بسم الله الرحمن الرحيم

Graduation Project

Design and Planning the Street Connection Dura & Tafouh (Ain Nonqur)

Project Team

Montaser Abu Aisheh **Abdalrahman Sabbah** **Mohammed Alshekh**

Project Supervisor

Eng. Musab Shahin

Submitted to the College of Engineering in partial fulfillment of the requirements for the Bachelor degree in Surveying and Geomatics Engineering

Palestine Polytechnic University
january 2025

The undersigned hereby certify that they have read, examined, and recommended to the Department of Civil Engineering and Architecture in the College of Engineering at Palestine Polytechnic University the approval of a project entitled:

Design and Planning the Street Connection Dura & Tafouh (Ain Nonqur**)**

: by Montaser Abu Aisheh and Abdalrahman Sabah and Mohammed Alshekh for partial fulfillment of the requirements for the bachelor's degree.

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Date….……………...…………………

جامعة بوليتكنك فلسطين

كلية الهندسة

مشروع تخرج بعنوان تصميم الطريق الرابط بين دورا وتفوح (عين ننقر)

مقدم إلى دائرة الهندسة المدنية في كلية الهندسة

للوفاء بجزء من متطلبات الحصول على

درجة البكالوريوس في الهندسة المدنية تخصص هندسة المساحة والجيوماتكس

إشراف :

م. مصعب شاهين

فريق العمل :

منتصر ابو عيشة   عبد الرحمن الصباح   محمد الشيخ

جامعة بوليتكنك فلسطين

الخليل – فلسطين

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بناء على توجيهات الأستاذ المشرف وبموافقة جميع أعضاء اللجنة الممتحنة تم تقديم مقدمة المشروع هذه الى دائرة الهندسة المدنية في كلية الهندسة للوفاء الجزئي بمتطلبات الحصول على درجة البكالوريوس .

توقيع مشرف المشروع   توقيع رئيس الدائرة

....

توقيع اللجنة الممتحنة

....

....

الخليل – فلسطين

يناير – 2025 م

ACKNOWLEDGEMENT

اللهم لك الحمد والشكر ، لا نحصي ثناء عليك أنت كما أثنيت على نفسك، ونصلي ونسلم

على من لا نبي بعده،

الشكر الله أولاً وأخرا وأحمده حمداً كثيراً ، أن منحني شرف حب العلم والمعرفة وأنعم علي بالجهد

والوقت في رحلتي العلمية وشكري لسيد البشرية أفصح من نطق بالعربية وحثنا

على العلم بأحاديثه التنويرية ف الله الحمد ولرسوله صلي الله عليه وسلم .

تكـــاد شمـــــوع الشكـــر تحــترق خجلاً لتضًيء كلمـــات عــجز اللســان والقــلم عنهـــا

تحـــيـّة إجـــــلال نـقدمـهـــا إلى كـــل مـــن لــه حــق عليـّنا فًي مسّيرتنـا التعليّمّية

إلى كـــل مـــن قــــدم لـــنـــا مــــعلومـــة نبقـــــا ممتنيـــّن لــــه بــاقي حًياتنــا

إلـــــــــى أســـــاتـــــذتـــنـــا جـــــمـــيـّـــعـــــاُ

إلى الدكتور القدير مصعب شاهين الـــــذي لـــــم ّيبخــل عليّنــا بأي معلومة أو مساعدة

لـــــهم جــــمّيعـــــــأ نـــــقدم جــزّيــــل الشكــــــر والإمتنان .

DEDICATION

الحمد لله اقصى مبلغ الحمد .... والشكر الله من قبل ومن بعد ... ... والصلاة والسلام على رسول الله ... نبينا محمد .... وعلى اله وصحبه ومن والاه

نهدي هذا العمل المتواضع الى :

.... من أعطاه الله الهيبة والوقار ووجهني لاغتنام الأفضل أينما صار ... الى قدوتي في الجد والإصرار .... اليك والدي الحبيب....

الى... من دفعتني وقالت لي ان الوصول طريقه الجد ليس التمني، ودعت الله لينير دربي الى معنى الحب والحنان ... الى ... . اغلى انسان في هذا الوجود اليك والدتي الغالية

إلى ... النعمة التي لا تعوض وإلى من يتأملون نجاحي ... إلى اخوتي واخواتي إلى ... الذين دعمونا وساندونا خلال دراستنا ... إلى أصدقائنا إلى ... الذين شاركونا نجاحنا و ايامنا ... إلى زملائنا

إلى ... كل من علمنا حرفا ... إلى أساتذتنا

إلى ... كل من مات لتحيا أرضه ... إلى الشهداء الابرار...

إلى... منهل العلم إلى... جامعتنا

إلى ... الذين هونوا علينا الطريق

إلى ... كل من له حق علينا

إليكم جميعا

ABSTRACT

Design and Planning the Street Connection Dura & Tafouh (Ain Nonqur)

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Montaser Abu Aisheh

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Road design projects are a cornerstone in the field of surveying engineering, given their numerous advantages such as enhancing efficiency and safety, as well as reducing costs and negative environmental impacts. Meticulous engineering design of roads contributes to achieving what is known as "quality of life," where roads serve the overall goals of the community, including facilitating access to employment opportunities, educational institutions, business activities, and residences. Design also considers the diversity of transportation modes from walking and cycling to public and private transport, with a focus on the overarching goal of reconfiguring and expanding roads to facilitate traffic flow and reduce congestion.

In this project, we will explore the significant importance of redesigning Dora Tafouh Road, located in the Ain Nonqur area, according to approved engineering standards.

We have visited Dora Municipality to gather all necessary information about the road, including its length, width, and number, along with the structural plans that we will follow as design criteria. Subsequently, we will proceed to the site to conduct a detailed survey of all road details, identify existing problems, then pinpoint control points along the road and correct these points. Finally, we will upload the points to engineering design software such as Civil 3D and Agi soft to begin the engineering and construction design process for the road.

مشروع تخرج بعنوان

تصميم الطريق الرابط بين دورا وتفوح (عين ننقر)

إشراف :

م. مصعب شاهين

فريق العمل :

منتصر ابو عيشة عبد الرحمن صباح محمد الشيخ

الملخص

تُعدُّ مشاريع تصميم الطرق ركيزة أساسية في مجال الهندسة المساحية، نظرًا لما تحمله من مزايا عديدة مثل تعزيز الكفاءة والأمان، فضلًا عن خفض التكاليف والتأثيرات السلبية على البيئة. يسهم التصميم الهندسي المتقن للطرق في تحقيق ما يُعرف بـ"جودة الحياة"، حيث يُشكّل الطرق بما يخدم أهداف المجتمع ككل، بما في ذلك تسهيل الوصول إلى فرص العمل، المؤسسات التعليمية، الأنشطة التجارية، والمساكن. كما يُراعي التصميم تنوع وسائل النقل من المشي وركوب الدراجات إلى النقل العام والخاص، مع التركيز على الهدف الأسمى وهو إعادة تهيئة وتوسيع الطرق لتسهيل الحركة المرورية والحد من الازدحام .

في مشروعنا هذا، سنبحث في الأهمية الكبيرة لإعادة تصميم طريق دورا تفوح، الكائن في منطقة عين ننقر، وفقًا للمعايير الهندسية المعتمدة .

لقد قمنا بزيارة بلدية دورا لجمع كل المعلومات اللازمة عن الطريق، بما في ذلك طوله، عرضه، ورقمه، بالإضافة إلى المخططات الهيكلية التي سنتبعها كمعايير تصميمية. بعد ذلك، سنتوجه إلى الموقع لإجراء المسح الدقيق لكل تفاصيل الطريق، وتحديد المشكلات الموجودة، ثم تحديد نقاط التحكم على امتداد الطريق، وتصحيح هذه النقاط. وأخيرًا، سنقوم بتحميل النقاط على برامج التصميم الهندسي مثل (سيفل ثري دي و الاجي سوفت) لبدء عملية التصميم الهندسي والإنشائي للطريق.

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1.1 General Overview

Roads are among the most crucial elements of communication, playing a significant role in the development of various peoples, civilizations, and economies. The construction of highly efficient and qualified roads directly enhances a country's economy by reducing travel time from one place to another, thereby lowering mobility costs. Moreover, roads are essential in our daily lives, being critical and indispensable; they facilitate the transportation of commercial goods, enable us to travel around the world, and gain new experiences and cultures. Therefore, roads must be well-designed, with the highest possible quality, minimal cost, and maximum safety. The engineering design of a road is defined as the process of determining its geometric dimensions and arranging its visual elements, such as the path, visibility distances, lane widths, and gradients.

1.2 About The street linking Dura and Tafouh,(Ain Nonqur)

The road linking Dura and Taffouh in Ain Nonqur, West Bank, Palestine, is a crucial transportation route that connects the two towns and serves the surrounding communities. It plays a significant role in facilitating the movement of people, goods, and services, contributing to the economic and social development of the region.

Road Overview:

The road is a vital transportation artery stretching approximately 1196 meters in a northerly direction between the southern outskirts of Dura and the northern entrance of Taffouh, passing through the village of Ain Nonqur. It serves as a crucial link between the two towns, facilitating the movement of people, goods, and services.

Importance of the Road:

The road serves as a vital link between Dura and Taffouh, facilitating the movement of people, goods, and services between the two towns. It is also an important route for accessing the surrounding villages and agricultural areas. The road is used by a variety of vehicles, including cars, trucks, buses, and motorcycles.

Economic Significance:

The road plays a significant role in the economic development of the region. It facilitates the transportation of goods to and from markets, enabling local businesses to trade and reach a wider customer base.

The road also supports the transportation of agricultural products from farms to markets, contributing to the agricultural sector's growth.

Social Impact:

The road has a positive impact on the social well-being of the communities it serves. It allows people to travel between Dura and Taffouh for work, education, healthcare, and other essential purposes.

The road also facilitates social interactions and cultural exchanges between the two towns and surrounding villages.

Potential Improvements:

While the road is generally in good condition, there are some areas that could benefit from improvements. These include:

Widening the road: Expanding the road to four lanes would accommodate increased traffic and improve safety for all road users.

Enhancing road markings and signage: Clearer road markings and signage would improve visibility and navigation for drivers, especially at night or in low-visibility conditions.

Upgrading road lighting: Installing adequate streetlights along the road would enhance safety for pedestrians and cyclists, particularly during nighttime hours.

Improving drainage: Enhancing drainage systems along the road would prevent waterlogging and reduce the risk of accidents caused by slippery conditions.

Strengthening safety measures: Implementing additional safety measures, such as guardrails and rumble strips, would further protect road users and reduce the risk of accidents.

By implementing these improvements, the road linking Dura and Taffouh in Ain Nonqur can be made even more efficient, safe, and beneficial for the communities it serves.

Figure 1-1The Project Location

1.3 Project challenge

The difficult terrain of the project area hinders the development of street networks and infrastructure. Conventional surveying equipment such as Global Positioning System (GPS) and total stations have faced limitations in this terrain. To overcome this obstacle, we used aerial photography to facilitate data collection.

Figure 1-2 A Picture for The Study Area

1.4 Project Objectives

This project was selected to meet the following thresholds:

-Linking theoretical information acquired during the study period with practical life information.

- Survey the road using a drone.
- Use the aerial photo from the drone and input it into Agisoft to create a 3D model
- Preparing a topo map, clarifying each element inside the road, and taking level points to create a contour map.

1.5 Methodology

Identification of Research Topic: Initially, the research topic was determined, followed by consultations with the project supervisor and relevant authorities, such as the Dura municipality, to ensure alignment with local regulations and requirements. Subsequently, structural plans and other pertinent information were procured from the municipality.

Phase 1: Data Collection The designated work area was identified, and a preliminary site visit was conducted to comprehensively assess the project's nature, associated challenges, and critical details, thereby facilitating the attainment of optimal and precise outcomes.

Phase 2: Project Initiation The study area was selected, and upon securing the supervisor's endorsement, a date was scheduled for an in-depth exploratory survey of the location.

Phase 3: Control Point Establishment Control points were established to monitor and guide the project's progress.

Phase 4: Aerial Survey An unmanned aerial vehicle (UAV), commonly known as a drone, was deployed within the study area to capture aerial imagery, which was then processed for further analysis.

Phase 5: Photogrammetric Processing The acquired images underwent processing, and control points were integrated using the Agi soft software to ensure spatial accuracy and consistency.

Phase 6: Topographic Mapping Within the Agi soft platform, general points were plotted, break lines were delineated, and the data was exported to create a topographic map utilizing civil engineering software.

Phase 7: Three-Dimensional Modeling Images were imported into Agisoft to construct a three-dimensional model, which facilitated the generation of an orthophoto—a geometrically corrected aerial photograph.

Phase 8: Urban Planning Streets were designed to run parallel to contour lines, ensuring that the road network efficiently services all plots within the study area.

1.6 Study Area

It is expected that the study area will be in AinNonqur, which is located west of Hebron. Specifically, the road linking Dura and Tafouh. The aerial photo shows the project location.
(The road drawn in orange color)

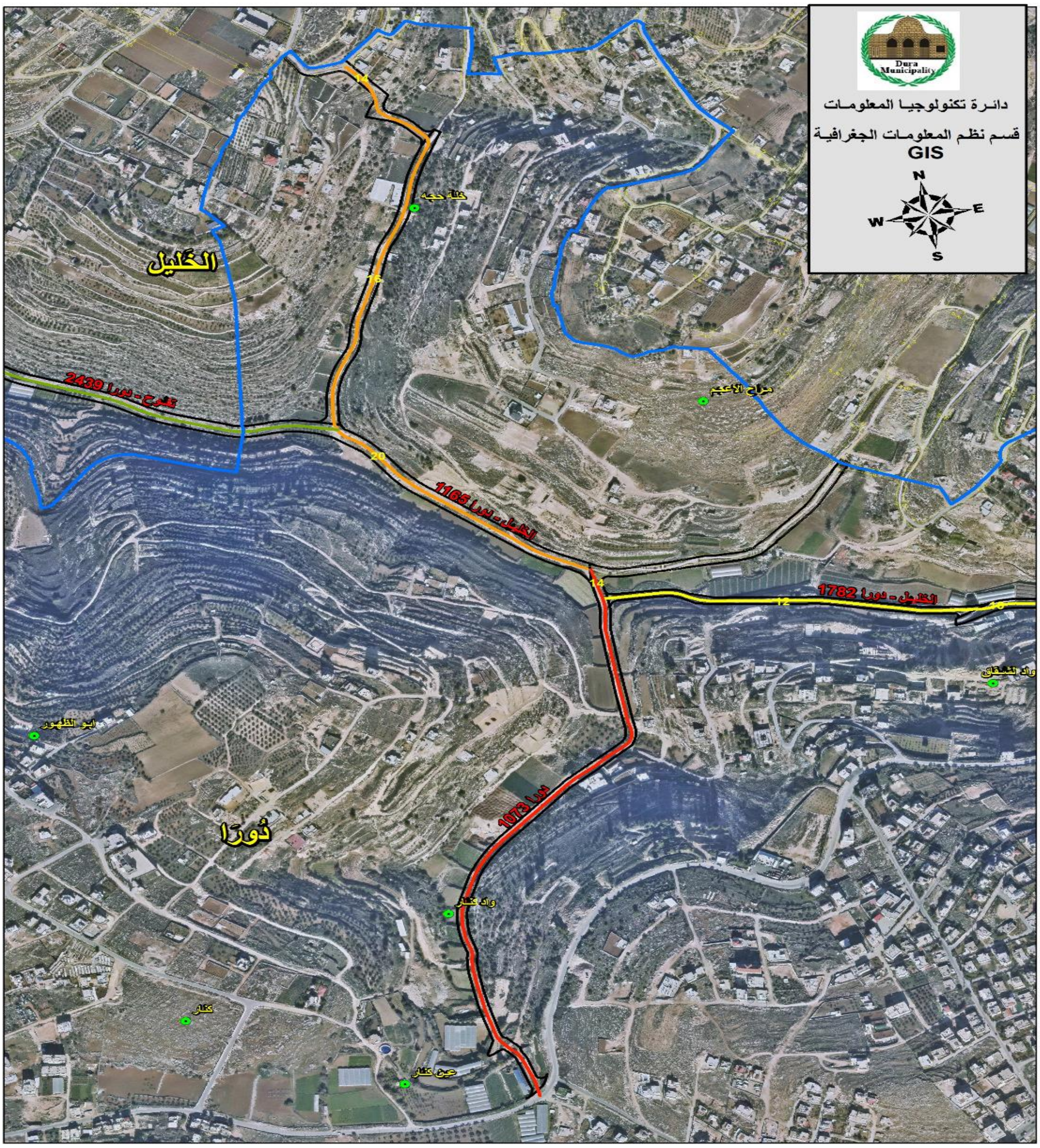


Figure 1-3 Aerial Photo of The Area

1.7 Project Timeline in Introduction:

Table 1-1 Time table for introduction

Weekly Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Selection and Information Gathering	●	●													
Survey Space		●	●												
Field Work				●	●	●	●	●							
Office work						●	●	●	●	●					
Computer drawing									●	●	●				
Preparing the initial report for the introduction of the project											●	●	●		
Preparing the final report for the introduction of the project												●	●	●	●

Table 1-2 Time table for Project

Weekly Activity	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Laboratory tests	●	●	●	●											
Design and necessary calculations		●	●	●	●	●	●	●	●	●					
Preparing the initial project report								●	●	●	●				
Initial project delivery												●	●		
Final delivery of the project														●	●

1.8 Programs used in the project

- Microsoft Office: It was used in various stages of the project, including text writing, formatting, and project output.

- AutoCAD 2022: Utilized for engineering drawing and designing structural details.

- ArcGIS Pro 3.0.0 / 2022: Employed for conducting geographical analyzes and creating maps.

- Agi soft: Used in photogrammetric image processing and creating 3D models.

- Civil 3D 2024: Used for civil engineering design, topographic planning, and infrastructure analysis.

These software tools are an integral part of the engineering process and contribute to improving efficiency and accuracy in engineering projects.

1.9 Surveying Equipment

1 - Global Positioning System (GPS): Use to take control points

2- Drone : Use it for conducting aerial survey of the road.

1.10 Challenges faced during the project implementation

Tree Density: The density of the trees prevented the possibility of a complete photography and survey of the entire road path.

Steep Terrain: The nature of the steep terrain in the area made it difficult to access some parts of the road, which hindered the survey process.

Drone Flight Height Restrictions: Due to restrictions imposed by the Israeli occupation, drones were unable to fly at high altitudes, which limited the scope of the aerial survey.
Show learns more suggestions.

CHAPTER 2 SURVEY WORK

2.1 Definition, Categories, and Purpose of Surveying

2.2 Drone Scanning Process

2.3 Units of Measurement

2.4 Uses of drones

2.5 Drone survey procedure

2.6 Drone survey data processing

2.1 Definition, Categories, and Purpose of Surveying

Surveying Fundamentals:

Surveying is the practice of determining the relative positions of natural and man-made features on Earth's surface. This information is presented visually in maps or numerically in tables. Surveyors use measurements and calculations to create these maps, define specific locations, and set out measurements on the ground. Their tasks may involve:

- Determining heights and distances
- Laying out foundations for buildings, bridges, and roads
- Calculating areas and volumes
- Drawing plans at specific scales

Surveying Categories:

Traditional surveying can be broadly categorized into two main types:

- **Plane Surveying:** This method assumes a flat Earth for smaller areas, neglecting the Earth's curvature for calculations.
- **Geodetic Surveying:** This method focuses on determining the Earth's size and shape, providing a highly accurate framework for other surveys. It requires the highest precision and covers vast areas where Earth's curvature becomes a significant factor.

