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Sustainable Approach for Geometric Design of Highway using OpenRoads: a Case Study of NH-05

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Abstract

Roads are said to be the backbone of the development of any nation. In the developing nations like India, it is the primary mode of transportation, which makes its significance much higher. Highway geometric alignment is an important aspect for maintaining road safety and the effective movement of traffic on any road. Highway geometry features are meant to be picked, sized, and placed in order to achieve various design goals including sight distance, car stability, driver convenience, drainage, economic growth, and aesthetic qualities. Due to the rapid increase in the growth of traffic in the past few years, it has become important to ensure safe design alignment to serve the future needs efficiently and economically. A case study of NH-05 is used in the present work to design the existing highway to improve its geometric features by considering future forecasted traffic and covering all safety measures given by the Indian Road Congress (IRC) recommendations. The OpenRoads software was used as a designing tool, and all designs were made keeping the design speed at 50 kmph. The roadway width has been decided to be 13.0 m, with the carriageway width set at 7.5 m and the width of the shoulder at 2.4 m. The cross-slope or camber has been determined to be 2.4% for bituminous surfaces and 3.6% for earthen surfaces, with a maximum super-elevation of 7%. Thus the results obtained can be used to solve the traffic congestion problems, particularly due to the high traffic volume, and enhance road safety.

1. Introduction

India is progressing at a very rapid speed, and transportation is playing a vital role in it. Transportation has been the backbone of human civilization for many centuries and has carried the burden of various human-generated problems [1]. Highway search and design procedures are still done using a manual approach that is more than 50 years old [2]. With the increase in urbanization, conventional roads are unable to hold the capacity because of the volume of traffic there is on the roads [3]. The alignment, pavement, cross-drainage structures, road furniture, environment, and safety all play a role in highway design [4-5]. The expense of the road and its geometric design are directly impacted by the change in these components' nature. Construction of new highways, bypass routes, and extending existing highways are often driven by rising highway traffic and safety issues [2]. Therefore, finding and creating the best alternatives becomes a challenge for highway agencies for the development, design, and management of roadway facilities, a study of many aspects of highway traffic is needed. Highway geometry features are meant to be picked, sized, and placed in order to achieve various design goals including sight distance, car stability, driver convenience, drainage, economic growth, and aesthetic qualities [6]. Highways must ensure user comfort and safety to facilitate optimal traffic movement.

Obtaining relevant data on geology, land use, slope, soil, and drainage is the first step in producing high-quality alignments [2]. Other issues include the ownership and value of the land, the social and economic effects, and the designation of environmentally sensitive areas [7,

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8]. The model presented in the study is intended to show road authorities how to upgrade each section of the existing road network without going over budget or using ineffective methods, therefore minimizing the impacts of implemented solutions.

1.1. Geometric design of highway

The area of transportation engineering known as geometric design of roadways is focused on locating the actual roadway elements in accordance with laws and restrictions. The main goal of geometric design is to achieve safety and efficiency, while reducing investments and damage to the environment. Vertical alignment, horizontal alignment, cross-section elements, intersection elements, and sight distance are the different elements of geometric design. The geometric design is impacted by a vehicle, driver, and traffic variables as these features change over time [9]. One of the oldest spatial issues is determining the best route through a given area. This challenge has lately been efficiently overcome using software technology. The existing geometric design guidelines, however, are not entirely useful to cover all of the requirements to assure the safety of the planned highway parts because the current geometric design techniques are deterministic in nature [10]. According to reports, compared to other roadway components, horizontal curves are responsible for the majority of accidents on a highway [11, 19], and to assure a highway is planned safely, sight distance considerations are crucial in this context.

Need for proper geometric alignment

- Proper alignment will help in the reduction of accidents.
- To address the driver's as well as vehicle requirements such as safety, comfort, and efficiency.
- To lessen the environmental damage.

1.1. OpenRoads software

OpenRoads software was created in 1996 by Bentley Systems, a UK-based company. Many challenges that we have when building highway alignment, cross-sections, intersection features, and so on can be solved with software. We can construct highways more effectively and affordably by identifying high-risk components early on [4]. OpenRoads is the greatest and most useful highway design application. It gives default values for classifying the variables that influence roadway design. When producing a detailed pavement design, this program supports surveying, geotechnical, drainage, subsurface utility, corridor modelling, analysis, and quantification [10]. It is a multidisciplinary 3D modelling application that helps to accelerate the delivery of road projects from design to construction. OpenRoads Designer includes the most up-to-date technology and tools for designing, modelling, and producing project deliverables in a dynamic, interactive, and parametric environment.

The important features which help in completing the highway design accurately and quickly are compiling and editing survey responses, surface contour knowledge, topography-based highway alignment adjustments, calculation-based vertical profile management, use of design codes for double-checking design criteria, etc. [6].

2. Literature Review

Designing highways has been important part of the urbanization and development of any place, own city as well as a nation. Various studies have been carried out by different researchers on it [4, 6, 10]. The highway's geometric layout is crucial and all the factors are to be considered while designing a highway. If the geometrics of the road are not good it may result in accidents [12]. Vehicles, roads, and humans are the three main contributors to accidents. If the geometrics of the road is good, then there are very less chances of having accidents. Subramani and Pari studied about the influence of the road's geometric factors on accident rates in cases of flat terrain, as well as how much of an impact they have on accident rates in rural areas [8]. Highway design is influenced by a number of variables, including orientation, pavement, cross-drain systems, highway furniture, environment, and safety. The geometry of the road and consequently its cost are directly impacted by the shifting nature of these components [3, 4]. The purpose of geometric design is to satisfy the fundamental requirements of the driver and the vehicle including those for efficiency, comfort, and safety, while driving the vehicle [12, 20]. Road alignment in hilly areas must be circuitous and is mainly governed by topography [13].

