A Parametric Finite Element Study on Concentrated Load Distribution in Corrugated Steel Decks

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Abstract - *Corrugated steel decking has been utilized in construction since around 1784. This is one of the oldest types of cold-formed steel products. Corrugated steel decks are commonly used mostly for building roof tiles and siding because they are strong, light, and simple to install. Several standard corrugated steel decks are generally available for building construction and other usage. There is an increasing tendency of corrugated iron decks being directly subjected to concentrated loads. Mechanical loads, stresses owing to plumbing and electrical elements suspended below the deck, and loads due to posts installed on top of the deck are all forms of concentrated loads. A thorough parametric research utilizing finite element models created in Ansys was done to gain a better knowledge of the performance of corrugated steel decks under concentrated loads. The parametric study investigated the effects of variables such as deck kinds, steel depth, deck span condition, deck span length, and concentrated load along the deck span, concentrated load application to different components of the deck cross - sections, and so on the deck's strength and behaviour.*

***Key Words*: Corrugated steel deck, Cold-formed steel, Concentrated load, Finite element analysis, Parametric study**

1. INTRODUCTION

In the construction industry throughout the world, corrugated col-formed steel (CFS) which are available in too many shapes and depths are being widely used. National standards might control the structural design of corrugated metal decks in different countries. Some countries have manuals which provide extra information on steel deck design and construction. Despite the widespread use of corrugated metal decks, some aspects such as the design of perforated steel decks, decks with openings, decks under concentrated loads, and built-up deck sections are either not addressed at all or are addressed with significant limitations in design standards and manuals. Recent concerns have been raised about the precision of the direct strength method's flexural strength predictions of many decks' profiles. Additional research on the strength and structural performance of certain types of corrugated metal decks and steel decks under different loading and support conditions is urgently needed [3]. Several early investigations were undertaken to establish which Finite Element model parameters are critical for achieving adequate prediction accuracy at the lowest possible computing cost, as presented herein. Preliminary studies were undertaken on the B deck (a trapezoid shaped deck having flat flanges), the 2R deck and 3 ½ R decks (re-entrant profiles), as well as the 4½ D and 7½D decks (all of which have been included in the parametric studies) (deep trapezoidal decks with intermediate longitudinal stiffeners in deck top flanges) [1].

Vitality. V. Degtyarev [1] presented the findings of a parametric finite element analysis of the distribution of concentrated loads in cold formed corrugated steel decks. The parametric investigation was done by using ANSYS software to make finite element analysis. Mesh densities, decking corner radii, and tool geometry imperfection distributions and magnitudes were selected as optimal finite element model parameters based on studies to meet the criteria of accuracy and computational efficiency. Physically nonlinear deck models with elastic-perfectly plastic materials properties were used. The models were geometrically nonlinear because of large deflection effects. Convergence studies were carried out in order to determine the best mesh density based on the accuracy and computing efficiency. Corner radii were also investigated for their effects on elastic buckling loads and maximum concentration loads.

V.V. Degtyarev [3] demonstrates the use of ANSYS to construct finite elements of corrugated metal deck in bending. On elastic buckling and ultimate moments of models, as well as their load-deflection curves, the effects of parameters such as shell components, mesh density, corner radius, amount of deck corrugations, appearance of transverse ties, tool geometry imperfection distribution and magnitude, deck boundary conditions, loading type, and stress-strain diagrams were investigated.

Under focused stresses, local buckling of corrugated metal sheets was investigated [4]. Experimental tests and theoretical research were used to discuss the load carrying capacity and failure form of corrugated steel plates. Trapezoidal shaped thin-walled metallic profiled sheets are used in composites floor building to facilitate quick construction and reduce reinforcement and form work needs in concrete casting [5]. However, early buckling failure of steel sections has also been documented. For composite flooring systems, there are also design rules that limit what can be done. As a result, the goal of this project was to create a new form of composite top-hat section for use in a composite slim-floor system. This paper evaluated the structural behaviour of these novel sections under various loading and support situations using a pilot experimental approach.

Existing composite slabs in the construction industry lack two-way action, resulting in an unequal distribution of forces along the weak axis, which typically aligns with the perpendicular direction of the stiffened steel deck that is used [6]. The main objective of this study is to develop an efficient two-way composite floor slab using innovative corrugated steel decking.

