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The Role of Geotechnical Engineering in Photovoltaic Solar Photovoltaic Energy in Arid Climate Regions

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ABSTRACT

The photovoltaic solar energy is comprised of many engineering disciplines. Geotechnical engineering is one of those disciplines in which it has important functions in the solar photovoltaic technology and particularly for large scale projects which usually employed in open areas such as parks or deserts. The aim of this paper is to present in depth the role of the geotechnical engineering in the solar photovoltaic energy and clarifying the common challenges facing this technology in arid climate regions. It is found that the lack of specialised codes and specifications that needed for foundation design and in selecting the proper foundation types. This would significantly affect the development of this technology in terms of efficiency and performance of the proposed solar photovoltaic systems. The hot weather climate and induced stresses by wind speed are also critical issues that should be considered. In order to avoid the uncertainty of data such as soil properties, the use of numerical modelling techniques is an effective method to help determining the most proper parameters needed for design and analyse purposes.

1. Introduction

The increasing rate of the population and the fast growing economy across the world and other social issues by means of life style needs and new habits of people in which the use of advanced technology is consequently increasing the energy demand. The dependence in conventional sources such as fossil fuels is significantly attributed in environment pollution issues such as global warming.

The importance of renewable energy is increasing day after day as the need of energy is increasing and this will eventually lead to energy depletion and particularly from the finite resources such as fossil fuels. Therefore, the implementing of renewable energy technology such as solar energy and wind energy become a necessary option even in the present time or near future. In terms of scientific field, it is generally agreed that the renewable energy technologies and specifically the solar energy, are constituted of multidiscipline fields [1] in which different science materials are involved in these types of technology. For example, chemical, mechanical, electrical and civil engineering specialised are needed in these types of technologies. In the current research, the focus will be placed on

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the solar photovoltaic technology which widely used and considered as a one of promising technologies. The capacity of implemented solar photovoltaic technology is highly increased with time and it is expected to reach 1 terawatt (TW) at the end of 2023 [2]. In addition to the reduction in the cost of this technology, the focus of researchers is focusing in developing the efficiency and performance of the solar modules [3,4]. It has been identified that the location, climate, type of technology used by means of the type of solar modules, the design methods and the ground are the main factors that affecting the solar system performance [5].

This study will investigate the role of geotechnical engineering on the large scale solar photovoltaic projects, and this will provide important benchmark data base for any conducted studies or projects by means of geotechnical engineering point view. The study will include the main processes from the initial's investigation of the proposed site and will illustrate the main geotechnical experimental tests conducted in the laboratory and at the field to assess the basic soil properties and other soil parameters usually needed to be used in the laboratory and field methods. The focus in this current paper will be placed on the ground mounting solar trackers which will be supported by foundation. The design configuration and solar module specifications will not be included in this study. Although the solar trackers are relatively light in weight, the adequate geotechnical investigation taking into account the uncertainties of the used parameters and using proper factor of safety will lead to satisfactory foundation designs [6].

The preliminary geotechnical site investigation for the proposed projects, starting from geologic reconnaissance and geophysical surveys and going throw laboratory and field testing is an important step in order to help identifying the feasibility of the project [7]. Therefor this would be an important step to determine the applicability of implementing the proposed solar photovoltaic systems in the proposed site. In other words, sites which are located in area that are regularly exposed to extreme wind speed or soiling materials or even in unstable region such as earthquake zone can be avoided in an early stage with minimum losses better than high losses in advanced stage. In addition, the ground basic properties and parameters which would be obtained by laboratory and field tests will also play important role in evaluating the feasibility of the proposed projects not only in terms of the stability and reliability of the project but also in terms of the efficiency and performance of the solar modules, particularly when using tracking systems such as single and dual-axis tracking systems (see Figure 1). In addition, it is founded that many of conducted feasibility studies have applied finite element methods using some advance software to check the behaviour of the solar structure and ground [8-15]. The scope of this current paper will cover the geotechnical investigation processes in deep with more examples and clarifications for the applied methods in this regard and the focus will be more on the arid climate environment.

