

## Zincalume Profiled Steel Sheet for Self-supporting Roofing Element

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### Abstract

*Profile steel shell structures are used popularly due to aesthetic and economical use of materials. The aim of this research work is to develop a self-supporting roofing element using profiled steel sheet such as Zincalume, with potential for application in affordable quality housing. An experimental study on the structural strength and behaviour of a selected roofing element is conducted to validate the numerical investigation. This kind of roofing system has significant advantages of removing the internal trussing and support. An attempt has been made to find out efficient, economic and aesthetically pleasing shape of shell elements to provide self-supporting roofing system on the basis of present results. It is showed that parabolic roofing element having crown height 1/6 of chord length is more efficient than others. It can be concluded that the proposed roofing system has a great potential to be exploited for housing construction.*

**Keywords:** Profile steel sheet, Zincalume, Self-supporting Roofing Element, Thin shell, FEM analysis.

### 1. Introduction

Shelter, the second basic need of man, has been a preoccupation for many governments all over the world trying to house their growing population. The roof protects the building and its occupants from the effects of weather, but it are also is an architectural feature that gives the building a desired appearance. Roof accounts to a substantial part (about 25%) of the total cost of a building whether it is residential or industrial [1]. Therefore, it demands high technical and design specifications for both of the individual products elements and for the roof as a whole in order to achieve a satisfactory design life. Recent trends, research and developments are directed towards developing a lightweight, economical and structurally strong material that can be precast or prefabricated and easily erected. Conventionally, profile steel sheet such as zincalume and galvanized iron sheet is using in roof as a covering. The use of the corrugated metal thin shells in roofs, leads to considerable saving in materials, labour and cost. Analytically critical loads of self-supporting cylindrical roofs can be found out by energy theorem [2]. The possibility of using these sheets in folded plate roofs was investigated [3]. A study has been performed on structural strength and practical applications of cylindrical shell roofs made of corrugated metal sheets [4]. The exact differential equations used to explain the behavior of orthotropic shells. More recently, a study was carried out to develop a procedure for the design of steel roof subjected to non-uniform loads such as drifted snow using purlins frame [5]. Self-supporting concept was not considered in their study. Rib steel deck ware used as a covering materials, without any attention paid to their structural capability. Geometric and materials nonlinearity also was ignored. Extensive study on support settlement of cylindrical shell roofs was carried out [6-8]. Experimentally an investigation on structural strength and behaviour of ferrocement semicircular roofing elements were conducted [9]. Theoretical studies relating to ferrocement have been reported in the literature observed and found out an optimum shape within selected five shapes [10-11].

The main objective of this study is to develop a self-supporting roofing system, with potential and efficiency for application in affordable quality housing. Structural behavior of Inverted V shape, Cylindrical, Parabolic, Doubly curve, Single pitch and Flat plane shell roofing system are investigated numerically to provide as a self-supporting roofing system. This research was an attempt to investigate the contribution of corrugated sheet in reducing the buckling and displacement and enhances its load carrying capacity. An experimental program was undertaken in the course of present study. The experimental results showed good agreement with those obtained theoretically. The deflection and stress behavior of different types of roofing

elements are compared each other. The efficient and economic shape of self-supporting roofing elements has been found out after a through investigation on the basis of present results.

