Structural Analysis and Design of Solar Car Park in College of Engineering-Dawadmi: A Move Toward Energy Efficient Campus

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1 Introduction

The Kingdom of Saudi Arabia has one of the highest solar radiation rates in the world. The study by Almarshoud [1] assesses the solar energy potential of various regions in Saudi Arabia by analyzing long-term solar radiation data obtained from meteorological stations across the country. The study concludes that Saudi Arabia has one of the highest solar energy potentials in the world, with an average annual solar radiation of 2100 kWh/m^2. In this context, Saudi Arabia's solar energy is enormous and can be exploited easily, and where it is considered clean energy, but efforts to benefit from it face some challenges, including the availability and low cost of oil compared to solar power generation and the impact of dust.

The Saudi Vision 2030 strategy, one of the key economic reforms in Saudi Arabia and the Middle East [2], sets out requirements such as the reduction of CO_2 emissions and sustainability in building construction and operation. The main objectives of the vision are to reduce energy consumption in all new buildings and significantly reduce the carbon footprint of transport and production in energy consumption. Tapping solar energy is considered to be one of the best solutions to reach the desired goals as it has a negligible environmental impact. Consequently, more and more houses and farms are increasingly becoming heavily dependent on solar energy, so solar panels are generally placed on roofs or backyards. Due to the high degree of external shading "optical systems" in urban areas, there is insufficient space for urbanization to install photovoltaic systems with vertical interfaces. Building surfaces, which are generally without external protection, are ideal for installing photovoltaic systems. Using the parachute area above parking spaces is appropriate for installing photovoltaic systems in road infrastructure. Because these shading surfaces are suitable for integrating solar

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Fig. 1 Saudi Aramco's solar car park in Dhahran

PV and generating solar power [3] that can be used locally or exported to the grid, car parks are mostly executed as multi-story as fixed public transportation capacity is getting depleted in their open parking lots. Construction will be necessary in the future as part of parking spaces. It will be the optimal solution in terms of environmental impact as well as the capacity of the grid for electricity production to operate at the point of consumption. For example, on the roof of the building, but their use in parking is uncommon. In Saudi Arabia, some projects applied the concept of solar parking, e.g., "Aramco's building in Dhahran," [4] as shown in Fig. 1.

This study proposes implementing a solar car park lot system in the College of Engineering located in Dawadmi. The college ambiance has ample space for car parking. The purpose is to make the existing parking lot a center for solar energy harvesting through which it is stored and can serve as a potential source for the supply of renewable energy.

2 Objectives

The main aim of this project is to provide a structural design of a solar car park using the existing car parking that can serve as a source of renewable energy for COE Dawadmi making it energy self-sufficient. Keeping in view the main aim of this project, the following objectives are to be achieved in the project:

1. To determine the electricity generated from solar car parking and compare it with actual electricity.

2. Structural analysis and design of solar car park lot including the various loads acting through its lifetime.
3. To be able to understand factors affecting the structural design of solar car park.

To achieve the objectives, the following methodology is adopted:

1. Review of available references.
2. Surveying and calculating all areas and dimensions required.
3. Analyze the economical costs.
4. Structural analysis and design using computer software.

Each step in the methodology will be explained briefly in the sections to be followed.

3 Literature Review

Solar car park lots are becoming increasingly popular due to their ability to generate electricity using renewable energy sources. However, the design and construction of these facilities must take into account the additional structural loads imposed by the solar panels and associated equipment. Various studies have been conducted to investigate the usage of car park lots for solar energy harvesting. The study by Nunes et al. [5] discusses the potential of using parking lots to solar-charge electric vehicles. The authors review the current state of the art and identify the main challenges, including the integration of renewable energy sources into the grid, the lack of standardization in charging protocols, and the high cost of energy storage systems. They propose a conceptual framework for the design and operation of a solar-powered parking lot, which includes the installation of photovoltaic panels, energy storage systems, and charging stations for electric vehicles. The authors also analyze the economic feasibility of this solution, taking into account the initial investment, operational costs, and potential revenue streams. A study by Yaseen and Nabil [6] proposes a solution to address the lack of charging point availability in the EVs market by utilizing existing gas stations for two purposes: installing PV solar systems and deploying them as charging points. An article by Saied et al. [7] discusses the challenges of energy management in urban electricity distribution networks. The authors attempt to integrate a smart parking lot (SPL), renewable energy sources (RESs), and local dispatchable generators (LDG) as a microgrid. In contrast, an energy management system is presented to consider uncertainties of wind speed, solar irradiation, and load consumption. A demand response program (DRP) based on a time-of-use tariff is used to reduce operational expenses. A new uncertainty modeling method based on Hong's two-point estimate method is employed to deal with the uncertainties of load consumption and wind generation. A study by Julieta et al. [8] showed that solar photovoltaic energy could be deployed without occupying additional land in regions with scarce land. A methodology has been developed to identify uncovered parking spaces and water deposits at the regional level and estimate how much of these areas could be used to deploy solar photovoltaic energy, which could cover 9% of the regional electricity demand.

