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Investigating the Load-Bearing Behavior of Composite Cold-Formed Steel Decking

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Abstract:

Many countries face challenges in renovating historical houses and residences, particularly those with wooden roofs that have deteriorated over time [1]The designed decking system effectively addresses this issue, offering a modern solution to reinforce and replace aging structures while preserving their historical value. This Paper outlines the evolution of decking system construction utilizing steel and timber. The proposed system integrates cold-formed sigma cross sections with wood-based boards, benefiting from the excellent load-bearing properties of steel and the aesthetic and thermal advantages of wood. This synergy showed a versatile solution particularly well-suited for the renovation of historical buildings and museums. [2]. The lightweight nature of the system materials allows for substantial structural upgrades and provides safety without compromising the integrity of existing structures [3].To assess and compare the performance of various composite cold-formed steel (CFS) decking systems, ABAQUS finite element software was employed, focusing on factors such as span variations and stiffened steel flanges. The findings indicate that incorporating solid plates at the system support significantly enhances the load-carrying capacity. This lightweight construction method offers an easy solution that respects architectural integrity while improving structural performance.

Keywords*: Decking, CFS, Structure, Analysis, Timber, capacity.*

Introduction

Building restoration is becoming an important economic and social necessity all over the world [4]. Due to the essential need to preserve the heritage building, This trend took a place in the construction market [5]. A significant amount of research is dedicated to creating innovative solutions and developing new restoration methods to save the countries culture. [6]. In this context, a decking system is essential for restoring heritage buildings, as all materials are evaluated against standard structural steel, which remains the most selected option for such projects [7].

Figure 1 Ruined old building - a- Elevation of the building - b- the destroyed floor of old building

At the same time Environmental sustainability and SDGs are becoming a major focus in contemporary construction practices [8]. Engineers are not only working to reduce materials and resources usage in structures but also aim to protect the environment through the decrease of energy consumption and carbon dioxide emissions across the entire life cycle of buildings. [9]. Consequently, renewable building materials like wood products, timber, and bamboo are being utilized in various structural applications, including composite flooring systems [10], [11].

A composite structure is one in which two or more materials are combined in a structural member. The main advantage of composite structures compared to non-composite structures is that the composite beams generally perform better the traditional one beam material [12], which means an increase in structural capacity and a contribution to the minimal utilization of resources by decreasing the sizes of structural members. [13], [14]

Also, Composite structures have been utilized widely since the early 20th century and have undergone significant and rapid development over the years [15]. Generally, composite beams consist of hot-rolled steel beams paired with reinforced concrete slabs, combined just to maximize the benefits of both materials, the steel and the concrete elements [16]. Many researchers mentioned in their studies that Timber is the most perfect and durable material for sustainable building practices, which possesses various benefits, including high strength-to-weight ratio, low-embodied energy, eco-friendly, and economical [17]. The Timber carbon footprint analyzed ranges from 114 to 151 kg CO_2/m^2 for conventional houses and from 127 to 157 kg CO_2/m^2 for low-energy houses, both of which are notably lower than the 292 kg CO_2/m^2 for a concrete-frame version of a similar building [10].

The composite beams contain cold-formed steel joists and wood-based panels are commonly used in commercial, industrial, and increasingly residential buildings due to their efficiency, cost-effectiveness, and durability [18]. The goal of this study is to propose an alternative solution for addressing the issues and restoring the floor to enable the reuse and the renovations of the building. This approach needs to prioritize reduced formwork and shoring, lightweight and easy transporting and handling, quick assembly, minimal equipment requirements, flexible design and durability. Consequently, the new flooring should consist of multiple units manufactured in the factory and then transported to the construction site. This decking system is composed of three elements: the web (1), the upper section (2), and the stiffening elements (3). The web consists of steel sigma sections, while the upper section is made from practical wood. Plates, made of horizontal steel, connect to the edges of the sigma. Various specimens have been tested with spans of 4.5, and 6 meters, utilizing practical wood in the decking system with various fasteners plates.