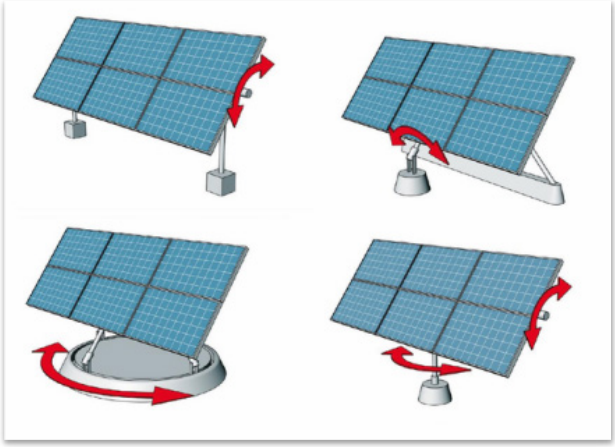

Figure 1. Different tracking systems [16]

A complete data information for any proposed project is one of the important aspects needed in order to conduct an effective and complete investigation of the large scale solar photovoltaic systems. A proper regional geology description of the site location would provide the designers and all stakeholders involved in the proposed project to take the most appropriate designs that would be suitable the nature of the project.

This research aims to explore the most important aspects for implementing solar photovoltaic energy systems in hot arid climate weather countries. It would also present the common challenges facing the use this technology. Recommendations and practical advice would be presented in this research. The author is keen to produce a solid reference that could be used for the stakeholders of this technology and particularly geotechnical engineers.

The most important aspects related to employing the solar photovoltaic projects would be presented in reasonable sequence of normal construction order. After analysing the geologic reconnaissance and geophysical surveys reports, the field investigation is starting by means of subsurface exploration to identify in detail the ground (soil layers under the proposed site) in terms of the layer depths and the basic physical soil properties. This would be an essential step to determine the geotechnical elements such as the soil bearing capacity to be used in designing the proper foundation for the proposed project. The site investigations are usually conducted by the field and laboratory tests.

2. Field and Laboratories Tests

The common field works are starting with excavation of test pits, boreholes test and electrical resistivity test. The test pit is an effective method to extract the soil samples at the desired depth and this can be done either manually or using mechanical excavator. Boreholes are the commonly used methods in geotechnical applications which are important and cost effective [17]. They provide the geotechnical engineers with detailed information about the thickness of soil layers and their main physical and mechanical characteristics properties. The electrical resistivity is defined as the soil resistance to the flow of electrical current applied [18]. The importance of this method can be realised in geophysical surveys and in grounding systems. Table 1 list and summarise the commonly used field tests.

The laboratory tests include the basic soil properties such as the bulk density the soil particle distribution percentages in addition to the soil index tests, shear strength parameters tests, compaction tests, permeability tests and chemical tests (Table 2).

Table 1. commonly used field tests

Fields Tests	Procedure	Reference
Standard Penetration Test	ASTM D-1586	[19]
Electrical Resistivity Test	ASTM G-57	[20]
Plate Load Test	ASTM D-1194	[21]
Cone Penetration Test	ASTM D-5778	[22]

Table 2. The laboratory tests include the basic soil properties

Laboratory Tests	Procedure	Reference
Sieve Analysis	ASTM D- 422	[23]
Moisture Content	ASTM D- 2216	[24]
Bulk Density	ASTM D- 6683-19	[25]
Atterberg Limits	ASTM D- 4318	[26]
Direct Shear	ASTM D- 3080	[27]
Triaxial compression tests	ASTM D- 7181-20	[28]
Constant/ Fall head Permeability test	ASTM D- 5084	[29]
Chemical Tests	BS-1377 Part 3	[30]

3. Types of Foundation Used to Support the Solar Modules

The selection of the appropriate foundations for the solar trackers is mainly dependent on several factors such as the geotechnical properties of the soil, for instance, the soil type. The economic consideration issues are involved in the type of foundation selection processes depending on the market availability materials and the duration of the project. In addition to technical issues related to implementing the solar foundations, the local approved code for the country, where the project is executed, is an important aspect which should be considered.