Surveying Disciplines:

Beyond these main categories, surveying encompasses various specialized disciplines:

- **Topographic Surveys:** Measure and map Earth's physical features, including natural and man-made elements.
- **Engineering Surveys:** Conducted for planning and construction of infrastructure like roads, railways, and drainage systems.
- **Cadastral Surveys:** Focus on measuring, defining, mapping, and recording property boundaries.
- **Hydrographic Surveys:** Map the underwater topography of lakes, rivers, harbors, and oceans, including water flow measurement and resource estimation.

Drone Surveying and its Connection:

While the text focuses on traditional methods, drone surveying aligns with several disciplines mentioned. Drone-captured data can be used for:

- **Topographic Surveys:** Capturing detailed terrain data for creating topographic maps.
- **Engineering Surveys:** Providing aerial imagery and 3D models for planning and monitoring construction projects.
- **Cadastral Surveys:** Assisting in mapping and measuring property boundaries in some cases.

Definition:

Drone surveying, also known as unmanned aerial vehicle (UAV) surveying, is a technique that utilizes drones equipped with various sensors to capture data for surveying and mapping purposes. This data is then processed to generate highly accurate 2D and 3D models of the surveyed area.

Figure 2-1 Drone

Categories of Drone Surveying (by Sensor):

Photogrammetry: This is the most common type of drone surveying. It involves capturing high-resolution, overlapping images from the air. Specialized software then processes these images to create detailed 3D point clouds, Digital Elevation Models (DEMs) - representing bare earth elevation, Digital Surface Models (DSMs) - representing the entire surface, and ortho mosaics - georeferenced image mosaics.

LiDAR (Light Detection and Ranging):

LiDAR sensors emit laser pulses and record the reflected light to create highly accurate 3D point clouds of the surveyed area. This is particularly useful for creating precise elevation models and capturing details obscured by vegetation in photogrammetry.

Thermal Imaging:

Thermal imaging cameras capture heat signatures, useful for applications like building inspections (identifying heat loss), environmental monitoring (detecting areas of pollution), and wildlife surveys (spotting animals at night).

Purpose of Drone Surveying:

Drone surveying offers numerous advantages over traditional surveying methods, making it a valuable tool across various industries.

Here are some key purposes:

Surveying and Mapping:

Creating accurate 2D and 3D maps for various purposes, including construction planning, infrastructure development, and topographic analysis.

Construction Progress Monitoring:

Tracking construction progress by capturing regular aerial images and comparing them to plans. This allows for early identification of deviations and facilitates better project management.

Volume Calculations:

Calculating stockpile volumes for materials like coal, sand, or grain. LiDAR data is particularly well-suited for this purpose due to its high accuracy.

Archaeological Surveys:

Documenting and analyzing historical sites with high-resolution imagery and 3D models. Drones can access areas difficult to reach with traditional methods.

Environmental Monitoring: Identifying areas of deforestation, erosion, or pollution by analyzing changes in vegetation cover or thermal signatures over time.

Disaster Response: Assessing damage after natural disasters like floods or earthquakes by providing rapid aerial imagery of affected areas.

Precision Agriculture: Optimizing crop yields and monitoring field health by analyzing high-resolution imagery and collecting multispectral data.

Roof Inspections: Safely inspecting roofs of buildings for damage or identifying potential maintenance needs.

Overall, drone surveying offers a cost-effective, efficient, and safe way to collect high-quality data for various surveying and mapping applications.

2.2 Drone Scanning Process

1. Mission Planning and Pre-flight Preparation:

- Define the survey area and objectives.
- Select the appropriate drone platform based on payload capacity, endurance, and sensor requirements.
- Plan the flight path, considering safety, regulations, and data coverage.
- Check weather conditions and obtain necessary permissions.

2. Takeoff and Flight:

- Launch the drone from a safe location.
- The drone follows the pre-defined flight path (grid or waypoint-based).
- Sensors collect data during flight.

3. Data Acquisition:

- Drones are equipped with various sensors:
    - RGB Cameras: Capture high-resolution images.
    - LiDAR (Light Detection and Ranging): Emit laser pulses to measure distances.
    - Multispectral Sensors: Capture specific wavelengths for vegetation analysis.
- Sensors collect data points (images, point clouds, etc.) during flight.

4. Photogrammetry and Point Cloud Generation:

- Photogrammetry:
  - Software processes overlapping images to create orthomosaics (georeferenced aerial images) and digital surface models (DSMs).
  - Triangulation principles are applied to calculate 3D coordinates.
- LiDAR:
  - Point clouds are generated by analyzing laser reflections.
  - Each point represents a 3D coordinate (x, y, z).

5. Georeferencing and Ground Control Points (GCPs):

- GCPs are surveyed reference points with known coordinates.
- Align drone data with real-world coordinates using GCPs.
- Correct distortions due to terrain and camera lens.

6. Data Processing and Analysis:

- Stitch ortho mosaics and DSMs.
- Extract features (roads, buildings, vegetation) from point clouds.
- Calculate volumes, distances, and elevations.
- Detect changes over time (e.g., land subsidence, crop growth).

7. Accuracy Assessment:

- Validate accuracy against ground truth data.
- Evaluate positional accuracy (RMSE, GSD, etc.).

8. Visualization and Interpretation:

- Visualize 2D/3D maps, contour lines, and profiles.
- Overlay data with other GIS layers.
- Interpret results for decision-making.

9. Reporting and Deliverables:

- Generate reports, maps, and visualizations.
- Share results with stakeholders.

10. Post-processing and Archiving:

- Store raw data and processed outputs.

The following tables shows the readings that were observed in the field where the coordinates were observed using the (fast static) method:

Table 2-1 control point

points	Column1	Column2	Column3
1	156932.139	101839.451	846.645
2	156930.115	101902.835	844.2 (as)
3	156887.966	101875.049	839.32 (as)
4	156834.369	101934.372	828.201 (as)
5	156785.062	101961.965	815.003 (as)
6	156725.484	102030.812	799.018 (as)
7	156699.801	102128.635	787.559 (as)
8	156724.137	102179.399	793.501 (as)
9	156781.009	102293.47	801.171 (as)
10	156798.163	102312.04	802.994 (as)
11	156678.076	102030.714	785.728
12	156605.747	102005.307	788.779
13	156572.011	101997.93	787.346
14	156553.691	102008.496	778.818
15	156520.496	102021.791	772.123
16	156479.963	102023.744	770.904
17	156383.096	102083.015	758.91
18	156331.176	102106.233	753.546
19	156345.138	102093.761	754.527 (level)
20	156346.218	102097.116	754.000 (level)
21	156347.976	102101.855	753.573 (level)

Drone surveys are typically more accurate than traditional methods.

1. Speed and Efficiency:
   - Drones can capture data much faster than manual ground-based methods.
   - For example, using drones to collect stockpile measurements can be up to **90% faster** than manual methods.
   - The table below illustrates the time comparison between traditional ground surveys and drone surveys:

Table 2-2 the time comparison between traditional ground surveys and drone surveys

Aspect	**Traditional (Ground) Survey**	**Drone Survey**
Mobile To Site	1 day	1 day
Data Collection/Post-processing	1-2 weeks	1-2 days
Delivery of Data Sets	1-2 weeks (includes PDF, CAD file, contour map)	1-2 days (same as ground-based, but also orthomosaic and point cloud)
Total Time	2-3 weeks	1-4 days

2. As you can see, drone surveying significantly reduces the time needed for data collection and processing, especially on large sites.
3. Accuracy:
    - Commercial-grade survey drones can deliver data accuracy to within **0.5 cm – 2 cm**^{2}.
    - While other drones may have an accuracy of around **5 m**^{2}.
    - These accuracies make drones a highly precise alternative to traditional surveying methods.
4. Cost Savings:
    - Drones enable firms to create highly accurate maps, discover costly job-site mistakes, and predict schedule delays, saving up to tens of thousands of pounds per week.
    - Reduced survey time also translates to cost savings in labor and equipment.
5. Improved Safety:
    - Drones significantly reduce the number of workplace hazards exposed to employees.
    - Surveyors can avoid dangerous areas and collect data remotely.

2.3 Units of Measurement

SI units the most commonly used in surveying being shown below:

Table 2-3 Si Units

Physical Quantity	Unit Name	Unit Symbol
Length	meter	m
Area	square meter	m^2
Volume	cubic meter	m^3
Angle	radian	rad
Mass	kilogram	kg
Temperature	kelvin	K

The S1 unit for an angle is the radian (rad), but most surveying instruments measure in degrees, minutes and seconds, which is known as the sexagesimal system. This is the only unit of measure that is not SI.

2.4 Uses of drones

Drones have revolutionized various fields, and their applications continue to expand

1. **land Surveying and Cartography**:
   - Survey Drones play a crucial role in land surveying and cartography. They generate high-resolution ortho mosaics and detailed 3D models of areas where low-quality, outdated, or even no data are available.
   - They enable the production of high-accuracy cadastral maps quickly and easily, even in complex or difficult-to-access environments.
   - Surveyors can extract features from the images, such as signs, curbs, road markers, fire hydrants, and drains.
   - After post-processing with photogrammetry software, these images can produce very detailed elevation models, contour lines, and break lines, as well as 3D reconstructions of land sites or buildings.
2. **Land Management and Development**:
   - Aerial images taken by drones greatly accelerate and simplify topographic surveys for land management and planning.
   - This is true for site scouting, allotment planning and design, as well as the final construction of roads, buildings, and utilities.
   - The images also provide the foundation for detailed models of site topography for pre-construction engineering studies.
   - The generated data can be transferred to any CAD or BIM software, allowing engineers to immediately start working from a 3D model.
   - As data collection by drones is easily repeatable at low cost, images can be taken at regular intervals and overlaid on the original blueprints to assess whether the construction work is moving according to plan specifications.
3. **Precise Measurements**:
   - High-resolution orthophotos enable surveyors to perform highly accurate distance and surface measurements.
4. **Slope Monitoring**:
   - With automated GIS analysis, it is possible to extract slope measurements from DTMs and DSMs generated by drone imagery.
   - Knowing the steepness of the ground’s surface, areas can be classified and used for slope monitoring purposes, including landslide mitigation and prevention.

- With ortho mosaics taken at different times, it is possible to detect changes in earth movement and to measure its velocity. This data can help predict landslides and prevent potential damage to roads, railways, and bridges.

5. **Urban Planning**:
   - The development of increasingly dense and complex urban areas requires intensive planning and therefore time-consuming and expensive data collection.
   - Thanks to drones, urban planners can collect large amounts of up-to-date data in a short period of time and with far fewer staff.
   - The images produced in this way allow planners to examine the existing social and environmental conditions of the sites and consider the impact of different scenarios.
   - Thanks to 3D models, buildings can also be easily overlaid onto their environment, giving planners and citizens an experimental perspective of a complex development project.
   - 3D models also allow analysis and visualization of cast shadows and outlooks/views.

2.5 Drone survey procedure

1. Pre-Flight Planning (Mission Design):

- Site Assessment:
  - A thorough evaluation is conducted to identify potential hazards like power lines, restricted airspace, and environmental factors like wind speed and precipitation.
    - Wind surpassing 40 km/h (25 mph) can significantly affect data quality (reference: Federal Aviation Administration (FAA) guidelines
    - Rain or snow can obscure sensors and hinder data capture.
- **Project Requirements:**
- Define the specific needs of the survey project, including:
  - Desired level of accuracy (e.g., centimeter-level for construction vs. meter-level for stockpile volume estimation)
  - Area to be covered
  - Type of data required (e.g., topographic mapping, stockpile volume calculation)
- **Flight Path Planning:** Specialized software is used to design an efficient flight path for the drone, considering:

   - **Image Overlap:** In photogrammetry missions, sufficient image overlap (typically 60-80%) is crucial for accurate 3D reconstruction. The software calculates the optimal path to achieve this overlap while minimizing flight time.
- **Ground Control Points (GCPs):** Accurately surveyed points marked on the ground with high-contrast targets. The drone captures images of these GCPs during the flight. Post-processing software utilizes the known coordinates of GCPs to georeference the captured data (assign accurate geographic coordinates) and improve overall accuracy.

2. Data Acquisition (Flight Execution):

- **Drone Selection:** Choose the appropriate drone based on payload capacity, flight time, and image quality requirements.
- **Sensor Selection:** The type of sensor payload depends on the data needed:
   - **High-Resolution Cameras:** For photogrammetry, high-resolution cameras with good radiometric properties are preferred for detailed images suitable for 3D reconstruction. Sensor specifications like pixel size and image resolution influence the final achievable ground resolution.
   - **LiDAR Sensors:** LiDAR (Light Detection and Ranging) uses lasers to measure distances. LiDAR sensors emit laser pulses and record the reflected light to create highly accurate 3D point clouds.
- **Flight Execution:** A certified drone pilot, adhering to safety regulations and airspace restrictions, executes the pre-planned flight path. During the flight, the chosen sensor captures the designated data:
   - **Photogrammetry:** The camera captures overlapping images at pre-programmed intervals along the flight path.
   - **LiDAR:** The LiDAR sensor continuously emits and records laser pulses, generating a dense point cloud representation of the surveyed area.

3. Post-Flight Processing (Data Exploitation):

- **Data Download:** The captured data (images or LiDAR points) is downloaded from the drone's storage device to a computer workstation.
- **Data Processing:** The type of processing depends on the data captured:

- **Photogrammetry Workflow:**
   - **Photogrammetric Software:** Software like Pix4D or Agi soft Meta shape is used for photogrammetry.

- **Orientation and Calibration:** The software performs initial processing steps like camera orientation (determining the position and direction of the camera when each image was captured) and lens distortion correction.
- **3D Point Cloud Generation:** The software utilizes photogrammetric principles to create a 3D point cloud by identifying corresponding features across overlapping images. This point cloud represents the 3D geometry of the surveyed area.

- **Digital Surface Model (DSM) & Digital Elevation Model (DEM):** A DSM is a 3D representation of the entire surface, including vegetation and buildings. A DEM represents the bare earth elevation, excluding vegetation. These models are derived from the 3D point cloud.
- **Ortho mosaic Generation:** An ortho mosaic is a georeferenced image mosaic created by stitching together the captured images and correcting for perspective distortion. This creates a realistic, top-down view of the surveyed area with accurate scaling.
- **LiDAR Processing:**
- **LiDAR Software:** Software specifically designed for LiDAR data processing is used.
- **Point Cloud Classification:** Raw LiDAR data often contains points from various objects like buildings, vegetation, and the ground. Classification involves separating these points into different categories to create a more usable 3D model.

4. Data Delivery:

- **Data Export:** The final processed data (3D point cloud, textured mesh, ortho mosaic, DEM, etc.) is exported into desired formats compatible with various software applications used for further analysis, modeling, or visualization. Common formats include LAS (LiDAR), OBJ (3D mesh), and Geo TIFF (imagery with geospatial reference).
- **Reporting:** Depending on the project

2.6 Drone survey data processing

Drone Survey Data Processing: Transforming Raw Data into Usable Insights

Drone survey data processing involves transforming the raw data captured by the drone (images or LiDAR points) into meaningful and usable outputs. The specific processing steps depend on the type of sensor used and the desired deliverables. Here's a breakdown of the process for the two most common types of drone surveying:

1. Photogrammetry Data Processing:

- **Software:** Specialized photogrammetry software like Pix4D, Agi soft Meta shape, or Bentley MicroStation are commonly used.
- **Workflow:**
- **Initial Processing:**
- **Image Orientation:** The software estimates the position and orientation of the camera for each captured image. This is achieved by analyzing features within the overlapping images.
- **Lens Distortion Correction:** Corrects for distortions inherent to camera lenses, ensuring accurate measurements in the final outputs.

- **3D Point Cloud Generation:**
- The software identifies corresponding features across overlapping images. Based on these matches and camera positions, it calculates the 3D location of each feature, building a dense point cloud representing the surveyed area.
- **Digital Elevation Model (DEM) and Digital Surface Model (DSM) Generation:**
- The software differentiates points belonging to the bare earth (ground) from those representing vegetation or buildings. This allows for the creation of a DEM (representing bare earth elevation) and a DSM (representing the entire surface, including vegetation and structures).

- **Ortho mosaic Generation:**
- Individual images are stitched together to create a seamless mosaic image. The software corrects for perspective distortion, ensuring accurate scaling throughout the image. This final product provides a realistic, top-down view of the surveyed area.

2. LiDAR Data Processing:

- **Software:** Software specifically designed for LiDAR data processing is used, such as LAS Tools, ArcGIS Pro, or Cloud Compare.
- **Workflow**

- **Point Cloud Cleaning:** Raw LiDAR data may contain noise (points resulting from sensor errors) and outliers (points not belonging to the surveyed area).
- Filtering algorithms are applied to remove these unwanted points.

- **Point Cloud Classification:** LiDAR data typically captures points from various objects like ground, vegetation, and buildings.
- Classification algorithms categorize these points into different classes (e.g., ground, vegetation, buildings) based on their properties like intensity or height.
- This allows for the creation of more informative 3D models.

- **Digital Terrain Model (DTM) Generation:** Similar to a DEM in photogrammetry, a DTM represents the bare earth elevation.
- Classified ground points from the LiDAR data are used to generate a highly accurate DTM.

- **Additional Processing:** Depending on the project requirements, further processing steps like volumetric calculations (e.g., stockpile volume estimation) or feature extraction (e.g., identifying power lines) may be performed.

Additional Considerations:

- **Ground Control Points (GCPs):** When GCPs are used during the drone flight, the processing software leverages their known coordinates to improve the overall accuracy of the georeferencing process (assigning accurate geographic coordinates to the captured data).
- **Quality Control:** Throughout the processing workflow, quality checks are performed to ensure the accuracy and completeness of the final outputs.

Deliverables:

The final products of drone survey data processing can include:

- **3D Point Cloud:** A dense set of data points representing the surveyed area in 3D space.
- **Digital Elevation Model (DEM):** A 2D representation of the bare earth elevation.
- **Digital Surface Model (DSM):** A 2D representation of the entire surface, including vegetation and buildings.
- **Ortho mosaic:** A high-resolution, georeferenced image mosaic providing a top-down view of the surveyed area.
- **Digital Terrain Model (DTM) from LiDAR data:** A highly accurate 2D representation of the bare earth elevation.
- **Volumetric Calculations:** Estimates of stockpile volumes or other relevant quantities.
- . **Feature Extraction:** Identification and extraction of specific features from the data (e.g., power lines, buildings).

