Evaluation of Roofing Systems in Malaysia Based on MS 1553, BS 6399, EC1-1-4 and IS 875 Wind Codes

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Keywords: averaging time, pressure, pullout, rectangular building, roofing sheet, wind speed.

Abstract. This paper evaluates the performance of different roofing sheet systems for different roof types using four different codes namely MS 1553, EC1-1-4, and IS 875 and BS 6399. The maximum roof pressures using different codes (MS 1553, EC1-1-4, IS 875 and BS 6399) on critical and general area of the different roof types considering buildings with non-dominant opening, dominant opening and canopies have been evaluated. The maximum recommended wind speed in MS 1553 namely 33.5 m/s has been used as the reference for the numerical comparison. The major differences in the codes include averaging time for wind speed, terrain, reference height, and pressure coefficients. The study examines the conservativeness or not of the codes if used in the Malaysian context, even though they have been developed for a different wind climate and region. Further, the results of static test on different steel roofing sheets used in Malaysia using AS 1562.1 available as the limit state wind pressure capacities in the technical brochures are compared with design wind pressures for critical and interior regions of the roof for different wind zones. The suitability of a particular roofing sheet system for a particular wind zone is then assessed.

Introduction

The roofing is a very critical element for the safety of buildings and has historically suffered severely during strong wind events. Roof systems have performed well under normal conditions of load. Their performance under extreme wind loads has been disastrous, the predominant failure mode being uplift [1,2,3,4,5,6,7,8,9]. Lysaght Company provides steel roof cladding materials in Malaysia and static testing of wind pressure capacities were conducted in company laboratory in Australia using AS 1562.1 method [10]. Wind codes being used in Malaysia are MS 1553 [11] and BS 6399-2 [12]. The introduction of Eurocodes for structural design in Malaysia necessitates examination of EC1-1-4 [13]. IS 875-3 [14] is the Indian wind code in which zone 2 has tropical climate with cyclones. It is necessary to examine the conservativeness of the wind codes if used in the Malaysian context and to provide guidelines on the suitability of particular roofing sheet system for a particular wind zone. All of them have been studied and reported.

Literature Review

Type of Roof Cladding, Material Specifications and Limit State Wind Pressure Capacities. Lysaght provides several types of thin steel roofing sheets with different thickness namely trapezoidal, square fluted, pierce fastened, corrugated and concealed fix fluted pan profile. The first four are fixed using self-driven bolts whereas the last one is of concealed fixed nature. Table 1 provides the base metal thickness (BMT) and minimum roof pitch of different types of steel roofing sheet. The sheets are available in two types: (1) Zincalume steel – which is metallic coated steel product, composed of 55% Aluminium, 43.5% zinc and 1.5% Silicon. (2) Colorbond steel – which combines the superior strength of steel, corrosion resistance of zinc/aluminium alloy steel coating. The limit state wind pressure capacities were tested in NATA registered laboratories in Australia according to AS 1562.1 [10] and AS 4040.2 [15]. The pressure capacities for serviceability are based on a deflection limit of (span/120) + (maximum fastener pitch/30). The pressure capacities for strength have been determined by testing the cladding to failure (ultimate capacity). The wind pressure capacities were tested with different types of steel roofing sheets of different thickness and types of connections for different spans (from 0.6m to 4.5m) for the single span, internal span and end span respectively. The results are given in the technical brochures [16,17,18,19,20].

Table 1: Different types of steel roofing sheets, BMT and Minimum roof pitch [16,17,18,19,20]

Type of sheet/ profile/cladding	BMT (mm)	Minimum roof pitch
Concealed fix, fluted pan	0.42, 0.48, 0.60	1 degree (1 in 57.3)
Trapezoidal steel	0.42, 0.48	3 degrees (1 in 20)
Subtle square fluted steel	0.35, 0.42, 0.48	2 degrees (1 in 30)
Pierce-fastened roofing	0.42, 0.55, 0.75	2 degrees (1 in 30)
corrugated	0.42, 0.48	5 degrees (1 in 12)

Types of Roof Cladding Connections and Method of Connection. Fig. 1a, 1b and 1c shows details of the connections of steel roofing sheets to the purlins as recommended by [8,10,16,17,18,19,20,21]. Use of 5 fasteners per sheet per support is recommended (either rib fixed or pan fixed) (Fig. 1a; 1b). For concealed fixing, the clips are provided corresponding to each rib (Fig. 1c).

