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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.

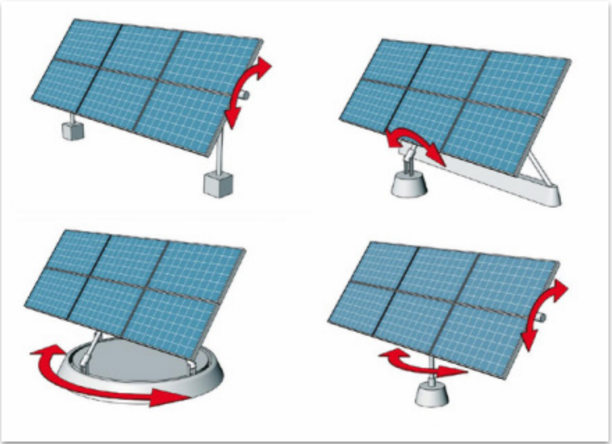

Figure 1. Different tracking systems [16]

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-

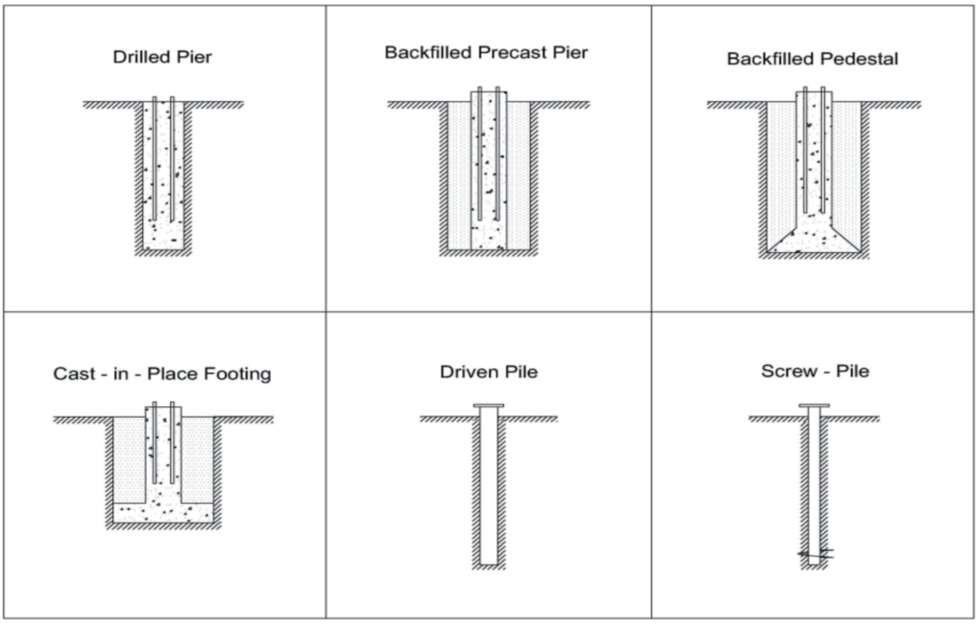

Figure 2. Categories of typical ground mount solar foundations [31]

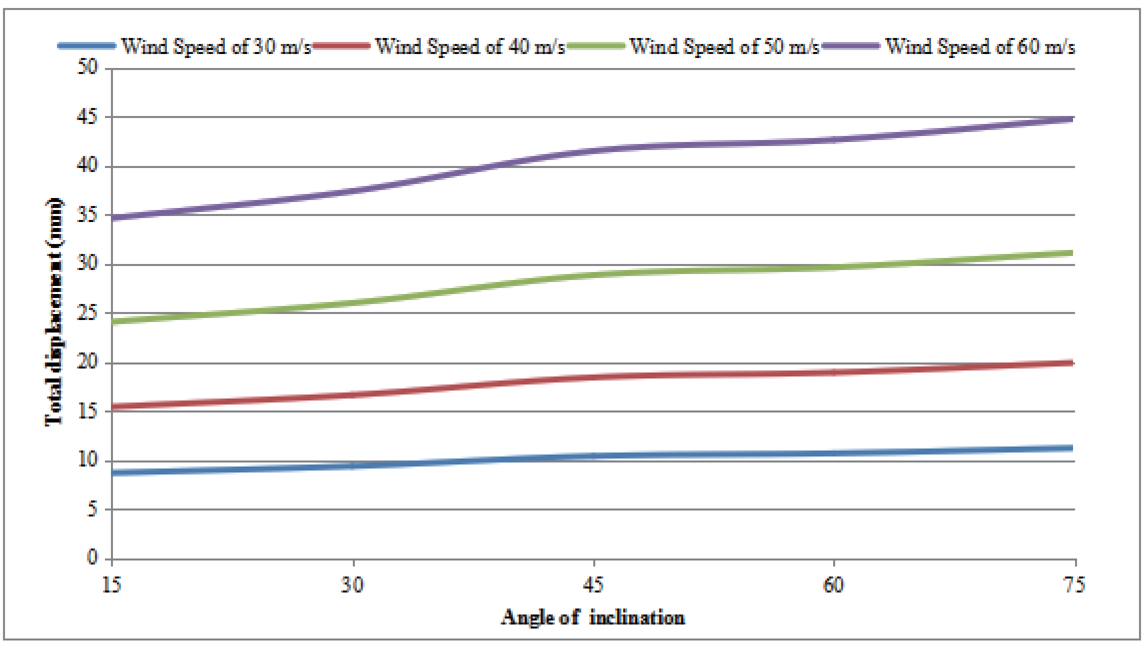

Figure 3. A comparison between different wind speed magnitudes with different inclination angles, based on displacement [5]

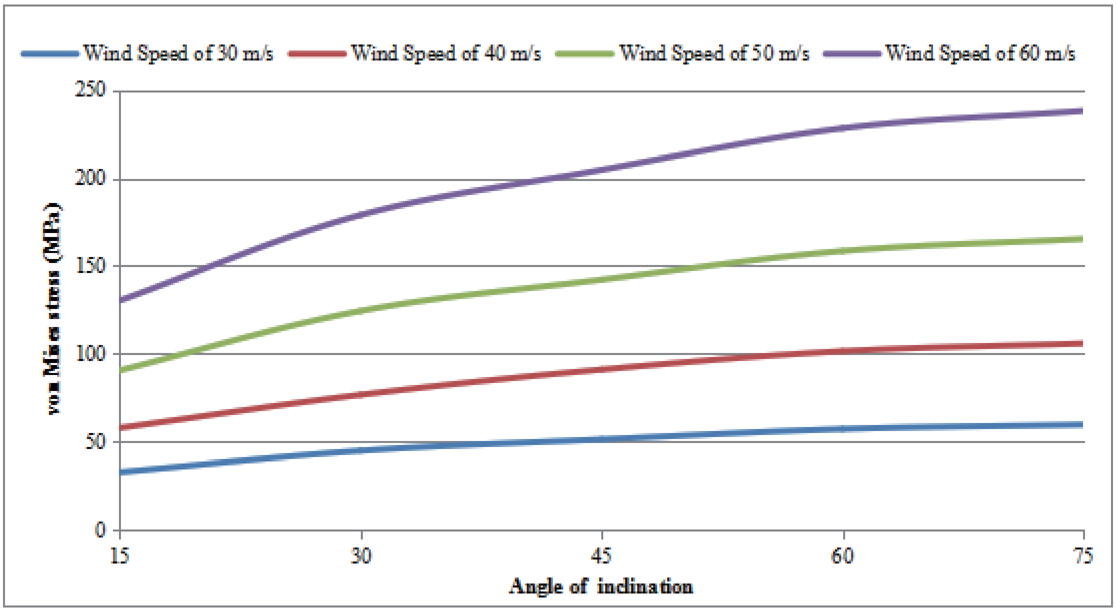

Figure 4. A comparison between different wind speed magnitudes with different inclination angles, based on von Mises stress [5]

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.