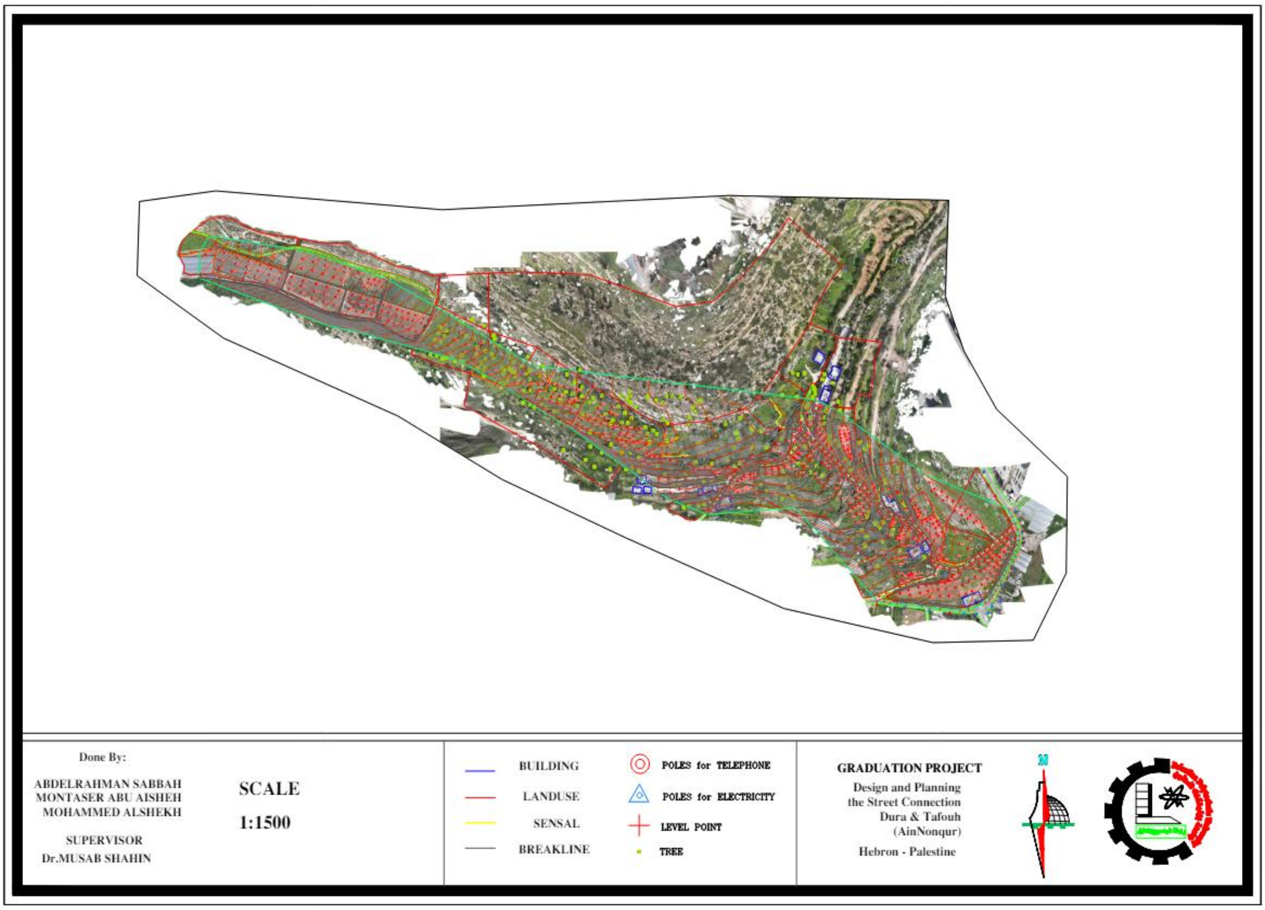


Figure 2-4 Plan of the Road

Figure 2-5 Drone in Project

Figure 2-6 Control Point in Project

CHAPTER 3 TRAFFIC DESIGN

3.1 Traffic Volume.

3.2 Traffic Counting.

3.3 Analysis.

3.1 Traffic Volume

3.1.1 Introduction

Traffic volume refers to the number of vehicles passing through a specific road, street, or pathway during a defined period. It is typically measured as the number of vehicles per unit of time, such as an hour or a day. This data is crucial for assessing key parameters such as traffic density, vehicle speed, and overall traffic flow efficiency, as well as identifying bottlenecks and congestion areas.

Traffic volume data impacts:

- Road Safety: Identifies high-risk areas to guide safer road designs.
- Transportation Efficiency: Reduces congestion and enhances reliability.
- Environmental Impact: Aids in modeling emissions and improving air quality.
- Economic Benefits: Lowers fuel costs and optimizes trade routes.
- Urban Development: Supports smart city infrastructure and sustainable growth.

Applications of Traffic Volume Data

1. Policymaking and Planning: Improves infrastructure with lanes, roundabouts, and interchanges.
2. Public Transportation: Optimizes transit schedules and routes.
3. Traffic Management: Deploys adaptive signals, dynamic lanes, and rerouting strategies.
4. Infrastructure Development: Guides construction of highways, bridges, and tunnels.
5. Environmental Management: Enables emission control and green mobility initiatives.
6. Emergency Response: Facilitates efficient deployment of emergency services.
7. Autonomous Systems: Develops algorithms for autonomous vehicles (V2V, V2I).

Technologies for Traffic Volume Measurement

- Inductive Loop Sensors: Detect vehicle presence and count.
- CCTV with AI: Classify vehicles and assess density.
- Radar/Lidar Sensors: Provide speed and volume precision.
- Mobile Apps/GPS: Real-time traffic insights from navigation apps.
- Weigh-in-Motion Systems: Analyze vehicle weight and speed.
- Drones: Aerial monitoring for congestion analysis.
- Microwave Counters: Reliable under varying weather conditions.
- Bluetooth/Wi-Fi Sensors: Estimate travel times and flow rates.

- Smart Traffic Lights: Dynamically adjust signal timings to reduce congestion.

Engineering Implications

- Design Standards: Shapes road geometry (lane widths, curves) per codes like AASHTO.
- Pavement Design: Determines thicknesses based on traffic loads.
- Structural Design: Guides bridge and overpass construction.
- Simulation Models: Enhances accuracy in traffic modeling tools.

3.1.2 The Aim of Studying Traffic Volume

The primary aim of studying traffic volume is to assess traffic density and speed, as well as to identify issues related to traffic flow such as congestion, accidents, and environmental impacts.

Understanding traffic volume is crucial for designing and planning roads, pathways, and urban infrastructure. This study helps in pinpointing traffic-related problems and developing suitable solutions to enhance traffic flow. Effective measures include traffic management, improving public transportation, and promoting alternative modes of transportation.

Ultimately, the goal of studying traffic volume is to enhance road safety and facilitate the efficient movement of people and goods. This leads to more economical and environmentally friendly transportation systems.

3.1.3 Basic Concepts

Annual Average Daily Traffic (AADT):

The average 24-hour traffic volume at a specific location over an entire year. It is calculated by dividing the total number of vehicles passing a site in a year by 365 days.

Average Annual Weekday Traffic (AAWT):

The average 24-hour traffic volume occurring on weekdays over an entire year. It is calculated by dividing the total number of vehicles passing a site on weekdays by the number of weekdays in a year (usually 260).

Average Daily Traffic (ADT):

The average 24-hour traffic volume at a specific location over a defined period of less than one year. Commonly, ADT is measured monthly throughout the year.

Average Weekday Traffic (AWT):

The average 24-hour weekday traffic volume at a specific location over a defined period of less than one year. Typically, AWT is measured monthly.

Design Hourly Traffic Volume:

The volume of traffic for a specific hour. For a day, there are 24 hourly traffic volumes, and for a year, there are 365×24 hourly volumes. The hourly volume used for design purposes is called the design hourly traffic volume.

Future Traffic Volume:

Predicting future traffic volume is challenging and depends on factors such as population growth, urbanization, economic development, and changes in transportation technology. Transportation planners use methods like analyzing current trends and statistical models to forecast future traffic volumes. Accurate predictions are crucial for planning and designing infrastructure that can meet future demand while ensuring safety, efficiency, and sustainability.

Road Capacity:

The maximum amount of traffic that a road or transportation facility can accommodate while maintaining an acceptable level of service. It is influenced by factors such as the number of lanes, lane width, type of intersection, and design speed. Adequate road capacity is vital for ensuring smooth traffic flow and reducing travel time, air pollution, and fuel consumption. Planners and engineers use various methods, including traffic flow analysis, capacity analysis, and simulation modeling, to determine road capacity and identify causes of congestion.

Table 3-1 Road capacity according AASHTO

Road Type	Capacity (Private Car/Hour)
Highway	2000 (Per lane, one direction)
Two lane road	3000 (Total, both directions)
Three lane road	4000 (Total, both directions)

3.1.4 Design Vehicles

Various types of vehicles travel on roads, including private cars, public transport buses, and small and large trucks. These vehicles differ in dimensions, sizes, and weights, making it essential to understand their characteristics for proper road design. The focus should naturally be on the most commonly used vehicles, as they constitute the majority of traffic volume. Key vehicle characteristics to consider include:

The overall length of the vehicle

The overall width of the vehicle

The height of the vehicle

The weight of the vehicle

The capacity of the vehicle

The distance between the front and rear wheels

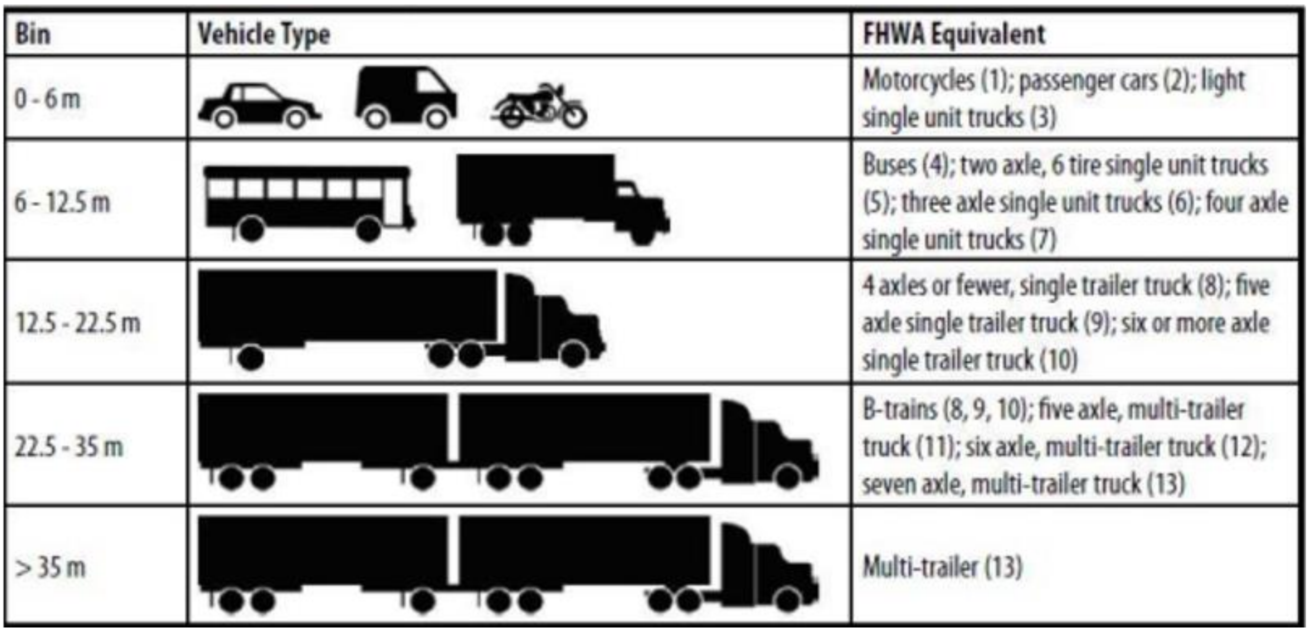
The distance between the front of the vehicle and the front wheels

The distance between the rear of the vehicle and the rear wheels

Studies have shown that trucks significantly impact road pavement, with their effect increasing alongside their weight.

Therefore, it is crucial to study the types of transport vehicles in terms of their dimensions, number of axles, and their impact on road pavement. Figure 3-1 illustrates the loads on the axles, and Table 3-2 shows the main dimensions of private cars and transport vehicles according to AASHTO specifications.

Understanding these characteristics ensures that the road design accommodates all vehicle types, ultimately enhancing safety and efficiency.



Bin	Vehicle Type	FHWA Equivalent
0 - 6 m		Motorcycles (1); passenger cars (2); light single unit trucks (3)
6 - 12.5 m		Buses (4); two axle, 6 tire single unit trucks (5); three axle single unit trucks (6); four axle single unit trucks (7)
12.5 - 22.5 m		4 axles or fewer, single trailer truck (8); five axle single trailer truck (9); six or more axle single trailer truck (10)
22.5 - 35 m		B-trains (8, 9, 10); five axle, multi-trailer truck (11); six axle, multi-trailer truck (12); seven axle, multi-trailer truck (13)
> 35 m		Multi-trailer (13)

Figure 3-1 Vehicle Types

Table 3-2 The main dimensions of the vehicle

Dimension	Private Car	Passenger Car	Commercial transport vehicle
length (m)	5.8	12.1	16.7
width (m)	2.1	2.6	2.6
width (m)	1.3	4.1	4.1
Distance between the front and rear wheels	3.4	7.6	6.1
Distance between the front of the vehicle and the front wheels	0.9	1.2	0.9
Distance between the rear of the vehicle and the rear wheels	1.5	1.8	0.6

3.2 Traffic Counting

3.2.1 Introduction

A Traffic Count Calculator is a tool used to estimate the volume of traffic that travels through a particular road section. Traffic counts are essential for road planning, design, and evaluating the effectiveness of traffic management strategies.

There are two main types of Traffic Count Calculators: manual and automatic.

Manual Traffic Count Calculators: Involve manually counting the number of vehicles that pass through a road section over a given period. This method is time-consuming and can be subject to human error.

Automatic Traffic Count Calculators: Use technology such as cameras, radar, or sensors to automatically count the number of vehicles.

Both manual and automatic Traffic Count Calculators provide valuable data for transportation planners and engineers. Traffic counts help identify traffic patterns, congestion points, and areas where safety improvements may be necessary. Traffic count data can also be used to forecast future traffic volume and plan for future road expansions or improvements.

Overall, Traffic Count Calculators are important tools that provide valuable data for road planning and design, ensuring safe and efficient traffic flow on our roadways.

3.2.2 Key Aspects of Traffic Counting

1. Types of Traffic Counting:
    - Manual Counting:
        - Involves individuals manually recording the number and types of vehicles or pedestrians.
        - Suitable for small-scale studies but can be time-consuming and prone to human error.
    - Automatic Counting:
        - Utilizes technologies such as cameras, infrared sensors, radar, or induction loops embedded in road surfaces.
        - Provides accurate, continuous, and real-time data for more comprehensive analysis.

2. Types of Traffic Data:
    - Volume Counts: Measures the number of vehicles or pedestrians over a specific period.
    - Class Counts: Categorizes vehicles into different types, such as cars, trucks, and motorcycles.
    - Speed Counts: Measures the speed of vehicles on the road.

3. Purposes of Traffic Counting:
    - Traffic Flow Analysis: To understand how traffic moves through a particular area.
    - Capacity Analysis: To evaluate the efficiency and capacity of roads and intersections.
    - Safety Assessment: To identify high-risk areas prone to accidents.
    - Planning and Design: To support the planning of new roads or improvements to existing ones based on traffic patterns.
4. Data Collection Methods:
    - Manual Surveys: Personnel count and record traffic data on-site.
    - Automatic Surveys: Use technology to collect data continuously over an extended period.

5. Data Analysis:
    - Traffic engineers and planners analyze the data to derive insights.
    - Statistical methods and software tools are often used for accurate interpretation.
6. Traffic Counting Technologies:
    - Video Cameras: Record and visually analyze traffic movements.
    - Induction Loops: Embedded in road surfaces to detect and count vehicles.
    - Radar and Lidar Sensors: Use radio waves or laser beams to detect and count vehicles.

3.2.3 Traffic Hypothesis from Dura Municipality

Under the auspices of Dura Municipality, and considering the difficult circumstances the country is facing due to wars and road closures, it was impossible to conduct an accurate traffic count due to numerous obstacles.

As a result, traffic data and statistics were obtained from Dura Municipality, indicating that the number of vehicles passing through the area during peak hours reached 425 vehicles.

Given that the proposed road aims to alleviate traffic congestion and improve mobility between Dura and Tafouh, the new road will be constructed in the Ain Nunger area, directly connecting Dura to Tafouh.

This project will enhance the efficiency of the road network in the area by providing an effective alternative route. It will reduce pressure on the main roads, especially the Sanger - Tahrir Roundabout road, ensuring smooth traffic flow and reducing congestion in the region

3.3 Analysis

Despite the challenges, data and traffic statistics were collected from the municipality, revealing the number of vehicles entering the street area during peak hours.

The street under study is considered an alternative to alleviate traffic congestion on the Sanger-Tahrir Roundabout road, especially for those heading towards Dura and Tafouh. The proposed road extends in the Ain Nunger area, specifically in Wadi Sued.

It is important to note that the primary goal of this design is to improve traffic flow and provide an effective alternative route. This initiative aims to reduce pressure on the Hebron entrance, contributing to the overall improvement of traffic management in the region. The current traffic will be analyzed using Synchro software.

CHAPTER 4 GEOMETRIC DESIGN

4.1 Introduction.

4.2 Horizontal Curve.

4.3 Vertical Curve.

4.4 Road Planning

4.1 Introduction.

Geometric design of roads refers to the process of crafting the physical layout of a road system. This encompasses the alignment, profile, cross-section, and intersection design, all of which aim to provide a safe and efficient roadway capable of accommodating the intended traffic volume and speed. Additionally, geometric design takes into account factors such as terrain, environmental considerations, and community needs.

1. Alignment Design:
   - Alignment design involves selecting the optimal path for the road, factoring in topography, land use, and environmental constraints. It also considers elements such as sight distance, stopping distance, and turning radii to ensure safe operation.
2. Profile Design:
   - Profile design determines the vertical shape of the road, including grades or slopes, and the location and height of crest and sag vertical curves. It also considers drainage and other factors affecting the comfort and safety of the road.
3. Cross-Section Design:
   - Cross-section design refers to the shape and dimensions of the roadway and its components, including lanes, shoulders, medians, and curbs. It also considers factors such as pavement structure, drainage, and roadside features.
4. Intersection Design:
   - Intersection design involves planning the layout where two or more roads meet. This includes considering the type of intersection (signalized or roundabout), traffic volume, and turning movements to ensure safe and efficient traffic flow.

Additional Considerations:

- Environmental Impact:
  - Designs must minimize adverse environmental impacts, preserving natural habitats and reducing pollution.
- Community Needs:
  - Incorporating community feedback and considering local traffic patterns and access requirements are vital.
- Safety Measures:
  - Implementing safety features like guardrails, proper signage, and pedestrian crossings is crucial.

4.1.1 Basic Concepts

Geometric design is a branch of mathematics that focuses on the study of shapes, figures, and their properties. It involves various fundamental concepts that are essential for understanding and analyzing geometric structures.

1. Points:
   - Points are basic entities in geometry with no size or dimension. They are represented by dots and have no length, width, or thickness.
2. Lines:
   - Lines are straight paths that extend infinitely in both directions. They are defined by two points and have length but no width or thickness.
3. Line Segments:
   - A line segment is a portion of a line with two endpoints. Unlike a line, it has a definite length and is finite.
4. Angles:
   - Angles are formed by the intersection of two lines or line segments and are measured in degrees or radians. They can be classified as:
     - Acute (less than 90 degrees)
     - Right (exactly 90 degrees)
     - Obtuse (between 90 and 180 degrees)
     - Straight (exactly 180 degrees)
5. Polygons:
   - Polygons are closed two-dimensional shapes formed by connecting line segments. Common examples include:
     - Triangles
     - Rectangles
     - Squares
     - Pentagons
6. Circles:
   - Circles are perfectly round shapes with all points on the boundary equidistant from the center. A circle is defined by:
     - Radius: The distance from the center to any point on the circle.
     - Diameter: Twice the radius.
7. Coordinate System:
   - Coordinate systems use sets of numbers or coordinates to locate points in a plane or space. Common coordinate systems include:
     - Cartesian Coordinate System (with x and y axes)
     - Polar Coordinate System (with a distance and angle)

4.1.2 Fundamentals of Design Processes

The road design process is a complex engineering operation that involves multiple steps and stages to ensure the construction of effective and safe roadways. Here are the fundamental aspects of road design operations:

1. Feasibility Study:
   - Identify the need for the road and analyze traffic patterns and potential user requirements.
2. Site Study:
   - Evaluate the targeted area for road construction, considering topography and environmental factors.
3. Traffic Analysis:
   - Collect data on traffic volume and speed distribution to estimate road capacity.
4. Terrain Analysis:
   - Examine the surrounding terrain to identify challenges and opportunities in road design.
5. Path Selection:
   - Determine the optimal road path based on topography, environmental needs, and economic considerations.
6. Engineering Design:
   - Define basic dimensions, curves, slopes, and other requirements for the road.
7. Traffic Control Design:
   - Develop a traffic control system, including signals and signs, to guide traffic safely.
8. Construction:
   - Execute the project and build the road according to the engineering designs.