Different techniques have been used by highway engineers for designing the roads such as Auto CAD Civil 3D, OpenRoads designer and manual method [4, 9, 14-15]. When done manually, designing flyovers, carriageway is a complex task that requires creativity and practicability. Thus [15] discussed how the proposed flyover road and the road intersection under the flyover were designed. Geometric design is labor-intensive, expensive, and highly error-prone when done manually. Additionally, the design will be flawed and there will only be a 2D view [12]. Manually creating geometric designs is frequently tedious, time-consuming, and highly susceptible to costly mistakes. The traditional approach also relies on a two-dimensional assessment, which does not guarantee an appealing design [9].

However, Civil 3D allows for the creation of 3D project models and their use in both small and large-scale projects. The amount of traffic influences the number of routes, width of the road, details of the project, and economic analysis [12]. AutoCAD modeling program called civil 3D makes it easy and convenient to complete modelling tasks [15]. Software aids in the design of the highway in a pleasant and relaxing manner. The design and development of geometric features is the main focus of highway geometric design. Although the project is still being aligned, it is beneficial to plan and design the road's geometric elements while taking prospective traffic growth into account [5, 12]. AutoCAD Civil 3D associate development and production drafting substantially speed up the process of implementing design changes and evaluating various situations [12, 15].

OpenRoads software helps in many problems which we face during designing of highway alignment, cross-sections, intersection elements, etc. By identifying high-risk areas, it assists engineers and planners in making informed decisions about road design and construction [6]. The software is equipped with various tools and features that enable users to optimize the alignment and profile of a highway for improved safety, cost efficiency, and environmental impact. One of the key features of the OpenRoads software is its ability to create 3D models of highway alignments, which can be used to simulate and analyze the behavior of vehicles on the road [4, 16]. This allows designers to evaluate different design alternatives and make adjustments to improve the overall performance of the road. Additionally, the OpenRoads software includes tools for generating cross sections of highways, calculating cut and fill volumes, and creating accurate earthwork models. These features help engineers to determine the best way to design a roadway while minimizing the impact on the surrounding environment [10]. Overall, the OpenRoads software is an essential tool for anyone involved in the design and construction of highways. Its powerful set of features and tools make it possible to create efficient, safe, and sustainable roadways that meet the needs of both drivers and communities. This study focuses on how to show roadway geometric design may be done quickly and accurately. The road design technique utilizing Bentley OpenRoads software is described in the paper. The manual geometric design of the route is a very traditional method of highway design. In the current situation, roadway geometry design relies on extremely developed computer technology, which provides the right values while saving a sizable amount of time and effort.

3. Methodology

Adopting a thorough modelling approach for highway geometric design is necessary from the standpoint of achieving a sufficient level of safety for all road users [7]. Figure 1 shows the methodology adopted for the designing of highway alignment using the OpenRoads software.

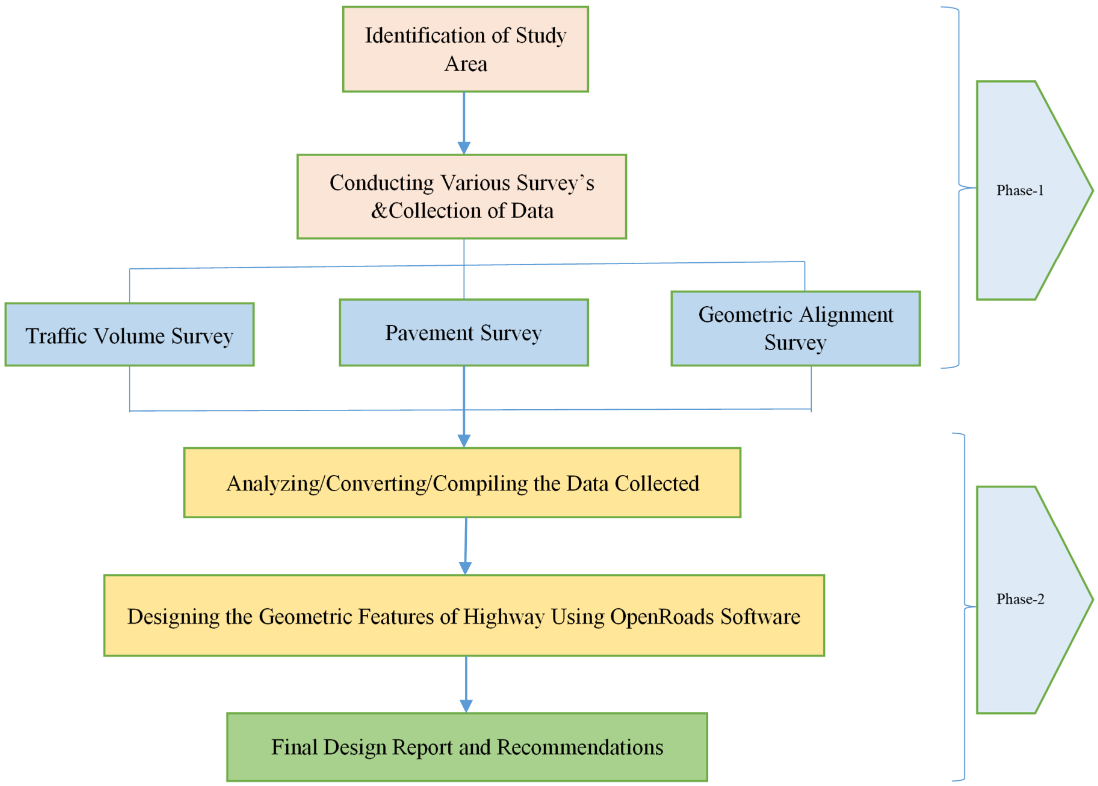


Figure 1. Methodology for designing of highway alignment.