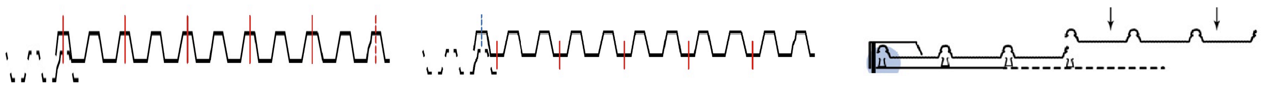

Fig. 1a: Screw Fix through Rib

Fig. 1b: Screw Fix through Pan

Fig. 1c: Concealed fix, fluted pan profile

Figure 1: Details of connecting the roofing sheets to purlins

Ultimate Pull-out Strength Capacities of Screws. The ultimate average pullout strength of screws connecting the roofing sheets to steel purlins are tested under the laboratory condition and the results are based on different thickness of the purlins, and available in technical brochure (Table 2)[22].

Table 2: Ultimate Average Pullout Data [22]

Base Thickness	G450 Steel	Base Thickness	G450 Steel
1.0mm	-	1.9mm	5500N
1.2mm	3100N	2.4mm	7300N
1.5mm	4200N	3.0mm	9800N

Wind Speeds. The wind speeds in MS 1553-2002, IS 875-3-1987, BS 6399-2-1997 and EC1-1-4-2005 are based on 3-second gusts, 3 second gusts, 10 minute mean and hourly means respectively.

Building Types. Rectangular plan buildings may have different roof types like mono-slope, pitched (gabled or hipped), canopy (pitched or troughed), saw tooth (single or multi span) and circular arch roofs. These building types are further classified based on percentage openings into non-dominant and dominant opening and open (canopy type). All of them have been considered in the study.

Reference Height. For calculation and comparison of wind pressures in different codes, MS 1553-2002 is used as the reference. The reference heights are calculated based on roof pitch of 10 degree and average roof height to width ratio of the building of 1.0. Buildings with average roof heights 3, 5, 10 and 15m are considered in this study. The different reference heights of the buildings with different wind codes have been discussed in [23,24,25,26,27].

Number of Terrain Categories (TC). EC1-1-4-2005 specifies 5 TCs (0, I, II, III and IV) whereas MS 1553-2002 and IS 875-3-1987 specify only 4 (I, II, III and IV). BS 6399-2-1997 defines three categories of terrains namely sea, country and town.

External Pressure Coefficients, Internal Pressure Coefficients and Net Pressures Coefficient. Determination of external, internal and net pressures coefficients as per MS 1553-2002, IS 875-3-1987, EC1-1-4-2005 and BS 6399-2-1997 have been discussed in [23,24,25,26,27].

Wind pressure on the roofs. Determination of roof pressures as per MS 1553-2002, IS 875-3-1987, EC1-1-4-2005 and BS 6399-2-1997 have been discussed in [23,24,25,26,27].

Objectives of Study

The objectives of the study were: (a) To compare the maximum positive and negative pressures on the local and general area of the roof for rectangular plan buildings with average roof height not greater than 15m for different roof types and building with different permeability or opening condition using MS 1553-2002 Simplified procedure, EC1-1-4-2005; BS 6399-2-1997 Standard procedure, and IS 875-3-1987. (b) To evaluate the suitability of roofing systems for building with different roof heights, terrains and wind zones.

Methodology

A comparison of the codes requires the wind speed to be converted to the averaging time used in different codes (since 3 second winds speeds have been tabulated in MS 1553-2002 for Malaysia). The roof pressures for different roof types and building permeability or openings condition have been compared. Since the reference heights in EC1-1-4-2005, BS 6399-2-1997 and IS 875-3-1987 are different, those values corresponding to the average roof heights assumed for MS 1553-2002 have been evaluated for use in the respective codes. The wind speeds at the reference height are used to evaluate the pressures on the roof using the pressure coefficients. Using the basic wind speed of 33.5 m/s, and appropriate values for other parameters, the design wind pressures are calculated. Considering external pressure and internal pressure towards the roof as positive, three cases of total pressure can be evaluated (Fig. 2). The value of the terrain height multiplier varies with height (z) and the terrain category. The critical positive (case b) and negative pressures (case c) in Fig. 2 have been evaluated for different height and terrain categories for different roof types and building conditions. Using wind speed of 33.5 m/s converted to the corresponding averaging time, the values of roof pressures as per MS1553-2002; EC1-1-4-2005, BS 6399-2-1997 and IS 875-3-1987 are evaluated and compared. The design maximum pressures calculated using MS 1553-2002 are compared with the limit state wind pressures for local and general areas on roof and suitability of spans are decided. Two methods are used to evaluate the wind loading on the screws (1) To use the finite element model to find out the reaction of the screw on the middle purlin under maximum loading and (2) To use the simple method of dividing the total load on the middle purlin by the number of screw fasteners on the middle purlin to get the reaction. The values are compared with the average pull-out strength of screws from purlin obtained from the technical brochures.