Road design requires collaboration between different engineers, including road engineers, civil engineers, and engineering design specialists, to ensure comprehensive and effective project implementation. Additionally, considerations for environmental impact, community needs, and future expansion should be integrated into the design process to enhance the overall functionality and sustainability of the road network.

4.2 Horizontal Curve

In geometric design, a horizontal curve refers to a bend or curve along a roadway or a linear profile in the horizontal plane. These curves are essential for transitioning from one straight section of the road to another while maintaining a constant radius of curvature. Horizontal curves are crucial for safely navigating changes in direction and are commonly found in highways, roads, and railway tracks.

Key Aspects of Horizontal Curves in Geometric Design:

1. Design Speed:
   - The speed at which vehicles are expected to travel on the curve. Design speed influences the other elements of the curve, such as its radius and super elevation.
2. Super Elevation:
   - The banking of the roadway at the curve to counteract the lateral acceleration of vehicles. It helps to keep vehicles safely on the roadway and improves comfort for the driver.
3. Minimum Radius:
   - The smallest allowable radius of the curve, based on the design speed and super elevation. A smaller radius requires a greater super elevation to maintain safety and comfort.
4. Sight Distance:
   - The distance a driver can see ahead on the curve. Adequate sight distance is essential for ensuring that drivers can see and respond to obstacles or changes in the road alignment.

4.2.1 Design Speed

Design speed in the context of road design refers to the maximum allowable speed that a road is designed to accommodate. This speed is determined by considering various factors to ensure safe and efficient travel. Key factors influencing the selection of design speed include:

1. Road Type:
   - Highways typically have higher design speeds compared to secondary or urban roads, reflecting the faster nature of traffic flow on highways.
2. Road Design:
   - The design speed takes into account the road's geometry and engineering features, such as curves and surface irregularities.
3. Traffic Volume:
   - Roads with higher traffic volumes may require higher design speeds to ensure effective traffic flow.

4. User Safety:
   - The design speed should be chosen to ensure user safety, considering various factors that impact the safety of road users.

Design speed plays a crucial role in defining road characteristics and impacts vehicle behavior and user safety. Careful consideration of design speed helps achieve a balance between traffic flow efficiency and road safety.

Table 4-1 Design Speed

Road classification	Minimum speed (Km/h)	Desired speed (Km/h)
Local road	30	5
Collector road	50	60
Arterial road	80	100
Less disturbance road	70	90
palpable disturbance road	50	60
EXPRESSWAT	90	120

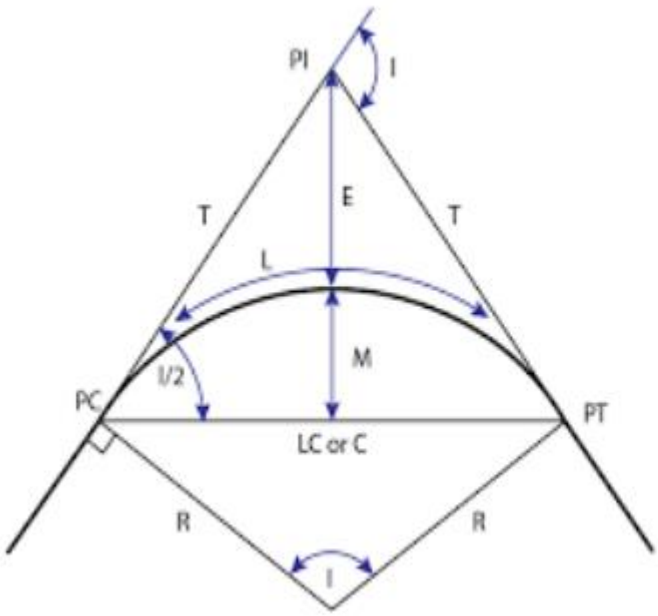


Figure 4-1 Horizontal Curve

-

Simple circular curve calculation equations :

Equation 1Length of Curve

Length of Curve (L): $L = (\pi R \cdot \Delta / 180)$ ……….. 4.1

where (R) is the radius and (Delta) is the deflection angle.

Equation 2Tangent

Tangent (T): $T = R \cdot \tan(\Delta/2)$ ……….. 4.2

Equation 3Long Chord

Long Chord (LC): $LC = 2R \cdot \sin(\Delta/2)$ ……….. 4.3

Equation 4External Distance

External Distance (E): $E = R \cdot (\sec(\Delta/2) - 1)$ ……….. 4.4

Equation 5Middle Ordinate

Middle Ordinate (M): $M = R \cdot (1 - \cos(\Delta/2))$ ……….. 4.5

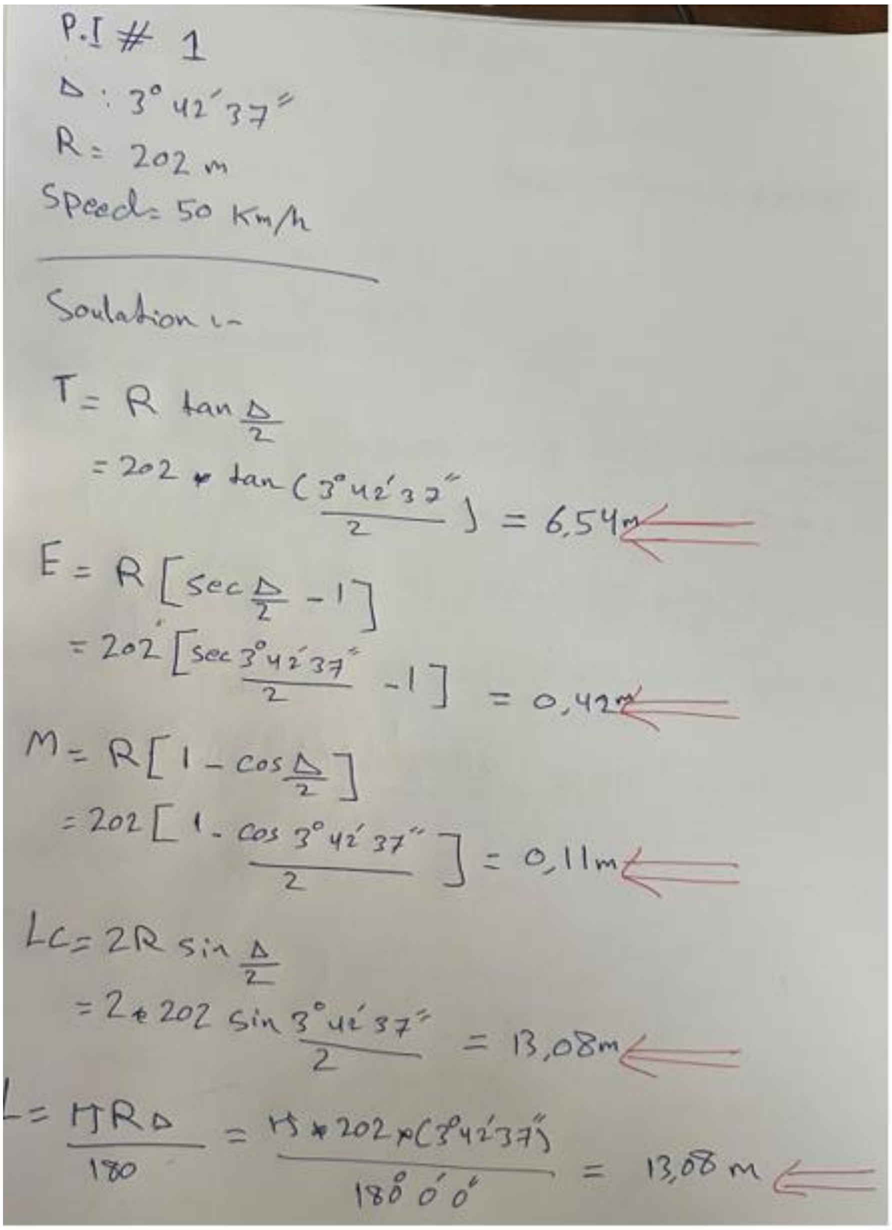


Figure 4-2 Calculate horizontal curve

4.2.2 Superelevation

In geometric design, superelevation is introduced to counteract the centrifugal force acting on vehicles as they travel through curves. This enhancement improves vehicle stability and reduces the risk of skidding or overturning. Key aspects of superelevation in geometric design include:

1. Centrifugal Force:
   - When a vehicle travels around a curve, a centrifugal force is generated due to the vehicle's inertia. This force pushes the vehicle outward, away from the curve's center. Superelevation helps counterbalance this force, keeping the vehicle on a safe and stable path.

2. Cross Slope:
    - Superelevation is achieved by providing a cross slope, which is the slope or incline of the roadway from the inner edge of the curve to the outer edge. This cross slope is typically measured as a ratio or percentage, indicating the rise or fall in the road surface over a specified horizontal distance.
3. Critical Speed:
    - The critical speed is the speed at which a vehicle can safely traverse a curve without relying on friction between the tires and the road surface to maintain stability. Superelevation is designed based on the critical speed, which is determined by factors such as curve radius, coefficient of friction between tires and pavement, and the desired level of safety.
4. Design Criteria:
    - Designing superelevation involves considering various factors, including the design speed, curve radius, and side friction factor (a measure of the road surface's ability to provide lateral friction). Design guidelines and standards provide specific criteria and formulas to determine the appropriate superelevation for a given curve.
5. Transition Lengths:
    - To ensure a smooth transition between the straight section of the roadway and the curved section, superelevation is gradually introduced over a transition length. Transition lengths are designed to avoid sudden changes in cross slope and provide a comfortable transition for drivers.

Superelevation is typically implemented on high-speed roadways, such as highways and expressways, where vehicles travel at higher speeds. It improves vehicle handling characteristics, allowing vehicles to negotiate curves more efficiently and with reduced risk.

Engineers use mathematical calculations, computer simulations, and design standards to determine the appropriate superelevation and transition lengths based on specific roadway conditions, design speed, and the desired level of safety.

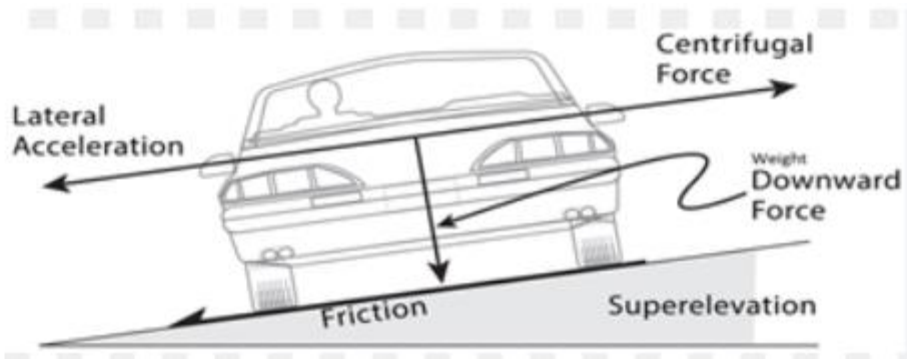


Figure 4-3 Superelevation

4.2.3 Minimum Radius

The minimum radius in a horizontal curve refers to the smallest radius of curvature that a road can have in a curved section. This radius is critical in determining the sharpness of the curve and plays a crucial role in road design, ensuring safe and efficient traffic flow.

Several factors influence the minimum radius in a horizontal curve, including:

1. Design Speed:
   - Higher design speeds typically require larger radii to ensure safety and comfort for drivers.
2. Road Type:
   - Different types of roads, such as highways, urban roads, or rural roads, have varying minimum radius requirements based on their intended use and traffic characteristics.
3. Terrain:
   - The surrounding terrain influences the feasibility and cost of constructing curves with larger radii.
4. Comfort and Safety:
   - The desired level of comfort and safety for drivers and passengers also dictates the minimum radius. A larger radius generally provides a smoother and safer curve.

It's important to note that the minimum radius is not solely determined by geometric considerations. Other factors such as superelevation (the banking of the road), sight distance, and lateral friction between tires and the road surface also play a significant role in determining the appropriate minimum radius.

By carefully considering these factors, engineers can design horizontal curves that ensure safe and efficient travel for all road users.

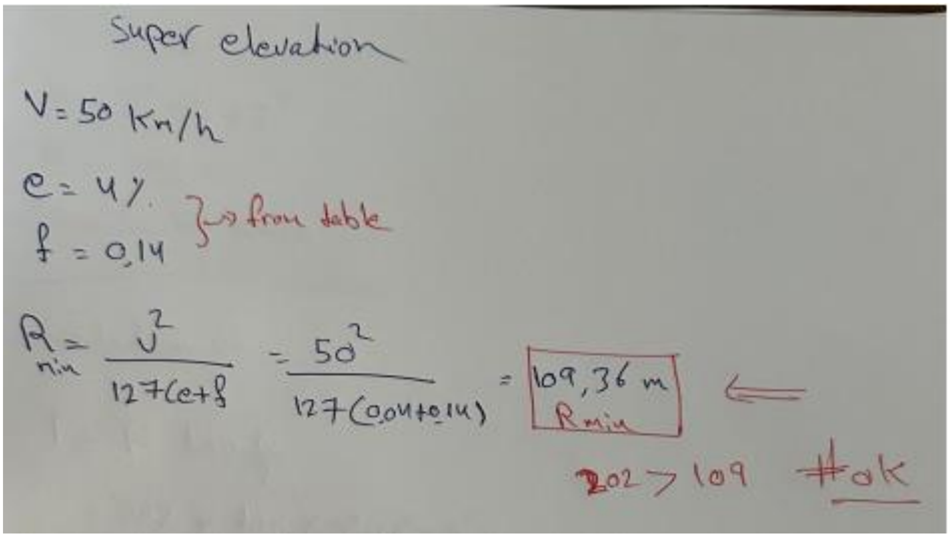


Figure 4-4 Calculate R min in super elevation

4.3 Vertical Curve

In geometric design, a vertical curve refers to the transition along a roadway that connects two different grades or slopes, ensuring a smooth and safe passage for vehicles, particularly when there's a change in elevation. Vertical curves are crucial for several reasons:

1. Safety:
    - Significant changes in the road's gradient can lead to driver discomfort, reduced visibility, and potential loss of control. Vertical curves help minimize these issues by gradually transitioning between different slopes, ensuring a smoother driving experience and improved safety.
2. Sight Distance:
    - Vertical curves are designed to provide adequate sight distance for drivers. The curve's length and shape ensure that drivers have a clear view of the road ahead, including any potential hazards or oncoming traffic.
3. Drainage:
    - Vertical curves facilitate proper drainage along the road. By incorporating a gradual slope change, water can flow smoothly off the roadway, preventing pooling and erosion issues.
4. Vehicle Performance:
    - Vertical curves consider the performance capabilities of vehicles. They are designed to accommodate safe and efficient vehicle movement, taking into account factors such as acceleration, deceleration, and braking capabilities.

4.3.1 Sag Curve

A sag curve is a type of vertical curve used to transition from an uphill slope to a downhill slope. This curve is concave upwards, creating a "U" shape. Sag curves are essential for ensuring that drivers can smoothly adjust their speed and maintain vehicle control as they descend from a higher to a lower elevation.

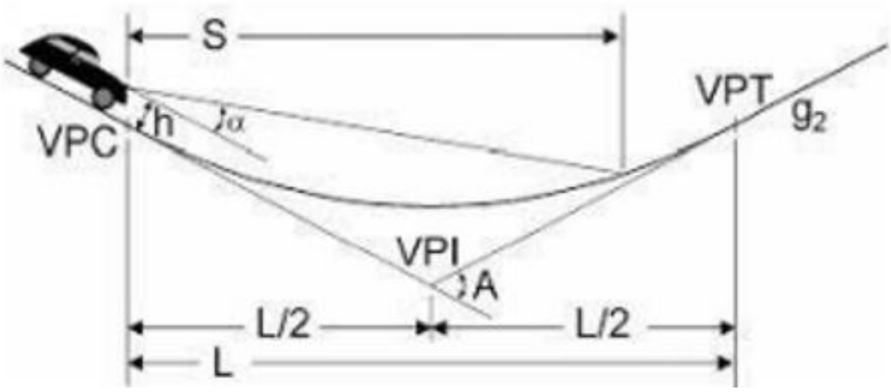


Figure 4-5 Sag Curve

Table 4-2 K Value for Sag Curve

Design Speed (mi/h)	Stopping Sight Distance (ft)	Rate of Vertical Curvature, K[a]	
		Calculated	Design
15	80	9.4	10
20	115	16.5	17
25	155	25.5	26
30	200	36.4	37
35	250	49.0	49
40	305	63.4	64
45	360	78.1	79
50	425	95.7	96
55	495	114.9	115
60	570	135.7	136
65	645	156.5	157
70	730	180.3	181
75	820	205.6	206
80	910	231.0	231

4.3.2 Crest Curve

A crest curve is used to transition from a downhill slope to an uphill slope. It has a concave downwards shape, resembling an inverted "U." Crest curves help drivers adjust their speed and maintain vehicle stability as they ascend from a lower elevation to a higher one.

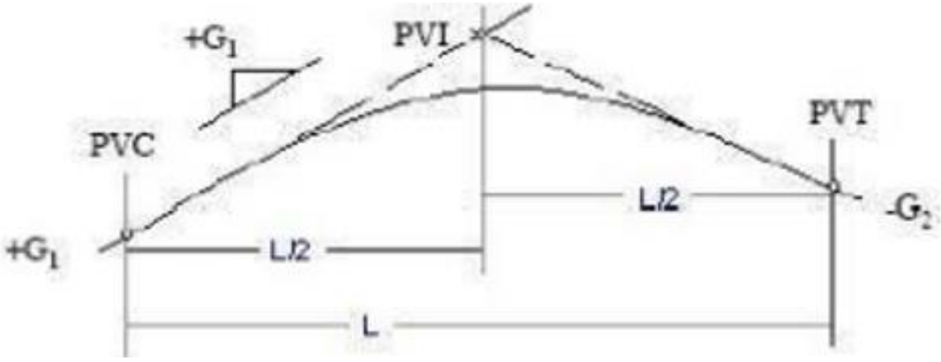


Figure 4-6 Crest Curve

Table 4-3 K Value for Crest Curve

Design Speed (mi/h)	Stopping Sight Distance (ft)	Rate of Vertical Curvature, K[a] Calculated	Rate of Vertical Curvature, K[a] Design
15	80	3.0	3
20	115	6.1	7
25	155	11.1	12
30	200	18.5	19
35	250	29.0	29
40	305	43.1	44
45	360	60.1	61
50	425	83.7	84
55	495	113.5	114
60	570	150.6	151
65	645	192.8	193
70	730	246.9	247
75	820	311.6	312
80	910	383.7	384

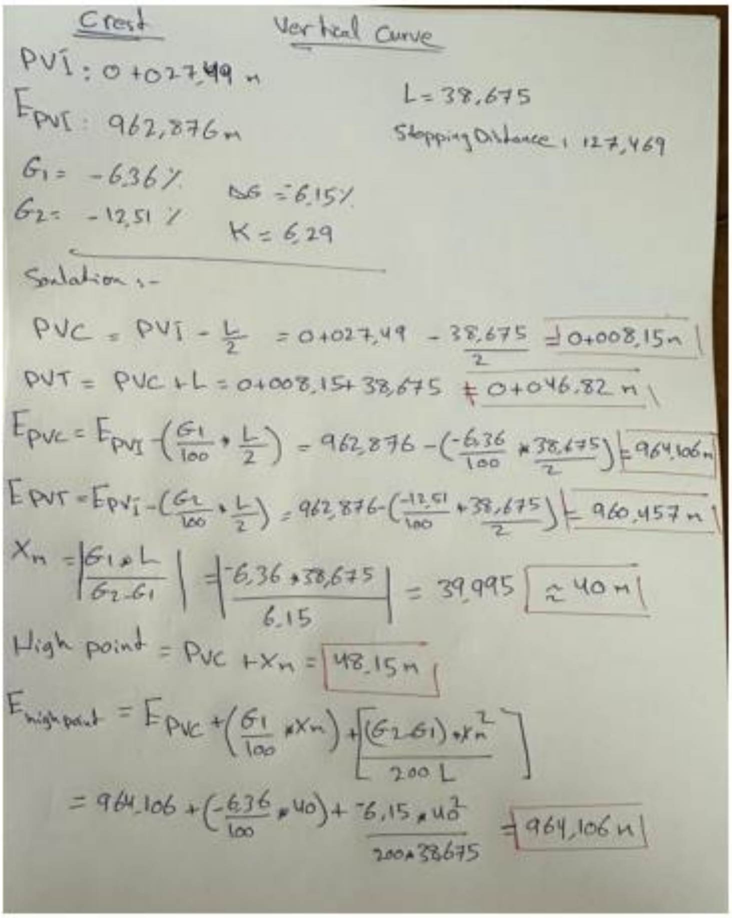


Figure 4-7 Calculate Crest Curve

4.3.3 Vertical Curve at Grade

A vertical curve at grade is used when transitioning between two different slopes that have the same grade. Typically, this type of curve is a straight line, providing a seamless transition without any noticeable curvature. This design ensures a smooth and continuous path for vehicles, enhancing both comfort and safety.