The research work has been divided into two phases: the first phase of the work focuses on identifying the study area and conducting various survey studies and data collection, and the analyzing of the data and designing of alignment in the study area is to be done in phase 2.

3.1. Phase 1

During Phase 1, the area of study will be chosen in accordance with the goals and parameters of the investigation. A literature review was conducted to gather necessary background information about the study area, related studies, and policies. Primary data collection techniques such as surveys, interviews, and focus group discussions was used to obtain relevant information from stakeholders and the community. The collected data was analyzed using appropriate statistical tools and software.

3.1.1. Studied area

The project site starts at the chainage between Solan (105.00 Km) to Kaithalighat (109.05 Km) in the Solan district of Himachal Pradesh as shown in Figure 2. Total length of the stretch is 4.05 Km. The project road connects to Shimla, which is one of the biggest tourist sites in India. People from all parts of the country visit this place, whereas Solan is also a hub for many tourist destinations and also attracts a lot of tourists annually. According to the 2011 Indian census, Solan has a population of 39,256, making it the second-largest city in Himachal, after Shimla. The project location is located at an average elevation between 1500 - 1600 meters. The NH-05 connecting Solan usually has high traffic flowing through it, while the roads are designed in a conventional way and not enough broad to hold that amount of traffic flowing through it. The peak traffic flows during summer and winter and considering that period the traffic volume data is collected in the month of December when traffic is at its annual peak.

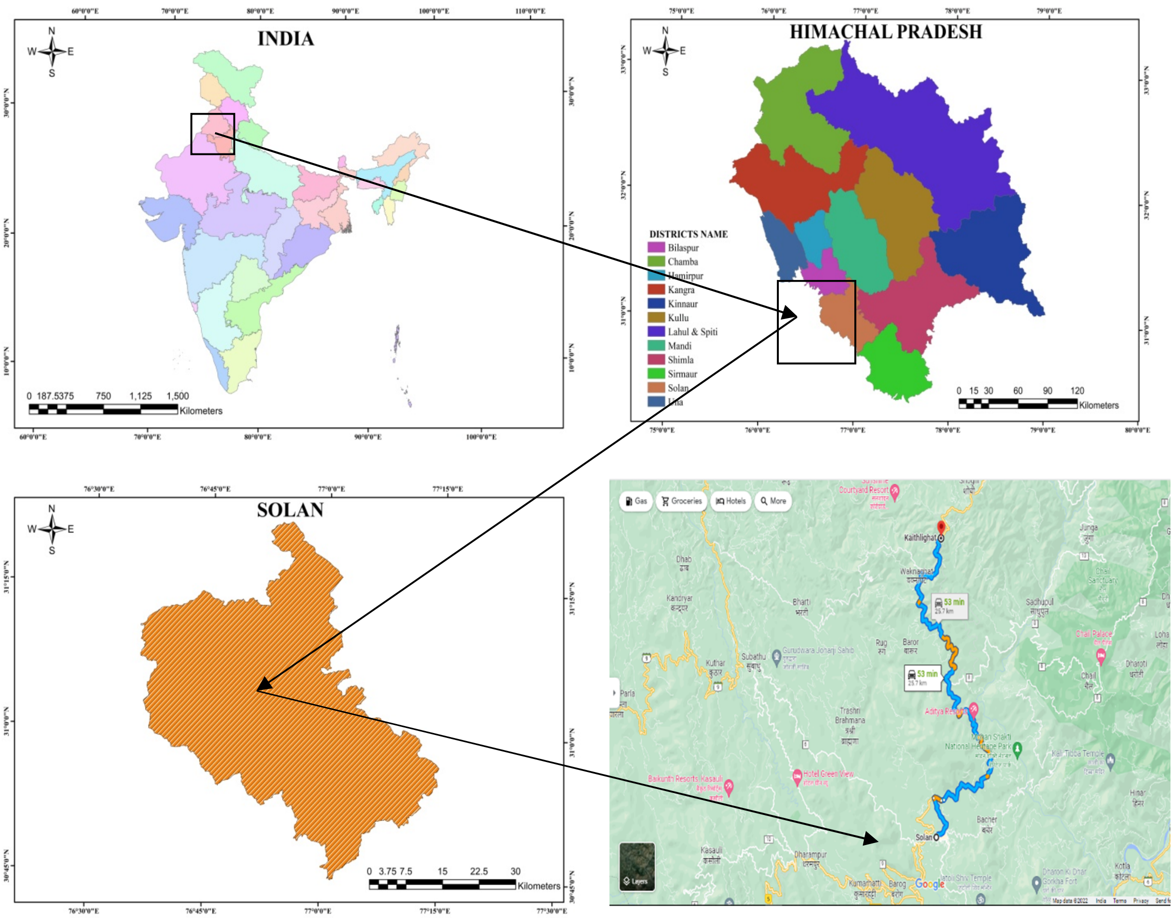


Figure 2. Studied area.

