A Contemporary House Proposal: Structural Analysis of Wood and Steel Bungalows

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ABSTRACT

The housing typologies that meet shelter and other basic needs are diverse, and bungalows are one of them. These buildings are generally single-story and mostly use wooden building materials. This paper introduces a new construction technique using steel, which is more durable than typical wooden bungalow houses. This design aimed to create a new building stock based on the logic of mass production, where modular steel bars can be prefabricated and transported to the construction site. An architectural design with a steel construction instead of a wooden one and a hexagonal plan instead of a rectangular one was developed. Structures designed with wooden and steel materials were compared using the structural analysis method. Structural analysis of the construction designs using wood and S235 steel grade was performed with the SAP2000 software. The structures were evaluated according to displacement, modal analysis periods, and self-weight, and their static suitability was tested. This new architectural design was developed because steel can maintain its strength for a long time compared to wood and has a higher modulus of elasticity. The results showed that wood and steel materials exhibit similar behavior under the same cross-sections, but the steel structure has come to the forefront as it is lighter than wood in terms of self-weight.

Keywords-building design; bungalow; house; steel construction; structural analysis; wood construction

I. INTRODUCTION

The concept of home has a different meaning for each person, as some people define it as a living space while others define it as a place of entertainment, rest, and sleep. Considering the house as a sheltering need is an indicator of its main function [1]. The origin of single-family houses dates back 2,000 years [2]. As the world population increases, housing production increases to meet current demands in the housing sector [3]. Parameters such as awareness, sense of responsibility, and waste management should be considered along with the increase in housing production [4]. High productivity, efficiency, quality, and sustainable steps are nowadays widely considered in the construction sector [5-6]. Sustainable architectural approaches to environmental problems are being developed for new houses to be built [3, 7]. Bungalows account for one such house type. In general, single-story bungalows without stairs form a living space [8]. Since this living space consists of a single space, it can have a simple basic geometry, or it can be produced from parametric plans using various shapes [9].

Colony-shaped portable bungalow prototypes have been used in the construction of modern houses [10]. Several studies have been conducted on bungalows. In 1999, a bungalow was designed in Malaysia with a photovoltaic panel system installed on its roof, and energy tests were carried out [11]. A study conducted in Great Britain showed that heating costs in detached houses and bungalows were higher than those in apartments [12]. Performance and economic analyses were performed with photovoltaic panels for a bungalow house in Damansara, Malaysia in [13]. Noise analysis was carried out in bungalow houses in the context of acoustics in England, evaluating environmental and socio-economic factors [14]. Thermal comfort tests and experiments were carried out in a detached bungalow-type house in Ireland using smart algorithms [15]. In building design, the use of materials is also important. In [16], wood and steel-reinforced concrete were evaluated in housing construction in terms of energy use and emissions. In [17], the mechanical properties and manufacturing technologies of engineered wood and bamboo composite materials were investigated and compared. In [18], cross-laminated timber and concrete slab flooring were analyzed in terms of structural performance, cost, and greenhouse gas emissions. The use of different approaches in building designs requires considering different parameters. Integration of different parameters improves the Architecture, Engineering, and Construction (AEC) industry. In addition to material differentiation, design phases [19-20], cost analyses [21-23], and entrepreneurial views [24] also contribute to the AEC industry.

As most of the bungalow studies are focused on energy, it can be observed that the structural analysis studies on bungalows and material comparison are limited. This study presents a contemporary bungalow proposal, performing a design and structural analysis comparison of a bungalow made of wooden and steel materials and hexagonal form, by bringing a new perspective to bungalows in traditional materials and forms. The structural analyses of the constructions designed with wood, which is a traditional building material, and S235 steel class were compared using the SAP2000 software and the finite element method. This software offers 2D and 3D modeling possibilities, from simple to complex geometries, that accelerate the engineering processes [25].