With increased depth and load bearing capacity, cold formed trapezoidal sheets are being employed more frequently with hanger bolted to a web of the sheeting [7The transfer of the applied load by the hangers to the profiled roof sheathing ribs as concentrated load per rib is frequently critical for the profile resistance in bending or to satisfy the deflection limit, but the distribution of the load between the ribs is unknown, so an advanced numerical analysis in Abaqus software was performed for several section types and loading conditions. The paper's show significant is a created design technique that allows for the possible transfer of concentrated load across ribs in the case of simply supported members when design is guided by deflection or bending resistance.

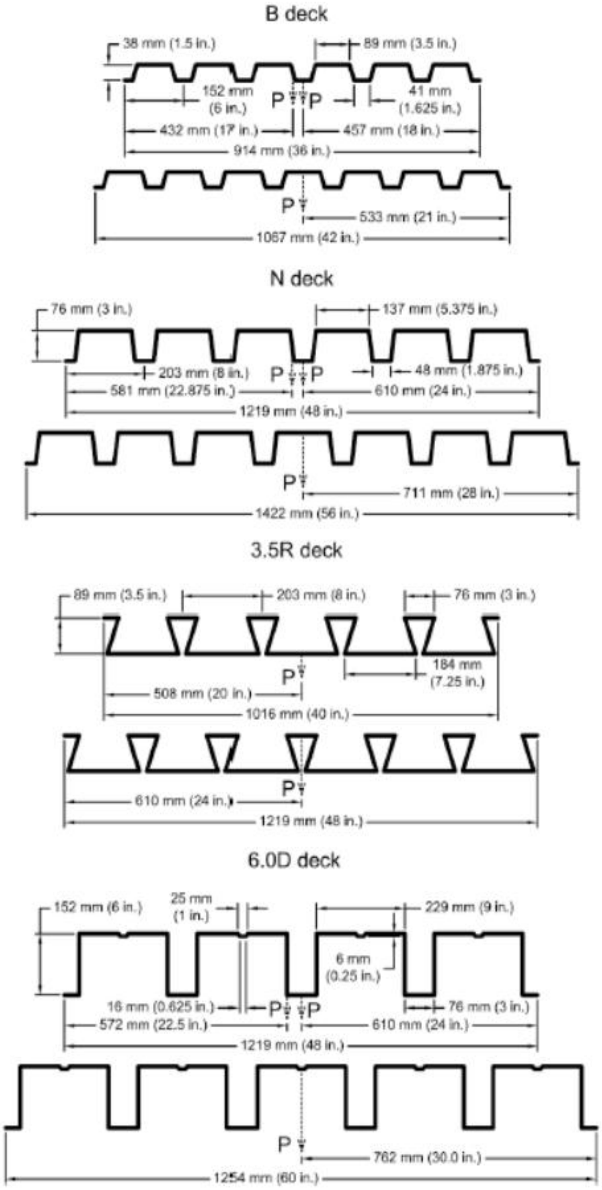
2. FINITE ELEMENT MODELS

Non-linear three-dimensional Finite Element models of corrugated cold-formed steel decks were created in ANSYS software [2], which is a general-purpose commercial FE package capable of performing number of different analyses that includes elastic buckling analysis and static analysis with material and geometric non-linearities employed in this discussion. For non-linear analysis change in thickness is accounted.

The bilinear isotropic hardening material (BISO) behaviour with Von Mises plasticity was used to model the corrugated metal deck as an elastic-perfectly plastic material. The deck was designed with a 2.03x105 MPa elastic modulus, a Poisson's ratio of 0.3, and a yield stress of 276 MPa.

Concentrated forces are applied to the deck bottom flange, top flange, and web in the center of the deck cover width, as shown in fig.1. When compared to bottom flange and web-loaded profiles, wider deck panels were employed to handle the center load application for profiles with loads applied to a deck top flange. Figure 2 depicts the boundary conditions of single, double, and triple span deck models employed in the parametric analysis. Supports are assumed to have zero widths. Vertical translation restrictions of all bottom flange nodes at deck support positions make up the boundary conditions. Longitudinal and transverse translation restraints of one node of each bottom flange at the deck supports were used to represent deck connections to supports. Loading is accomplished by applying imposed vertical displacements to the node in small increments that correspond to the concentrated load sites.