3.1.2. Traffic volume Survey

According to Abed, a traffic volume survey counts the number of vehicles that pass through a specific area of a road over a specified amount of time [17]. It is frequently evaluated and quantified in terms of Passenger Car Units (PCU) in order to assess the level of service provided by the road as well as other relevant elements like traffic, maximum capacity, volume/capacity (V/C) ratio, identifying peak or extended peak hours, etc.

3.1.3. Pavement condition survey

The pavement condition survey is an important step in highway maintenance, with time the pavement deteriorates due to constant traffic load conditions, adverse weather conditions, and many other factors. As per IRC pavement survey should be done every year [18]. The survey will be done through visual inspection and the road will be inspected.

3.2. Phase 2

In Phase 2, the analyzed data was evaluated to draw conclusions based on the research objectives. The study findings were presented through various means such as graphs, tables, charts and maps. Based on the study findings, relevant recommendations were given with regards to planning, design, and management of the study area. This phase consisted of analyzing, converting, and compiling the data, and designing the highway alignment using the OpenRoads software.

4. Results and Discussion

For the design of a three-dimensional road, with the aid of OpenRoads, the geometric design of the carriageway is said to be very functional and user-friendly. The traffic survey was carried out for 12 hours between 7:00 Am–7:00 Pm keeping in mind the peak hour factor.

4.1. Average daily traffic on project road

Figure 3 shows the average daily traffic on the study area from Solan to Kaithalighat as well as from Kaithalighat to Solan.

The passenger car unit traffic data has been forecasted over 15 years (i.e. 2023-2037), as shown in Table 1, assuming a 7% growth rate (IRC:108-2015), guidelines for traffic forecast on highways (first revision).

Table 1. Traffic forecasted data.

Year	Solan to Kaithalighat	Kaithalighat to Solan
2023	4430	4045
2037	8577	7825

Percentage of type of vehicle travelling from Solan to Kaithalighat and from Kaithalighat to Solan in a single day is shown in Figure 4 and Figure 5, respectively.

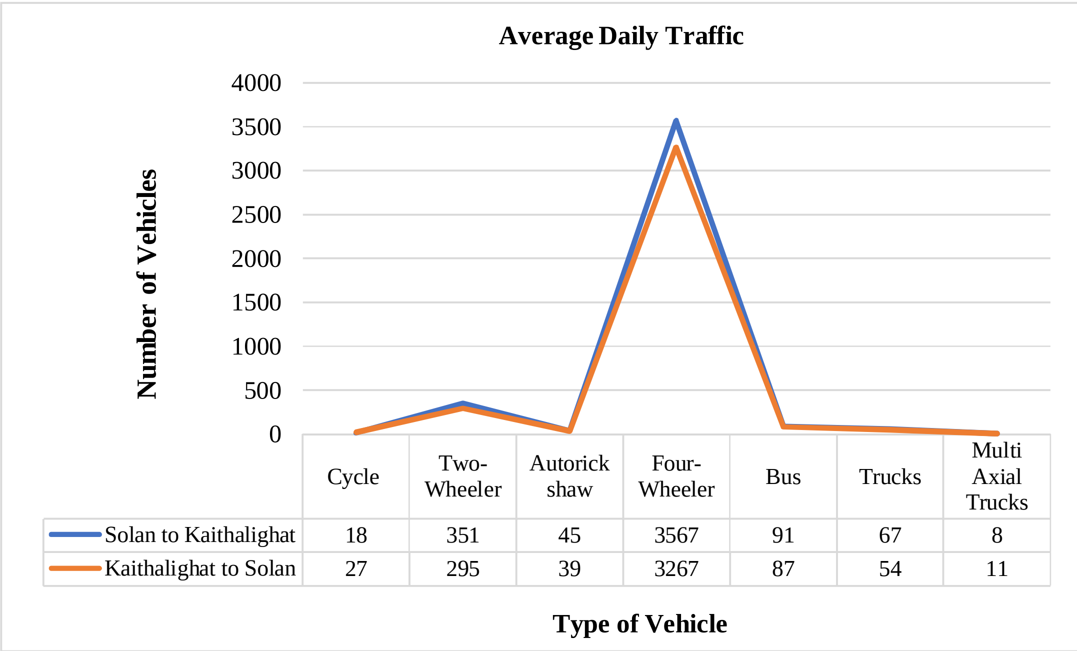


Figure 3. Average daily traffic on the project road.

