey portal frame is provided by Morris and Plum,1996, who also caution about plastic analysis programs based on the modified stiffness matrix method, which may produce false solutions. Complete information on the elastic and plastic design method of portal frames is provided by King, 2005.

Large scale testing of portal frames has been reported by Li and Li, 2002 & Mahendran and Moor, 1999. It has been found that by including the effect of end frame and cladding, in a three dimensional analysis program, more realistic values of bending moments and deflections can be obtained (Mahendran and Moor 1999).

Several software packages are available for the analysis and design of portal frames (www.structural-engineering.fsnet.co.uk). While attempting a plastic design, in addition to member strength (capacity) check, the following checks must also be carried out

➤ Reductions in the plastic moment due to the effect of axial force and shear force. ➤ Instability due to local buckling, lateral buckling and column buckling ➤ Frame stability ➤ Brittle fracture ➤ Deflection at service loads

In addition the connections should be designed properly such that they are capable of developing and maintaining the required moment until the frame fails by forming a mechanism.

Selection of Roofing and Wall Material

The roofing choice affects the type of roof deck, the type of purlin used, purlin spacing, deflections of secondary structural members, roof pitch and drainage requirements. The roof weight also affects the gravity load design of the roof system and in the case of seismic calculations, the lateral load design.

Similar considerations apply to the cladding/wall systems. In selecting the cladding/wall system, the designer should consider the following items:

➤ Cost ➤ Interior surface requirements ➤ Aesthetic appearance (including colour) ➤ Acoustical and dust control ➤ Maintenance ➤ Ease and speed of erection ➤ Insulating properties ➤ Fire resistance

Note that cladding carries only its own weight plus the loads imposed by wind. In the case of roofs, the sheeting supports insulation and water proofing in addition to the self weight and loads due to wind and/ or snow and hence often termed as roof decking. The cladding/wall system will have an impact on the design of girts, wall bracing, eave members and foundation.

In India corrugated galvanized iron G.I. sheets are usually adopted as coverings for roofs and sides of industrial buildings. Now light-gauge cold formed ribbed steel or aluminium decking (manufactured by cold drawing flat steel or aluminium strips through dies to produce the required section) are also available. Sometimes asbestos sheets (A.C.) sheets are also provided as roof coverings due to their better insulating properties. Their insulating properties may be enhanced by painting them white on the top surface. Note that asbestos sheets are prohibited in several countries due to the risk of lung cancer. We shall discuss briefly about Steel or aluminium decking/ cladding which are normally used in pre-engineered buildings.

Steel or Aluminium Decking /cladding

The modern built-up roof system consists of three basic components: Steel/aluminium deck, thermal insulation and membrane. The structural deck transmits gravity, wind and earthquake forces to the roof framing. Thermal insulation is used to cut heating and cooling costs, increases thermal comfort and prevents condensation on interior building surfaces. The membrane is the water-proofing component of the roof systems. On sloping roofs the insulation consists of insulation board or glass wool. On flat roofs, insulation board, felt and bitumen are laid over the steel decking as shown in Fig. 7.

The steel decking has a ribbed cross-section, with ribs generally spaced at 150 mm centres and 37.5 mm or 50 mm deep (See Fig. 8). The sloped-side ribs measure about 25 mm across at the top for narrow rib decking, 44 mm for intermediate rib deck and 62.5 mm for wide rib decking. Wide rib decking is more popular, which can be used with 25 mm thick insulation boards. Thinner insulation boards may require narrow deck rib opening. The wide rib decking also has higher section properties than other patterns and hence can be used to span greater distances. These steel decks may be anchored to supporting flexural members by puddle welds, power-activated and pneumatically driven fasteners and self-drilling by a welder, as soon as the deck is placed properly on the rafters or top chord of roof truss. (Vinnakota, 2006).

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Steel decks are available in different thicknesses, depths, rib spacing, widths, and lengths. They are