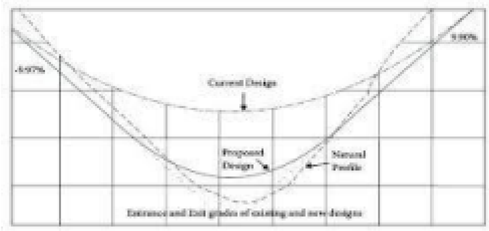


Figure 4-8 Vertical Curve at Grade

4.3.4 Stopping Sight Distance

The stopping sight distance (SSD) for a vertical curve in roadway design refers to the distance required for a driver to safely come to a stop when encountering an obstacle or condition that necessitates stopping. Ensuring adequate SSD is crucial for the safety of drivers and passengers. The stopping sight distance for a vertical curve is influenced by several factors, including:

- Design Speed: The speed at which the road is designed to accommodate traffic affects the required stopping distance.
- Gradient of the Vertical Curve: The slope of the curve impacts the distance needed for a vehicle to stop safely.
- Height of the Driver's Eye: The typical height of the driver's eye above the road surface is considered to ensure proper visibility.
- Deceleration Rate: The rate at which a vehicle can decelerate, taking into account factors like road conditions and vehicle braking capabilities.

By carefully considering these factors, engineers can design vertical curves with adequate stopping sight distance, ensuring that drivers have sufficient visibility and time to react to any obstacles, enhancing overall road safety.

Table 4-4 Stopping Sight Distance

Metric					US Customary				
			Stopping sight distance					Stopping sight distance	
Design speed (km/h)	Brake reaction distance (m)	Braking distance on level (m)	Calculated (m)	Design (m)	Design speed (mph)	Brake reaction distance (ft)	Braking distance on level (ft)	Calculated (ft)	Design (ft)
20	13.9	4.6	18.5	20	15	55.1	21.6	76.7	80
30	20.9	10.3	31.2	35	20	73.5	38.4	111.9	115
40	27.8	18.4	46.2	50	25	91.9	60.0	151.9	155
50	34.8	28.7	63.5	65	30	110.3	86.4	196.7	200
60	41.7	41.3	83.0	85	35	128.6	117.6	246.2	250
70	48.7	56.2	104.9	105	40	147.0	153.6	300.6	305
80	55.6	73.4	129.0	130	45	165.4	194.4	359.8	360
90	62.6	92.9	155.5	160	50	183.8	240.0	423.8	425
100	69.5	114.7	184.2	185	55	202.1	290.3	492.4	495
110	76.5	138.8	215.3	220	60	220.5	345.5	566.0	570
120	83.4	165.2	248.6	250	65	238.9	405.5	644.4	645
130	90.4	193.8	284.2	285	70	257.3	470.3	727.6	730
					75	275.6	539.9	815.5	820
					80	294.0	614.3	908.3	910

Note: Brake reaction distance predicated on a time of 2.5 s; deceleration rate of 3.4 m/s^2 [11.2 ft/s^2] used to determine calculated sight distance.

4.4 Road Planning

4.4.1 Introduction

Road planning is a crucial aspect of urban and regional development, involving the systematic design, construction, and maintenance of road networks to ensure efficient and safe transportation. The process encompasses various stages, including surveying, feasibility studies, design, and implementation. Effective road planning plays a pivotal role in enhancing connectivity, reducing congestion, promoting economic growth, and ensuring the overall well-being of communities.

Key Components of Road Planning:

1. Surveying and Data Collection:
    - Gathering accurate data on existing road conditions, traffic patterns, and land use. This information helps planners make informed decisions about the design and alignment of roads.

2. Design:
    - Based on collected data and feasibility studies, engineers create detailed designs for the road network. This includes considerations for road geometry, traffic flow, safety features, and environmental sustainability.
3. Land Acquisition:
    - Acquiring the necessary land for road construction, often a complex process. Planners must navigate legal, social, and economic considerations while minimizing disruptions to existing communities.
4. Construction and Maintenance:
    - Once the planning and design phases are complete, road construction can commence. Regular maintenance is crucial to ensure the longevity and safety of the road network.

Effective road planning is essential for creating a sustainable and interconnected transportation infrastructure that meets the needs of growing populations. It contributes to economic development, environmental conservation, and improved quality of life for residents. As cities and regions continue to evolve, strategic road planning remains a cornerstone for fostering progress and connectivity.

4.4.2 Location

The location of road planning can refer to both the geographical area where road planning is taking place and the specific administrative and organizational context within a government or planning agency. Let's explore both aspects:

1. Geographical Location:

- Urban Areas:
    - In urban settings, road planning focuses on addressing the transportation needs of cities or metropolitan regions. Planners consider factors such as population density, land use, existing infrastructure, and anticipated growth when designing and improving road networks.
- Rural Areas:
    - In rural settings, road planning aims to connect remote communities, improve transportation links for agriculture, and ensure access to essential services. The emphasis is on creating efficient and reliable transportation routes in less densely populated regions.

- Regional and National Levels:
    - At broader scales, road planning can occur at the regional or national level to enhance connectivity between cities, states, or countries.

2. Organizational and Administrative Location:

- Government Agencies:
    - Road planning is typically undertaken by government agencies responsible for transportation and infrastructure. These agencies may operate at different levels of government, such as municipal, county, state, or national departments of transportation.
- Planning Departments:
    - Within government structures, specific planning departments or divisions may be dedicated to road and transportation planning. Planners in these departments collaborate with engineers, environmental experts, and other professionals to develop comprehensive road plans.
- Public-Private Partnerships:
    - In some cases, road planning involves collaboration between government entities and private organizations. Public-private partnerships (PPPs) can bring together expertise and resources from both sectors to implement road projects.
- International Organizations:
    - For large-scale projects that cross national borders, international organizations and collaborations may play a role in road planning. These entities work to harmonize standards, improve cross-border infrastructure, and facilitate regional development.
- Local Communities:
    - Local communities and stakeholders often have a say in the road planning process. Community input is crucial for identifying local needs, addressing concerns, and ensuring that road projects align with the priorities and values of the people who live in the affected areas.

The location of road planning thus encompasses a broad spectrum, ranging from specific geographic locations to the administrative and organizational contexts in which planning activities take place. It involves a multidisciplinary approach that considers social, economic, environmental, and engineering factors to create sustainable and effective road networks.

4.4.3 Right of Way

The road verge is the area surrounding the main roadway that must remain free of elements and structures to enhance user safety and ensure road safety. It is an essential part of road design and engineering infrastructure planning. Properly determining the size and design of the road verge is vital for enhancing the overall safety and effectiveness of roads. The size and design of the road verge depend on several factors, including:

1. Road Type:
   - The road verge may vary depending on the type of road. For example, highways may require a larger verge than secondary roads.
2. Traffic Volume:
   - Road verge requirements are influenced by the volume of traffic and expected traffic movements.
3. Permissible Speed:
   - The permissible speed on the road plays a role in determining the road verge size, as higher speeds may necessitate a larger verge.
4. Safety and Visibility:
   - The size of the road verge is related to ensuring good visibility for drivers and providing sufficient distance for emergency reactions.
5. Soil and Environment:
   - The design of the road verge should consider the environmental and geographical characteristics of the surrounding soil.
6. General Planning:
   - The determination of the road verge is part of the overall planning for the area and development guidelines.

Effectively determining the road verge contributes to maintaining the overall safety of roads, enhances traffic organization, and supports the long-term sustainability of road infrastructure.

Table 4-5 Right of way

Road type	Right-of-way width (m)
Two-lane road	22 - 36
Three-lane road	30 - 42
Four-lane road	37 - 93

4.4.4 Lane Width

Lane width refers to the total horizontal distance of an individual traffic lane on the road. It is a crucial factor in road design and traffic planning, influenced by several factors, including:

1. Road Type:
    - Lane width may vary depending on the type of road. Highways typically have wider lanes compared to local roads.
2. Traffic Density:
    - Traffic density affects lane width, with high-traffic roads often requiring wider lanes.
3. Speed Limits:
    - The allowed speed on the road influences lane width. Higher speeds may necessitate wider lanes.
4. Presence of Additional Features:
    - The existence of features such as shoulders or bike lanes can impact lane width.
5. User Safety:
    - Lane width is chosen to ensure the safety of users, including drivers and cyclists.

Lane width plays a crucial role in determining how traffic is organized and ensuring the safety of road users. According to AASHTO guidelines, lane widths typically range from 2.75 to 3.65 meters.

4.4.5 Crossing Elements

A crossing element in road design refers to any infrastructure or feature that allows pedestrians, cyclists, or vehicles to traverse a road safely. Crossings are essential components of transportation planning and urban design, facilitating the movement of people and goods while ensuring user safety. Here are some common crossing elements:

1. Pedestrian Crosswalks:
    - Zebra Crossings: Marked with distinct white stripes on the road, zebra crossings are designated areas where pedestrians can cross safely. They often include painted lines and, sometimes, pedestrian crossing signs or signal lights.
2. Traffic Signals:
    - Pedestrian Signals: Traffic lights specifically designed for pedestrians, providing signals such as "Walk," "Don't Walk," and countdowns indicating the remaining time to cross safely.

    - Signalized Crosswalks: Pedestrian crossings equipped with traffic signals to regulate the flow of both pedestrian and vehicular traffic, ensuring a safe crossing experience.
3. Crossing Islands and Medians:
    - Pedestrian Islands: Raised or lowered islands placed in the middle of the road provide pedestrians with a refuge, allowing them to cross one direction of traffic at a time.
    - Raised Medians: Central medians with physical barriers or landscaping create safer crossing points for pedestrians and help manage turning movements for vehicles.
4. Crossing Signs and Markings:
    - Crosswalk Signs: Informative signs alerting drivers to the presence of pedestrian crosswalks and indicating the need to yield to pedestrians.
    - Road Markings: Painted lines and symbols on the road surface, such as pedestrian crosswalk lines and symbols, guide pedestrians and drivers.
5. Cyclist Crossings:
    - Bike Lanes and Crossings: Designated lanes for cyclists with accompanying markings and crossings to facilitate safe passage across roads.
6. Uncontrolled Crossings:
    - Unmarked Crossings: Locations where pedestrians are legally allowed to cross but may not have designated markings. Drivers are still required to yield to pedestrians.

Proper planning and implementation of crossing elements are critical for creating a safe and efficient transportation network. Considering factors such as traffic volume, pedestrian activity, and the surrounding environment helps determine the most appropriate type of crossing element for a given location. Integrating these elements into road design contributes to overall traffic safety and improves the accessibility of urban and suburban areas.

4.4.6 Alignment Selection

Alignment selection in road design refers to the process of choosing the horizontal and vertical alignment for a road. Horizontal alignment refers to the layout of the road in plan view, while vertical alignment involves the profile or elevation of the road along its length. The goal is to create a safe, efficient, and economically viable road that accommodates the topography and meets its intended purpose. Here are key considerations in alignment selection:

1. Topography and Terrain:
    - The natural topography of the land influences alignment selection. Engineers strive to minimize earthwork and cut-and-fill operations by aligning the road with the contours of the terrain.
2. Geometric Design Standards:
    - Adherence to established geometric design standards ensures that the road provides safe and comfortable travel for users. Standards include criteria for curve radii, superelevation (banking of curves), sight distance, and lane widths.
3. Traffic Conditions:
    - The expected traffic volume and types of vehicles using the road influence alignment selection. Highways designed for faster-moving traffic may have different alignment requirements than local roads with lower speeds and traffic volumes.
4. Land Use and Development Plans:
    - Alignment should consider existing and future land use. Roads must integrate with development plans, providing access to residential, commercial, and industrial areas while minimizing disruption to existing communities.
5. Safety:
    - Safety is paramount in alignment selection. Engineers must consider sight distance, clear zones, and other factors to minimize the risk of accidents. Proper alignment ensures good visibility for drivers and safe turning radii at intersections.
6. Environmental Impact:
    - Minimizing the environmental impact of road construction is essential. Alignment selection should consider avoiding ecologically sensitive areas, wetlands, and habitats, and incorporate measures to protect the environment.
7. Economic Considerations:
    - The cost of construction and maintenance is a crucial factor. Engineers aim to minimize construction costs by selecting alignments that require reasonable earthwork, avoid costly structures, and utilize existing infrastructure where possible.
8. Aesthetic and Cultural Considerations:
    - In some cases, alignment selection may consider aesthetic and cultural factors. Roads passing through scenic areas or near historical sites may be designed to enhance the overall experience and preserve the cultural landscape.

9. Accessibility:
    - The road must be accessible to all users, including pedestrians and cyclists. Alignment selection should include provisions for sidewalks, crosswalks, and bike lanes where appropriate.
10. Future Expansion and Upgrading:

- Planning for future growth and the potential need for road expansion or upgrading is essential. Alignment should allow for future widening or improvements to accommodate changing traffic patterns and needs.

The alignment selection process involves a comprehensive analysis that considers a range of technical, economic, and environmental factors. It requires collaboration between engineers, planners, environmental specialists, and other stakeholders to ensure that the chosen alignment aligns with the overall goals of the transportation system and the community it serves.

Figure 4-9 Alignment selection for project

4.4.7 Profile

In geometric design, a profile refers to a cross-sectional view or representation of an object or shape. It provides a detailed description of the shape's outline or contour at a specific point or along a specific line. Profiles are commonly used in engineering and road design.

A profile typically includes the following aspects:

1. Outline or Boundary:
    - The outermost boundary or silhouette of the shape. It defines the shape's overall form and can be represented by a continuous curve or a series of line segments.
2. Dimensions:
    - Measurements and specifications related to the size and proportions of the profile. This may include lengths, widths, heights, angles, and radii, depending on the specific requirements of the design.
3. Curvature:
    - The curvature of the profile describes how the shape's contour changes along its length or at specific points. Curvature can be uniform, varying, or include specific sections with specific curvature properties.
4. Features:
    - Any additional details or features that are integral to the design or function of the object. These could include holes, slots, notches, fillets, chamfers, or other geometric elements.

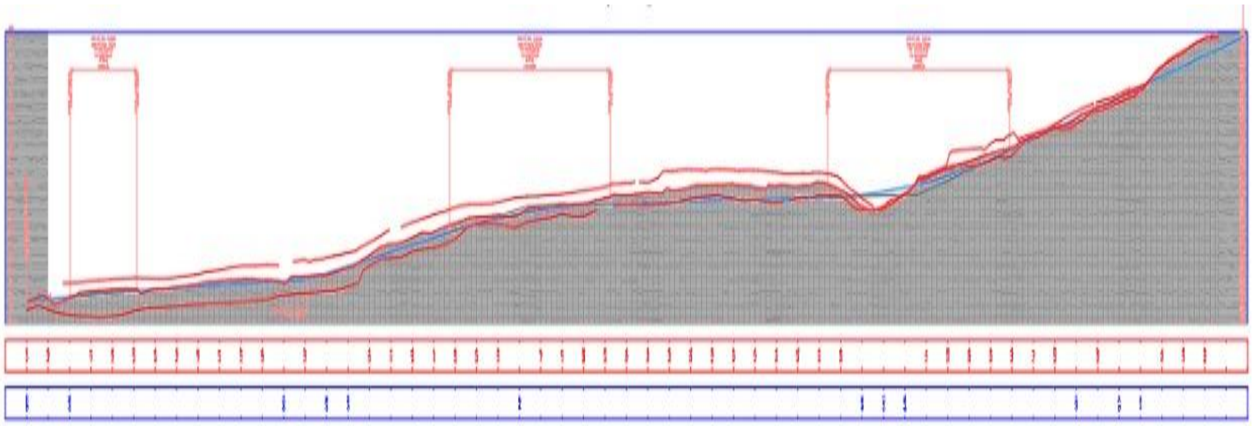


Figure 4-10 Profile selection for project

4.8 Cross-Section

In geometric design, a cross-section refers to a two-dimensional representation or view of a roadway or any linear infrastructure project taken perpendicular to its alignment. It provides a detailed illustration of the shape, dimensions, and features of the roadway or structure at a specific location along its length. Cross-sections play a crucial role in the design, analysis, and construction of roads, highways, railways, canals, and other linear projects.

Key Aspects of Cross-Sections in Geometric Design:

1. Geometry:
    - A cross-section depicts the geometric properties of the roadway or structure, including the width, height, slopes, curvatures, and transitions. It represents the shape of the road surface, cuttings, ditches, medians, shoulders, and any other elements present.
2. Grading:
    - Cross-sections show the grading or slope of the terrain and the roadway itself. This includes the slopes of embankments (fill sections) or cuttings (excavated sections) and any necessary transitions between different grades.
3. Profiles:
    - Cross-sections often include profiles that display the vertical variation of the roadway, showing the elevations and grades at specific points along the cross-section. Profiles are essential for assessing the vertical alignment, including changes in elevation, vertical curves, and vertical clearances.
4. Features and Elements:
    - Cross-sections illustrate various features and elements of the roadway, such as lanes, shoulders, curbs, sidewalks, medians, traffic barriers, drainage structures, signage, and utilities. These elements are typically represented with different symbols, colors, or linetypes to provide clarity.
5. Dimensions:
    - Cross-sections include measurements and dimensions that are essential for construction and analysis purposes. These dimensions may include widths of lanes, shoulders, and other features, as well as slopes, curvatures, and clearances.
6. Construction Details:
    - Cross-sections can show construction details, such as pavement layers, subbase materials, and typical cross-sectional configurations at specific locations. These details help in the construction and quality control processes.

By examining cross-sections at multiple locations along the alignment, designers can ensure consistency, identify potential issues, and optimize the design for safe and efficient transportation or infrastructure projects.