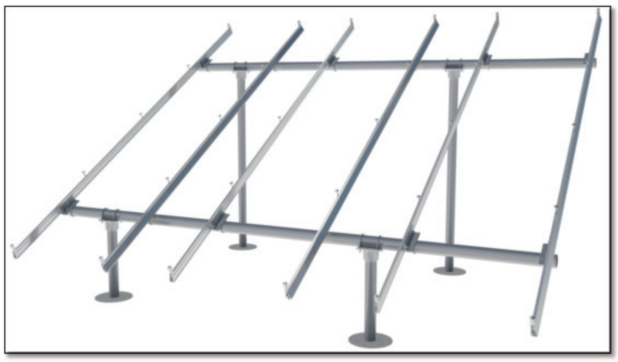

Figure 6. The main elements on the structure that supporting the solar modules [41]

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.

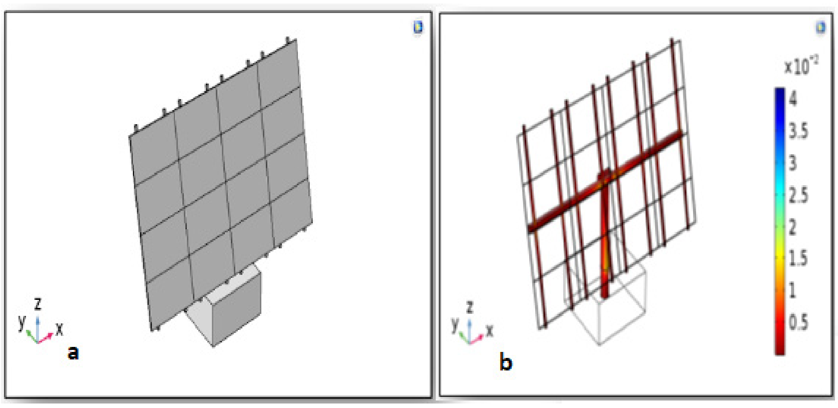

Figure 7. (a) Shows the used numerical geometry in the study and (b) show the Usage fatigue factor [9]

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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DCLR Modified Petroleum Asphalt Optimization and Mixture Road Performance

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ABSTRACT

In recent decades, modified asphalt materials have been used in enhancing the traffic load on the roads. The main objective of this paper is to explore the modification effect of direct coal liquefaction residue (DCLR) on asphalt binders and investigate the effectiveness of DCLR in improving the performance of asphalt road. This paper prepared modified petroleum asphalt under different process conditions and tested its penetration, softening point and ductility index. Based on the experimental data, according to gray correlation degree, the performance for the asphalt was compared. The performance for the modified asphalt is simulated and predicted using polynomial functions. The modified asphalt was analyzed by FT-IR, TGA, SEM and HPLC. The results show that the optimal process conditions for DCLR modified asphalt are shear mixing time of 45 min, shear mixing temperature of 150 °C and shear mixing rate of 4000 r/min. The predicted fit with the experimental data of 0.993 further demonstrates the effectiveness of the method. The characterization results show no significant chemical change between the DCLR and the asphalt. DCLR can significantly improve the high temperature performance and water stability of the asphalt, but it has little impact on its low temperature performance.

1. Introduction

In recent decades, the paving of highway roads has gained rapid development to satisfy the increasing number of trucks, cars, and other vehicles all over the world. Especially in China, the huge traffic flow causes increasingly serious damage to the road, which pushes urgent demands for high-quality asphalt materials for paving high-grade highways. In addition, the outdoor ambient temperature in north China changes variably at different seasons, exerting a great influence on road performance. Hence, the usage of fluxes is necessary to mix with the base asphalt to improve the road properties, such as the asphalt durability, adhesion, deformation resistance, etc. [1]. The main mod-

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ifiers used at present are coal tar pitch, tire rubber, and polymers. Although the road property could be improved to some degree, some environmental and economic problems appeared concomitantly [2].

The Trinidad Lake Asphalt (TLA) modifier is the most effective flux for improving the relative properties of paving asphalt. TLA modifier has been widely used in China due to its excellent modification performance, including Jiangyin Bridge, capital international airport, Chengdu-Chongqing expressway, etc. By analyzing the TLA composition, it was found that modifiers with multiple aromatic structures and more polar functional groups would show better modifying ability [3]. Namely, strong adsorption capacity on the surface of quartz and limestone and good anti-stripping performance could be presented. After preliminary analysis, it has been found that coal direct liquefaction residue (DCLR) has a similar structure to TLA and is a potential alternative asphalt modifier [4].

Typically, DCLR is rich in organic compounds with high molecular weight, varied heteroatomic species, rich aromatic cyclic compounds and strong polarity. These organic macro-molecules doped with polar groups (i.e. N, S) have strong adsorption ability on the mineral surface, such as silicate, limestone, quartz and so on [5]. The excellent adsorption performance could enhance the anti-peeling property of the asphalt mixture obviously. In recent studies, it was shown that the DCLR can improve the high-temperature performance and durability of road asphalt. However, lots of researches focused on the binary modifying effect of DCLR coupled with other polymer compounds, while rarely probed into the single DCLR modifier. Hence, it was necessary to determine the optimal condition in the preparation of high-quality DCLR modified asphalt [6].

Nevertheless, the experimental studies would hardly give a consistent conduction for all kinds of DCLR species since it was difficult to test the road performance of the whole DCLR modified asphalts. Noticeably, different kinds of DCLR had the same aromatic structure and similar chemical or physical properties, which gave a possibility to use scientific predictions for evaluating the road performance. BP neural network is the core part of the forward neural network and the essence of the entire artificial neural network system [7]. In network applications, about 80% of neural networks adopt BP networks or improved. The asphalt model can be optimized on the basis of self-learning, which is very suitable for the establishment and prediction of DCLR modified asphalt road performance model [8]. Zhao et al. used BP neural network to study the asphalt pavement compaction prediction model in 2020, the results showed that it was feasible to use this model to predict asphalt pavement compaction [9]. Xie (2017) used BP neural network to predict the fatigue performance of asphalt mixture. It was suggested that all the statistical indexes obtained by the neural network model were obviously better than that of fatigue equation model [10]. And the neural network also had the function of index weight analysis. Dou et al. (2016) used BP neural network to predict the ductility of asphalt, the result showed that the trained BP neural network had a good prediction ability for the ductility of blending asphalt [11].

Generally speaking, DCLR is a promising flux to improve the high temperature and sensitive properties of road asphalt. While the modified process needed to be further investigated. The preparing condition is vital to the road performance of modified asphalt. Hence, this paper established basic research for the physical engineering promotion of DCLR modified asphalt. In addition, to broad the applicability of the preparation method of the DCLR modified asphalt, BP artificial intelligence was used to predict relative road properties and optimize the modifying condition. Through the combination of experimental research and mathematical simulation and prediction, the preparation method and performance evaluation of DCLR modified asphalt can be further improved, and its popularization and application can be realized.

2. Experimental

2.1 Raw Materials

The DCLR modifier used in this experiment was the residue of Shenhua coal direct liquefaction demonstration plant in Inner Mongolia. The 90# base petroleum asphalt was derived from Shenhua Group. The basic road properties and compositions of base petroleum asphalt and DCLR were listed in Table 1 and Table 2.