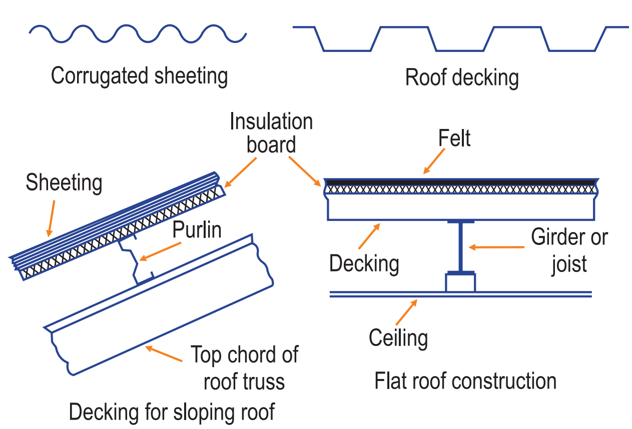

Fig.7 Roof Materials and Constructions

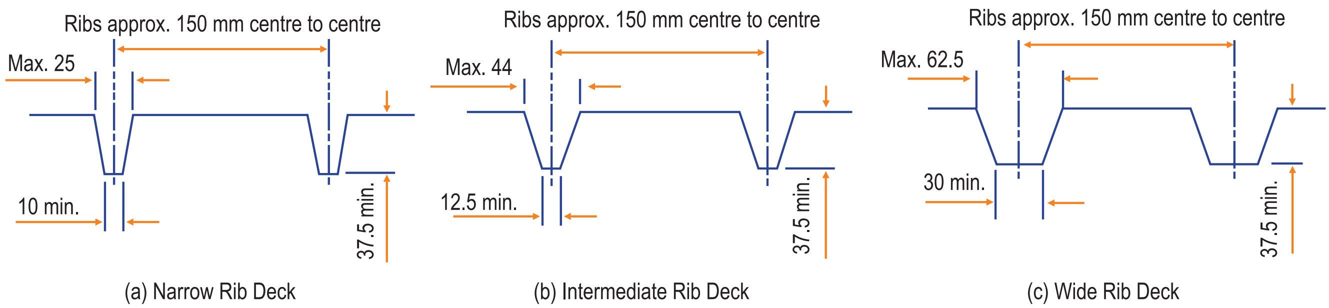

Fig. 8 Typical Profiles of roof Deck

available with or without stiffening elements, with or without acoustical material, as in cellular and non-cellular forms. The cellular decks can be used to provide electrical, telephone and cable wiring and also serve as ducts for air distribution. They are also available with different coatings and in different colours. They are easy to maintain, durable and aesthetically pleasing. They are easy to maintain, durable and aesthetically pleasing.

When properly anchored to supporting members, steel/aluminium decks provide lateral stability to the top flange of the structural member. They also resist the uplift forces due to wind during the construction stage. Steel decks may be considered as a simply supported or continuous one way beam depending on the purlin and joist spacing. Aluminium sheets also offer excellent corrosion resistance. But they expand approximately twice as much as steel and easily damaged in hail storms. Moreover, aluminium sheeting should be separated not only from steel purlins but also from any non-aluminium roof-top framing and conduits in order to avoid bi-metallic corrosion. The fasteners connecting aluminium sheets to steel purlins should be of stainless steel. The aluminium alloy panels should be at least 0.8mm thick and for longer spans 1mm thick.

The load carrying capacity of the deck is influenced by the depth of the cross-section, the span length, the thickness of metal and whether it is simply supported or continuous. The profile steel decking may be assumed to have design strength of 0.93 times the characteristic strength or the specified yield strength and Young's modulus of 210 GPa. The calculations of section properties to determine the effects of bending, shear, deflections etc are complex (similar in nature to those for the design of cold formed sections and are thus iterative). It should be noted that the moment carrying capacity is limited to that just causing yield and hence is based on elastic section modulus (Martin and Purkiss, 1992). The manufacturers provide load tables, which can be used to select the deck for the required span. Note that these decks are available in lengths of 6 m and above and have thickness in the range of 0.37 mm (28 gauges) to 1.5 mm (16 gauges). The weight of roofing varies from 0.3 kN/m2 to 1.0 kN/m2 including the weight of joists, and 0.05 kN/m2 to 0.1 kN/m2, excluding the weight of joists. For exact information, the manufacturer's literature should be consulted.

Metal roofing can be classified by the method of attachment to supports. Through-fastened roofs are attached directly to purlins, usually by self-tapping screws or self-drilling or lock rivets. Standing-seam roofing, on the other hand, is connected indirectly by concealed clips formed into the seams. Though the through-fastened lapped-seam roofing is inexpensive, straightforward and easy to erect, it is penetrated by fasteners and hence is susceptible to leaking; The only protection against leaking is the rubber or neoprene washer provided under the head of the fastener (A properly installed screw has its neoprene washer slightly visible from under the edge of the metal washer. The fasteners also prevent the sheets from thermal expansion and contraction. Repeated expansion and contraction may tear the metal around the connecting screws and eventually lead to leaking.