Critical literature review suggests that very limited studies have been carried out on the structural analysis and design of such structures. This study tries to address the research gap by combining the economic studies with the structural design aspect of solar car parking structure. The realization of the studies is expected to bring millions of Saudi Arab Riyal as benefit annually while being able to safely resist the loads of nature to which it is exposed.

SBC 301 [9] and SBC 306 [10] will be used in this study for the application of load and structural steel design, respectively. The load combinations applied to the structure in this study will be used as per Sect. 2.3.6 of SBC 301.

4 Surveying and Calculation of Shaded Areas

The College of Engineering premises contains three sections of parking as shown in Fig. 2. Each of these sections has parking portal frames slightly differing in size from each other as shown in Fig. 3. Manual surveying was carried out to find the dimensions of each type of frame, and the shading areas of the frame are calculated in the following sections.

Likewise, the dimensions of the existing structure were taken to model the structure geometry in the analysis and design software as shown in Fig. 4a. The existing structure is made of hollow structural steel circular tubes with an outside diameter of 130 mm and a thickness of 5 mm as shown in Fig. 4b.

a b c

Fig. 2 **a** Back parking view from Google Earth. **b** Front parking view from Google Earth. **c** Left parking view from Google Earth

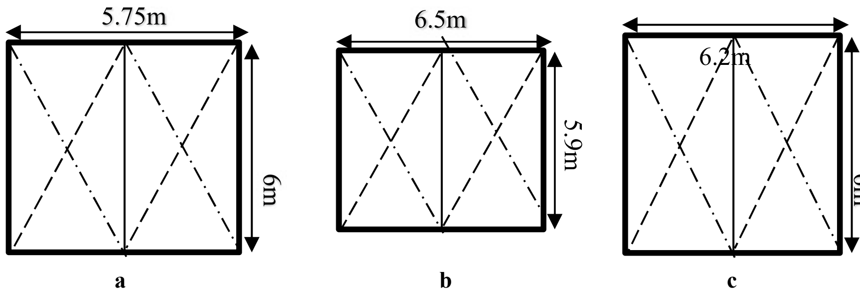


Fig. 3 **a** Back parking canopy dimensions, Back parking area calculations, Number of Car-parking canopies: 128, Area under one canopy=34.5 m^2, Total area of parking = 4416 m^2. **b** Front parking canopy dimensions, Front parking area calculations, Number of Car-parking canopies: 48, Area under one canopy=38.35 m^2, Total area of parking = 1840 m^2. **c** Left parking canopy dimensions, Left parking area calculations, Number of Car-parking canopies: 229, Area under one canopy=38.35 m^2, Total area of parking = 1840 m^2

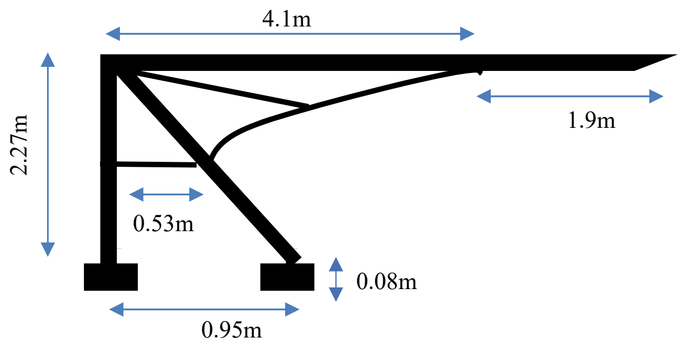
5 Cost–benefit Analysis

Cost–benefit analysis can be used to assess the potential advantages and drawbacks of a proposed project or policy. When used in the context of solar car park lots, CBA can help determine the financial feasibility of investing in this type of infrastructure and provide decision-makers with valuable insight into the possible benefits and drawbacks of the project. A solar car park lot is a parking facility that harnesses solar panels to produce electricity, which can be used to power the parking lot's lighting and electrical systems. Furthermore, any extra energy generated can be supplied back to the grid, resulting in additional revenue.

To initiate this study, the monthly consumption of electricity in the College of Engineering was monitored over a period of twelve months. The price of the units consumed in this case comes under the public building category. The results of these monitoring are listed in Table 1. Average consumption monitored over a year was obtained as 756,953 kWh. Correspondingly, the monthly average price paid by the institution was obtained as 240,240 SAR.