2.2 Preparation of Modified Asphalt

The 90# base petroleum asphalt was heated to liquid status by oil bath in a 0.5 L uncovered vessel at 125 °C. Then the DCLR or TLA modifier was added into the container and mechanically stirred for 90 min to prepare DCLR modified asphalt. The base asphalt mass was kept in the same quality to decrease the system deviation during the preparation process.

2.3 Optimization of DCLR Modified Petroleum Asphalt Process

2.3.1 Orthogonal Test

Generally, the road performance of modified asphalt would be affected directly by the blending process and

Table 1. Composition and properties of base asphalt

The basic road properties			
Items	Softening point/℃	Penetration /0. 1mm, 25 ℃	ductility(25 ℃)/cm
Test result	49.9	72. 1	>140
Proper range	≥46	60~80	>140
Chemical composition proportion / %			
Saturation point	Aromatics	Asphaltene	Colloid
11.2	50.8	12.3	25.7

Table 2. Composition and properties of DCLR

Properties of DCLR									
Items	Softening point/℃	Penetration /0. 1mm, 25 ℃	Ductility(25℃)/cm						
Test result	190	5	6						
Composition of DCLR / %									
Saturation point	Aromatics	Asphaltene	Colloid						
11.2	50.8	12.3	25.7						
Composition content analysis of DCLR family/%									
heavy oil	asphaltene	Pre-asphalt	organic detritus	inorganic ash					
8.04	14.97	10.37	36.44	30.18					
DCLR ash composition and content/%									
SiO_2	Al_2O_3	FeO_3	CaO	MgO	SO_3	TiO_2	K_2O	Na_2O	P_2O_5
20.3	8.65	33.69	17.06	1.01	15.34	0.84	0.07	1.79	1.25

preparing condition. It was necessary to study and analyze the reaction conditions systematically. The optimal incorporation of DCLR was 8%. The orthogonal design method was used to investigate the effects of temperature, shear time and shear rate on the road properties of modified petroleum asphalt, such as penetration, softening point and ductility.

2.3.2 Grey Correlation Analysis

Grey correlation analysis was applied to analyze the correlation degree among different factors, which could combine qualitative analysis with quantitative analysis effectively [12]. The main calculation steps of grey correlation analysis were listed below.

The main calculation steps were conducted as follows: Determining the reference; comparing and equalizing each sequence; finding the correlation coefficient, the maximum and minimum difference between the two poles; calculating the grey correlation degree and sorting by gray correlation size [13].

Table 3. Orthogonal experimental design

Level factor	Shear temperature/ A	Shear time/B	Rate of shear/C
1	150 ℃	30 min	2000 r/min
2	160 ℃	45 min	4000 r/min
3	170 ℃	60 min	6000 r/min

Table 4. Orthogonal experiment scheme

Number	Shear temperature/ A	Shear time/ B	Rate of shear/C	Combination
1	150 °C	30 min	2000 r/min	$A_1B_1C_1$
2	150 °C	45 min	4000 r/min	$A_1B_2C_2$
3	150 °C	60 min	6000 r/min	$A_1B_3C_3$
4	160 °C	30 min	4000 r/min	$A_2B_1C_2$
5	160 °C	45 min	6000 r/min	$A_2B_2C_3$
6	160 °C	60 min	2000 r/min	$A_2B_3C_1$
7	170 °C	30 min	6000 r/min	$A_3B_1C_3$
8	170 °C	45 min	2000 r/min	$A_3B_2C_1$
9	170 °C	60 min	4000 r/min	$A_3B_3C_2$

3. Results and Discussion

3.1 Determination of the Optimal Condition

The parameter of penetration represents the hardness of the asphalt, the low penetration value indicates the strong hardness of road materials. Normally, this value was basically between 50 and 70 (25 ℃, 5 s, 0.1 mm) according to the latest TLA modified asphalt standard. (JTG E20-2011). PI is an important index to evaluate asphalt temperature sensitivity. PI values can also be used to evaluate the colloidal structure of asphalt in addition to evaluating the temperature sensing properties of asphalt. PI<-2 shows that asphalt is a sol-shaped structure and a pure viscous fluid, such as coal tar pitch. -2<PI<2 shows that asphalt is a sol-gel structure, have elastic effect; PI>2 shows that the asphalt is a gel structure, showing typical thixotropy, such as oxidized asphalt (Ge, 2016).

From Table 5, compared with the base asphalt, the penetration value was decreased from 52 mm to 71 mm. Hence, the penetration index was enhanced by the additive of DCLR, which was extremely vital for preparing the high-quality road asphalt. In addition, the penetration property of DCLR modified asphalt meted the current standard and the high value of R (19.00) indicated shear time was the main factor to affect the asphalt hardness. For the parameter of ductility, it can be observed that the ductility value was decreased with the addition of DCLR flux. It was attributed that the DCLR and petroleum asphalt were not completely melted, forming a sol-based structure with macro molecular particles and leading to the decrease of shear strain resistance. The analysis of the range R value showed that the main indicator affecting the modified asphalt was the shear time.

Table 5. Orthogonal experiment results analysis

Surveillance project		Shear temperature A/℃	Shear time B/min	Rate of shear C/r/min
	$\overline{K}_1$	56. 1	52.0	57.2
	$\overline{K}_2$	56.7	64.4	57.5
Penetration /0. 1mm, 25 ℃	$\overline{K}_3$	62. 1	71.0	68.4
	R	6.0	19.0	11.2
	Factor sort		B > C > A	
	Optimal group		$A_2B_2C_3$	
	K_1	8.9	13.7	9.6
	K_2	9.5	10.6	8.1
	K_3	9.9	10.7	8.9
Ductility(25℃)/cm	R	1.0	3.1	1.5
	Factor sort		B > C > A	
	Optimal group		$A_2B_1C_2$	
	K_1	49.9	51.3	50.4
	K_2	50.9	51. 1	49.3
	K_3	49.5	50.6	48.9
Softening point/℃	R	1.4	0.7	1.5
	Factor sort		B > C > A	
	Optimal group		$A_2B_2C_3$	
	K_1	1.032	1.039	0.996
	K_2	1.012	1.067	1.083
	K_3	1.066	1. 115	1.047
PI	R	0.054	0.076	0.09
	Factor sort		C > B > A	
	Optimal group		$A_3B_2C_1$	

For the parameter of softening point, it showed that the value of DCLR modified asphalt was 49.2 °C, which was 0.7 lower than the base asphalt. The additive of DCLR had a significant influence on softening point property. This was attributed to the heterogeneity of the mixture, which was prepared by physical blending method. Although this index was decreased, the softening point index of modified asphalt still meted the current standard. The main factor was the shear rate to affect softening point according to the R value (1.50). For the PI value, the result indicated that the structure of DCLR modified petroleum asphalt belonged to sol-gel structure (PI= 1.047). Then the analysis of the range R results showed that the main indicator affecting the modified asphalt is the shear rate (R=0.90). With the comprehensive consideration of all parameters, the optimum technological conditions of DCLR modified petroleum asphalt were prepared at 45 min (shear time), 4000 r/min (shear rate) and 150 °C (shear temperature).

3.2 Grey Correlation Analysis

The grey association coefficient of DCLR modified asphalt was presented in Table 6. The result indicated that the four parameters had different influence degree on the road performance of modified asphalt. Specifically, the factor proportion was 25.03%, 25.02%, 25.01% and 24.92% respectively for the penetration, PI, ductility and softening point.