The web elements are assembled by placing two sigma sections back-to-back. The lower element is the steel plate used to fasten the lower flanges of the web elements. Moreover, it increases the tension spots in the steel area. The upper element is a wood plate. The system's stiffening isn't installed in all specimens to compare it with the non-stiffened systems. The stiffening elements increase the strength, decrease deformation and increase the load capacity of the decking system.

The failure modes, ultimate capacity and load-deflection observed from the numerical tests are thoroughly analyzed. The proposed system offers greater restorative benefits compared to existing market solutions. Its construction is quick and easy to handle, and it boasts a high strength-to-weight ratio, ensuring minimal impact on the structural integrity of older buildings. The system can be assembled at the factory and easily transported to the site, requiring less equipment and manpower.

Finite element analysis

To Investigate the Load-Bearing Behavior of Composite Cold-Formed Steel Decking, a three-dimensional finite element model is established by ABAQUS software which has been widely used in the past for the analysis of cold-formed steel members [19].

Material modelling

The numerical analysis of the decking system incorporates both material and geometric nonlinearities. The same mechanical properties were used for the finite element (FE) models of the specimens. Steel is treated as an isotropic material; therefore, Young's modulus and Poisson's ratio were defined in **Table 1**. The plates are modeled using the solid element SOLID65, while cold-formed steel sections are represented by the shell element SHELL181.

Figure 2 Practical Wood

Table 1 Material Properties of Floorboard

Thickness of Floorboard t_b mm	Young's Modulus GPA	Poisson's ratio
38	2.3	0.2

The cross-sectional shape of the tested steel beams as well as their average measured dimensions are provided, taking into account that the decking system spans varied from 4500 mm up to 6000 mm, this range is significant because most older buildings fall within it.

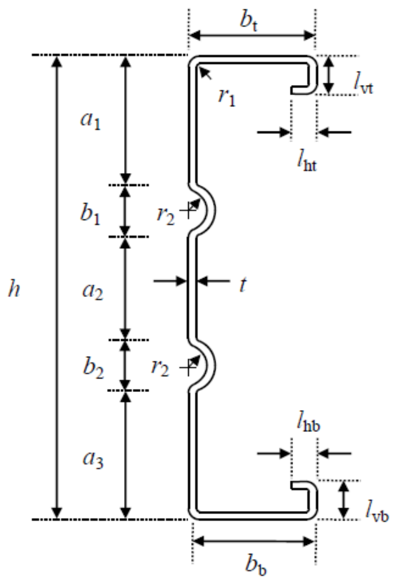

Figure 3 Cross-sectional shape and labelling

of dimensions of tested cold-formed steel

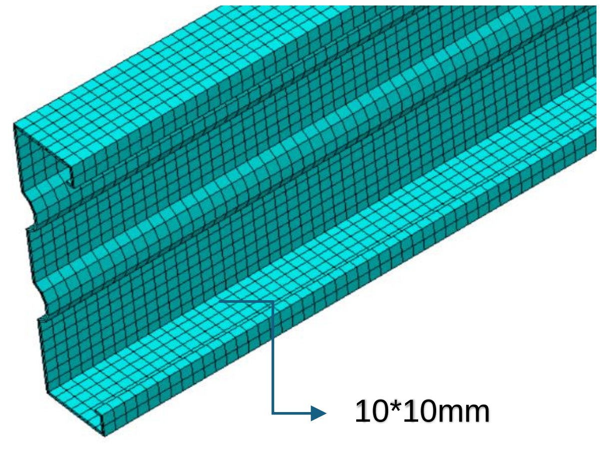

Figure 4 Meshing size

Meshing and boundary condition

A mesh with dimensions of 10 mm x 10 mm was applied to both steel and timber. **Error! Reference source not found.** provides details about the meshing.