To conduct a CBA of a solar car park lot, both the costs and benefits of the project must be identified and evaluated. Costs may include initial installation expenses, ongoing maintenance costs, and financing costs. Benefits may consist of reduced energy expenses, revenue from excess energy generation, and environmental benefits like decreased greenhouse gas emissions.

After the costs and benefits have been identified, they can be quantified and compared using financial metrics like net present value (NPV), internal rate of return (IRR), and payback period. These metrics can assist decision-makers in assessing the financial feasibility of the project and weighing the costs against the benefits. Hence, CBA can be used to evaluate a solar car park lot project and provide decision-makers with an accurate understanding of the potential financial benefits and drawbacks



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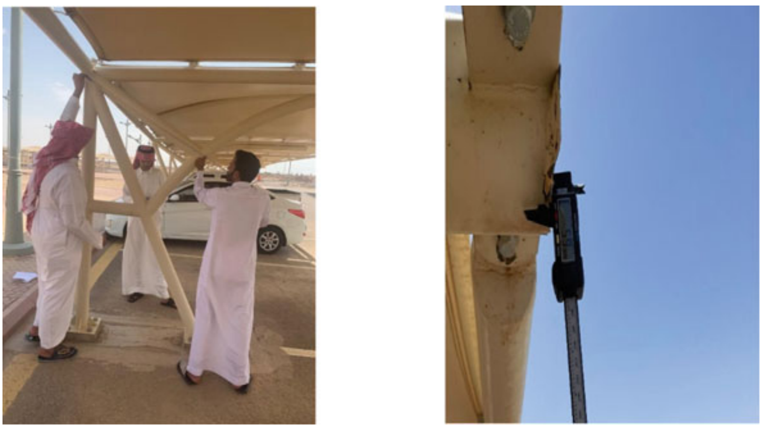

b

Fig. 4 **a** Parking structure dimensions (Back parking). **b** Surveying for parking structure dimensions

associated with investing in this type of infrastructure, enabling them to make well-informed decisions. Table 2 provides a summary of the economic analysis carried out. For the purpose of this study, panel-type monocrystalline with a capacity of 540 W is selected. The area covered by each panel is around 2 sq.m. Price per panel is obtained from local vendors. This is a conservative cost; considering the scale of the application, the same panels could be obtained at fairly lower prices from large-scale vendors. Also, the sunshine hours are assumed to be fairly conservative at 6.5 h a day. Earlier studies [11] have shown that the minimum amount of sunshine hours is around 7.26 h in Saudi Arabia during the winter. However, the maximum can also go up to 10.15 h during the month of June, which is summer. The total cost of the panels incurred can be recovered in 24 months, as mentioned in Table 2. As the car parking steel structure is already installed, the only additional components will be PV panel mounting to the structure. It is also evident that the average electricity

Table 1 Electricity consumption of COE Dawadmi

Month	Consumption (kWh)	Price (SAR)
August	760,358	240,863
September	756,184	239,093
October	760,016	240,349
November	767,807	239,969
December	773,470	243,296
January	752,762	244,068
February	747,198	239,714
March	738,253	240,099
April	740,287	239,118
May	759,005	236,521
June	776,383	242,465
July	751,716	237,325
Average	756,953	240,240

Table 2 Cost analysis

Month	Consumption (kWh)
Panel type	Monocrystalline, 540 W
Size of each panel	2 m × 1 m
Price per panel	760 SAR
Total shaded area available for PV installation	14775 m^2
Proposed total no. of panels to install	7387 panels
Total price for panels	5,614,120 SAR
Assumed sunshine hours	6.5 h
Average electricity generated per month	777,851.1 kWh
Average electricity consumed per month	756,953 kWh
Actual average monthly bill	240,240 SAR/month
No. of months to recover the cost	24 months

generated clearly surpasses the average electricity consumed in a month, making the premises energy self-sufficient.

6 Structural Analysis and Design of Proposed Model

The structure geometry has been modeled using the dimensions obtained in Sect. 5 of this paper. Figure 5a shows the geometric model of the structure. The sections used for the existing model contain a hollow circular section of diameter 130 mm and

5 mm thickness as shown in Fig. 5b. The base plate of the structure contains four bolts attached with the help of a rigid connection. The additional sections that are proposed for mounting the solar panels are shown in Fig. 5c. Several trial sections have been tested and finally, L35 × 25x4 has been selected to account for the additional loads due to panels. The demand-to-capacity ratio has been kept up to 90% to optimize the structure. Figure 5d shows the critical service load deflections diagram which are under permissible limits as per SBC 306 [10].