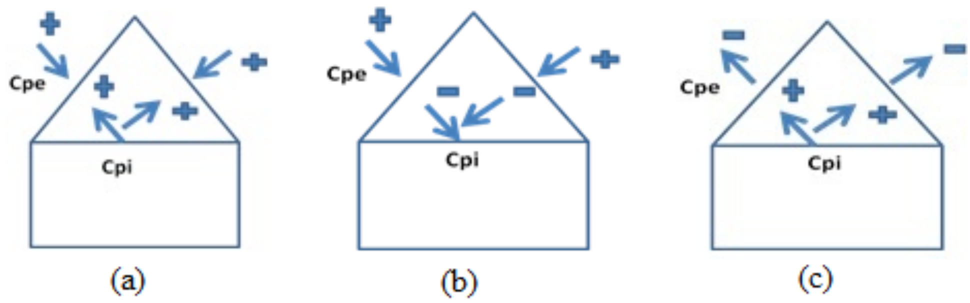

Figure 2: Cases of roof wind pressure on duopitch rectangular buildings

Results and discussion

General. The analysis has been done considering the maximum 3 second basic wind speed in Malaysia, which is 33.5m/s. The corresponding 10 minute mean wind and mean hourly wind speeds are calculated with conversion factors (0.697 and 0.658) obtained from the Durst curves available in ASCE 7-10 [28] as 23.4 m/s and 22.0 m/s respectively.

Comparison of roof pressures. The maximum negative and positive pressures on general and local areas for all types of roofs with as per MS 1553, EC1-1-4, IS 875-3 and BS 6399-2 for different terrains indicate increasing trend of values with increasing height and decreasing trend from TC 1 to TC 4, as expected [23-27]. To determine conservativeness of the different codes if used in Malaysia, all pressures determined using different codes have divided by the corresponding pressures determined using MS 1553.

Roof pressure ratios for buildings with non-dominant opening. Ratios for all terrain categories for EC1-1-4-2005 are generally higher than 1.0 for all types of roofing considered except in TC4 for circular arch roof where the ratio of the maximum negative pressure on local and general areas are less than 1.0. For IS 875-3-1987 in the case of duopitch roofs, the ratios are generally less than 1.0 for TC1 and TC2. For monoslope and flat roofs all ratios are less than 1.0. For circular arch roofs, the ratios of the negative pressures are less than 1.0. For multi sawtooth and multi duopitch roofs, all ratios are generally less than 1.0 expect for the maximum positive pressure on general areas which are greater than 1.0. For BS 6399-3-1997, all ratios for duo-pitch, mono-pitch and multi duo-pitch roofs are generally greater than 1.0 except for local areas of TC1 where the ratios are less than 1.0. For flat roofs the ratios are generally less than 1.0 except for the ratios of maximum negative pressure on general areas in TC3 and TC4. For multi span sawtooth roofs, the ratios on local areas are generally less than 1.0 except for TC3 and TC4 where the maximum negative pressure ratios on local areas are higher than 1.0.

Roof pressure ratios for buildings with dominant openings. Ratios for all terrain categories for EC1-1-4-2005 are generally higher than 1.0 for all types of roofing considered except for circular arch roof where the maximum negative pressure ratios on local areas are less than 1. For IS 875-3-1987 in the case of flat roofs, multi span duo-pitch, multi span sawtooth, duo-pitch, monoslope roofs the ratios are generally less than 1.0. For circular arch roofs, except for maximum negative pressure ratios for local areas, all values are generally greater than 1.0. Ratios for all terrain categories for BS 6399-3-1997 are generally higher than 1.0 for all types of roofing considered except for the maximum negative pressure ratios for local areas in TC1 are less than 1, the minimum ratio is about 0.87.

Roof pressure ratios for canopies. Ratios for all terrain categories for EC1-1-4-2005 are generally higher than 1.0 for all types of canopies considered except for monoslope canopies where the maximum negative pressure ratios for block under are less than 1, the lowest ratio is about 0.58. Ratios for all terrain categories for IS 875-3-1987 are generally higher than 1.0 for all types of canopies considered except for monoslope canopies where the maximum negative pressure ratios for block and empty under are less than 1, the lowest ratio is about 0.61. Ratios for all terrain categories for BS 6399-3-1997 are generally higher than 1.0 for all types of canopies considered except for monoslope canopies where the maximum negative pressure ratios for block under are less than 1 for TC1, the lowest ratio is about 0.81.

Consideration of Bending Failure of the Roofing Sheets. The suitable spans for each type of roofing sheets have been determined for different terrains and height of the structures for all roof types and buildings with different permeability or opening condition. The overall results of the suitability of spans are summarized below.