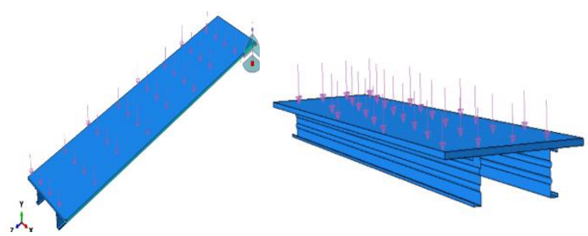

Table 2 Specimens dimensions

Specimen	**t**	**h**	**b_t= b_b**	**L_{vt} = l_{vb}**	**L_{ht}**	**a_1=a_3**	**a_2**	**b_1=b_2 *mm***
250-3-6000-0P	3	250	65	18	7	61.7	48.8	27.8
250-3-6000-1P	3	250	65	18	7	61.7	48.8	27.8
250-3-6000-2P	3	250	65	18	7	61.7	48.8	27.8
250-3-6000-3P	3	250	65	18	7	61.7	48.8	27.8
250-3-5000-0P	3	250	65	18	7	61.7	48.8	27.8
250-3-5000-1P	3	250	65	18	7	61.7	48.8	27.8
250-3-5000-2P	3	250	65	18	7	61.7	48.8	27.8
250-3-5000-3P	3	250	65	18	7	61.7	48.8	27.8
250-3-4500-0P	3	250	65	18	7	61.7	48.8	27.8
250-3-4500-1P	3	250	65	18	7	61.7	48.8	27.8
250-3-4500-2P	3	250	65	18	7	61.7	48.8	27.8
250-3-4500-3P	3	250	65	18	7	61.7	48.8	27.8

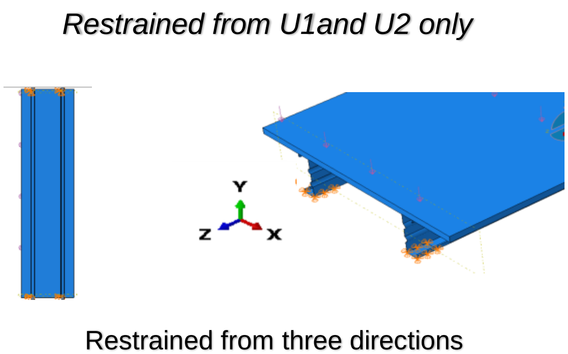

Figure 5 Boundary Condition

The model simulates a simply supported beam, with one end roller-supported and the other end Fixed. The roller support was allowed to rotate freely about the three axes(X,Y,Z), while the Fixed support was fully constrained against vertical and horizontal movement mentioned in **Error! Reference source not found.** . The vertical load was applied as Uniform load on the flooring plane.

Contact modelling

The contact interaction between the top flange of the cold-formed steel beams and the bottom fiber of the flooring timber panels was simulated as a surface-to-surface hard contact option. The parameter Adjust=0.0 has been used in conjunction with the contact pair between the Timber flooring panels and the Sigma top flange.

Geometric imperfections

It's very common that cold-formed steel sections are more vulnerable to local instabilities, such as local and distortional buckling, geometric imperfections as well can have a crucial effect on the buckling response and the ultimate load carrying capacity of cold-formed members. Therefore, initial geometric imperfections have been included in finite element models for accurate capturing of the ultimate load, failure mode and post-buckling mechanism of cold-formed steel members. Eigen value has been utilized to obtain the least buckling value of the decking system and assign it as Geometric imperfection.

Solution scheme

Due to the high instability of the model arising from the local buckling, Riks solver has been utilized through the nonlinear analysis of the model.