The evaluation was performed in two stages: first, elastic buckling analyses were carried out using the Block Lanczos eigen value extraction method to obtain elastic buckling modes and elastic buckling loads, and then non-linear static analysis was carried out to model collapse behaviour and obtain the maximum concentrated load for each analyzed model.



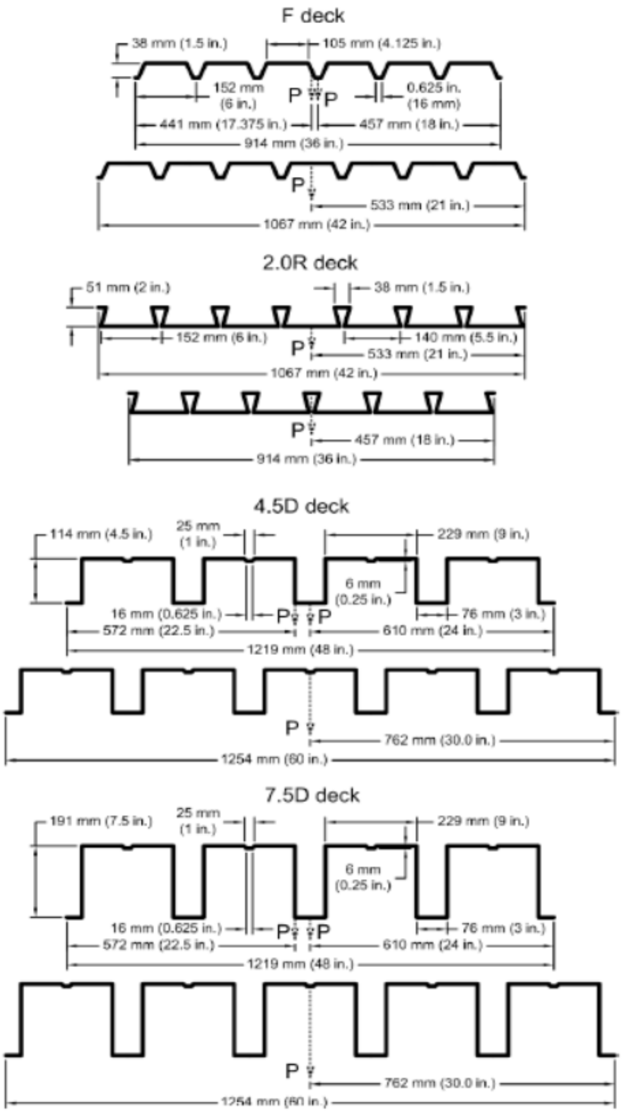


Fig -1: Deck profiles with point loads applied to bottom flanges, top flanges and webs

2.1 Finite element discretization

Discretization of deck models were done [1] with quadrilateral element meshes. A convergence study was conducted to determine the appropriate mesh density on shallowest B deck and deepest 7.5D deck. And it was concluded that the mesh density which provided reasonable accuracy and simulation time was the medium mesh density. Steel thickness taken for B deck was 0.75 and 1.52mm and that for 7.5D deck was 0.91 and 1.52mm. For B deck 1.83m and for the 7.5D deck it was 8.23.

Application of concentrated load was done at the mid span of simply supported deck to the bottom flange, the top flange or the web at the center of the deck panel. Corners of the deck were modelled with sharp corner radii. Three mesh densities; coarse, medium and fine which are considered in the study are shown in fig.3.

The flat widths of the deck flanges in compression decrease as corner radii grow, resulting in a rise in local elastic buckling loads.