Hence the width of building with through-fastened roofs should not exceed about 18m. When subjected to strong fluctuating wind loading, these sheets experience metal fatigue and may fail locally, by cracking around the fasteners (Xu, 1995; and Lynn & Stathopoulos, 1985). The size and spacing of fasteners depend upon the forces they are designed to resist. The fastener spacing may be closer in the roof areas subjected to high wind loading than in the field of the roof. For durability against corrosion stainless steel or aluminium fasteners should be used in exposed areas. Galvanized or cadmium-plated screws are suitable for interior applications.

Standing-seam metal roof consists of metal panels running vertically on the roof deck. Each panel has two seams that stand up vertically and are snapped or crimped together to seal the joint, thus avoiding penetration of the roofing material (See Fig.9). A standing seam also avoids water from collecting on the surface. A factory applied sealant is normally placed in the female corrugation of the seam. To accommodate expansion and contraction, the panels are attached to purlins by concealed clips that permit the roof to move (see Fig. 9d). Standing-seam roofing is often used in the USA and was introduced by Butler Manufacturing Company in 1969. The biggest

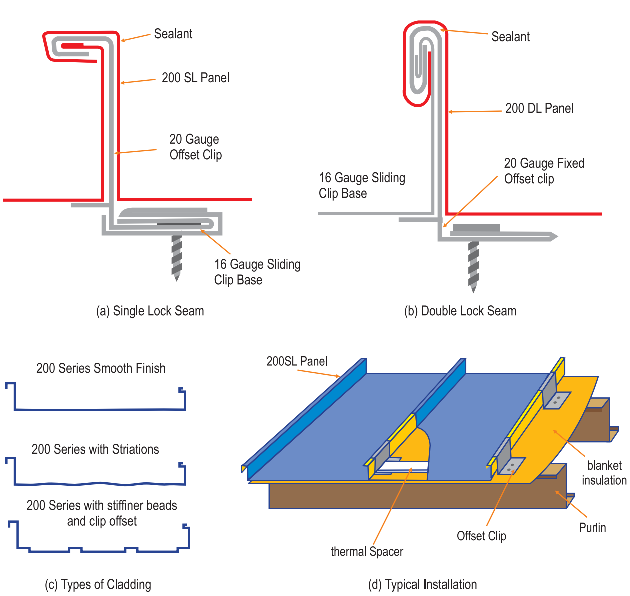

Fig.9 Standing-Seam metal Roof (source: http://www.archmetalroof.com)

disadvantage of the standing-seam roof is that it provides no lateral bracing to purlins and offers little diaphragm action. Hence a separate system of purlin bracings and a separate horizontal diaphragm structure are required. Moreover, standing-seam roofing is best suited for rectangular building layouts only. Though they may be expensive initially, life-cycle cost calculations may prove them to be economical in the long run.

The most popular anti-corrosive coating for steel roofing are based on metallurgically bonded zinc, aluminium or a combination of the two. Zinc-aluminium coated roofing has displaced galvanized roofing in the USA. When another layer of protection is required, acrylic, polyester or fluorocarbon based paints are sprayed onto the metal and baked on at the factory. More details about steel decking are provided by Petersen, 1990; Newman, 2004; and Schittich, 2001.

Summary

Depending on the structural framing system adopted, industrial buildings may be classified as braced frames and unbraced frames. In braced frames, trusses rest on columns with hinge type connections and the stability is provided by bracings in three mutually perpendicular directions.

Unbraced frames in the form of portal frames offer several advantages over braced frames. These portal frames are often prefabricated in the factory and assembled at site and termed as pre-engineered buildings or metal building systems. The lateral stability of portal frames in the longitudinal direction is provided by bracings. Though these portal frames may be designed economically by using plastic methods of structural analysis, elastic methods can also be employed. It is important to design and detail the connections of portal frames properly such that they are capable of developing the required design moment resistance. Braced frames may be economical than unbraced frames in situations where the labour costs are low.

The roofing choice affects the type of roof deck, the type of purlin used, purlin spacing, deflections of secondary structural members, roof pitch and drainage requirements. Steel or aluminium decking/ cladding are normally used in pre-engineered buildings. Steel decks are available in different thicknesses, depths, rib spacing, widths, lengths, and colours. Though the through-fastened lapped-seam roofing is inexpensive, straightforward and easy to erect, it is penetrated by fasteners and hence is susceptible to leaking. Hence Standing-seam metal roofs consisting of metal panels running vertically on the roof deck are used in present day constructions. In standing-seam roofs, each panel has two seams that stand up vertically and are snapped or crimped together to seal the joint, thus avoiding penetration of the roofing material.

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