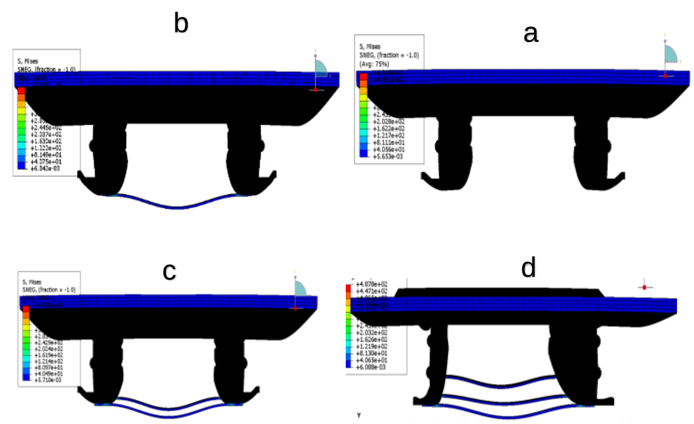

Figure 6 Comparison of failure modes for a decking system with a 6-meter span considering different stiffened spans: a) without tie plate, b) One tie plate, c) Two tie plates, and d) Three tie Plates

Load deflection-curve

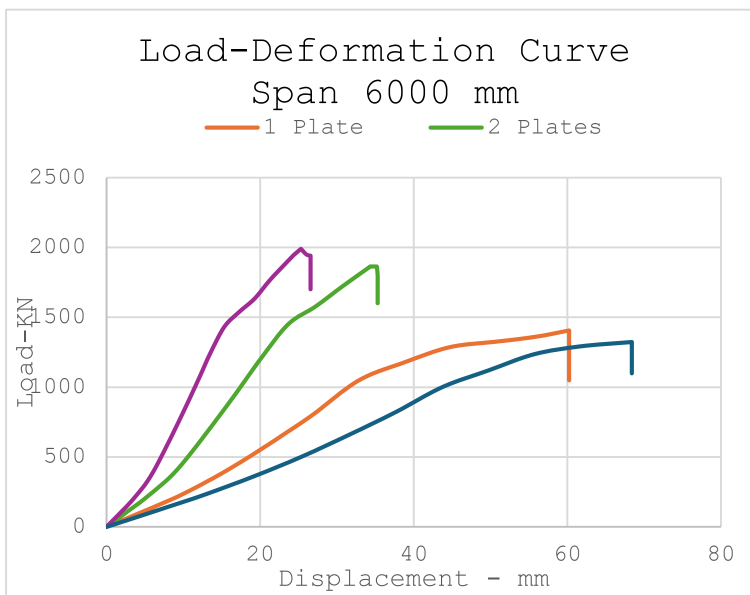

Figure 7 Load-deflection curve – Span 6000 mm

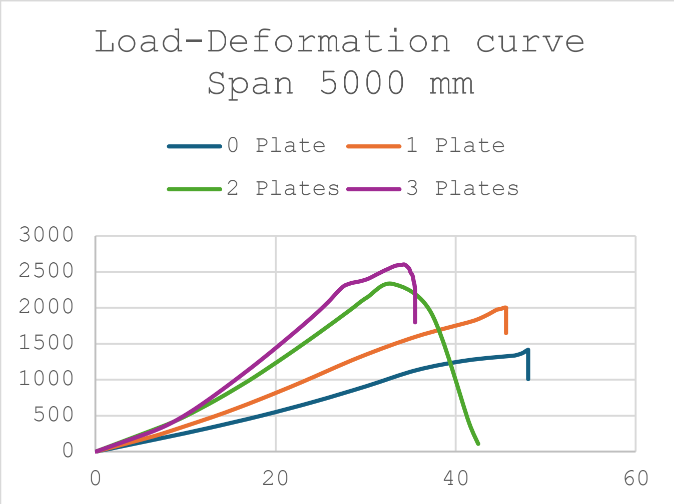

Figure 8 Load Deflection curve- Span 5000 mm

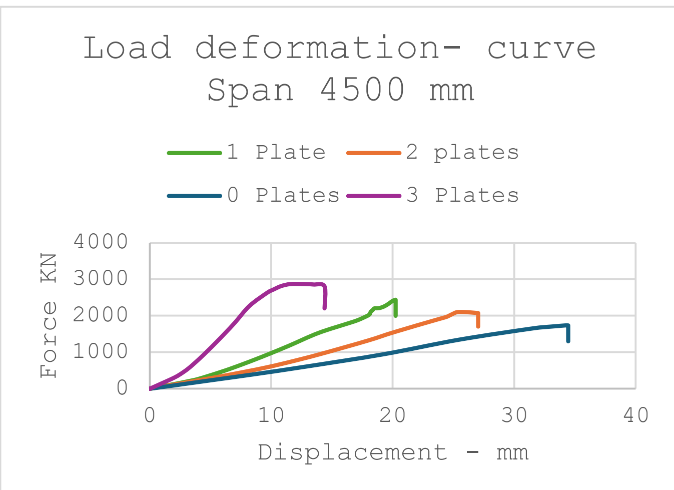

Figure 9 Load-deflection curve – Span 4500 mm

Conclusion

This study investigated the load-bearing behavior of a composite cold-formed steel (CFS) decking system combined with wood-based panels, focusing on its application in the restoration of heritage and aging structures. Through ABAQUS program for finite element analysis, the performance of the system was evaluated under varying parameters, including span length and stiffened plates spacing. The results revealed that the usage of wood-based panels is the most highly alternatives than the usage of precast

inclusion of steel stiffeners significantly improves the system's load-carrying capacity and stiffness. Configurations with multiple stiffeners (two or three plates) exhibited higher resistance to deformation on all span length and greater ultimate load capacity compared to systems without any plates. This underscores the critical role of plates in

timber components, thereby optimizing structural efficiency.

Systems with **steel stiffeners** reduced deflection by around 40% in the three spans, but the effect was more pronounced in the longer span due to its inherent flexibility. This finding emphasizes the necessity of stiffeners' usage in practical applications to enhance system capacity and reduce deflection.

Also, the finite element analysis revealed critical differences in the load-bearing behavior of the composite cold-formed steel (CFS) decking system between the 6,000 mm, 5,000 mm and 4,500 mm spans, particularly in terms of deflection, ultimate load capacity, and the influence of steel plates.