II. MATERIALS AND METHODS

Bungalow houses are usually built with wooden materials. This study used S235 steel, which is a frequently used and long-lasting building material [26-27]. The reason for choosing steel is its robustness, its ability to be used in frame systems, and its potential for improved aesthetics and functionality. Although wooden construction materials are also used in frame systems, when compared to steel in the same span, the material cross-section is larger and does not provide an effective solution. While there are common structural steel types such as S235 (St37), S275 (St44), and S355 (St52), S235 unalloyed structural steel has higher strength, is used by steel manufacturers and designers in Turkey, and is wider than other steel types [28]. Figure 1 shows the flowchart of this study.

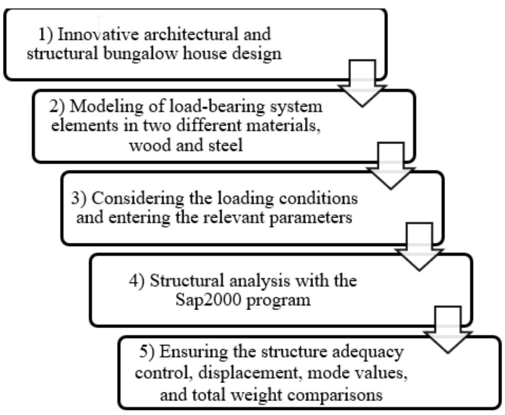

Fig. 1. Flow chart of the study.

The displacements in the X and Y directions were calculated under self-loads, considering weights for the structural analysis of the wooden and steel structures. The required strength for the system and elements was determined according to different critical load combinations, specifically: G+Q, 1.4G, and 1.2G+1.6Q. The mode values were also used to determine the dynamic state of the designs. Fixed support was used for the elements of the structures that rest on the ground. Steel construction profiles can be produced in square, rectangular, and pipe forms. For the steel cross-section, a hollow circular steel structural element was chosen to avoid sharp ends in frame systems and provide ease of application. Similarly, the wooden structure used circular structural elements. The wood and steel construction elements had a pipe section of 500mm in diameter, and the steel construction elements had a wall thickness of 15mm. Table I shows the properties of the structural wood and steel used in the designs.

TABLE I. PROPERTIES OF STRUCTURAL MATERIALS

WOOD	**Density**	0.800kg/m^3	**Shear modulus**	3800N/mm^2
	Modulus of elasticity	9.8GPa (9800MPa)	**Poisson's ratio**	0.3
STEEL	**Density**	7,850kg/m^3	**Minimum yield strength of steel**	235N/mm^2
	Modulus of elasticity	200GPa (200000MPa)	**Poisson's ratio**	0.286-0.315 (0.3 taken.)
	Shear modulus	8100kN/cm^2	**Tensile strength**	360–510MPa

III. CASE STUDY – BUNGALOW HOUSE

Bungalow houses can be used in the countryside and provide the opportunity to live a life in touch with nature. Today, the importance of nature is more evident in the city centers due to the dense construction and population. This study considered a steel-built design, which is an innovative and sustainable building material that does not take up much space. The design focused to keep the construction area small on the land by increasing the vertical elevation of the structure. To this result, the upward-rising structure was expanded, and the architectural spaces were increased. Structural elements must be modular manufactured for easier transport. In the design, the steel elements that form the frame of the building should be manufactured as modular and transported to the construction site. The geometry of the structure was formed from a regular hexagon, which allows steel members of equal length to be produced modularly. The durability and the cost of the two types of structures were investigated. Figure 2 shows the appearance of the designed bungalows.

Fig. 2. The exterior and the location of the bungalow.

Figure 3 shows the structural design. The structure rises 12m on a regular hexagonal plan, covers a 12×12m area, and has an expanded frame with a 1.5-meter-long cantilever. After raising 6m, the frame of the structure narrows, and a square horizontal frame of 6×6m was obtained at the top level of 12m. The building structure was completely formed from wooden and S235 steel structural materials. A beam was added between the two longest corners of the regular hexagon geometry at the 6-meter level. Wooden and steel construction elements were connected with rigid connections.