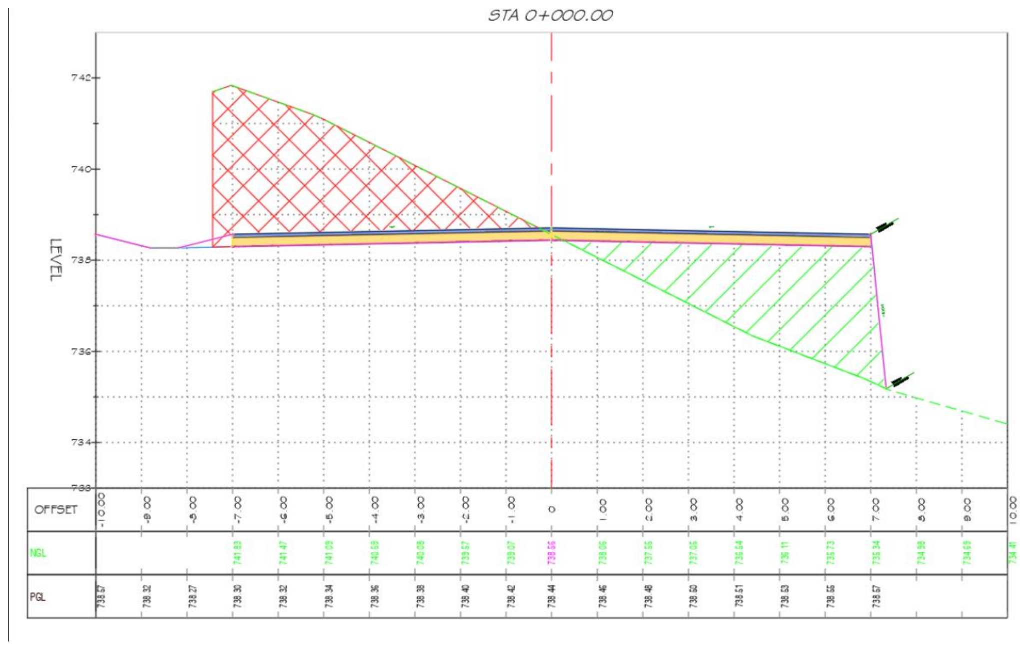


Figure 4-11 Cross – Section

CHAPTER 5 PAVMENT STRUTURE DESIGN

5.1 Introduction.

5.2 Soil.

5.3 Traffic count for asphalt.

5.4 Pavement Design.

5.5 Structural Design.

5.1 Introduction

Pavement structure design is a critical aspect of civil engineering that focuses on creating a durable and safe road surface capable of supporting traffic loads and environmental conditions. The design process involves a systematic approach to ensure the longevity and functionality of roads. Here is an introduction to pavement structure design:

1. Definition and Purpose:
   - Pavement structure design refers to determining the composition and specifications of the layers constituting the road surface. The primary purpose is to create a structure that can withstand the stresses imposed by traffic loads and environmental factors over an extended period.
2. Functional Layers:
   - A typical pavement structure comprises multiple layers, each serving a specific function. These layers often include the surface course, base course, sub-base course, and subgrade. Each layer is designed to distribute loads, provide support, and resist environmental effects.
3. Traffic Analysis:
   - The design process begins with a thorough analysis of expected traffic conditions, including the volume, type, and weight of vehicles using the road. This analysis helps determine the appropriate thickness and composition of each pavement layer to ensure sufficient strength and durability.
4. Material Selection:
   - Pavement designers must carefully select materials for each layer based on factors such as strength, flexibility, and resistance to environmental conditions. The choice of materials significantly influences the overall performance and lifespan of the pavement.
5. Structural Design:
   - The structural design involves determining the thickness and composition of each layer to achieve the required load-bearing capacity. This ensures that the pavement can effectively distribute stresses and prevent premature failure.
6. Environmental Considerations:
   - Pavement structure design takes into account environmental factors such as temperature variations, moisture, and freeze-thaw cycles. Proper design considers these elements to prevent deterioration and extend the life of the pavement.

7. Sustainability and Cost-Effectiveness:
    - Designers strive to balance sustainability and cost-effectiveness by selecting materials and techniques that minimize environmental impact while optimizing the economic aspects of construction and maintenance.
8. Quality Control and Assurance:
    - Throughout the design and construction phases, quality control measures are implemented to ensure that the pavement structure meets specified standards. This includes testing materials, monitoring construction processes, and conducting performance assessments.

In conclusion, pavement structure design is a multifaceted process that integrates engineering principles, material science, and environmental considerations to create road surfaces capable of withstanding the challenges posed by traffic and the surrounding environment. A well-designed pavement structure contributes to the safety, efficiency, and sustainability of transportation infrastructure.

5.2 Soil

Soil is a vital component of the Earth's surface, serving as the foundation for terrestrial ecosystems and playing a crucial role in supporting life. It is a complex mixture of minerals, organic matter, water, air, and living organisms that forms the top layer of the Earth's crust. Soil provides a habitat for plants, animals, and microorganisms, and it plays a fundamental role in various ecological processes.

Key Components of Soil:

1. Mineral Particles:
    - Soil is composed of mineral particles, including sand, silt, and clay. The proportions of these particles determine the soil texture. Sandy soils have larger particles, while clayey soils have smaller particles.
2. Organic Matter:
    - Organic matter in soil consists of decomposed plant and animal residues. It contributes to soil fertility by providing essential nutrients for plant growth and improving soil structure.
3. Water:
    - Soil acts as a reservoir for water, holding moisture that is essential for plant growth. The water-holding capacity of soil depends on its texture and organic matter content.

4. Air:
    - Spaces between soil particles contain air, which is crucial for the respiration of plant roots and soil organisms. Adequate soil aeration ensures the supply of oxygen to support biological activities.
    -
5. Microorganisms:
    - Soil hosts a diverse community of microorganisms, including bacteria, fungi, protozoa, and nematodes. These organisms contribute to nutrient cycling, decomposition of organic matter, and other essential soil functions.

Functions of Soil:

1. Engineering Support:
    - Soil properties influence construction and engineering activities, such as building foundations, road construction, and agricultural practices.

Soil Types:

Different regions exhibit various soil types based on factors like climate, parent material, topography, and vegetation. Major soil classifications include sandy, loamy, clayey, and peaty soils, each with unique characteristics.

Understanding soil properties is essential for agriculture, environmental management, and sustainable land use planning. Soil science, or pedology, is the scientific discipline dedicated to studying the formation, classification, and mapping of soils to optimize their use for various purposes while ensuring conservation and environmental sustainability.

5.3 Traffic Count for Asphalt

When designing roads and selecting the type of asphalt, it is crucial to consider the expected traffic load and the weights of the vehicles that will use the road. Traffic count and vehicle loads are key factors in determining the thickness and quality of the asphalt. Here are some important points to consider:

1. Traffic Study:
    - Conduct traffic flow analysis to estimate the number of vehicles and expected loads over time.
2. Load Determination:
    - Determine the expected loads of vehicles using average and standard weights for vehicles passing on the road, considering additional loads in some cases.

3. Asphalt Design Factors:
   - Select the type and thickness of the asphalt based on the traffic load and vehicle weights.
   - Use asphalt design equations, such as those from the American Association of State Highway and Transportation Officials (AASHTO), to estimate the required asphalt thickness.
   -
4. Subgrade Evaluation:
   - Evaluate the subgrade soil to ensure it can accommodate the expected loads effectively. In some cases, soil improvement techniques, such as fiber reinforcement or lime stabilization, may be used.
5. Maintenance Considerations:
   - Consider future maintenance needs. In some cases, specific types of asphalt are chosen to provide good resistance to wear and extend the road's lifespan.
6. Distortion and Rutting:
   - Assess the impact of vehicle weights on asphalt distortion and rutting, and design the asphalt to withstand these effects.

Determining traffic counts and vehicle loads requires collaboration between road and traffic engineers and experts in asphalt design. An engineering approach ensures that the road can withstand the expected traffic loads over the long term without damage or deterioration.

5.4 Pavement Design

5.4.1 Introduction

Highway pavements are divided into two main categories:

1. Rigid Pavement:
   - The wearing surface of a rigid pavement is usually constructed of Portland cement concrete, acting like a beam over any irregularities in the underlying supporting material.
2. Flexible Pavement:
   - The wearing surface of flexible pavements is constructed of bituminous materials, which remain in contact with the underlying material even when minor irregularities occur.

Flexible pavements typically consist of a bituminous surface underlaid with a layer of granular material and a suitable mixture of coarse and fine materials.

Traffic loads are transferred by the wearing surface to the underlying supporting materials through the interlocking of aggregates, the frictional effect of the granular materials, and the cohesion of the fine materials.

Flexible pavements are further divided into three subgroups:

1. High-Type Pavements:
   - These pavements have wearing surfaces that adequately support the expected traffic load without visible distress due to fatigue and are not susceptible to weather conditions.

2. Intermediate-Type Pavements:
   - These pavements have wearing surfaces that range from surface treated to those with qualities just below that of high-type pavements.
3. Low-Type Pavements:
   - These are mainly used for low-cost roads and have wearing surfaces that range from untreated natural materials to surface-treated earth.

Understanding the differences between these types of pavements helps engineers select the appropriate design and materials to ensure durability and safety for various traffic conditions and environmental factors.

5.4.2 Structural Components of a Flexible Pavement

The structural components of a flexible pavement include several layers, each playing a critical role in the overall performance of the pavement. Figure 5.1 illustrates the typical layers of a flexible pavement, which are as follows:

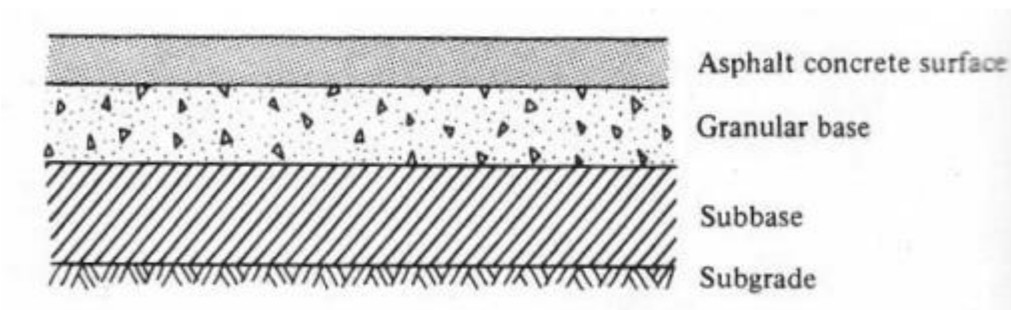


Figure 5-1 Components of a flexible pave

1. Subgrade (Prepared Road Bed):
    - The subgrade is usually the natural material located along the horizontal alignment of the pavement, serving as the foundation of the pavement structure. It may also consist of a layer of selected borrow materials, well compacted. It may be necessary to treat the subgrade material to achieve certain strength properties required for the type of pavement being constructed.
2. Subbase Course:
    - Located immediately above the subgrade, the subbase component consists of material of superior quality compared to that used for subgrade construction. The requirements for subbase materials are usually specified in terms of gradation, plasticity, and strength. When the quality of the subgrade material meets the requirements for subbase materials, the subbase component may be omitted.
3. Base Course:
    - The base course lies immediately above the subbase or directly on the subgrade if a subbase course is not used. This layer typically consists of granular materials such as crushed stone, crushed or uncrushed slag, and crushed or uncrushed gravel. The specifications for base course materials usually include stricter requirements than those for subbase materials, particularly regarding plasticity, gradation, and strength. Materials that do not have the required properties can be used as base material if they are properly stabilized with Portland cement, asphalt, or lime.
4. Surface Course:
    - The surface course is the upper layer of the road pavement, constructed immediately above the base course. In flexible pavements, the surface course typically consists of a mixture of mineral aggregates and asphaltic materials. It must be capable of withstanding high tire pressures, resisting the abrasive forces due to traffic, providing a skid-resistant driving surface, and preventing the penetration of surface water into the underlying layers. The thickness of the wearing surface can vary from 3 inches to more than 6 inches, depending on the expected traffic on the pavement.

Each component's satisfactory performance is essential to the overall effectiveness of the pavement, requiring proper evaluation of the properties of each layer separately to ensure durability and functionality.

5.4.3 General Principles of Flexible Pavement Design

In the design of flexible pavements, the pavement structure is usually considered as a multilayered elastic system, with the material in each layer characterized by specific physical properties, such as the modulus of elasticity, resilience, and the Poisson ratio.

Key principles and considerations in flexible pavement design include:

1. Layer Assumptions:
   - The subgrade layer is typically assumed to be infinite in both horizontal and vertical directions, whereas the other layers are finite in the vertical direction and infinite in the horizontal direction.
2. Stress Distribution:
   - The application of a wheel load causes a stress distribution within the pavement layers, as shown in Figure 5.2. Maximum vertical stresses are compressive and occur directly under the wheel load, decreasing in depth from the surface.

   - Maximum horizontal stresses also occur under the wheel load and can be either tensile or compressive. When the load and pavement thickness are within certain ranges, horizontal compressive stresses will occur above the neutral axis, and horizontal tensile stresses will occur below the neutral axis.
3. Temperature Distribution:
   - Temperature distribution within the pavement structure affects the magnitude of stresses, as shown in Figure 5.2.
4. Design Methods:
   - The availability of advanced computerized solutions and recent advances in materials evaluation has led to the development of several design methods based wholly or partly on theoretical analysis. Some commonly used design methods include:
     1. Asphalt Institute Method
     2. American Association of State Highway and Transportation Officials (AASHTO) Method

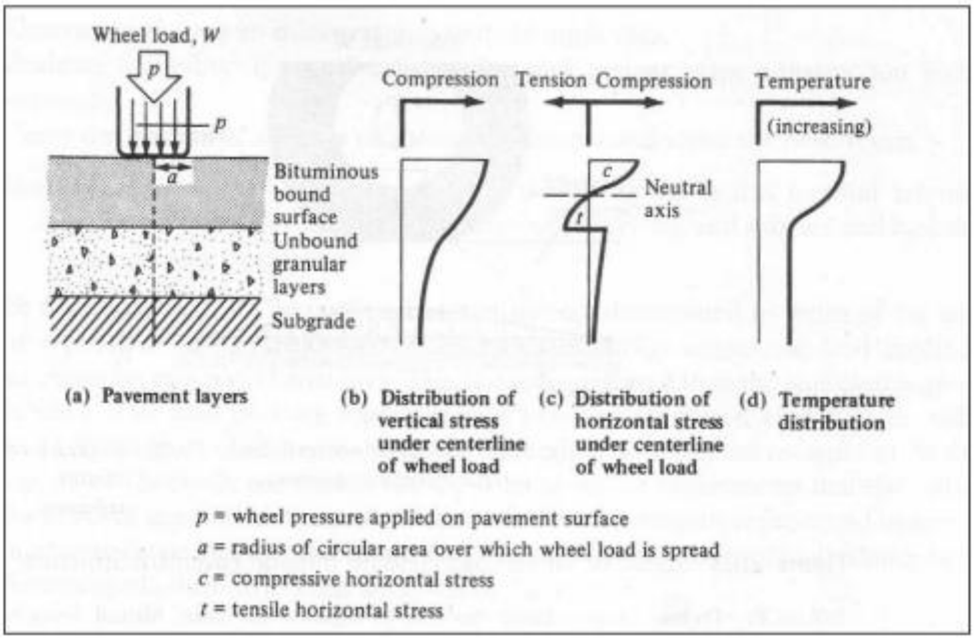


Figure 5-2 Typical Stress and Temperatur Distributions in a Flexible Pavement Under a wheel load

Asphalt Institute Design Method

In the Asphalt Institute design method, the pavement is represented as a multilayered elastic system. The wheel load WW is assumed to be applied through the tire as a uniform vertical pressure p0p_0, which is then spread by the different components of the pavement structure and eventually applied on the subgrade as a much lower stress pvp_v, as shown in Figure 5.3. Experience, established theory, and test data are then used to evaluate two specific stress-strain conditions.

The first condition, shown in Figure 5.3(b), illustrates how the stress p0p_0 is reduced to pxp_x within the depth of the pavement structure. The second condition, shown in Figure 5.4, highlights the tensile and compressive stresses and strains imposed on the asphalt due to the deflection caused by the wheel load.

Design Procedure:

The design procedure aims to determine the minimum thickness of the asphalt layer that can adequately withstand the stresses that develop from two strain criteria: the vertical compressive strain at the surface of the subgrade and the horizontal tensile strain at the bottom of the asphalt layer. Design charts are prepared for a range of traffic loads, typically sufficient for normal traffic volumes encountered in practice. When this range is exceeded, a computer-based version should be used.

The procedure consists of five main steps:

1. Select or Determine Input Data:
    - Gather relevant data, including traffic load, environmental conditions, and material properties.
2. Select Surface and Base Materials:
    - Choose appropriate materials for the surface and base layers based on their performance characteristics and the expected traffic loads.
3. Determine Minimum Thickness Required for Input Data:
    - Use design charts or computational methods to calculate the minimum thickness of each layer to ensure adequate performance under the expected conditions.
4. Evaluate Feasibility of Staged Construction and Prepare Stage Construction Plan, if Necessary:
    - Assess the potential for implementing the construction in stages to manage costs and logistical challenges, and prepare a detailed construction plan.
5. Carry Out Economic Analyses of Alternative Designs and Select the Best Design:
    - Perform cost-benefit analyses of different design alternatives and select the most cost-effective and efficient design.

By following these steps, engineers can design a pavement structure that meets performance criteria, ensures durability, and provides cost-effective solutions for various traffic and environmental conditions.

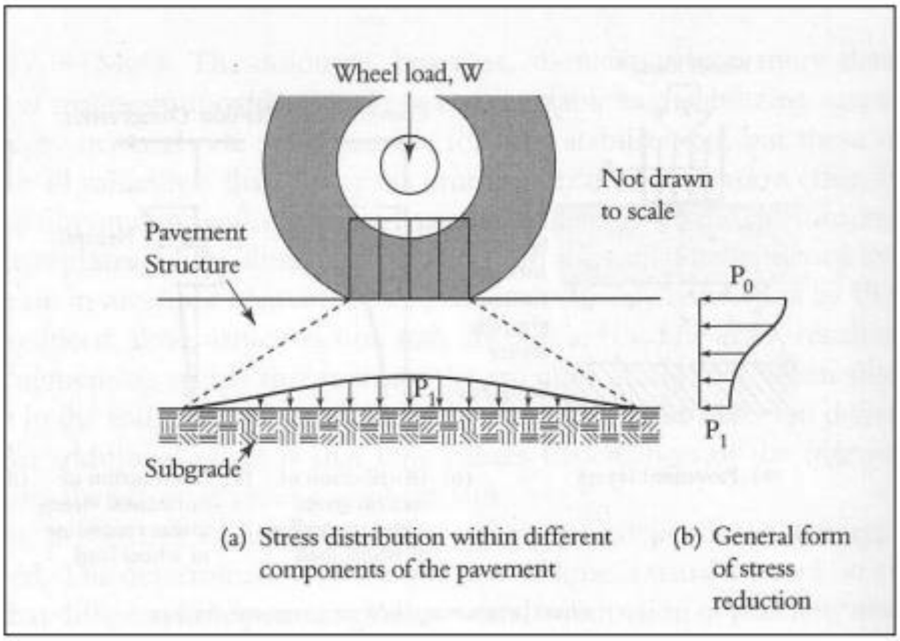


Figure 5-3 3 Spread of Wheel Load Pressure through Pavement Structure

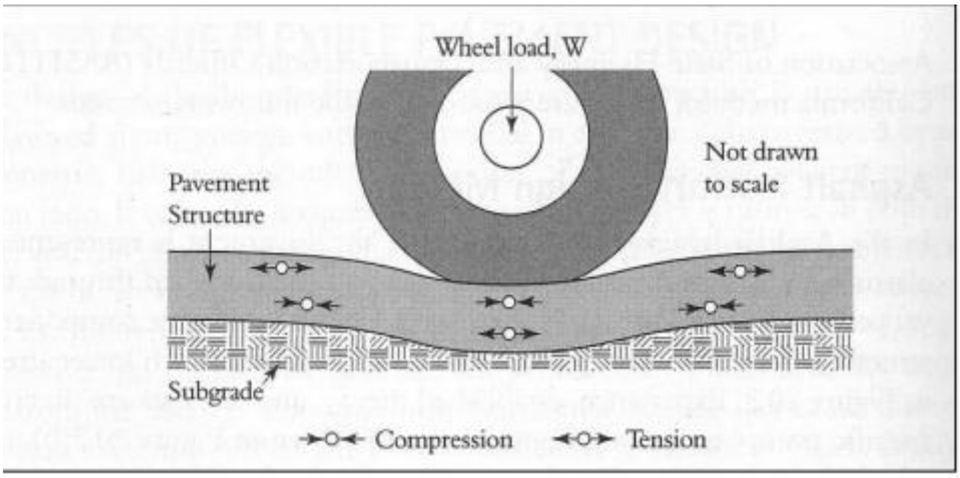


Figure 5-4 Schematic of Tensile and Compressive Stresses in Pavement Structure

Step 1: Determine Design Inputs

The design inputs in the Asphalt Institute design method include traffic characteristics, subgrade engineering properties, and subbase and base engineering properties.