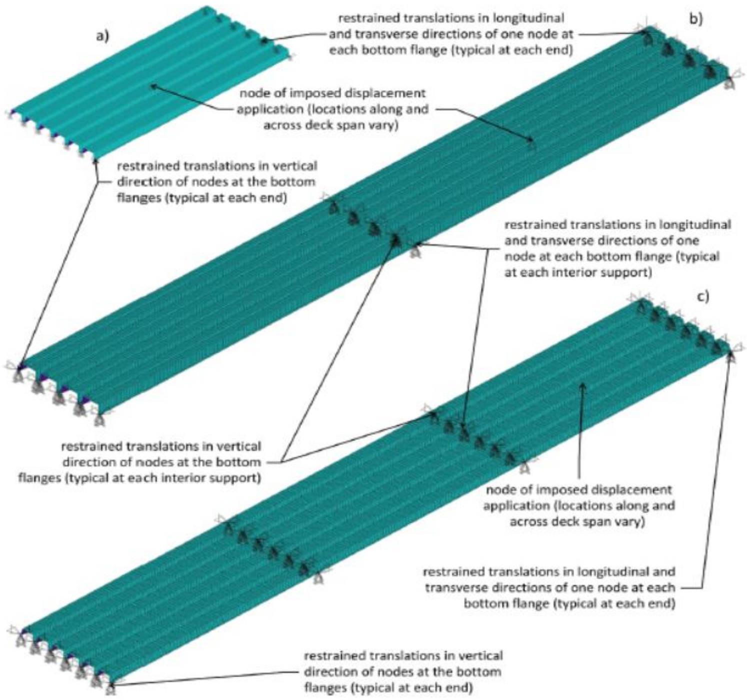


Fig -2: Boundary conditions of (a) single, (b) double and (c) triple span deck models

3. PARAMETRIC STUDY

The geometrical study includes eight different deck types, as shown in fig.1. These are trapezoidal profiles with flat flanges of types B, F, and N; re-entrant profiles of types 2.0R and 3.5R; and deep trapezoidal profiles with intermediate stiffeners in the top flanges of types 4.5D, 6.0D, and 7.5D. Steel roof decks, which are extensively utilised in the United States, have been chosen for the study. The study encompassed a wide range of decks of varying depths and shapes, including shallow and deep trapezoidal profiles and re-entrant profiles[1].

Steel thicknesses of 0.75mm, 1.20mm, and 1.52mm were investigated for the B, F, N, and 2.0R decks, and 0.91mm, 1.20mm, and 1.52mm for the 3.5R, 4.5D, 6.0D, and 7.5D decks. Deck panels were thought to be easily supported and multi-span continuous.

When symmetry was considered, the placement of the concentrated load along deck span was modified to cover all conceivable load sites. The load was placed from L/8 to L/2 for single spans, L/8 to 7L/8 for double spans, and L/8 to 3L/2 for triple spans. The increment of load location was L/8 for all span conditions.

For the concentrated loads applied to the deck top and bottom flanges, different deck panel widths are selected to ensure that the load is located at the centre of the deck cover width.

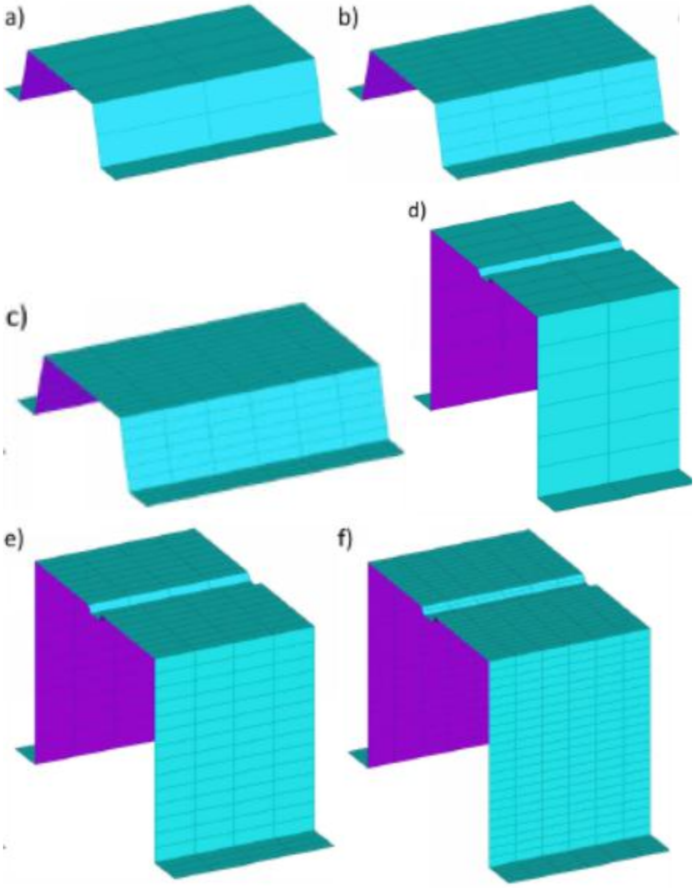


Fig -3: Mesh densities used in convergence study (one 152mm long deck flute is shown for clarity): (a), (b) and (c) B deck with coarse, medium and fine meshes respectively; (d), (e) and (f) 7.5D deck with coarse, medium and fine meshes respectively

The parametric analysis employs nonlinear three-dimensional Finite Element models of steel decks. Steel deck panels were discretized using medium density meshes and sculpted with sharp corners. The deck was modelled as an elastic-perfectly plastic material using the bilinear isotropic hardening material behaviour (BISO) with von Mises plasticity, with an elastic modulus of 2.03x105MPa, a Poisson's ratio of 0.3, and a yield stress of 276MPa.