Direct drilled concrete piers, precast concrete piers, cast-in-place concrete piers driven piles and helical piles are the most commonly used footings for solar photovoltaic systems [31]; they are usually selected based on the soil properties and the site conditions.

It should be highlighted here that an appropriate selection of the type of foundation would be an important step in order to avoid the failure and collapse of the solar tracker structure [32]. Moreover, the selection of the type of solar foundation should be taken into account the effects of environmental factors as well as the geotechnical properties of the proposed area. In addition, the lack of complete and specialised codes for the design and standards for the design of the foundations of solar foundation is an important issue which will require more focus to be placed on the design stage in order to avoid the adverse conditions such as excessive settlement of the solar foundation which will eventually lead to decrease the performance of the proposed systems [33].

As stated above the soil conditions and the soil types are the main parameters used to select the type of foundations, for examples, helical piles foundations are normally used on sandy soils where driven pile foundations are usually used on clayey soil and dense sandy soils [34]. The helical piles are basically deep foundation which are consisted of spaced helical steel plates in proper spacing and are connected to a slender steel shaft [35].

For the cases where tough soil layers and difficulty for inserting the piles through the soil layers to the desired depth or in special circumstances where the penetrating of the piles through the soil may cause problems to other surrounding facilities such in case of landfills, the use of earth-screws foundations may be the best option [34]. In general, the steel piles are the most common used foundations and particularly for large scale solar photovoltaic systems. Figure 2 shows the most common types used for solar foundations. In this regard, it is important to clarify one of the important issues that most of engineers are not dealing with it effectively. In the design stage of solar photovoltaic foundations, the designers should put more effort on the effects of aerodynamics forces created by wind more than the compression forces resulted from the weight of the solar structures as most of them are made from light weight structures [36].

The effect of wind speed magnitude can be realised by Figures 3 and 4. It can be seen that it has a major influence on the solar structure behaviour in terms of the induced

stresses and strains in solar structure elements. Figure 5 shows the damaged and collapsed caused by strong wind. This is one of the critical situations that the proposed solar photovoltaic systems may have if it is not properly designed. The partial collapse or failure of the solar tracker systems will lead to serious consequences in technical and economic aspects for the proposed systems. Therefore, properly designed systems are needed in all design aspects such as geotechnical and mechanical issues. In addition, applying safe mode system, in which the solar tracker is pointing parallel with zero angle inclination with ground, in case of high wind speed is needed to avoid the failure or the damage of the whole used system.

In general, the main objective of the foundation design is to avoid the shear failure and the excessive settlement [38]. All the design parameters related to the solar structure such as the dead and live loads should be included and employing proper factor of safety. The nature of loads af-