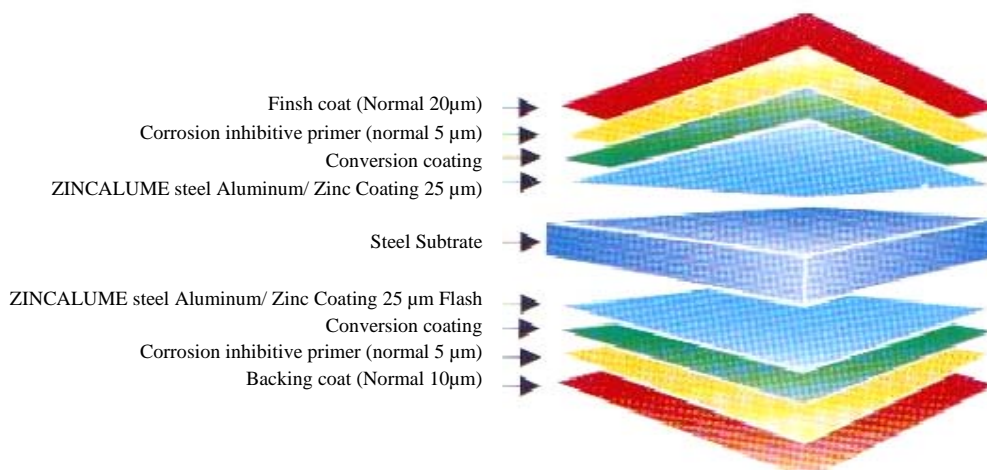
## 2. Roofing Material Zinalume

Normally corrugated metal sheet such as Zinalume is used in roofs as a covering only, while depending on different types of intermediate support. A self-supporting roofing system is when a roof runs its continuous length from on end to other end support by eliminating internal supports such as purlins, rafter, fastener and truss. This method provides a particularly neat and attractive solution to roofing whilst eliminating the ridge capping, thereby avoiding any possibility of leakage along this fitting. This roof can save material, construction and erection cost.

The shape and size of precast/prefabricated roofing element is chosen to satisfy the general requirements of strength and stiffness, lightness and economy, ease of handle and erection, proper seating and leak proof joint. There are different types of materials for construction of roof frame and roof covering. Common types of materials are metal sheet, ferrocement, plastic, and concrete and clay tile for roof covering. Timber and metal are normally used for the trusses. For this investigation the corrugation metal sheet Zinalume was chosen in an effort to develop the self-supporting roofing system. The main features of using of Zinalume sheet as a roofing material as according to Bluescope-Lysaght [12] are as follows;

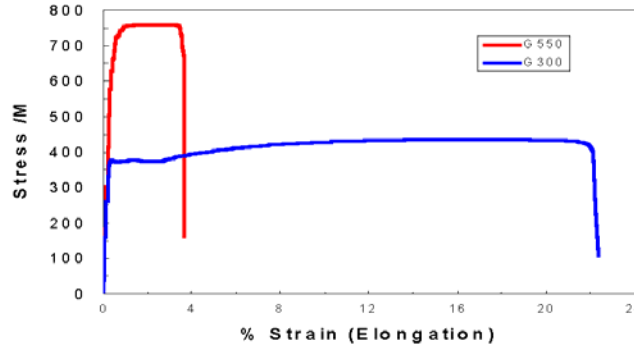
- (a) Speedy installation; no shuttering required, Less installation errors
- (b) 30-40% cost saving over RCC roofing
- (c) Lower dead load on the walls, Light weight and easy handling
- (d) High strength to weight ratio
- (e) Easy to for into complex shapes, new shape more efficiently allowing to be used.
- (f) Elegant profile and uniform sizes, large span possible with intermediate supports
- (g) Abundantly available, and inexpensive, corrosion-resistant
- (h) Fire registrant, Material consistency high
- (i) Unaffected by termites and longevity
- (j) Does not required paint
- (k) No materials wastage, recycling system is applicable
- (l) Economical considering mean service life

Zinalume sheet can be considered as the best and most durable roofing elements for affordable quality housing in the world. Zinalume consists of high strength steel substrate protected with corrosion inhibitive treatments and coatings designed to provide the broad spectrum of performance that is essential for long life and minimum maintenance. All steel sheets used in the manufacture of the roofing sheets shall have a protective metallic alloy coating of zinc (43.5%) aluminium (55%) and silicon (1.5%), applied by the hot dip process and having a coating thickness of 0.05mm as stipulated in AS1397-1993 for coating class AZ 150. Chromic acid sealed, zinc phosphate pretreatment is applied after alkaline cleaning for coating. Galvanized steel is treated on both sides with phosphate conversion coating followed by application of an impervious epoxy primer incorporating a corrosion inhibiting compound. Modified polyester coating of 20 micrometers is used for finish coat to ensure maximum durability. Composition layer of zinalume is shown in Figure 1.



**Fig. 1.** Different composition layer of Zinalume sheet of Bluescope-Lysaght [12]

Zincalume, which is used in the investigation, are locally available in Malaysian, Singapore and Australian market. It is obtained strength as steel grade ASTM A446 E, minimum yield strength 550 Mpa, Modulus of elasticity  $E = 210 \text{ Gpa}$ , poissons ratio  $\nu = 0.30$ : mass =  $4.7 \text{ Kg/m}^2$  (for thickness of  $0.47 \text{ mm}$  sheet). Zincalume obtained two basic strength grades G 550 and G 300, which is shown in Figure 2. High tensile steel G550 was used in this study to develop self-supporting roofing elements.