Table 6. The grey association analysis of modified asphalt

Group	Penetration/ 0.1mm, 25 ℃	Grey correlation degree		PI
		Ductility (25℃)/cm	Softening point/℃	
ξ_1	0.985	0.977	0.987	0.997
ξ_2	0.959	0.962	0.976	0.965
ξ_3	0.973	0.966	0.939	0.971
ξ_4	0.884	0.985	0.914	0.908
ξ_5	0.926	0.925	0.917	0.916
ξ_6	0.917	0.898	0.887	0.896
ξ_7	0.963	0.966	0.975	0.963
ξ_8	0.982	0.952	0.989	1.000
ξ_9	0.97	0.925	0.938	0.942
Association degree	0.951	0.9506	0.9469	0.9509
Factor proportion / %	25.03	25.01	24.92	25.02

4. DCLR Modified Asphalt Performance Test and Mixture Test

4.1 DCLR Modified Asphalt Performance Test

The FT-IR spectra of base asphalt and DCLR modified asphalt was shown in Figure 1. Typically, the peak wave numbers of 2918.19 cm^{-1} and 2848.18 cm^{-1} indicated the asymmetric and symmetric stretching vibration of methylene. 1592.47 cm^{-1} and 1453.2 cm^{-1} meant aromatic ring skeleton vibration, 2362.61 cm^{-1} was C≡C or C≡N stretching vibration peaks. And the 700-900cm^{-1} absorption peaks were mainly caused by hydrocarbon bonds of substituted aromatic rings. From Figure 1, the characteristic absorption peak of the sample at 3100-3300cm^{-1} is caused by alcohol, carboxylic acid and ester C=O; 3000-3100cm^{-1} is the absorption vibration peak of aromatic hydrocarbon C-H; 2800-2900cmcm^{-1} is caused by saturated fatty hydrocarbon-CH2-expansion vibration [14]. The result suggested that DCLR has more influence on asphalt, and the strength and width of all absorption peaks are weakened.

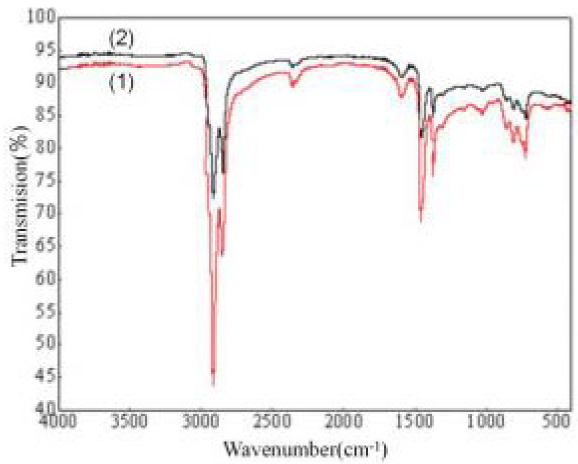

Figure 1. FT-IR spectra of DCLR and modified asphalt

The TG curves of base asphalt, modified asphalt and DCLR feedstocks were depicted in Figure 2. The results showed that the initial decomposition temperature of DCLR is about 230 °C and the maximum weight loss rate occurred at 520 °C. While the initial decomposition temperature of base asphalt and modified asphalt was around 350 °C, and the maximum weight loss rate occurred at 500 °C. The maximum residual weight of the DCLR was 67%, which indicated that the DCLR contained more macro-molecular substances. With the increasing temperature, DCLR volatiles released and the weight decreased gradually. In addition, the maximum weight loss of modified asphalt was less than 80% while it was more than 80%

for base asphalt. This indicated that the modified asphalt contained more high temperature resistant substances than the base asphalt. Therefore, the additive of DCLR to base asphalt could improve the high temperature properties.

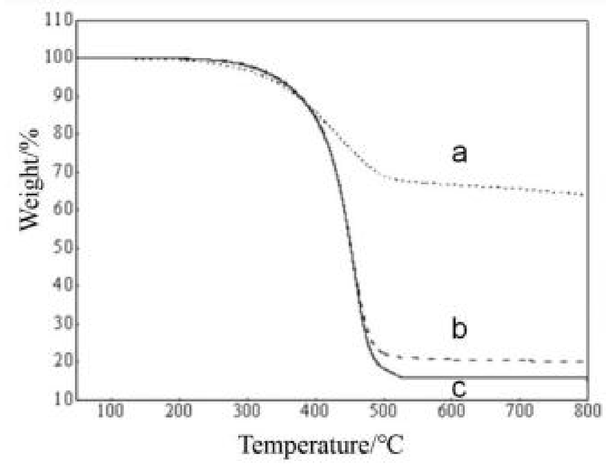

Figure 2. TG analysis of base asphalt, modified asphalt and DCLR

The HPLC test was applied to further investigate the components contained in the road asphalt, which was conducted with the flow phase of THF at 60 °C. The results were shown in the Figure 3and Figure 4. The compositions were divided into heavy group area (5.12 min <t <10.92 min), medium group section (10.92 min <t <11.67 min), and light group section (11.67 min <t <14.67 min) according to the difference of the complex macro molecular mixture [15]. The proportion of each peak area in the whole sample was calculated by normalizing the spectral line area. It can be obtained that the proportion of heavy, medium and light components in base asphalt were 20.82%, 21.65%, 57.53%, and the values were 22.36%, 21.67%, 55.97% for DCLR modified asphalt. This indicates that the heavy components become higher and less light components during the modification process.

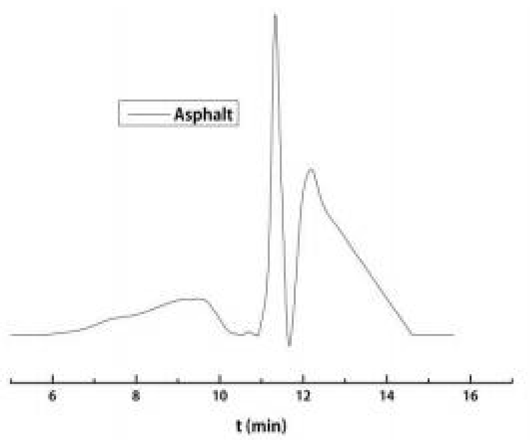

Figure 3. HPLC of base asphalt

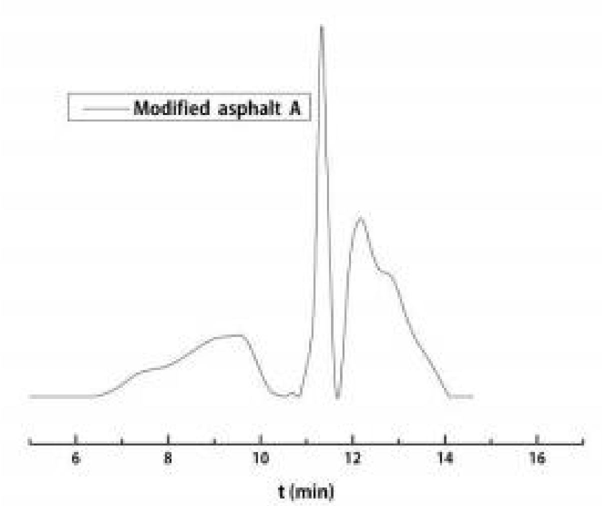

Figure 4. HPLC of modified asphalt

4.2 Mixture Test

The asphalt mixture was prepared by a certain graded synthetic method with modified asphalt severed as materials. Then the asphalt mixture was usually used as surface layer of asphalt pavement, which went through the direct damage from a variety of vehicle loads and environmental factors. Hence the performance of asphalt mixture greatly affected the service performance and service life of the pavement [16].