Terrain Category I, height from 3m - 5m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm with span below 1.2m. For Subtle Square fluted, Trapezoidal, HR-29 and Custom blue orb 17 with BMT of 0.48mm, 0.48mm, 0.42m and 0.8mm respectively are suitable to use with 1.5m span. HR-29 with BMT of 0.55mm can use up to 2.1m span. Custom orb 16 with minimum BMT of 0.42mm is recommended to use with span not greater than 0.9m. Klip Lok Optima is not recommended to use. From 10m-15m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm with span below 0.9m. For Subtle Square fluted, Trapezoidal, HR-29 and Custom blue orb 17 with BMT of 0.48mm, 0.48mm, 0.42m and 0.8mm respectively are suitable to use with 1.2m span. HR-29 with BMT of 0.55mm can use up to 1.8m span. Custom orb 16 with minimum BMT of 0.42mm is recommended to use with span not greater than 0.9m. Klip Lok Optima is not recommended to use.

Terrain Category II, height from 3m - 5m: It is suitable and economical to use profile Subtle square fluted with minimum BMT of 0.42mm for span below 1.5m. For trapezoidal and Subtle square fluted with BMT of 0.48mm can support the span up to 1.8m. Using HR-29 with minimum BMT of 0.42mm can use with 2.1m span. Custom orb 16 with minimum BMT of 0.42mm is recommended to use with span not greater than 1.2m. Klip Lok Optima is not recommended to use. From 10m-15m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm with span below 1.2m. For trapezoidal, Subtle square fluted and custom blue orb 17 with BMT of 0.48mm, 0.48mm and 0.80mm respectively can use with 1.5m span. HR-29 with BMT of 0.42mm can use with 1.8m span. Custom orb 16 with minimum BMT of 0.42mm is recommended to use with span not greater than 1.2m. Klip Lok Optima is not recommended to use.

Terrain Category III, height from 3m - 5m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm with spans below 1.8m. For trapezoidal, Subtle square fluted and Klip Lok Optima with BMT of 0.48mm, 0.48mm and 0.6mm respectively can support span up to 2.1m. HR-29 and Trapezoidal with BMT of 0.42mm and 0.48mm respectively can use up to 2.4m span. Custom orb 16 and custom blue orb 17 with minimum BMT of 0.42mm and 0.6mm respectively are recommended to use with spans not greater than 1.5m. Klip Lok Optima without edge stiffener is not recommended to use. From 10m – 15m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm for the spans below 1.5m. For trapezoidal and Subtle square fluted with BMT of 0.48mm can support the span up to 1.8m. Using HR-29 with BMT of 0.55mm can use with 2.4m span. Custom orb 16 with minimum BMT of 0.42mm is recommended to use with span not greater than 1.2m. For Custom blue orb 17 and Klip Lok Optima with BMT of with 0.60mm can use with spans not greater than 1.5m. Klip Lok Optima without edge stiffener is not recommended to use.

Terrain Category IV, height from 3m - 5m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm for the span below 1.8m. For trapezoidal, Subtle square fluted and Klip Lok Optima with BMT of 0.42mm, 0.48mm and 0.6mm respectively can support the span up to 2.1m. Using HR-29 and Trapezoidal with BMT of 0.42mm and 0.48mm respectively can use with 2.4m span. Custom orb 16 and custom blue orb 17 with minimum BMT of 0.42mm and 0.6mm respectively are recommended to use with span not greater than 1.5m. Klip Lok Optima without edge stiffener and Custom blue orb 17 with BMT of 0.6mm and 0.48mm respectively can use with 1.8m span. From 10m – 15m: It is suitable and economical to use Subtle square fluted with minimum BMT of 0.42mm for the span below 1.8m. For trapezoidal and Subtle square fluted with BMT of 0.42mm, 0.48mm respectively can support the span up to 2.1m. Custom orb 16 and custom blue orb 17 with minimum BMT of 0.42mm and 0.6mm respectively are recommended to use with span not greater than 1.5m. Klip Lok Optima with and without edge stiffener and Custom blue orb 17 with BMT of 0.6mm, 0.6mm and 0.8mm respectively can use with 1.8m span.

Consideration of Pull-out Failure of the Screws. All design pull out loads on the screws (5 screw fasteners per sheet) for all terrain categories with all roof types and different buildings conditions are lower than 3100N which is the minimum ultimate average pull out strength of the screws from purlin of 1.2 mm section thickness (Table 2). It is indicated using 5 screw fasteners per sheet for all type of roofing sheets connected to the purlin are safe under static loading.

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