**Fig. 2.** Stress-strain diagram for Zincalume steel of Bluescope-Lysaght [12]

### 3. Field Application of Profiled Steel Sheet for Roofing

The purpose of a structure is to transfer external forces to the supports through structural elements. The trend of modern architecture is now changing from traditional flat surface towards curved shapes that encloses a volume of space. Shells are structures that can be idealized mathematically as curved surface for building roofs. Shells are being used on an increasing scale for roof. Shell element is suitable for roofing because of its efficiency as load carrying member with a high degree of reserved strength and structural integrity, high strength to weight ratio, very small thickness ratio to other dimension, very high stiffness and containment of space. A shell which is formed by translating a curved line along a straight longitudinal axis and which span longitudinally between supporting diaphragms is termed as cylindrical shell. The cylindrical shell is the simplest form of shell, which can be employed in roofing engineering due to its singly curved surface. Figure 3, 4 and 5 illustrates the different applications of profile parabolic shell roof.



**Fig. 3.** Profile Parabolic Shell Roofing Element Bluescope-Lysaght [12]



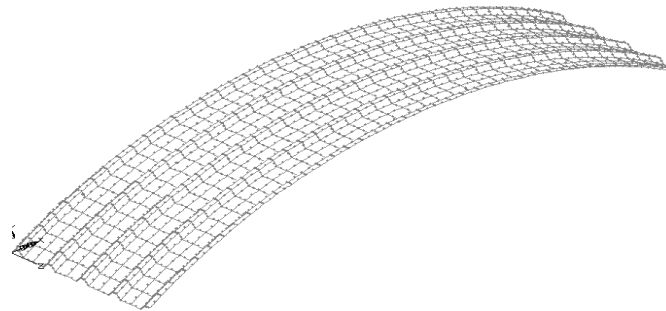
**Fig. 4.** Profile doubly Curve Shell Roofing Element of Bluescope- Lysaght [12]



**Fig. 5.** Self-supporting roofing element at Universiti Putra Malaysia

#### **4. Finite Element Models**

The shell roofing element were models and analysed employing the finite element software LUSAS [13]. The shell-roofing element was analysed as a 3-D problem. It was discretised by means of 8-noded semi-loof elements having three translational displacements in the global axes at the corner and mid side nodes and one rotations with respect to axes in the plane of middle surface as shown in Fig.6. At first an arc was drawn by three Cartesian points and then translate required width and corrugation for profile sheet. Width of different types of roofing elements was considered as 0.76m and 8.0m for analysis. Thickness of flat sheet and profile sheet were assigned as 1.2mm and 0.47mm respectively. A nonlinear analysis was carried out assuming Zinalume to be elastic-plastic material. The model was subjected to global distributed load along the vertical direction. Different types of roofing element such as Inverted V shape, cylindrical, parabolic, doubly curve, single pitch and flat plane have been subjected to incremental global distributed load. The boundary conditions for the roofing element were assumed as fixed, pin and simple supported to make a comparative study of effect of boundary condition. Different mesh sizes and different numbers of element were tried so that accurate results could be obtained.



**Fig. 6.** Finite element model of profile of parabolic shell roof

#### **5. Experimental Investigation**

In order to verify the validity of the finite element analysis of different type of roofing elements, critical and limited model test is conducted. The dimension of the model was span 3.0m, width 0.76 m and crown height 0.125m, 0.25m, 0.5m, 1.0m and 1.5m respectively. All specimens were tested to ensure curve edge free and straight edge hinged. U type metal channel were used to provide hinge support at straight of cylindrical and parabolic shell roofing element to maintain self- supporting condition. All the specimens were tested in the vertical position. Sand bag loading was used to provide uniformly distributed load. Each bag was contained 5 kg load. The load was applied manually by gradually increased until yield failure of the model. 4 deformation gauge, 2 LVDT and 10 electronic strain gauge are used to measure deflection and stain. Deformation gauge and LVDT were set at the center of bottom surface for the specimen with required stand. Strain gauges also were used the mid position of top surface of the specimen. Figure 7 and 8 are shown sand bag loading and failure mode respectively.



Fig. 7. Sand bag loading on cylindrical shell roofing



Fig. 8. Experimental deflected shape

## 6. Results and Discussions

In shell elements, it is observed that corrugated sheet is structurally 10 times stiffer than flat sheet, which is shown in Table 1. Profile sheet is stronger because of its rib and section modulus. According to the non-linear finite analysis, parabolic shell roofing element is more efficient than other type of roofing element due to its less deflections and stresses. Parabolic and cylindrical roofing elements obtain arch action so load carrying was higher. Non-linear analysis and those obtained experimentally that is shown in Figure 9. The load –deflection, stress strain and deform shape profiles for investigated roofing element showed that parabolic roofing element having crown height 1/6 of chord width is more efficient than others as self supporting condition [14]. It is observed that a parabolic shape roofing element with optimum crown height is structurally and economically able to use as a self-supported supporting roofing system for 8 m span lengths using 1.2 mm thick corrugated Zinalume. Nine types of roofing elements are studies in the present work. The presence of corrugation in the metal roofing element resulted in a significant improvement on the roof's structural performance compared to flat sheet element. Experimental load-deflection profile of different crown height parabolic roof using 0.47mm thick corrugated Zinalume sheet, 3 m span, 0.76m width and pin support along the straight edge are shown in Fig. 9. Good agreement was found between the results from non-linear analysis and those obtained experimentally as shown in Fig. 10.