There are many commercial software used for the design of steel structures. Staad.pro is one of the most widely used software. The same has been used for the purpose of this study. However, it is not still integrated with Saudi Building Codes. Therefore, AISC 7-10 [12] has been selected in the software for the purpose of this study, which has parameters very close to what has been used for developing SBC.

Wind load has been carefully calculated as per the guidelines provided in SBC 301. The basic wind speed has been taken from the Fig. 6.4-1 of SBC 301. This figure provides basic 3-s gust wind speed in kmph for selected cities in Saudi Arabia. For the purpose of this study, wind speed is taken after interpolation from the nearest cities. A value of 170 kmph (47 m/s) is used in the study. Wind directionality factor is taken

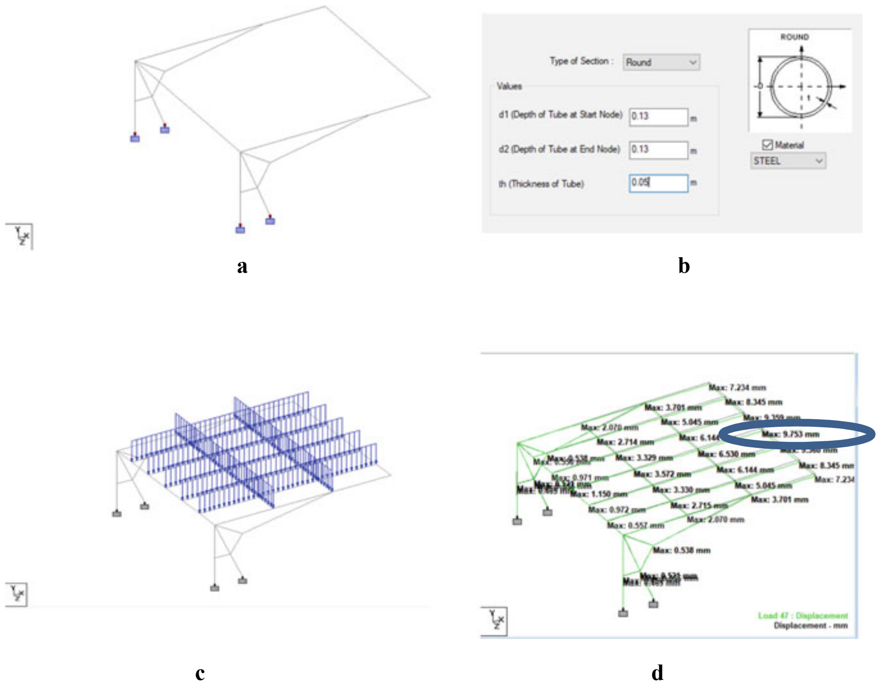

Fig. 5 **a** Geometric modeling of existing structure with fixed supports. **b** Sectional details of the existing structure. **c** Proposed additional sections for supporting solar panels. **d** Deflection diagram for critical service load combination

as 0.85 as the structure itself is main wind force resisting system as per Table 6.4-1 of SBC 301. Exposure category is considered as C category, as the terrain is mostly flat with unobstructed area. Topographic factor K_{zt} is considered to be 1, since the site location is not situated on a hill or 2d-escarpments. Gust effect factor is considered to be 0.85, assuming the structure to be rigid and having a fundamental natural frequency of less than 1.0 Hz.

Earthquake load parameters are provided in Fig. 9.4.1 of SBC 301. The 0.2 s spectral response acceleration Ss and 1 s spectral response acceleration S1 for the Dawadmi region are now fed in the software.

The gravity loads expected to be acting on the car parking structure is mainly of two types, dead and live loads. The dead load predominantly coming from the self-weight of the structure and the PV panels. Minimum live load is taken from the SBC 301 to account for the regular maintenance and accidental loads.

7 Conclusions and Summary

The following are the conclusions based on the current study:

1. The study conducted proves that the college of engineering can be made 100% energy self-sufficient by implementing the proposed solar car park lot.
2. Various loads acting during the lifetime of the proposed structure have been carefully analyzed and applied to the structural model.
3. Cost–benefit analysis shows that the cost of installation will be recovered within 24 months of the start of operations.
4. By using the proposed structural model, a capacity-to-demand ratio of up to 90% was achieved by satisfying the strength and serviceability limits under different load combinations.

Based on the current study following, future studies are recommended:

1. Thermal analysis for the interaction between the structures and the parked vehicles.
2. CFD simulations interactions between the vehicles and the structure, to predict the pressure, velocity, and density response.

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