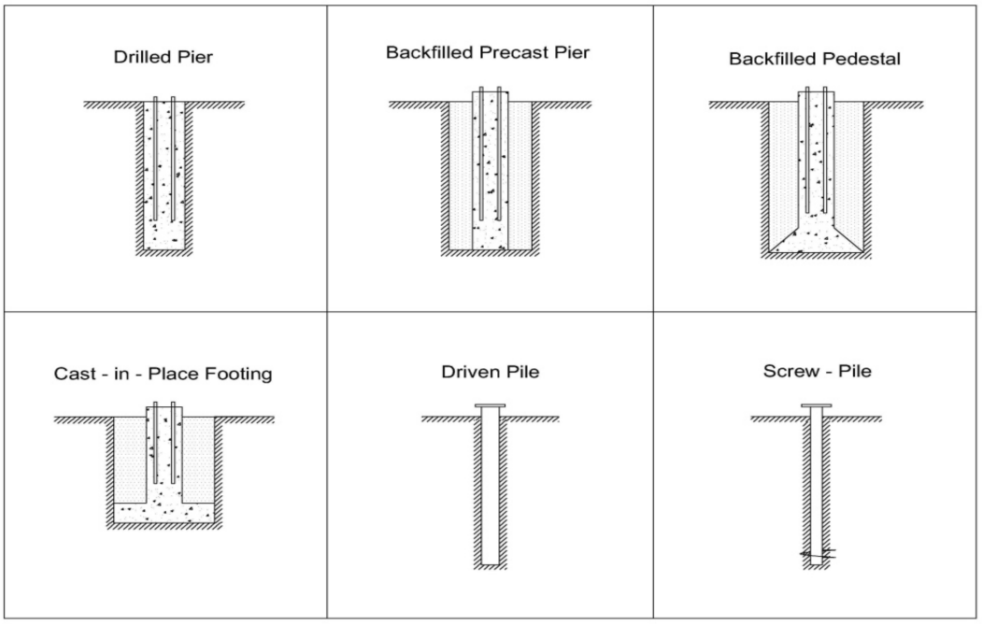

Figure 2. Categories of typical ground mount solar foundations [31]

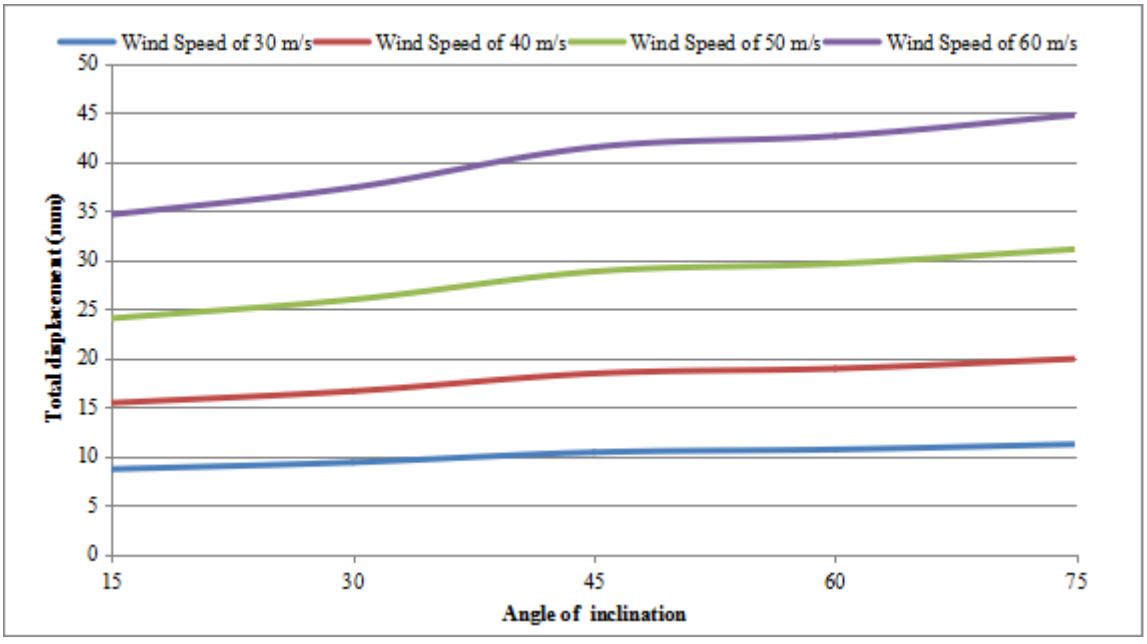

Figure 3. A comparison between different wind speed magnitudes with different inclination angles, based on displacement [5]