The AC-20 asphalt mixture was selected to test the properties of DCLR modified asphalt. The mineral grading process was implemented according to the test code of asphalt and asphalt mixtures of ministry of communications (JTG E20-2011). The mineral material grading design used in this article was listed in Table 7.

In order to obtain the optimum asphalt ratio of asphalt mixture, the interval of 0.5% and take 5 different asphalt ratios were used to proceed Marshall test. For the measurement index and relevant mechanical indicators, the test results were shown in Table 8.

Considering the relevant and mechanical indexes of asphalt mixture, the optimum asphalt stone ratio was 4.38%.

4.2.1 Evaluation on the High-temperature Performance of the Asphalt Mixture

If the stress is applied to the asphalt mixture for a long time, the strain will increase over time, and the deformation of the asphalt will gradually recover after the stress disappears, but it will still undergo permanent deformation, especially under high temperature conditions. Rut test is used to evaluate the high temperature stability of the asphalt mixture. Table 9 shows the test results.

Table 7. Asphalt AC-20 gradation

Mesh size（mm）	19	16	13	9.5	4.75	2.36	1. 18	0.6	0.3	0. 15	0.075
Specification upper limit	100	92	80	72	56	44	33	24	17	13	7
Lower specification	90	78	62	50	26	16	12	8	5	4	3
Synthetic grading	95	88	78	65.5	41	28.5	17.6	11.3	7.4	6.1	5.1

Table 8. Marshall stability experiment result of bitumen blended stock

Bitumen aggregate Ratio (%)	3.3	3.8	4.3	4.8	5.3
Porosity (%)	6.7	5.7	3.9	2.6	1.7
Mineral material clearance ratio (%)	13.3	13.5	13.3	12.8	13.0
Asphalt Saturation (%)	49.8	57.7	70.3	79.7	87.2
Stability (KN)	10.27	10.77	15. 16	10.45	9.89
Flow value (mm)	30.9	27.4	27.7	33.5	34.3

Table 9. Rutting test result of bitumen blended stock

Type of mixture	45min deformation（mm）	60min deformation（mm）	Dynamic stability（secondary/mm）
Matrix- based asphalt mixture	6.031	7.016	3546
DCLR modified asphalt mixture	6.013	6.925	3714

If the stress was applied to the asphalt mixture for a long time, the strain would increase over time, and the deformation of the asphalt would gradually recover when the stress was removed. However, the asphalt would undergo the permanent deformation, especially in the high temperature conditions. Generally, rut test was used to evaluate the high temperature stability of the asphalt mixture. From Table 9, the dynamic stability of the base asphalt mixture met the specification requirements (dynamic stability ≥ 2400/mm). Compared with the latter, the value increased from 3546/mm to 3714/mm, having 4.8% increment. The deformation degree of the asphalt mixture increased with the time extended, and the value was 6.031 mm and 6.013 mm at 45 min respectively for the base asphalt mixture and DCLR modified asphalt mixture. While it was 7.016 mm and 6.925 mm at 60 min. DCLR modified asphalt mixture decreased by 2% and 1.3% compared with the base asphalt mixture. The result showed that the high temperature performance of DCLR modified asphalt mixture is better than the base asphalt mixture.

4.2.2 Evaluation on the Low-temperature Performance of the Asphalt Mixture

The low temperature crack resistance of asphalt mixture was directly related to the low temperature service performance of pavement. Then it would affect the service life of pavement. The low temperature bending experiment of small beam was used to evaluate the crack resistance of modified asphalt mixture. In Table 10, the curved tensile strain of DCLR modified asphalt mixture was 3% lower than the base asphalt mixture, which was failed to meet the current requirements (greater than 2300 με in the JTGE20-2011). The result indicated that DCLR modified asphalt mixture had a deficient problem on the low temperature crack resistance. This was attributed to the poor mutual solubility between DCLR and base asphalt. Then a solvent structure was generated to form in the form of macro-molecular particles. Therefore, the heterogeneous mixture making the mixture material, resulting in the general improvement of low temperature performance.

Table 10. At low temperature bending test results

Type of mixture	Bending- tensile strength/ MPa	Rupture strain /με	Failure strength measure modulus/ MPa
Matrix- based asphalt mixture	6.56	2385	2845
DCLR modified asphalt mixture	6.69	2373	2913

4.2.3 Evaluation of Water Stability of Asphalt Mixture

Water stability of asphalt mixture referred to the water entering the asphalt pavement into the asphalt pavement. Under the repeated action of the dynamic wheel load, water gradually penetrated into the asphalt and decreased the asphalt adhesion, resulting in the final asphalt stripping from the ore surface. In this case, the asphalt mixture started to drop grain, loose, and damage the overall performance. Frozen-melt cracking strength was used to evaluate the water stability energy of the asphalt mixture. From Table 11, the DCLR modified asphalt mixture improved the split tensile strength of the test piece. The maximum load of the test piece after the freeze-melting cycle increased from 8.9 KN to 9.6 KN, and the freeze-melting cracking strength ratio increased from 83.1% to 87.1%. The result indicated that the DCLR could improve the water stability of the asphalt.

Table 11. Freeze-thaw split test results

Type of mixture	Splacking tensile strength of unfrozen-thaw circulating test piece		Splitting-resistant tensile strength of test specimen after freeze-thaw cycle		Frozen-melt splitting strength
	Maximum load (kN)	Splitting strength (MPa)	Maximum load (kN)	Splitting strength (MPa)	ratio (%)
Base asphalt mixture	9.2	0.894	8.1	1. 15	83.3
DCLR modified asphalt mixture	9.61	1.00	8.9	1.36	87. 1

5. Conclusions

Based on the obtained data, the following conclusions were made:

1) This study through the design of orthogonal experiment, the optimum technological conditions of DCLR modified petroleum asphalt are as follows: shear time 45 min, shear rate 4000 r/min, shear temperature 150 °C ; Through the analysis of grey correlation degree, the maximum correlation degree of needle entry degree is calculated;

2) The FT-IR spectra of base asphalt and DCLR modified asphalt was shown that DCLR has more influence on asphalt, and the strength and width of all absorption peaks are weakened. The TG curves of base asphalt, modified asphalt and DCLR indicated that the modified asphalt contained more high temperature resistant substances than the base asphalt.

3) Testing on the asphalt mixture has found that DCLR can significantly improve its high temperature performance and water stability, but it has little impact on its low temperature performance.

Data Availability Statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

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Analysis of the Relations between Highway Geometric Design and Traffic Safety in Bangladesh, China, and America

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ABSTRACT

Transportation plays a critical role in the economic sector in Bangladesh. Since its independence, infrastructure has been developing rapidly, including land, water, and air transportation. National economy is increasing at a relatively high rate, leading to the better-off of people's lives. As the living standards keep improving, people are more concerned about safety issues in transportation. This article makes an analysis of the status quo of traffic safety in Bangladesh and compares the Bangladeshi code with American code AASHTO from the geometric aspects of horizontal and vertical alignment, in an effort to provide reference to the highway design in Bangladesh. Through a reasonable design, the traffic safety will be under control and accident rate as well as economic loss will be minimized.

1. The Status Quo of Traffic Safety in Bangladesh

As an important part of Bangladesh transportation system, there is a prospect for highway to be used widely in urban areas. With the rapid economic development, traffic volume of urban roads is skyrocketing, resulting in severe congestion. Due to the mismatch of highway capacity and traffic volume, the urban traffic is highly congested, imposing adverse impact on the development of cities and people's lives. A proper highway planning can provide a safe and reliable driving environment, meanwhile, reduce accident rate, save passengers' lives, and minimize economic losses [1].