The concentrated stresses applied to the webs of the re-entrant profiles were not included in the study because the condition is nearly difficult to create in practice because to the limited flute hole at the bottom of the deck. Load-deflection curves were obtained from nonlinear finite element simulations for each investigated deck model.

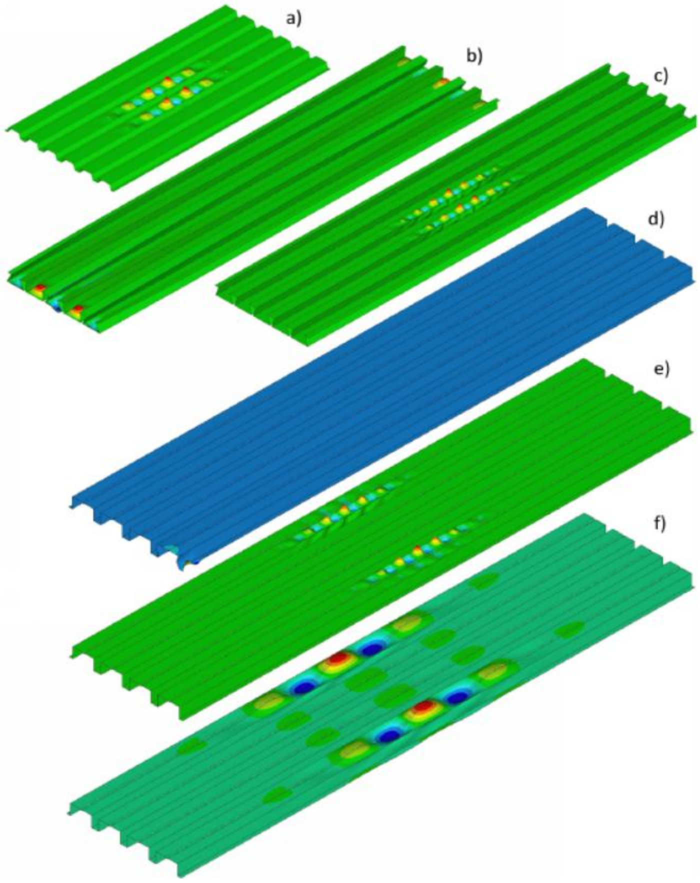


Fig -4: Different buckling modes of studies corrugated steel deck profiles: (a) local top flange elastic buckling (first elastic buckling mode) of trapezoidal deck with flat flanges, (b) first elastic buckling mode of re-entrant deck, (c) local top flange elastic buckling of re-entrant deck, (d) first elastic buckling mode of deep trapezoidal deck with intermediate stiffeners in top flanges, (e) local top flange elastic buckling of deep trapezoidal deck with intermediate longitudinal stiffeners in the top flanges, (f) distortional elastic buckling of deep trapezoidal deck with intermediate longitudinal stiffeners in the top flange.

3. CONCLUSIONS

In the study [1], nonlinear three-dimensional models of corrugated steel decks subjected to concentrated loads were developed using shell elements in ANSYS. The developed models can be used for parametric studies of corrugated steel decks under concentrated loads, since the developed FE models with optimum parameters showed good agreement with available test results.

Corrugated steel decks of types B and F were modeled, subjected to concentrated loads and found the strength and behavior [2]. The parameters varied in the study were: deck gage, span length, span condition, concentrated load locations along and across the deck span. Discussion is done on the observations of deck behavior under concentrated loads and the effects of parameters on the effective transverse distribution widths governed by the deck strength and stiffness.

Steel deck was modeled with linear 4-node and quadratic 8-node structural shell element in ANSYS [3]. In the study the effects of different constitutive steel models on the moment capacity, flexural stiffness and load-deflection diagrams were considered. The study showed that the effect of deck corner radii is such that it had relatively small effects on the moment capacity and the distortional elastic buckling, but had a greater effect on the local elastic buckling moment.

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