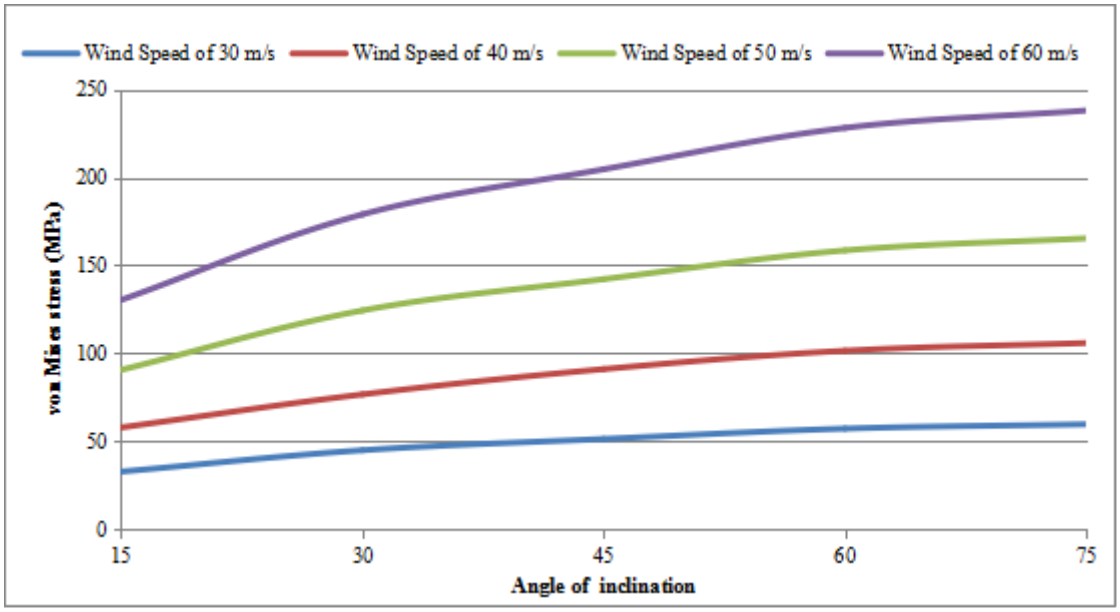

Figure 4. A comparison between different wind speed magnitudes with different inclination angles, based on von Mises stress [5]

Figure 5. Failure and damage of the mount ground solar tracker caused by strong wind [37]

fecting the solar structure, such as wind, should be properly assisted. For example, the nature of stresses induced by wind is different from normal dead loads; the wind loads are variable in magnitude and direction over time depending on the wind speed and direction. This kind of loads usually causes the fatigue failure problems which cause the failure for many of structural members in amounts of stresses less than the ultimate stresses of their materials.

4. Geotechnical Challenges in Solar Photovoltaic Energy

The fact that the solar energy is a promising technology and has achieved a fast rate development and does not mean it is not facing constraints by means of technical and economic issues. As the scope of this study is on geotechnical issues, the other issues related to this technology will not include such as the efficiency and the performance of the proposed systems in terms of used solar modules and their specifications.

Although the quite acceptable numbers of recently conducted projects and research for using large scale photovoltaic solar systems even in parks or opened area such as desert, there is lack of published research that included the geotechnical part by means of detailed information about the used foundation. In other words, the focus was placed on the specifications and the performance of the proposed

systems. This makes it difficult to investigate and analyse a quite enough data for the geotechnical aspect of this technology. As the efficiency and the performance of solar trackers and specifically for single and dual-tracking systems are highly affected by solar tracking systems [3,4,39] and the fact that tilt angles of the solar modules which are directly affected by any movement of the solar tracker structure resulting from the footing due to any geotechnical issues such as soil settlement. Therefore, more focus should be placed on the geotechnical part of this technology. Moreover, it should be lighted her again that the inadequacy of the site geotechnical properties will lead to severe problems in terms increasing cost and thus understanding the behaviour of soil under the solar structure is extremely important to avoid such of these problems. In addition, a lot of important issues such as the lack of codes and standards specialised for the photovoltaic solar energy in terms of design and the proper methods for this technology as well as high temperature in summer should be taken into considerations; the following subsections more explanations and suggested method for solving these issues.