Currently, 160 deaths on average are caused per 10,000 motor vehicles, the death rate of which is rarely seen worldwide. Approximately, 70%-80% traffic accidents happen on expressway and rural roads and 70% traffic accidents endangers the pedestrians. A high traffic accident rate not only put people's lives at risk, but also impose enormous economic burden on the country, as much as 50 billion TAKA (equivalent to 710 million U.S. dollars) each year. 80% of the deaths are aged between 5 and 45 years old, adversely affecting socio-economic development.

Statistics show that the fatality per 10,000 vehicles in the U.S. and China is less than 0.9% of that in Bangla-

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desh. Death toll due to traffic accidents remains startlingly high. It has become a pressing task to reduce and prevent the occurrence of traffic accidents to better the urban traffic safety [2].

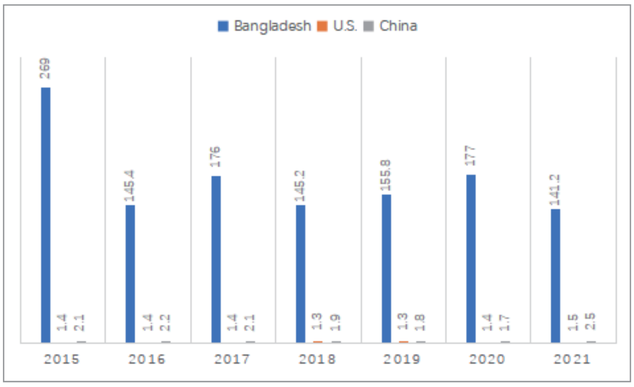

Figure 1. Fatality per 10,000 vehicles in Bangladesh, the U.S. and China.

2. Cause Analysis of Traffic Accidents

Traffic safety is worth research. Various causes lie behind the traffic accidents. The traffic facilities should be in place that take full consideration of the relationship between humans, vehicles, and roads. With safety as a priority, due attention should also be paid to the comfort, convenience, and appearance. A proper highway planning can effectively control the traffic, thus lessening the traffic accidents and economic losses. In geometric design of highway, sufficient consideration should be given to the coordination between horizontal, vertical alignment and cross section and the sight distance should be made adequate. If the alignment design lacks some considerations, the traffic capacity will be lowered and the drivers suffer from losses both in terms of time and economically [3].

The main factors that lead to traffic accidents are drivers, road characteristics and vehicles. The drivers' capability plays decisive role in traffic safety, whereas, studies show the drivers' fault along will not give rise to the most serious accidents. A more important factor is related to the dangerous roads. That is to say, the road characteristics are the root of accidents, which directly or indirectly induce traffic accidents. The accidents due to the interaction between drivers and road features account for as much as 30%. In this article, Bangladeshi code will be compared with American code AASHTO. The influence of road factor on traffic accidents is analyzed in details to determine the relationship between road alignment and traffic safety. The key factors affecting traffic safety are extracted for reference of future design in Bangladesh.

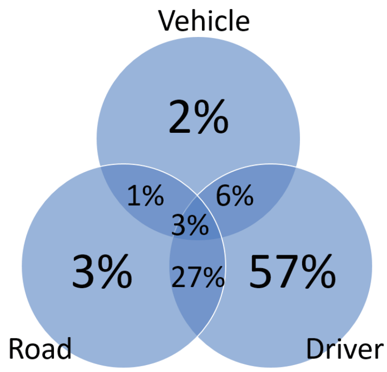

Figure 2. The distribution of causes of traffic accidents

3. The Importance of Road Geometric Design for Traffic Safety

Traffic engineering is complicated and systemic and plays a crucial part in road construction. It brings the road functions to full play by providing a fast, comfortable and safe driving experience, thus reducing traffic accidents and maximize the road capacity. The layout of traffic engineering plans the road to improve its functions according to geographical and ground features, on the basis of road geometric design. For the drivers, the advantages of a three-dimensional design lie in its safety, swiftness, and comfort.

To ensure the safety, comfort and coordination, the three-dimensional design of road shall be properly designed. Safety must come first. Effective measures shall be taken to provide safety and humane service, enhancing the transportation safety and service level. Since the landform and geography can't be changed along the route, the road geometric design shall be considered at the time of planning, which will dictate the safety of during construction and operation.

The geometry must be properly designed to ensure the driving speed and safety. A well-designed embankment is a precondition for the safety and stability. A holistic consideration shall be taken about the landform, maintenance, land utilization and environmental protection to achieve a coordinated and consistent alignment design. The road geometry is a key factor of traffic safety. An unreasonable design will lower the road capacity, cause time and economic losses, and even lead to traffic accidents.

The geometric design considers the plan & profile and coordination with cross section as well as sight distance. In highway design, sufficient consideration should be given to the steering direction, speed, distance, drivers' view, and sight distance so that expected outcome can be achieved by the drivers. Despite numerous factors that affect the road safety, including road alignment, design, safety facilities design, location and shape of structures, the geometric design is the most important. Once the direction of road is fixed, geometry determined, other projects, like the choice of bridge structure, safety measures are based on the former.

The function of roads, driving safety as well as natural environment should all be considered at the time of route selection. Not only the safety of road facilities and operation should be combined, but also prevent accident-prone locations and safety hazards. Driving safety issues are resolved from root by means of improving horizontal & vertical alignment. Specifically, the driving safety on grade shall be given due attention.

In summary, road geometric design, among others, shall prioritize safety and take effective measures to tackle safety issues and indeed promote the traffic capacity and level of service.

4. Comparative Analysis of Geometric Design of Bangladeshi & American Highway

4.1 Basic Theory

The basic theory applied for highway geometric design is consistent in Bangladeshi and American code, with slightly different emphasis and expression forms. Some design concepts, though, are quite different [4].

Based on basic theoretical research, the Bangladesh Code specifies the geometric design of highways such as curve radius, superelevation, and gradient, which is the basis for highway design. Unlike Bangladesh highways, the US AASHTO specification is only a design guideline. It proposes a series of guidelines for the geometric design of highways. Designers can have a certain degree of flexibility in using this guideline. The book clearly states in the preface that the purpose of this book is to provide guidelines for designers, and to provide recommended design value ranges for critical dimension designs. Allowing sufficient flexibility is to encourage special design solutions that are suitable for specific situations.

4.2 Sight Distance

As a key factor in road geometry and alignment design, sight distance has a crucial impact on road traffic safety. In order to drive safely, the driver should be able to see a considerable distance in front of the bicycle at any time [5]. Once an obstacle or an oncoming vehicle is found on the road ahead, he can take timely measures to avoid collision. This shortest distance is the sight distance necessary for driving safety.

In both Bangladeshi code and American AASHTO code, stopping sight distance shall be met for the highway with median divider and intermediate sight distance met if without. Combined with terrain, set sections of road that meet overtaking sight distance.

In Bangladeshi code, the road geometry design is closely related to sight distance. Reasonable plan & profile parameters shall be selected according to the design speed. SSD, ISD and OSD are stipulated in the code as well as corresponding minimum radii. Since the minimum radii are larger than those in Chinese and American code, sight distance is met as long as the radius chosen for the curve meets the code, thus it's unnecessary to check the sight distance.