Traffic Characteristics:

- The traffic characteristics are determined in terms of the number of repetitions of an 18,000-lb (80 kN) single-axle load applied to the pavement on two sets of dual tires. This measure is usually referred to as the Equivalent Single-Axle Load (ESAL).

- The dual tires are represented as two circular plates, each with a radius of 4.51 inches, spaced 13.57 inches apart. This representation corresponds to a contact pressure of 70 lb/in^2.
- The use of an 18,000-lb axle load is based on experimental results showing that the effect of any load on the performance of a pavement can be represented in terms of the number of single applications of an 18,000-lb single axle.
- A series of equivalency factors are used in this method for different axle loads, as shown in Table 5.1.

Table 5-1 Load Equivalency

Gross Axle Load		Load Equivalency Factors		
kN	*lb*	*Single Axles*	*Tandem Axles*	*Tridem Axles*
4.45	1,000	0.00002		
8.9	2,000	0.00018		
17.8	4,000	0.00209	0.0003	
26.7	6,000	0.01043	0.001	0.0003
35.6	8,000	0.0343	0.003	0.001
44.5	10,000	0.0877	0.007	0.002
53.4	12,000	0.189	0.014	0.003
62.3	14,000	0.360	0.027	0.006
71.2	16,000	0.623	0.047	0.011
80.0	18,000	1.000	0.077	0.017
89.0	20,000	1.51	0.121	0.027
97.9	22,000	2.18	0.180	0.040
106.8	24,000	3.03	0.260	0.057
115.6	26,000	4.09	0.364	0.080
124.5	28,000	5.39	0.495	0.109
133.4	30,000	6.97	0.658	0.145
142.3	32,000	8.88	0.857	0.191
151.2	34,000	11.18	1.095	0.246
160.1	36,000	13.93	1.39	0.313
169.0	38,000	17.20	1.70	0.393
178.0	40,000	21.08	2.08	0.487
187.0	42,000	25.64	2.51	0.597
195.7	44,000	31.00	3.00	0.723

Gross Axle Load		Load Equivalency Factors		
kN	*lb*	*Single Axles*	*Tandem Axles*	*Tridem A*
204.5	46,000	37.24	3.55	0.868
213.5	48,000	44.50	4.17	1.033
222.4	50,000	52.88	4.86	1.22
231.3	52,000		5.63	1.43
240.2	54,000		6.47	1.66
249.0	56,000		7.41	1.91
258.0	58,000		8.45	2.20
267.0	60,000		9.59	2.51
275.8	62,000		10.84	2.85
284.5	64,000		12.22	3.22
293.5	66,000		13.73	3.62
302.5	68,000		15.38	4.05
311.5	70,000		17.19	4.52
320.0	72,000		19.16	5.03
329.0	74,000		21.32	5.57
338.0	76,000		23.66	6.15
347.0	78,000		26.22	6.78
356.0	80,000		29.0	7.45
364.7	82,000		32.0	8.2
373.6	84,000		35.3	8.9
382.5	86,000		38.8	9.8
391.4	88,000		42.6	10.6
400.3	90,000		46.8	11.6

Note: kN converted to lb are within 0.1 percent of lb shown.
SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets,* Manual Series No. 1, The Asphalt In[illegible] Lexington, Ky., February 1991.

To determine the Equivalent Single-Axle Load (ESAL), you must know the number and types of vehicles, such as cars, buses, single-unit trucks, and multiple-unit trucks, expected to use the facility during its lifetime.

This information is typically obtained from classification counts conducted by highway agencies at regular intervals.

If specific data are unavailable, you can refer to Table 5.2, which provides representative values for the United States. When the axle load of each vehicle type is known, you can convert these loads to equivalent 18,000-lb loads using the equivalency factors in Table 5.1. If the axle load is unknown, you can determine the 18,000-lb load equivalent by using a truck factor for that vehicle type.

By following this process, you can accurately estimate the traffic load in terms of ESALs, which is critical for designing pavements that can withstand the expected traffic over their intended lifespan.

The truck factor is defined as the number of 18,000-lb single-load applications caused by a single passage of a vehicle. This factor is determined for each class of vehicle using the following expression:

$$\text{truck factor} = \frac{\sum(\text{number of axles} \times \text{load equivalency factor})}{\text{number of vehicles}}$$

Table 5-2 Distribution of Trucks on different classes of Highways

Truck Class	Percent Trucks											
	Rural Systems						Urban Systems					
	Interstate	Other Principal	Minor Arterial	Collectors Major	Collectors Minor	Range	Interstate	Other Freeways	Other Principal	Minor Arterial	Collectors	Range
Single-unit trucks												
2-axle, 4-tire	43	60	71	73	80	43–80	52	66	67	84	86	52–86
2-axle, 6-tire	8	10	11	10	10	8–11	12	12	15	9	11	9–15
3-axle or more	2	3	4	4	2	2–4	2	4	3	2	<1	<1–4
All single-units	53	73	86	87	92	53–92	66	82	85	95	97	66–97
Multiple-unit trucks												
4-axle or less	5	3	3	2	2	2–5	5	5	3	2	1	1–5
5-axle**	41	23	11	10	6	6–41	28	13	12	3	2	2–28
6-axle or more**	1	1	<1	1	<1	<1–1	1	<1	<1	<1	<1	<1–1
All multiple units	47	27	14	13	8	8–47	34	18	15	5	3	3–34
All trucks	100	100	100	100	100		100	100	100	100	100	

* Compiled from data supplied by the Highway Statistics Division, Federal Highway Administration.
**Including full-trailer combinations in some states.
SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

To determine the truck factors for different classes of vehicles, it is advisable to collect data on axle loads for the types of vehicles expected to use the proposed highway. This approach ensures realistic truck factors are determined from that data. Table 5.5 provides values of truck factors for various vehicle classes, which can be a useful reference.

The total ESAL (Equivalent Single-Axle Load) applied on the highway during its design period can only be determined after knowing the design period and traffic growth factors. The design period refers to the number of years the pavement will effectively carry the traffic load without requiring an overlay. Considering traffic growth over time helps accurately estimate the

cumulative ESAL, which is crucial for designing a pavement structure that ensures long-term durability under expected traffic conditions.
By taking into account these inputs, engineers can design pavements that are well-suited to handle the anticipated traffic loads, thereby enhancing the road's performance and lifespan.

Flexible highway pavements are typically designed for a 20-year period. Since traffic volume does not remain constant over this period, it is essential to determine the rate of growth and apply it when calculating the total ESAL (Equivalent Single-Axle Load). Annual growth rates can be obtained from regional planning agencies or state highway departments, based on traffic volume counts over several years.
Key Considerations:

1. Annual Growth Rates:
    - It is advisable to determine annual growth rates separately for trucks and passenger vehicles, as they may differ significantly. In the United States, the overall growth rate is between 3% and 5% per year, although growth rates of up to 10% per year have been suggested for some interstate highways.

2. Growth Factors:
    - Table 5.4 shows growth factors (Gf) for different growth rates (J) and design periods (t). These factors can be used to determine the total ESAL over the design period.
3. Design Lane:
    - The portion of the total ESAL acting on the design lane (fd) is crucial for determining pavement thickness. Either lane of a two-lane highway can be considered the design lane, while for multilane highways, the outside lane is considered. Identifying the design lane is important because more trucks may travel in one direction or may travel heavily loaded in one direction and empty in the other.
4. Determination of Relevant Proportion:
    - It is necessary to determine the relevant proportion on the design lane. When data are not available, percentages given in Table 5.7 can be used as a reference.

$$ESAL_i = f_d \times G_{jt} \times AADT_i \times 365 \times N_i \times F_{Ei}$$

where

$ESAL_i$ = equivalent accumulated 18,000-lb (80 kN) single-axle load for category i

f_d = design lane factor

G_{jt} = growth factor for a given growth rate j and design period t

$AADT_i$ = first year annual average daily traffic for axle category i

N_i = number of axles on each vehicle in category i

F_{Ei} = load equivalency factor for axle category i

When truck factors are used, the ESAL for each category of truck is given as:

$$ESAL_i = AADT_i \times 365 \times f_i \times G_{jt} \times f_d$$

Table 5-3 Distribution of Truck Factors (TF) for Different Classes of Highways and Vehicles-United States

	Truck Factors											
	Rural Systems						*Urban Systems*					
Vehicle Type	*Interstate*	*Other Principal*	*Minor Arterial*	*Collectors Major*	*Collectors Minor*	*Range*	*Interstate*	*Other Freeways*	*Other Principal*	*Minor Arterial*	*Collectors*	*Range*
Single-unit trucks												
2-axle, 4-tire	0.003	0.003	0.003	0.017	0.003	0.003–0.017	0.002	0.015	0.002	0.006	—	0.006–0.015
2-axle, 6-tire	0.21	0.25	0.28	0.41	0.19	0.19–0.41	0.17	0.13	0.24	0.23	0.13	0.13–0.24
3-axle or more	0.61	0.86	1.06	1.26	0.45	0.45–1.26	0.61	0.74	1.02	0.76	0.72	0.61–1.02
All single units	0.06	0.08	0.08	0.12	0.03	0.03–0.12	0.05	0.06	0.09	0.04	0.16	0.04–0.16
Tractor-semitrailers												
4-axle or less	0.62	0.92	0.62	0.37	0.91	0.37–0.91	0.98	0.48	0.71	0.46	0.40	0.40–0.98
5-axle**	1.09	1.25	1.05	1.67	1.11	1.05–1.67	1.07	1.17	0.97	0.77	0.63	0.63–1.17
6-axle or more**	1.23	1.54	1.04	2.21	1.35	1.04–2.21	1.05	1.19	0.90	0.64	—	0.64–1.19
All multiple units	1.04	1.21	0.97	1.52	1.08	0.97–1.52	1.05	0.96	0.91	0.67	0.53	0.53–1.05
All trucks	0.52	0.38	0.21	0.30	0.12	0.12–0.52	0.39	0.23	0.21	0.07	0.24	0.07–0.39

Note: Compiled from data supplied by the Highway Statistics Division, Federal Highway Administration.

*Including full-trailer combinations in some states.

**For values to be used when the number of heavy trucks is low, see original source.

SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

Table 5-4 Growth Factor

Design Period, Years (n)	Annual Growth Rate, Percent (r)							
	No Growth	2	4	5	6	7	8	10
1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	2.0	2.02	2.04	2.05	2.06	2.07	2.08	2.10
3	3.0	3.06	3.12	3.15	3.18	3.21	3.25	3.31
4	4.0	4.12	4.25	4.31	4.37	4.44	4.51	4.64
5	5.0	5.20	5.42	5.53	5.64	5.75	5.87	6.11
6	6.0	6.31	6.63	6.80	6.98	7.15	7.34	7.72
7	7.0	7.43	7.90	8.14	8.39	8.65	8.92	9.49
8	8.0	8.58	9.21	9.55	9.90	10.26	10.64	11.44
9	9.0	9.75	10.58	11.03	11.49	11.98	12.49	13.58
10	10.0	10.95	12.01	12.58	13.18	13.82	14.49	15.94
11	11.0	12.17	13.49	14.21	14.97	15.78	16.65	18.53
12	12.0	13.41	15.03	15.92	16.87	17.89	18.98	21.38
13	13.0	14.68	16.63	17.71	18.88	20.14	21.50	24.52
14	14.0	15.97	18.29	19.16	21.01	22.55	24.21	27.97
15	15.0	17.29	20.02	21.58	23.28	25.13	27.15	31.77
16	16.0	18.64	21.82	23.66	25.67	27.89	30.32	35.95
17	17.0	20.01	23.70	25.84	28.21	30.84	33.75	40.55
18	18.0	21.41	25.65	28.13	30.91	34.00	37.45	45.60
19	19.0	22.84	27.67	30.54	33.76	37.38	41.45	51.16
20	20.0	24.30	29.78	33.06	36.79	41.00	45.76	57.28
25	25.0	32.03	41.65	47.73	54.86	63.25	73.11	98.35
30	30.0	40.57	56.08	66.44	79.06	94.46	113.28	164.49
35	35.0	49.99	73.65	90.32	111.43	138.24	172.32	271.02

Note: Factor = $[(1+r)^n - 1]/r$, where $r = \frac{\text{rate}}{100}$ and is not zero. If annual growth is zero, growth factor = design period.
SOURCE: *Thickness Design—Asphalt Pavements for Highways and Streets*, Manual Series No. 1, The Asphalt Institute, Lexington, Ky., February 1991.

Table 5-5 Percentage of total truck on design lane

Number of Traffic Lanes (Two Directions)	Percentage of Trucks in Design Lane
2	50
4	45 (35–48)*
6 or more	40 (25–48)*

*Probable range.
SOURCE: Adapted from *Thickness Design—Asphalt Pavements for Highways and Streets*, phalt Institute, Lexington, Ky., February 1991.

5.4.4 AASHTO Design Method

The AASHTO method for the design of highway pavements is based primarily on the results of the AASHTO road test conducted in Ottawa, Illinois. It was a cooperative effort carried out under the auspices of 49 states, the District of Columbia, Puerto Rico, the Bureau of Public Roads, and several industry groups. Tests were conducted on short-span bridges and test sections of flexible and rigid pavement constructed on A-6 subgrade material. The pavement test sections consisted of loops and four larger ones, each being a four-lane divided highway.

Design Considerations

The factors considered in the AASHTO procedure for the design of flexible pavement, as presented in the 1993 guide, are:

1. Pavement Performance:
    - Structural Performance: Related to the physical condition of the pavement with respect to factors that negatively impact the pavement's capability to carry the traffic load. These factors include cracking, faulting, raveling, etc.
    - Functional Performance: An indication of how effectively the pavement serves the user. The main factor considered here is riding comfort.
2. Traffic:
    - The treatment of traffic load in the AASHTO design method is similar to that presented for the Asphalt Institute method. The traffic load application is in terms of the number of 18,000-lb single-axle loads (ESALs). The procedure to determine the design ESAL is used here. However, the equivalence factors are based on the terminal serviceability index to be used in the design and the structural number (SN).
3. Roadbed Soils (Subgrade Material):
    - The 1993 AASHTO guide uses the resilient modulus (Mr) of the soil to define its properties. The method allows conversion of the CBR (California Bearing Ratio) or R value of the soil to an equivalent Mr value using the following conversion factors:
    - conversion factors: Mr. (lb/in.2) = 1500 CBR (for fine-grain soils with soaked CBR of 10 or less) Mr (lb/in.2) = 1000 + 555 x R value (for R < 20)
4. Materials of Construction
5. Environment
6. Drainage
7. Reliability

Table 5-6 Axle Load Equivalency Factors for Flexible Pavements, Single Axles

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0004	.0004	.0003	.0002	.0002	.0002
4	.003	.004	.004	.003	.002	.002
6	.011	.017	.017	.013	.010	.009
8	.032	.047	.051	.041	.034	.031
10	.078	.102	.118	.102	.088	.080
12	.168	.198	.229	.213	.189	.176
14	.328	.358	.399	.388	.360	.342
16	.591	.613	.646	.645	.623	.606
18	1.00	1.00	1.00	1.00	1.00	1.00
20	1.61	1.57	1.49	1.47	1.51	1.55
22	2.48	2.38	2.17	2.09	2.18	2.30
24	3.69	3.49	3.09	2.89	3.03	3.27
26	5.33	4.99	4.31	3.91	4.09	4.48
28	7.49	6.98	5.90	5.21	5.39	5.98
30	10.3	9.5	7.9	6.8	7.0	7.8
32	13.9	12.8	10.5	8.8	8.9	10.0
34	18.4	16.9	13.7	11.3	11.2	12.5
36	24.0	22.0	17.7	14.4	13.9	15.5
38	30.9	28.3	22.6	18.1	17.2	19.0
40	39.3	35.9	28.5	22.5	21.1	23.0
42	49.3	45.0	35.6	27.8	25.6	27.7
44	61.3	55.9	44.0	34.0	31.0	33.1
46	75.5	68.8	54.0	41.4	37.2	39.3
48	92.2	83.9	65.7	50.1	44.5	46.5
50	112.0	102.0	79.0	60.0	53.0	55.0

In the context of the AASHTO design method, the constants AA and BB can vary, with AA ranging from 772 to 1155 and BB ranging from 369 to 555. The Asphalt Institute uses the maximum values of AA and BB, while AASHTO recommends using values of 1000 and 555, respectively.

Materials of Construction:

The materials used for construction in the AASHTO design method are classified into three general groups:

1. Subbase Construction:
   - The subbase layer consists of materials that provide additional support to the base layer and help distribute traffic loads to the subgrade.
2. Base Construction:
   - The base layer is constructed with materials that provide structural support and distribute loads to the subbase and subgrade layers.
3. Surface Construction:
   - The surface layer, often made of asphalt, is designed to withstand traffic wear and provide a smooth driving surface. It is the topmost layer of the pavement structure.

Subbase Construction Materials:

The quality of subbase construction materials is determined in terms of the layer coefficient (a3a_3), which is used to convert the actual thickness of the subbase to an equivalent Structural Number (SN). For instance, the sandy gravel subbase course material used in the AASHTO road test was assigned a value of 0.11. Layer coefficients are usually assigned based on the material description. However, due to varying environmental, traffic, and construction conditions, it is essential that each design agency develops layer coefficients suitable for its specific environment.

Granular Subbase Materials:

- Charts correlating layer coefficients with different soil engineering properties have been developed. Figure 5.5 illustrates one such chart for granular subbase materials.

Base Course Construction Materials:

Materials selected for the base course should meet the general requirements for base course materials. A structural layer coefficient (a2a_2) for the material used should also be determined. This can be done using Figure 5.6.

Surface Course Construction Materials:

The most commonly used material for the surface course is a hot plant mix of asphalt cement and dense-graded aggregates with a maximum size of 1 inch. The procedure discussed in Chapter 19 for the design of asphalt mix can be utilized. The structural layer coefficient (a1a_1) for the surface course can be extracted from Figure 5.7, which relates the structural layer coefficient of a dense-graded asphalt concrete surface course with its resilient modulus at 68°F.