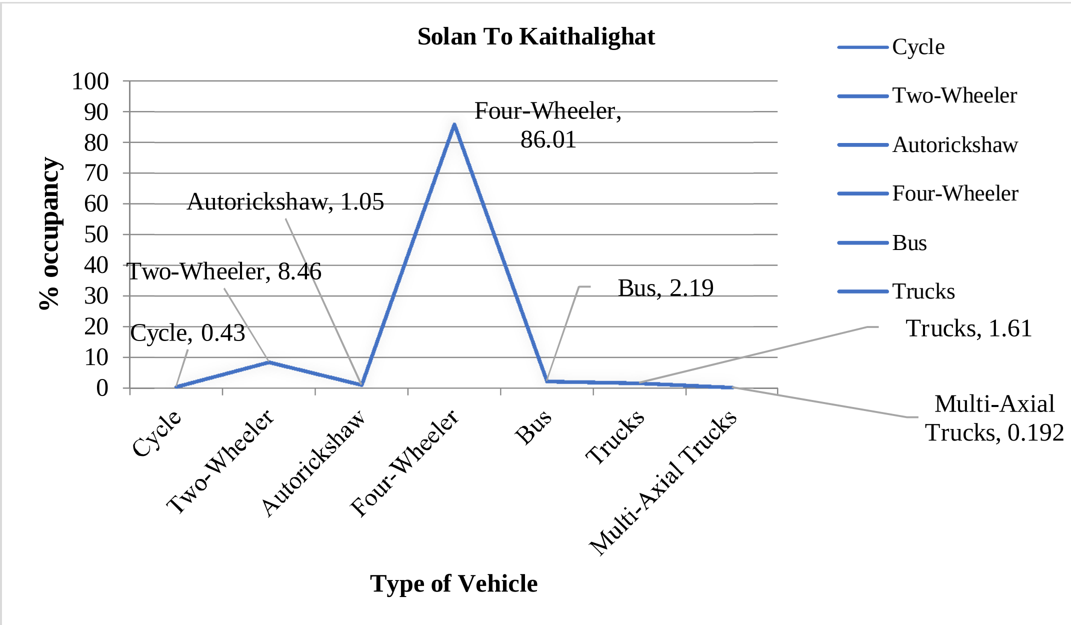


Figure 4. Percentage of type of vehicle travelling from Solan to Kaithalighat in a single day.

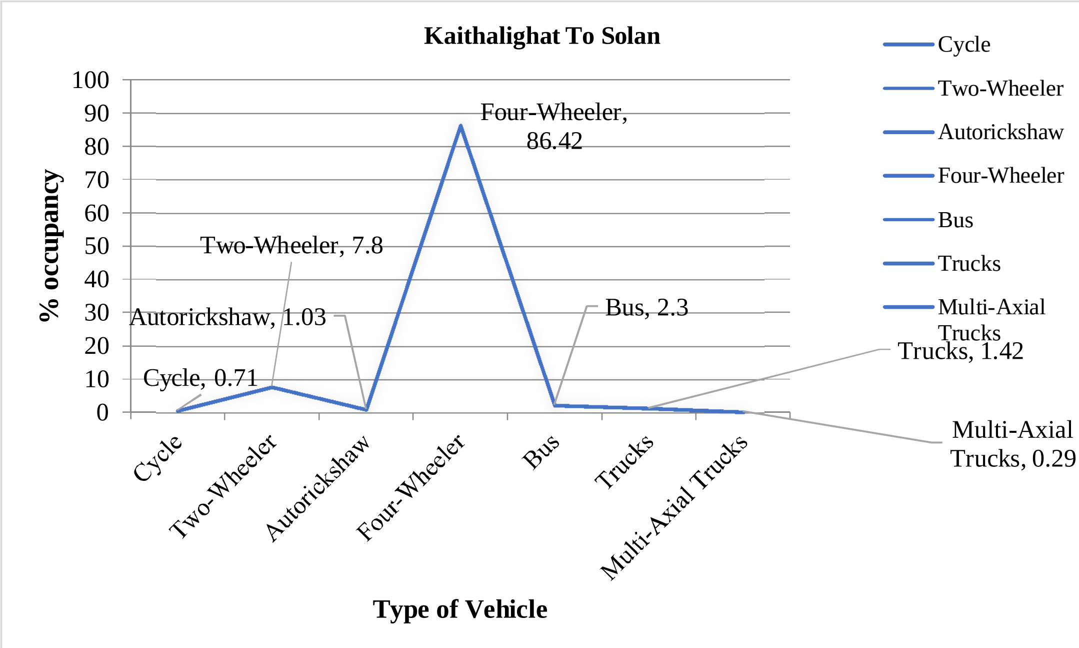


Figure 5. Percentage of type of vehicle travelling from Kaithalighat to Solan in a single day.

5. Collection of data co-ordinates

A total station was used to conduct a topographic survey, in the locations where the accidents have happened. The data collected was visualized in AutoCAD, and designing was done based on this in OpenRoads software (ORS). To design the carriageway in ORS first the northing, easting, and elevation value of the particular site were collected using total station.

6. Design process in ORS

6.1. Model launching and workspace creation

Step 1: Creating a workspace in OpenRoads software using Indian Standards, as shown in Figure 6. Indian standards were chosen as the benchmark. The first seed file is created when the survey point data is imported into the 3D file using the Terrain Ribbon and import file button (Start, Designer and Edition, 2019). After the 3D seed file has been created, the 2D file is created separately by selecting "new file" from the file tab. The 3D file should be imported using the home tab on the ribbon's reference.

Table 2. Some of the values of northing, easting, and elevation obtained.

Northing	Easting	Elevation
3422918.18	700334.00	1465.002
3422933.13	700341.11	1463.758
3422957.53	700352.64	1469.455
-	-	-
-	-	-
-	-	-
3423384.06	702861.75	1472.083
3423392.48	702872.09	1460.875
3423416.41	702885.04	1462.613

Figure 6. Workspace using Indian standards.

Step 2: The road design plan must be based on already existing ground data. There are numerous options for importing the data. Import the AutoCAD file in the OpenRoads software, which is further used for the design of highway, as shown in Figure 7.

Step 3: Creating the required highway alignments and providing corridor.

6.2. Geometry

The centerline was obtained using reference points in the OpenRoads software considering Indian Standards specifications. With the help of the centerline, both horizontal and vertical alignment was established, as shown in Figure 8. After assigning the horizontal and vertical alignments, super-elevation was assigned to the alignment. Table 3 shows the results obtained for the horizontal alignment of some points.