It's stipulated in AASHTO that the stopping sight distance is the sum of two distances: (1) the distance traversed during the brake reaction time, and (2) the distance to brake the vehicle to a stop. It is also stipulated that the sight distance at the most unfavorable locations, such as the inner lane of the horizontal curve and the start and end points of the vertical curve, shall be checked stake by stake. The distance is dependent on the height of the drivers' eye above the road surface, the specified object height above the road surface, and the height and lateral position of sight obstructions within the drivers' line of sight. SSD should be modified according to gradient. The computed distance on level roadways is developed from the following equation:

$$SSD = 0.278\mathrm{Vt} + 0.039\frac{V^2}{a}$$

Also used for checking sight distance, the equation is provided in AASHTO to calculate the distance M from the center line of the inner lane on a plane curve to the roadside obstructions:

$$M = \mathrm{R}[1 - \cos\left(28.65 \times \frac{\mathrm{S}}{\mathrm{R}}\right)]$$

where:

M = distance to ensure stopping sight distance

R = the plane curve radius of the inner lane, m

S = stopping sight distance, m

Under special circumstances, where the road intersection is not provided appropriately and where obstructions exist in the range of sight distance, the sight distance is not required to be checked in Bangladeshi code, leaving no room for the improvement of sight distance with technical and engineering measures, which leads to traffic accident.

4.3 Straight (Tangent)

Straight is one of the basic elements of horizontal alignment. Being too long or too short will both cause higher accident rate. If it is too short, frequent steering adds to the workload of drivers and a rapid change in alignment is prone to induce accidents. Moreover, the combination with short straights forms a broken-back curve, which gives the drivers a wrong signal and imposes great safety risks. However, if the straight is too long, the driver's visual reaction and mental conditions are related to traffic safety. A monotonous alignment is apt to cause fatigue, lags in response and wrong perception, resulting in car crash in unexpected situations.

Bangladeshi code encourages a succession of curves and straights in horizontal alignment. By so doing, drivers are better able to assess the distances and speeds of other vehicles. They are more likely to remain alert, and there is less headlight glare at night. It's also suggested that a straight section should be inserted between two curves that go in opposite directions (reverse curves), yet no specific requirements are stipulated in terms of the maximum and minimum length of straight section.

It's stipulated in AASHTO that the maximum length of a straight is the distance traversed in 3 minutes at design speed. Assuming the speed is 100 km/h, the distance is 5 km or 50 times of the speed value. Yet, the minimum length of straights is not required.

Bangladesh is located on the delta plain in the northeastern subcontinent. Plain accounts for 85% of its territory, making it unnecessary for fit the highways to the terrain by plane curves. For this reason, the roads in Bangladesh are relatively straight. Drivers will gradually become insensitive to speed when driving on a long, straight road. Their misperception of speed incurs great safety hazards, especially when driving on a curve at a high speed. Before entry to a curve, drivers think the speed is substantially lowered while in fact, remains high. On the curve, the vehicles are prone to skid or find it difficult to steer due to high speed. In summary, too long straight section should be avoided, let alone a long straight connected with small radius curve.

4.4 Circular Curve

According to automobile mechanics, the lateral stability is lost before longitudinal stability. Therefore, the curve radius is determined based on the lateral stability of vehicles. The minimum radius should ensure that the resultant of centrifugal force and the component of vehicle gravity perpendicular to the road surface should be no more than the lateral cohesive force between tires and road surface. The comfort of passenger should also be considered.

Studies have shown that 10%-12% of accidents happen on the plane curves. The smaller the radius is, the more likely the accidents will happen. The accident rate soars if the radius is less than 400 m.

British scholar Glanville studied the relations between the curvature of plane curves and road accidents through experiment, as shown in the figure below.

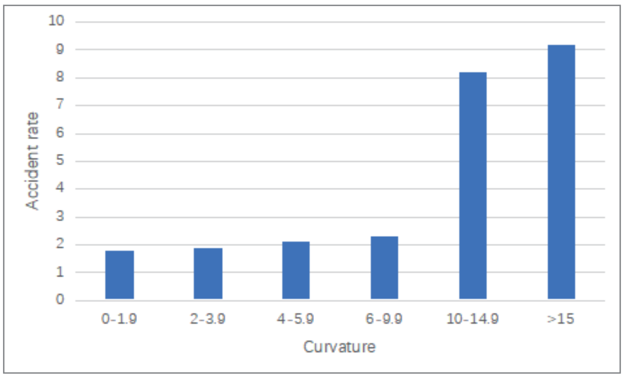

Figure 3. Relations between curvature and accident rate

In Bangladesh code, the minimum curve radii are stipulated as below according to different types of road and sight distance, to be determined by the designers based on actual situation.

In AASHTO, the minimum radii are determined on the condition that vehicles can drive safely and comfortably on the curve. The equation for calculating the minimum radii is provided in this code.

Table 1. Minmum Curve Radii (metres)-Bangladesh

Design Speed (km/h)	Single Lane Roads (3.7 m carriageway)	Two Lane Single Carriageway Roads (6.2 and 7.3 m carriageway)			Dual Carriageway Roads (2×7.3)
	ISD	SSD	ISD	OSD	ISD
30	120	35	120	500	-
40	250	65	250	1000	-
50	500	120	500	2000	500
65	1000	250	1000	4000	1000
80	-	500	2000	8000	2000
100	-	1000	4000	-	4000

$$R_{min} = \frac{V^2}{127(e_{max} + f_{max})}$$

R_{min}-Minimum radius of curve measured to a vehicle's center of gravity, m

e_{max}-Maximum rate of roadway superelevation, percent

f_{max} -Maximum side friction factor

V- Vehicle speed, km/h

The mimimum radius can be calculated based on e_{max} and f_{max}.

Table 2. Minimum circular radii under different vehicle speeds and elevation in AASHTO

Design Speed (km/h)	30	40	50	80	100
4%	22	47	86	280	492
6%	21	43	79	252	437
8%	20	41	73	229	394
10%	19	38	68	210	358
12%	18	36	64	194	328

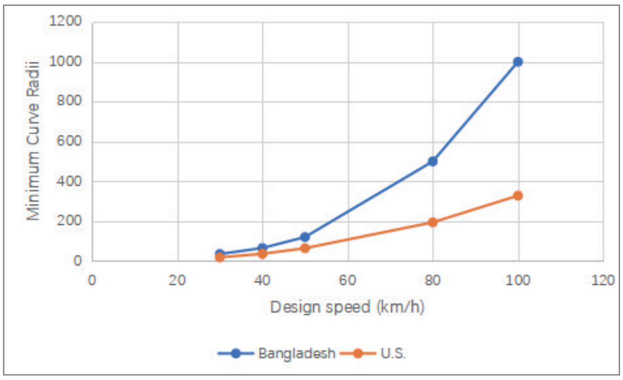

Figure 4. Allowable Minimum Radii in Bangladeshi and American Code

The minimum radii under different speeds in two codes are shown in the figure. It can be seen that the radii in Bangladeshi code are larger than in American code, which effectively curbs the application of small radius curve and avoids possible traffic accidents.

4.5 Maximum Superelevation

In AASHTO, there are five superelevation, i.e. 4%, 6%, 8% and 12% to choose from. And five circular curve standards are provided accordingly. For expressways, the maximum superelevation is stipulated as 8%, 10% or 12%; for elevated bridges, 6% or 8%. It's worth noting that 12% is newly added in the latest standards, reflecting the need to fit high-speed driving.

It's stipulated in Bangladeshi code that for the section with curve radius less than the minimum radius not requiring the superelevation, crossfall towards inner side of curve is required. The maximum superelevation crossfall is 7%. In the code, the superelevation of circular curve is clearly stipulate. The designers can choose values in the table according to design speed and radius of circular curve.

The maximum superelevation is determined according to actuation situation like climate, topographical conditions, and the percentage of low-speed vehicles.