4.1 Codes and Standard

The specialised codes and specifications are essential issues for engineers to be implemented in their works. They build their judgment and critical decisions based on them and for special cases they used their experience to tackle what they face from different problems in their theoretical and practical applications even on office or fields. For example, the stresses, induced by wind loads hitting the solar modules, are calculated using the code of the American Society of Civil Engineers [40] which is mainly used in determining the minimum design loads for buildings and other structures. Therefore, the variation and difference in the solar trackers structures make it important to get a specialise codes and specifications to be used in this technology which will definitely take into account all the missing and not well estimated parameters which will lead to using uncertain results.

4.2 High Temperature in Summer

Solar modules achieve their maximum rated efficiency at the standard test conditions at temperature of 25 °C and the increase of the temperature will decrease the efficiency of the solar system, it is important to look at the solar structure which supporting the solar modules from engineering side in terms of the thermal stresses that would be initiated and added to the total stresses induced on the solar trackers and systematically transferred to the foundations. There is no doubt that the high temperature weathering will affect the solar modules that are exposed to the sunlight to receive the maximum amount of solar radiation to generate electricity which is the main function of the solar photovoltaic systems. However, it should be recall her that one of the main factors that affecting both the efficiency and performance of the solar modules and solar tracker structures is the hot weather and particularly in the summer in arid climate regions. The high increase in temperature will subsequently increase the total induced stresses in the solar tracker structure as a result of the increase in the thermal stresses of the main body of the solar structures (Figure 6) which are mainly made from conducting materials such as steel. This will transfer mechanical to the soil beneath the foundations and therefor more precisions steps are necessary needed to include any possible effects such as hot weather climate and the wind loads effects as well.

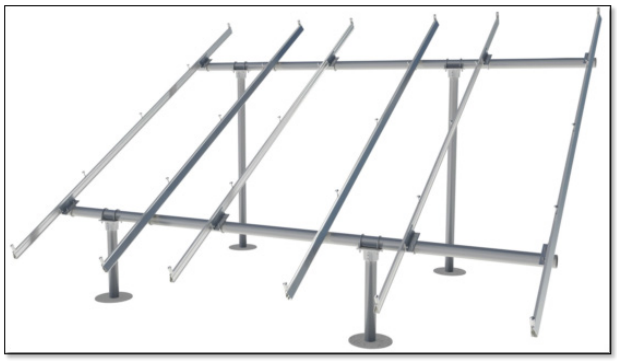

Figure 6. The main elements on the structure that supporting the solar modules [41]

5. Recommendations and Future Works

Creating new codes and standards is crucial step in the solar photovoltaic technology for large scales projects. This will make it easy for engineers and technicians that are working in this field to execute their activities in field with more confidence and enable them to use the most proper options in their works. In addition, this will increase the performance and the quality of the conducted works in the field. From economic point view, in addition to what have been stated above, the projects expanses for more change orders will be neglected or at least reduced to low level and that would be significantly positively contribution in terms of economic aspect.

The use of types of solar trackers which are recommended for hot weather regions is a key point which will help reducing the effects of hot weather conditions. This is usually done by the manufacturing companies which use specialised materials at the surface of the solar trackers

which are mainly made from steel materials. Also using water in frequent cycles of time for the cooling the steel parts of solar trackers, and also for the solar modules is an effect way to increase the efficiency of the solar modules and also to reduce the negative impact of high temperature weather on the solar tracker. However, it should be aware that the use of water for cleaning and cooling purposes should not affect the materials of both the solar track and solar modules.

As stated above the importance of proper geotechnical investigations of the soil properties and site condition is extremely important issues of the solar photovoltaic systems as any bad estimate or wrong design and analyses would cause severe consequences on the whole implemented system in terms of economic or technical performance issues.