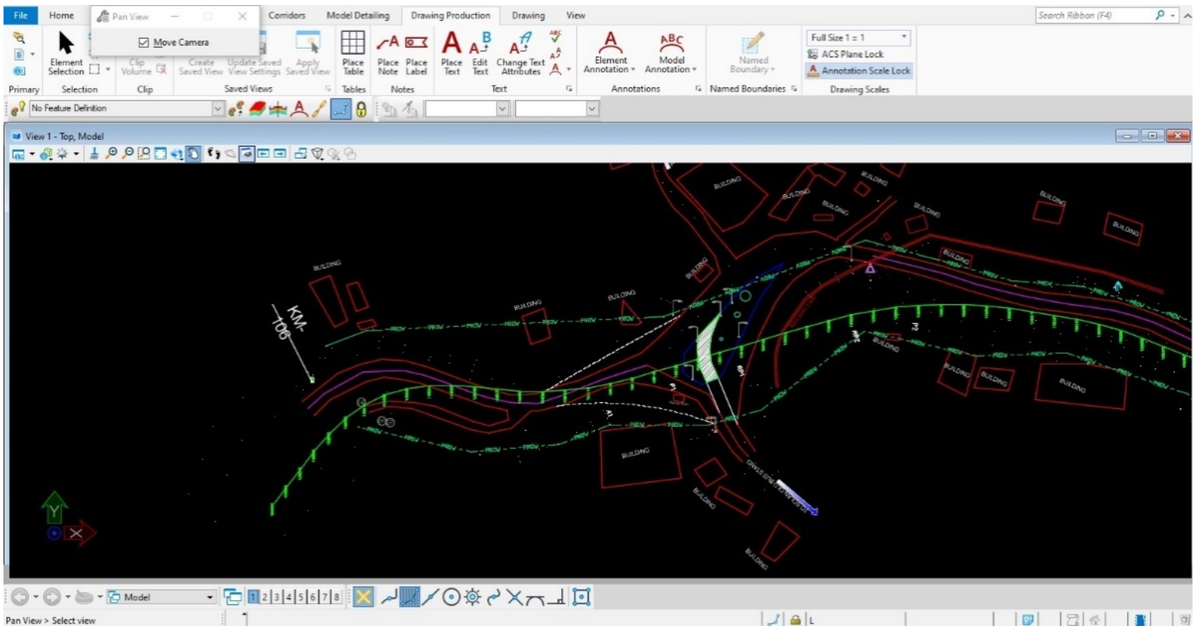
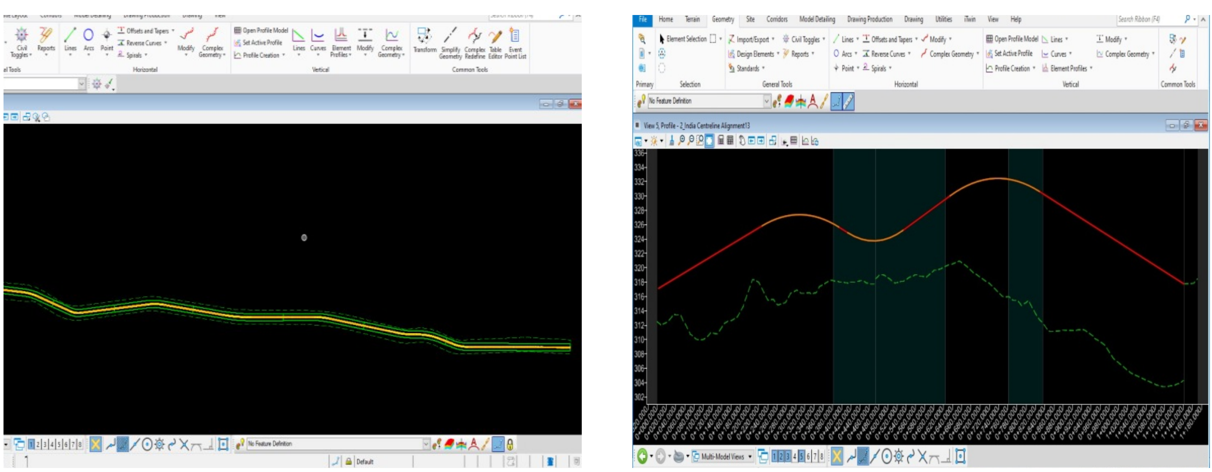


Figure 7. AutoCAD file used for design of highway.



(a) **(b)**

Figure 8. Part of a) Horizontal alignment; b) Vertical alignment.

Table 3. Part of horizontal alignment report.