4.6 Transition Curve

Both American and Bangladeshi code are basically consistent in the principles of providing transition curve: when the radius of the circular curve is less than the minimum radius of the circular curve without the transition curve, in order to adapt to the driving trajectory of the vehicle and meet the needs of superelevation transition, the transition curve should be set for the horizontal curves. Generally, spiral is used as transition curve. The length of the spiral is determined based on the driving comfort and the offset of the vehicle. When the vehicle enters the curve, the appropriate length of the spiral will not make the driver feel uncomfortable with the increase of the centripetal acceleration, and it can also ensure that the vehicle runs on a normal trajectory, and its lateral offset will not exceed its own lane. However, if the length of the spiral is too long, the driver will be misled into thinking that the radius of the circular curve ahead is small, and there will also be potential safety hazards.

The starting point of the superelevation transition is fixed on a straight line at a certain distance (Lt) from the T.S. point. At T.S. Point, the crossfall of outer side has been rotated to be flat. This approach helps the driver better adjust the driving state. Besides, it can provide visual comfort and driving safety without reverse-superelevation section on transition curve.

In Bangladeshi code, the minimum length of transition curve is related to design speed and superelevation and is provided accordingly.

Table 3. Minimum Design Transition Length(m)-Bangladesh

Design speed (km/h))	7%	5%	3%	
	Tab.3 Minimum Design Transition Length(m)Bangladesh			
30	25	15	10	10
40	35	20	13	13
50	45[55]	25[35]	15[20]	15[20]
65	55[65]	35[45]	20[25]	20[25]
80	65[75]	45[55]	25[35]	25[35]
100	75[95]	55[65]	35[45]	35[45]

The equation for calculating the minimum, maximum and expected radii is provided in this code.

$$L_{smin} = 0.0214 \times V^3/RC$$

$$L_{smax} = \sqrt{24(P_{max})R}$$

where:

L_{smin}- the minimum length of spiral, m

L_{sman}- the maximum length of spiral, m

V- Design speed, km/h

R-Circular curve radius, m

C-Maximum rate of change of centripetal acceleration (1.2 m/s^3)

P_{max}-Minimum offset of the vehicle on the transition curve between the straight and the circular curve (0.2 m)

It's considered in AASHTO that when the length of the spiral is approximately equal to the length of the natural trajectory of the vehicle, the driving state of the vehicle is the most ideal. If they are too different, steering problems will occur. At the end of transition curve, the vehicle produces excessive lateral velocity and lateral displacement. Therefore, AASHTO provides the expected length of spiral, equal to the distance traversed by vehicles in 2 seconds at design speed.

Table 4. Desirable Length of Spiral Curve Transition(m) in AASHTO

Design speed (km/h)	80	90	100	110	120	130
Desirable Length of Spiral Curve Transition (m)	44	50	56	61	67	72

In actual design, for circular curves of different radii, if the desirable length of the spiral is less than the minimum value calculated by the above formula, the minimum value calculated by the formula should be used in the design.

Meanwhile, it is suggested that the length of the spiral should be the same as that of the superelevation transition. If the length of the superelevation is less than the minimum value of the spiral calculated by the formula, the length of the superelevation should be adjusted appropriately to make it close to the length of the spiral.

It can be seen from the above analysis that the American AASHTO code has more detailed requirements for the transition curve and superelevation transition, which enables the designer to design the most suitable horizontal alignment according to the actual situation of each project; while the Bangladesh code is relatively simple, so It may cause a sharp superelevation transition, the driver's reaction time is too short;or it may cause the superelevation transition too gentle, resulting in the risk of water logging and hydroplaning.

4.7 Gradient

The vertical alignment also has a significant influence on the traffic safety and it is often the direct cause of traffic accidents. The climbing ability of vehicles is an important factor in limiting the gradient. Therefore, the impact of the longitudinal slope on the heavy-duty vehicles is more significant than that on the cars. When the car is going up a steep slope, it will inevitably lead to a reduction in the speed of the vehicle. If the steep slope is too long, the climbing will cause the car water tank to boil and steam resistance so that the driving is slow and weak and the wear and tear of the parts increases. With the driving conditions deteriorating, the engine even stalls and traffic accident occurs. When going down a long steep slope, due to the need for a long time to decelerate and brake, it will cause the heat failure or burnout of brake, resulting in traffic accidents.

German scholar Biezlu investigated the relationship between the gradient of German highways and the road traffic accident rate, and concluded that the steeper the slope, the greater the accident rate. When the gradient is greater than 4%, the accident rate will rise sharply.

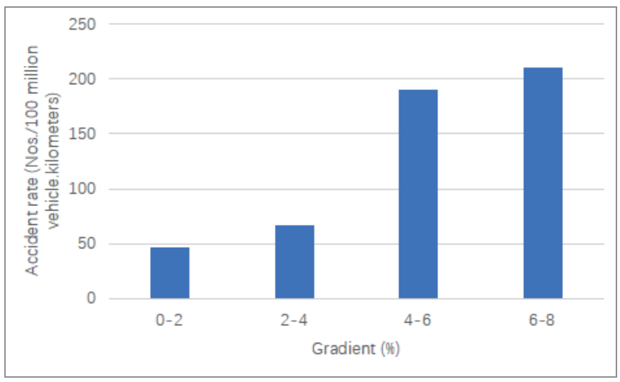

Figure 5. Relations between Gradient and Accident Rate in German Highways

The maximum gradient stipulated by the Bangladeshi Code is only related to the terrain. For highways of various grades and design speeds, it is 0 to 3% in the plain area, 1% to 5% in the hilly area, and 1% to 7% in the mountainous area.The code does not specify the maximum slope length.

It's stipulated in AASHTO that the maximum gradient is determined based on types of terrain and design speed. Maximum grades of about 5 percent are considered appropriate for a design speed of 110 km/h. For a design speed of 50 km/h, maximum grades generally are in the range of 7 to 12 percent, depending on terrain. If only the more important highways are considered, it appears that maximum grades of 7 or 8 percent are representative of current design practice for a 50-km/h design speed.

The requirements on the minimum gradient are relatively loose and are determined after comprehensive consideration.

On the road without curb stones, if the road camber is sufficient to satisfy the lateral drainage of the road surface, then a gentle gradient can be used in the design; On the road with curb stones, in order to facilitate the lateral drainage of the pavement, a minimum gradient of 0.5% is usually used.But on high-grade highways where the roadbed is firm and it requires precision for the road camber design, a minimum gradient of 0.3% can also be used.

The minimum slope length is not clearly specified, and the maximum slope length has nothing to do with the design speed, and is determined on the basis of the speed reduction of the loaded vehicles' speed lower than the average speed.

The recommended value of the speed reduction is 15 km/h.

Due to the lack of relevant requirements on the maximum slope length in the Bangladeshi code, if the road adopts a long and steep slope, and the performance of vehicles in Bangladesh is generally low, traffic accidents are more likely to occur in practice.

5. Conclusions

Due to the multiple factors for traffic accidents, the geometry design is not the only one to blame. However, a well-thought-out geometry design effectively ensures the traffic safety and reduces traffic accidents and causalities involved.

This article made an analysis of the causes of high traffic accident rate in Bangladesh, and the relations between the three components of road transport, i.e. humans, vehicles and roads, concluding the relations between the road geometry conditions and traffic safety. Starting from the relationship between the geometric elements including Plan & Profile and traffic safety, the influence of various indicators in the geometry design on safety is elaborated, and the relevant requirements and differences between the Bangladeshi standard and the American AASHTO standard are analyzed. It's found that the Bangladeshi code lacks the detailed requirements on multiple road elements, possibly leading to "compliant with code yet unreasonable" design in practice. The findings of this article can provide reference for the road design in Bangladesh.

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