**Table 1.** Displacement of parabolic roofing elements with different span length

Type of Roofing System	Thickness of Materials (mm)	Applied load KN/ M <sup>2</sup>	Span 3 m	Span 4 m	Span 5 m	Span 6 m	Span 7 m
			Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)
Parabolic shell roof	0. 65 (Flat sheet)	0.528	44.5	171	384	688	1210
	0.47 (Profile sheet)	0.528	4.99	9.58	21.54	42.50	228.0

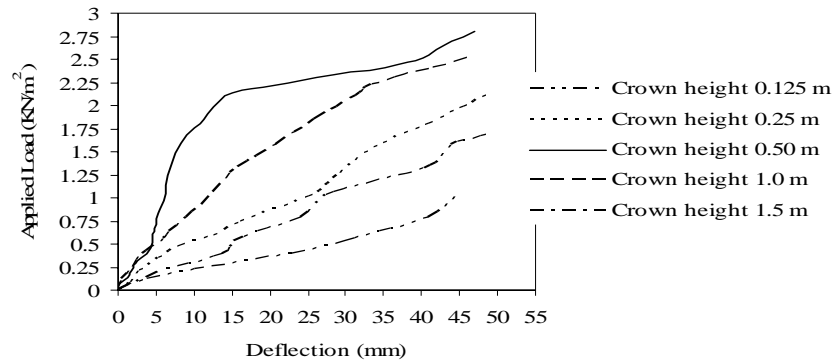


Fig. 9. Experimental load deflection profile of different crown height parabolic shell roofing element

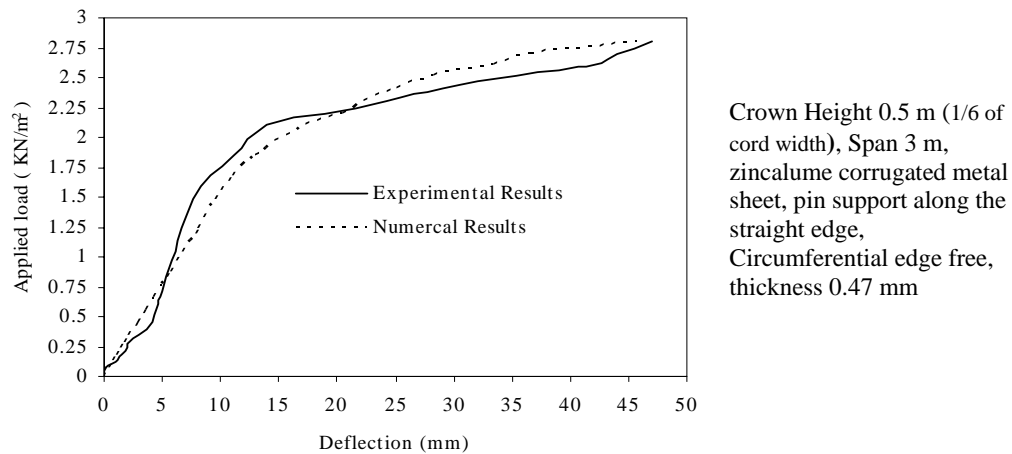


Fig. 10. Comparison between Experimental and Numerical deflection for parabolic roofing element

## 7. Conclusions

Conventionally, metal sheet such as Zinalume and GIS is using in roof covering through truss as a covering. It has been implemented a novel and new approach to provide self- supporting roofing system. The behavior of nine different types of roofing element is studied to find out an economical, efficient, architecturally pleasing shape in self -supporting condition. Nonlinear effect has been adopted in the finite element analysis. From the parametric study, it is found that the central deflection and stresses are least in parabolic shape of roofing element with crown height about 1/6 of chord length. On the basis of the present analysis, it is found that the parabolic shape profiled Zinalume steel shell element is the most economical, efficient, architecturally pleasing shape in self- supporting condition.

## 8. Acknowledgement

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