Note: otherwise		**All values are in meters unless specified**		
Alignment name:			NH-05	
Alignment style:			Alignment\Road\Geom_baseline	
		Station	**Northing**	**Easting**
		Element: Linear		
START	( )	105950	3422918.18	700334.13
TS	( )	105966.483	3422933.135	700341.061
Tangential direction:		N24.864˚E		
Tangential length:		16.483		
		Element: Clothoid		
TS	( )	105966.483	3422933.135	700341.061
SPI	( )	105993.376	3422957.536	700352.369
SC	( )	106006.483	3422966.634	700362.396
Entrance radius:		0		
Exit radius:		50		
Length:		40		
Angle:		22.918˚	Right	
Constant:		44.721		
Long tangent:		26.894		
Short tangent:		13.54		
Long chord:		39.716		
Xs:		39.365		
Ys:		5.273		
P:		1.326		
K:		19.894		
Tangent direction:		N24.864˚E		
Radial direction:		S65.136˚E		
Chord direction:		N32.493˚E		
Radial direction:		S42.217˚E		
Tangent direction:		N47.783˚E		
		Element: Circular		
SC	( )	106006.483	3422966.634	700362.396
HPI	( )	106018.212	3422974.515	700371.083
CC	( )		3422929.604	700395.993
CS	( )	106029.525	3422977.712	700382.369
Radius:		50		
Delta:		26.405˚	Right	
Degree of Curvature (Arc):		114.592˚		
Length:		23.042		
Tangent:		11.73		
Chord:		22.839		
Middle Ordinate:		1.322		
External:		1.357		
Back-tangent direction:		N47.783˚E		
Back-radial direction:		S42.217˚E		
Chord direction:		N60.985˚E		
Ahead radial direction:		S15.813˚E		
Ahead tangent direction:		N74.187˚E		
		Element: Clothoid		
CS	( )	106029.525	3422977.712	700382.369
SPI	( )	106043.065	3422981.401	700395.396
ST	( )	106069.525	3422978.074	700422.083
Entrance radius:		50		
Exit radius:		0		
Length:		40		
Angle:		22.918˚	Right	
Constant:		44.721		
Long tangent:		26.894		
Short tangent:		13.54		
Long chord:		39.716		
Xs:		39.365		
Ys:		5.273		

Continuous of Table 3.

P:		1.326		
K:		19.894		
Tangent direction:		N74.187°E		
Radial direction:		S15.813°E		
Chord direction:		N89.477°E		
Radial direction:		S7.106°W		
Tangent direction:		S82.894°E		
Element: Linear				
ST	( )	106069.525	3422978.074	700422.083
TS	( )	106077.456	3422977.093	700429.954
Tangential direction:		S82.894°E		
Tangential length:		7.931		

6.3. Super-elevation

The super-elevation of the horizontal alignment was designed and calculated as per IRC specifications. The design speed was kept to be 50 kmph considering the hill road with snow. Table 4 shows the part of report of super-elevation assigned to the horizontal alignment. The horizontal curve details were obtained for different northing and easting, as shown in Table 5.

Table 4. Part of super-elevation report.

Input Grid Factor: Note: All units in this report are in meters unless specified otherwise.			
Section Name:	SE-1		
Base horizontal name:	2_India Centerline Alignment24		
Design speed:	50		
Pivot method:	Crown		
E section:	IRC 38:198 | 73:1980 | Hill Road with snow		
L section:	Hill road with snow		
Super-elevation: CL-EOP_LT			
Station	**Cross-slope**	**Point type**	**Transition type**
0.00	-0.025	Normal crown	
644.473	-0.025	Full super	Linear
854.248	-0.025	Full super	Linear
1177.506	-0.025	Normal crown	Linear
Super-elevation: CL-EOP_RT			
Station	**Cross slope**	**Point type**	**Transition type**
0.00	-0.025	Normal crown	
644.473	-0.025	Full super	Linear
854.248	-0.025	Full super	Linear
1177.506	-0.025	Normal crown	Linear

Table 5. Horizontal curve details

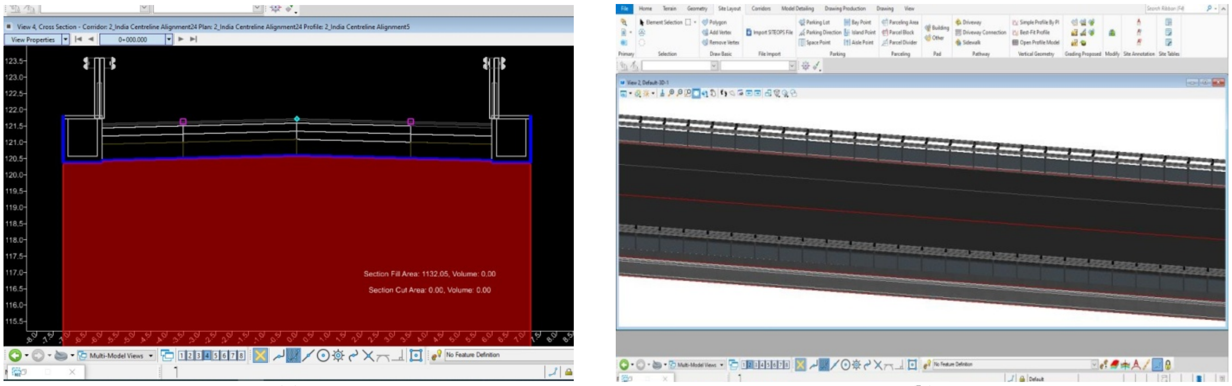
Easting (X)	**Northing (Y)**	**Chainage**	**Radius (m)**	**Transition length, L_s (m)**	**Curve length, L_c (m)**	**Tangent length, T_s**	**External distance, E_s**	**Total deflection, D (deg.)**	**Design speed (V)**
700385.99	3422974.13	106016.80	60	35	25.705	13.053	9.561	97.969	50 kmph
700471.06	3422974.53	106101.93	-150	15	42.312	21.297	2.843	21.892	50 kmph
700705.77	3423004.41	106343.18	150	15	17.263	8.641	0.934	12.323	50 kmph
701509.90	3423140.40	107366.94	-80	25	9.959	4.986	2.282	25.038	50 kmph
:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:
701863.18	3423271.44	108024.87	-300	10	48.031	24.067	1.423	11.083	50 kmph
701874.52	3423376.04	108130.54	60	35	25.080	12.726	9.361	57.372	50 kmph

6.4. Corridor modeling

Using create and calculate ribbon, the super-elevation is placed, computed, and reported in the Corridor. The cross-section is then created for roads that meet the specifications of the designs after applying the super-elevation. Additionally, after importing the template from the program files, the corridor is then assigned to the alignment. The corridor assigned for the study area was 4-lane two way as shown in Figure 9 (a). The quantity report is then created and exported to excel files for additional research. If a corridor has two different widths, a transition between them needs to be built for proper alignment and user engagement. One can also view the 3D view of the corridor in the OpenRoads software, as given in Figure 9 (b).