Taking benefits of applying numerical modelling investigations in advance, for instance, in feasibility study stage is crucial. Form engineering point view, implementing numerical modelling methods using many of available and approved software will enable the engineer to have a wide range of area to check a lot of parameters related to the soil properties, solar structure, solar foundation as well as different climate conditions such as wind speeds in order to consider the best options for many different issues related to the project. For example, [9] investigated the structural stability of a dual-tracking system in Kuwait and also checked the effects of wind speed in terms of fatigue criterion using numerical modelling software, COMSOL Multiphysics. In addition, the critical regions, which are susceptible for failure, were determined (see Figure 7). This will give the designer a beforehand indication to the realistic circumstances and will also allow for changing and taking best options in estimating and checking the effects of either the quality of used materials or the accurately of the available data.

In addition, the achieved development in numerical modelling has provided advanced methods by means of constitutive modelling to analyse the behaviour of soils and other structural elements in different circumstances in high quality level results (Table 3). This also would encourage the researchers and stakeholders to look for new economic and effective methods for improving the geotechnical properties of the soil layers and selecting the best option in terms of the foundation types and soil improvement techniques methods.

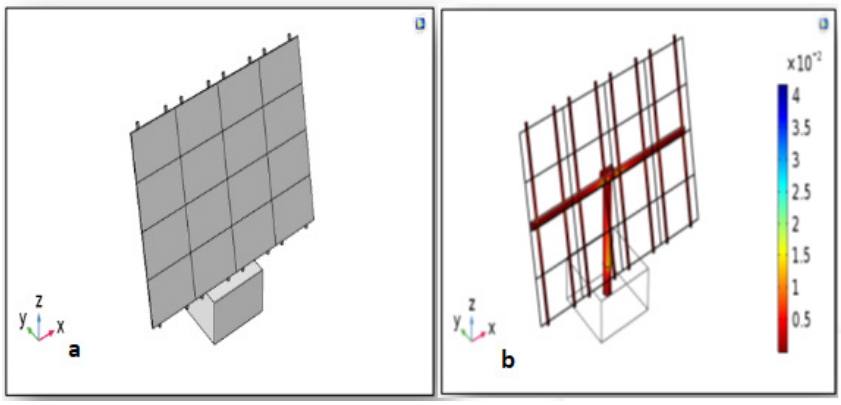

Figure 7. (a) Shows the used numerical geometry in the study and (b) show the Usage fatigue factor [9]

Table 3. Common constitutive Models

Model	Description	Reference
Mohr-Coloumb Yield Criterion	It is widely used in advanced complex geotechnical applications, and it is simple and provides finite element solutions to be compared with other plasticity models.	[42]
Tresca Yield Criterion	It is the most suitable model for defining the metals yield criterion.	[43]
Von Mises Yield Criterion	It is suited for metals and can be used to represent modelling the behaviour of metals yield criterion.	[43]
Drucker Prager Yield Criterion	It is widely used for soils and concrete materials. It is based on smoothing the surface of Mohr-Coulomb model and modifying the Von Mises constitutive model.	[44]

6. Conclusions

The geotechnical role involved of implementing solar photovoltaic energy in arid climate regions has been presented in this study. The relevant and commonly used laboratory and field tests that the engineers and technicians need to determine the basic soil properties and the soil design parameters have been also presented. And finally, the common types of the solar photovoltaic foundations have been reviewed. The study is strongly referee that the solar photovoltaic solar systems efficiency and performance is highly affected by the design and execution of the solar tracker structure and the foundation, in which, proper design will maintain the optimal tilting angle of the solar modules in order to achieve the best output energy of the proposed systems. Moreover, improper and underestimated of the soil properties and selected proper foundation type will lead to huge consequences in terms of damage or failure of the solar photovoltaic systems. It is found that this promising technology is still facing a lot of technical issues and field challenges in engineering aspects such as the unavailability of specialised codes and standards for design purposes such as wind calculation code for solar photovoltaic structures. In addition, the effect of hot weather and especially in summer is not affecting the solar systems efficiency and performance only, it is also affecting the main body of the solar structure which are usually made from steel materials. It is found also that using finite element methods by means of available and robust numerical modelling software is an effective way to solve and avoid the uncertainty of the used data.

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