The 4,500 mm span exhibited significantly **lower mid-span deflection** under identical loading conditions compared to the5,000 and 6,000 mm span. This aligns with Euler beam theory, where deflection is proportional to the cube of the span length. For instance, at a uniform load of 2 kN/m², the 6,000 mm span showed ~30% greater deflection than the 5,000 mm span , and the 5,000 mm span showed ~25% greater deflection than the 4500 mm.

The **shorter beam span (4,500 mm)** demonstrated a **higher ultimate load capacity** (20–25% increase) compared to the 5,000 mm span, as buckling effects became more dominant in the longer span. The addition of stiffeners at quarter points increased the ultimate load by ~35% in the 6,000 mm span , ~30% in the 5,000 mm span and ~25% in the 4,500 mm span, confirming that longer spans benefit more from intermediate stiffening.

For **historical buildings** the 4,500 mm span offers a safer, stiffer solution with fewer plates.

Longer spans (6,000 mm) require **strategic plate placement** to meet serviceability limits, making them suitable for open-plan renovations like museums or warehouses.

Finaly, this proposed decking system offers a lightweight, modular, and easy-to-install solution for renovating historical buildings and aged structures. Its high strength-to-weight ratio minimizes additional load on existing structures, while factory prefabrication reduces on-site labor and equipment requirements. These attributes make the proposed system an ideal choice for projects prioritizing architectural preservation, sustainability, and construction efficiency.
By combining cold-formed steel with timber material, the system leverages the environmental benefits of timber (low embodied energy, carbon sequestration) and the mechanical advantages of steel (high strength, durability). This aligns with contemporary sustainability goals, offering a viable alternative to traditional concrete and hot-rolled steel systems.

Future Research Directions: Further studies could explore the long-term performance of the decking system under other criteria like dynamic loads, fire resistance, and environmental exposure. Additionally, optimizing fastener spacing and material combinations (e.g., alternative wood species or steel grades) could refine the system's cost-effectiveness and applicability to diverse structural scenarios.

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