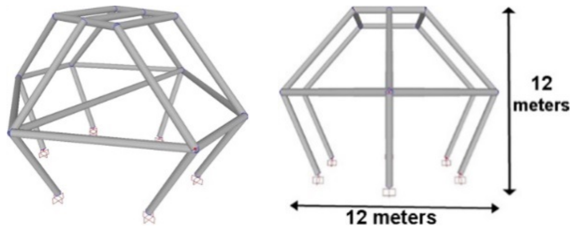

Fig. 3. The structure of the bungalow and the connections of the steel elements.

The total mass and rigidity of the structure with the incoming loads affect the amount of displacement. In addition, the calculation of vibration periods plays an important role. In steel frames, the material and its diameter along with the thickness of the wall cause these values to vary [29]. The elastic properties of the structure should also be considered during the design phase [30]. Using displacement data, the static and dynamic properties of buildings are analyzed for safety [31], while displacement also changes the performance-based designs [32]. Table II shows the values of the building structures according to the displacement analyses.

TABLE II. DISPLACEMENTS UNDER SELF-LOADING

		Δx	Δy	Δz
WOOD	**Displacement under self-loads**	-	-	-0.42mm
	Displacement in the X-direction	1.35mm	-	0.7mm
	Displacement in the Y-direction	-	2.04mm	0.98mm
STEEL	**Displacement under self-loads**	-	-	-0.33mm
	Displacement in the X-direction	1.53mm	-	0.76mm
	Displacement in the Y-direction	-	2.13mm	1.05mm

The performance analysis identified the period values of the system. Mode values are defined as the values of the natural vibration period on the principal axes of the structure [33]. The mode concept plays a role in showing the deformation patterns of periods. Modal analysis is also essential for determining structural damage [34]. In the mode values, the first three values of the natural vibration period with the highest mass participation are considered. The connection points of the bar elements also play an active role in the mode values [35]. This study examined the first three mode values that provide the most mass participation in terms of mode value. Horizontal and vertical vibration periods may occur in three-dimensional structures. A high period value means low rigidity, as there is an inverse proportional situation. At this point, a comparison between the period value and stiffness can be made. Table III shows the mode values of the structural system. The total weights of the structures having the same geometry and cross-sections of the structural elements were obtained. By looking at the total weight values, inferences can be made about the costs. Table IV shows the weights of the wood and steel structure designs.

TABLE III. DEFORMATIONS AND FIRST NATURAL VIBRATION PERIODS

WOOD		
Mode-1	**Mode-2**	**Mode-3**
0.09s	0.09s	0.06s
STEEL		
Mode-1	**Mode-2**	**Mode-3**
0.31s	0.28s	0.21s

TABLE IV. TOTAL WEIGHTS OF STRUCTURES (Kg)

Self weight of the systems	
Wood	**Steel**
6805kg	3467kg

IV. CONCLUSION

Building construction techniques vary according to the characteristics of the buildings. There are also different construction techniques in houses. Structure materials used in houses have changed from the past to the present. The use of local materials, which are found predominantly in the construction area, is dominant in the construction of buildings. The use of local materials is at the forefront in bungalows, which form one of the housing types. These structures have been used in different combinations throughout history. It is possible to encounter this situation in the need for luxury housing or accommodation for refugees. This study presented a new architectural design for such buildings. The design used high-strength steel for the construction due to its innovative and durable characteristics. The proposed steel design was evaluated by comparing it with a similar wooden one.

Structural analyses were performed on the two bungalow designs. At first, the displacement of the structures under self-loads was examined. Due to the tests carried out toward gravity and along the X and Y-axis, it was observed that the maximum displacement values were in the Y-axis direction. Considering the displacement values obtained, it can be inferred that the proposed steel system provides positive feedback. The modal analysis results showed that an ideal system was designed. A comparison of the self-weights of the structures shows that the wooden material is approximately 50.1% heavier than steel, providing an advantage for the steel load-bearing design. As a result, the designed steel bungalow house met the structural criteria, showing its advantages and usability.

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