6.5. Drawing production

OpenRoads produces detailed drawings of the horizontal and vertical alignments, which can be used by different authorities for the design of the road-section. Figure 10 shows some of the drawing productions obtained for the alignments of the studied area.



(a) (b)

Figure 9. a) Corridor assigned to alignment; b) 3-D view of corridor.

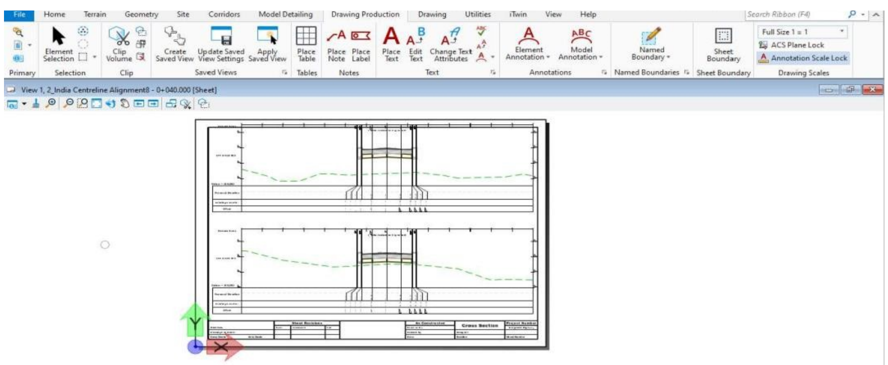


Figure 10. Map production of alignment.

7. Conclusions

The proposed design values for the project work, using the OpenRoads software, have taken into account all of the Indian Road Congress (IRC) requirements and the project corridor's existing features. The design speed has been set at 50 kmph, with the cross-section elements consisting of a carriageway of 30 m, a width of the control line of 100 m, and a width between the building line of 50 m. The roadway width has been decided to be 13.0 m, with the carriageway width set at 7.5 m and the width of shoulder at 2.4 m. The alignment mostly travels over steep, mountainous terrain with a cross slope of 45% to 60% and a high curvature that typically exceeds 200 degrees per km. The route even includes several spots with steep inclines. The project road has a valley on one side and a hill on the other due to the alignment of the road along the hill's face. The cross-slope or camber has been determined to be 2.5% for bituminous surfaces and 3.5% for earthen surfaces, with a maximum super-elevation of 7%. Additionally, there will be an extra widening of the carriageway at curves, set at 0.6 m. The project's main goal is to solve transportation problems like congestion and traffic, particularly due to the high traffic volume on this stretch connecting various tourist attractions. By new highway design the issue of traffic congestion and high traffic volume has been resolved ensuring smoother vehicular flow.

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رویکرد پایدار برای طراحی هندسی بزرگراه با استفاده از نرم‌افزار OpenRoads: مطالعه موردی NH-05

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چکیده:

گفته می‌شود جاده‌ها ستون فقرات توسعه هر ملتی هستند. در کشورهای در حال توسعه مانند هند، این روش اصلی حمل و نقل است که اهمیت آن را بسیار بیشتر می‌کند. تراز هندسی بزرگراه یک جنبه مهم برای حفظ ایمنی جاده و حرکت موثر ترافیک در هر جاده است. ویژگی‌های هندسی بزرگراه به منظور دستیابی به اهداف طراحی مختلف از جمله فاصله دید، پایداری خودرو، راحتی راننده، زهکشی، رشد اقتصادی و کیفیت‌های زیبایی‌شناختی انتخاب، اندازه و قرار می‌گیرند. با توجه به افزایش سریع رشد ترافیک در چند سال گذشته، اطمینان از تراز طراحی ایمن برای پاسخگویی به نیازهای آینده به طور کارآمد و اقتصادی اهمیت یافته است. مطالعه موردی NH-05 در کار حاضر برای طراحی بزرگراه موجود برای بهبود ویژگی‌های هندسی آن با در نظر گرفتن ترافیک پیش‌بینی‌شده در آینده و پوشش تمام اقدامات ایمنی ارائه شده توسط توصیه‌های کنگره جاده هند (IRC) استفاده می‌شود. نرم افزار OpenRoads به عنوان ابزار طراحی مورد استفاده قرار گرفت و تمام طراحی ها با حفظ سرعت طراحی در 50 کیلومتر در ساعت انجام شد. عرض جاده 13,0 متر با عرض 7,5 متر و عرض شانه 2,4 متر تعیین شده است. شیب متقاطع یا کمبر برای سطوح قیری 2,4 درصد و برای سطوح خاکی 3,6 درصد تعیین شده است که حداکثر ارتفاع آن 7 درصد است. بنابراین نتایج به‌دست‌آمده می‌تواند برای حل مشکلات تراکم ترافیک، به‌ویژه به دلیل حجم بالای ترافیک، و افزایش ایمنی جاده‌ها مورد استفاده قرار گیرد..

کلمات کلیدی: OpenRoads، طراحی هندسی، تراز بزرگراه، ارتفاع فوق العاده.