Table 5-7 Axle Load Equivalency Factors for Flexible Pavements, Tandem Axles

Axle Load (kips)	Pavement Structural Number (SN)					
	1	2	3	4	5	6
2	.0001	.0001	.0001	.0000	.0000	.0000
4	.0005	.0005	.0004	.0003	.0003	.0002
6	.002	.002	.002	.001	.001	.001
8	.004	.006	.005	.004	.003	.003
10	.008	.013	.011	.009	.007	.006
12	.015	.024	.023	.018	.014	.013
14	.026	.041	.042	.033	.027	.024
16	.044	.065	.070	.057	.047	.043
18	.070	.097	.109	.092	.077	.070
20	.107	.141	.162	.141	.121	.110
22	.160	.198	.229	.207	.180	.166
24	.231	.273	.315	.292	.260	.242
26	.327	.370	.420	.401	.364	.342
28	.451	.493	.548	.534	.495	.470
30	.611	.648	.703	.695	.658	.633
32	.813	.843	.889	.887	.857	.834
34	1.06	1.08	1.11	1.11	1.09	1.08
36	1.38	1.38	1.38	1.38	1.38	1.38
38	1.75	1.73	1.69	1.68	1.70	1.73
40	2.21	2.16	2.06	2.03	2.08	2.14
42	2.76	2.67	2.49	2.43	2.51	2.61
44	3.41	3.27	2.99	2.88	3.00	3.16
46	4.18	3.98	3.58	3.40	3.55	3.79
48	5.08	4.80	4.25	3.98	4.17	4.49
50	6.12	5.76	5.03	4.64	4.86	5.28
52	7.33	6.87	5.93	5.38	5.63	6.17
54	8.72	8.14	6.95	6.22	6.47	7.15
56	10.3	9.6	8.1	7.2	7.4	8.2
58	12.1	11.3	9.4	8.2	8.4	9.4
60	14.2	13.1	10.9	9.4	9.6	10.7
62	16.5	15.3	12.6	10.7	10.8	12.1
64	19.1	17.6	14.5	12.2	12.2	13.7
66	22.1	20.3	16.6	13.8	13.7	15.4
68	25.3	23.3	18.9	15.6	15.4	17.2
70	29.0	26.6	21.5	17.6	17.2	19.2
72	33.0	30.3	24.4	19.8	19.2	21.3
74	37.5	34.4	27.6	22.2	21.3	23.6
76	42.5	38.9	31.1	24.8	23.7	26.2
78	48.0	43.9	35.0	27.8	26.2	28.8

Environment

In the AASHTO method, temperature and rainfall are the two primary environmental factors considered when evaluating pavement performance. These factors significantly impact the durability and functionality of asphalt pavements.

Effects of Temperature:

- Thermal Stresses: Temperature changes induce stresses within the pavement due to expansion and contraction.
- Creep Properties: Temperature variations can alter the creep properties of asphalt, affecting its long-term deformation under sustained loads.
- Freezing and Thawing: Cycles of freezing and thawing can affect the subgrade soil, leading to potential issues such as frost heave and loss of support for the pavement layers.

Effects of Rainfall:

- Surface Water Penetration: Rainfall can lead to the penetration of surface water into the underlying materials, potentially altering their properties. This can result in weakened support layers and reduced pavement performance.
- Preventive Measures: Different methods to prevent water penetration, such as proper drainage systems and sealing techniques, are crucial to maintaining pavement integrity.

Test results have shown that the normal modulus (i.e., the modulus during summer and fall seasons) of materials susceptible to frost action can reduce by 50% to 80% during the thaw period. Additionally, the resilient modulus of a subgrade material may vary throughout the year, even without a specific thaw period. This variation is particularly evident in areas subject to very heavy rains during certain periods of the year, affecting the strength of the material.

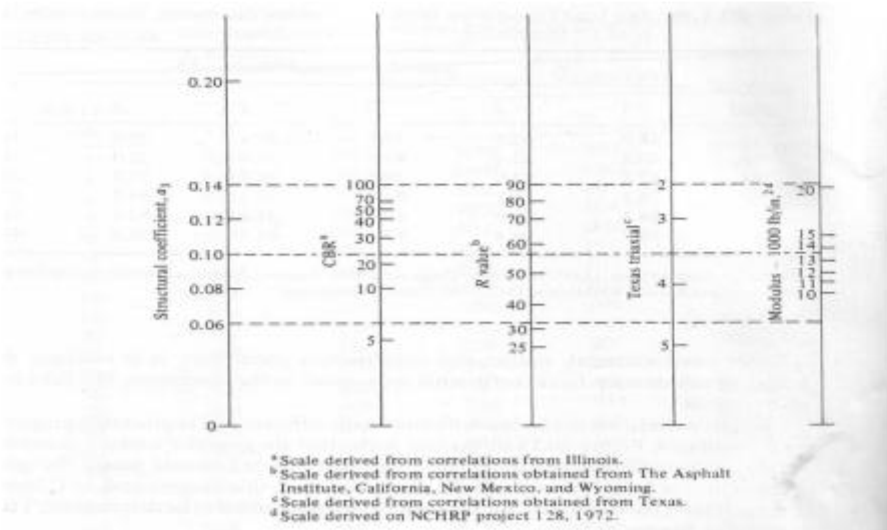


Figure 5-5 Variations in Granular Subbase Layer Coefficient, a3, with Various Subbase Strength Parameters

To account for the variation in the resilient modulus of the subgrade material due to environmental factors such as frost and heavy rains, the procedure involves determining an effective annual resilient modulus.

Effective Annual Resilient Modulus

This approach ensures that the change in the Pavement Serviceability Index (PSI) over a full year will be the same whether the effective resilient modulus is used for the entire year or the appropriate resilient modulus for each season is used. Essentially, the effective resilient modulus represents the combined effect of the varying resilient modulus throughout the different seasons of the year.

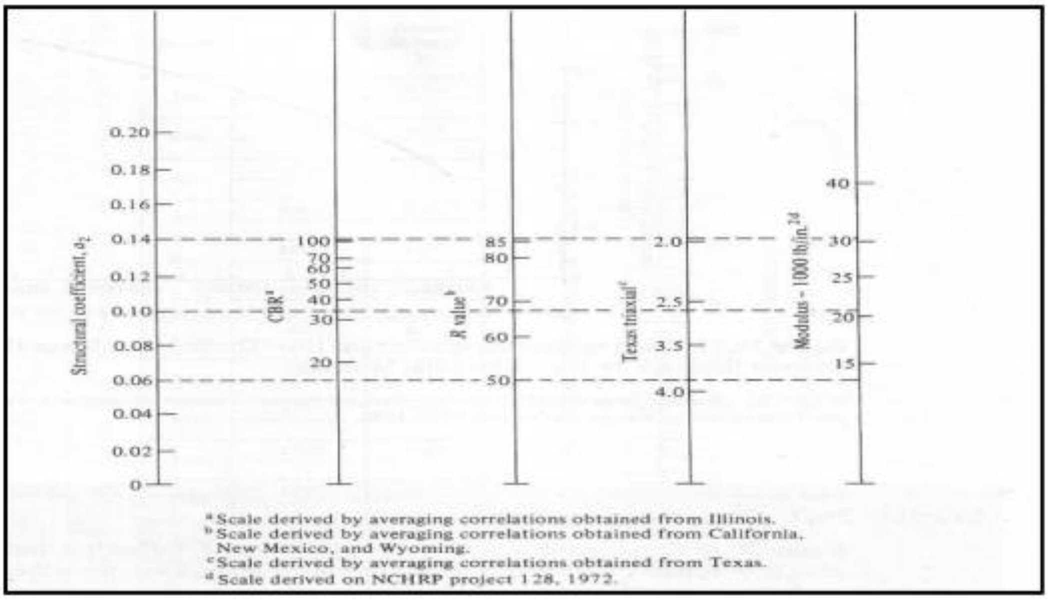


Figure 5-6 Variation in Granular Base Layer Coefficient a2, with Various Subbase Strength Parameters

The AASHTO guide suggests two methods for determining the effective resilient modulus. I'll describe the first method here:

Method for Determining Effective Resilient Modulus

1. Relationship Development:
   - Develop a relationship between the resilient modulus of the soil material and moisture content using laboratory test results.
2. Seasonal Resilient Modulus:
   - Use this relationship to determine the resilient modulus for each season based on the estimated in situ moisture content during that season.
3. Time Intervals:
   - Divide the whole year into different time intervals that correspond to the different seasonal resilient moduli. The AASHTO guide suggests not using a time interval less than one-half month.
4. Relative Damage UjU_j:
   - Determine the relative damage UjU_j for each time period using a chart or an equation provided in Figure 20.18.
5. Mean Relative Damage:
   - Compute the mean relative damage UjU_j and use it to determine the effective subgrade resilient modulus. This effective modulus accounts for the combined effect of different resilient moduli throughout the year.

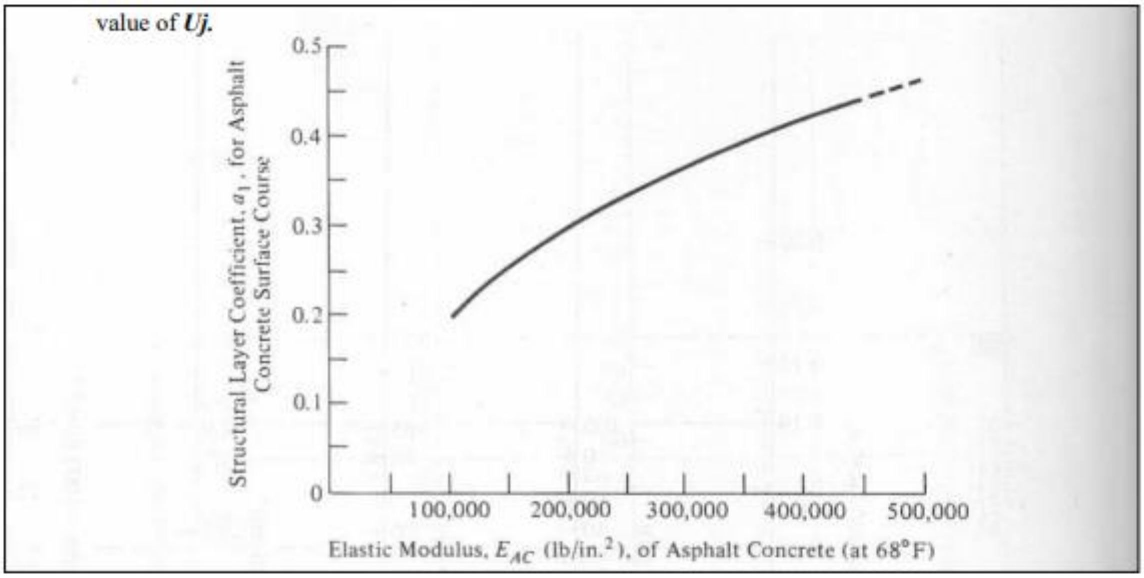


Figure 5-7 Chart for Estimating Structural Layer Coefficient of DenseGraded/Asphalt Concrete Based on the Elastic (Resilient) Modulus

Drainage

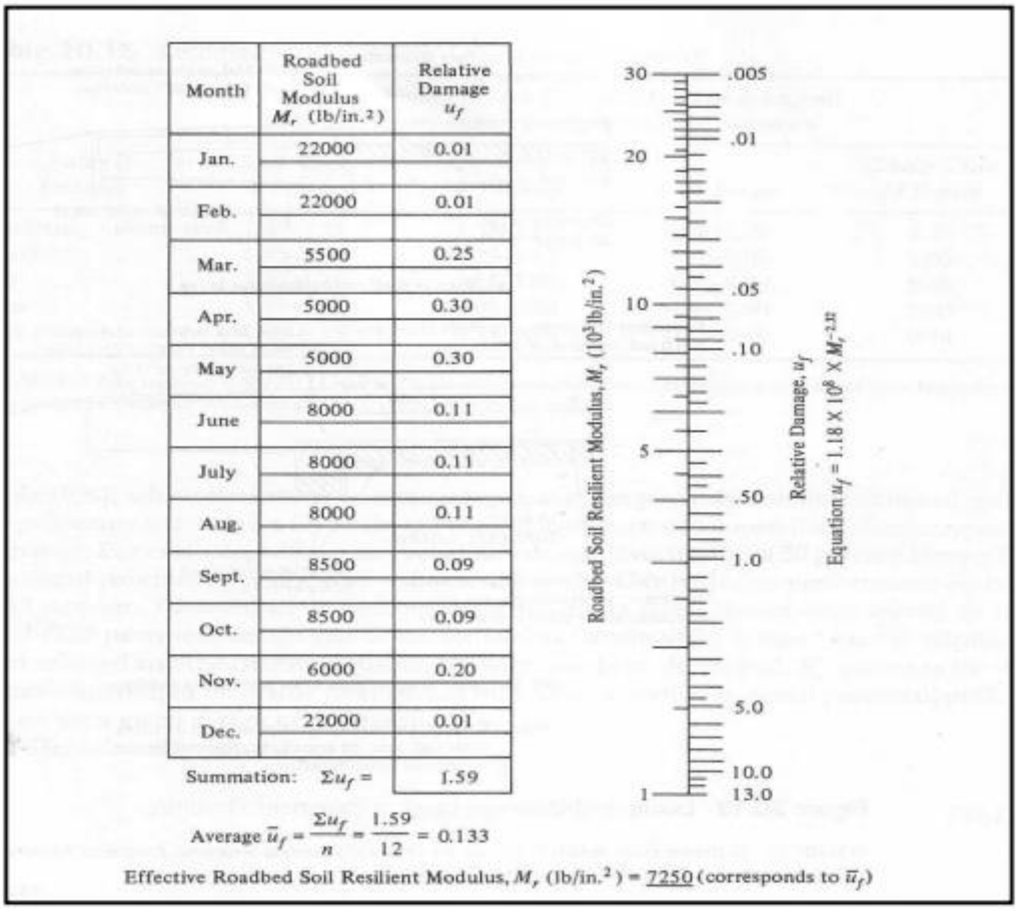
The effect of drainage on the performance of flexible pavements is considered in the 1993 AASHTO guide with respect to how water impacts the strength of the base material and roadbed soil. The approach aims to provide rapid drainage of free water (no capillary action) from the pavement structure. This is achieved by including a suitable drainage layer, as shown in Figure 5.8, and modifying the structural layer coefficient.

Modification of Structural Layer Coefficients:

- The structural layer coefficients for the base (a2a_2) and subbase (a3a_3) layers are adjusted by incorporating a factor MiM_i.
- These factors are based on the percentage of time the pavement structure is nearly saturated and the quality of drainage, which depends on the time it takes to drain the base layer to 50% saturation.

Quality of Drainage:

- Table 5.8 provides definitions of different levels of drainage quality.
- Table 5.9 recommends MiM_i values for various levels of drainage quality.



Month	Roadbed Soil Modulus M_r (lb/in.^{2})	Relative Damage u_f
Jan.	22000	0.01
Feb.	22000	0.01
Mar.	5500	0.25
Apr.	5000	0.30
May	5000	0.30
June	8000	0.11
July	8000	0.11
Aug.	8000	0.11
Sept.	8500	0.09
Oct.	8500	0.09
Nov.	6000	0.20
Dec.	22000	0.01
Summation: Σu_f =		1.59

Average $\bar{u}_f = \frac{\Sigma u_f}{n} = \frac{1.59}{12} = 0.133$

Effective Roadbed Soil Resilient Modulus, M_r (lb/in.^{2}) = 7250 (corresponds to $\bar{u}_f$)

Figure 5-8 Chart for Estimating Effective Roadbed Soil Resilient Modulus for Flexible Pavements Designed Using the Serviceability Criteria

Reliability

Reliability in pavement design addresses the uncertainties in traffic and performance predictions. It is crucial because the cumulative Equivalent Single-Axle Load (ESAL) is a significant input for any pavement design method, and its determination often relies on assumed growth rates, which might not be precise. While most design methods do not account for this uncertainty, the 1993 AASHTO guide incorporates a reliability factor to handle these uncertainties.

Key Points about Reliability in the AASHTO Method:

1. Traffic Prediction Uncertainty:
   - The reliability factor considers the possible inaccuracies in traffic predictions, as growth rates may not always be accurate.
2. Performance Prediction Uncertainty:
   - It also accounts for the potential variations in performance predictions, ensuring that the pavement design remains robust under different scenarios.

3. Reliability Factor:
    - The methodology involves using a reliability factor that adjusts the design to account for the uncertainties. This factor helps in designing pavements that are more resilient to unexpected changes in traffic volumes and performance conditions.

Table 5-8 Definition of drainage Quality

Quality of Drainage	Water Removed Within*
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very poor	(water will not drain)

*Time required to drain the base layer to 50 percent saturation.
SOURCE: Adapted with permission from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993.

Table 5-9 recommended mi Values

Quality of Drainage	Percent of Time Pavement Structure Is Exposed to Moisture Levels Approaching Saturation: Less Than 1 Percent	1–5 Percent	5–25 Percent	Greater Than 25 Percent
Excellent	1.40–1.35	1.35–1.30	1.30–1.20	1.20
Good	1.35–1.25	1.25–1.15	1.15–1.00	1.00
Fair	1.25–1.15	1.15–1.05	1.00–0.80	0.80
Poor	1.15–1.05	1.05–0.80	0.80–0.60	0.60
Very Poor	1.05–0.95	0.95–0.75	0.75–0.40	0.40

SOURCE: Adapted from *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, D.C., 1993. Used by permission.

Reliability levels (R%) have been developed for different types of highways to determine assurance levels that the pavement section designed using the procedure will survive for its design period. For example, a 50 percent reliability design level implies a 50 percent chance for successful pavement performance—that is, the probability of design performance success is 50 percent. Table 5.11 shows suggested reliability levels based on a survey of the AASHTO pavement design task force.

Reliability factors, FR > 1, based on the reliability level selected and the overall variation, have also been developed. This accounts for the chance variation in the traffic forecast and the chance variation in actual pavement performance for a given design period traffic, Wl8.

The reliability factor FR is given as follows:

Table 5-10 Suggested Levels of Reliability for Various Functional Classifications

	Recommended Level of Reliability	
Functional Classification	*Urban*	*Rural*
Interstate and other freeways	85–99.9	80–99.9
Other principal arterials	80–99	75–95
Collectors	80–95	75–95
Local	50–80	50–80

Table 5-11 Standard Normal Deviation (ZR) Values Corresponding to Selected Levels of Reliability

Reliability (R%)	*Standard Normal Deviation, Z_R*
50	−0.000
60	−0.253
70	−0.524
75	−0.674
80	−0.841
85	−1.037
90	−1.282
91	−1.340
92	−1.405
93	−1.476
94	−1.555
95	−1.645
96	−1.751
97	−1.881
98	−2.054
99	−2.327
99.9	−3.090
99.99	−3.750

5.5 Structural Design

The objective of the design using the AASHTO method is to determine a flexible pavement Structural Number (SN) adequate to carry the projected design Equivalent Single Axle Loadings (ESALs). The designer is given the freedom to select the type of surface, which can be asphalt concrete, a single surface treatment, or a double surface treatment. This design procedure is applicable for ESALs greater than 50,000 for the performance period, while designs for ESALs less than this are typically considered under low-volume roads.

The 1993 AASHTO guide provides the expression for SN as follows:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

where

m_i = drainage coefficient for layer i

a_1, a_2, a_3 = layer coefficients representative of surface, base, and subbase course, respectively

D_1, D_2, D_3 = actual thickness in inches of surface, base, and subbase courses, respectively

The basic design equation given in the 1993 guide is

$$\log_{10} W_{18} = Z_R S_o + 9.36 \log_{10}(\mathrm{SN} + 1) - 0.20 + \frac{\log_{10}[\Delta\mathrm{PSI}/(4.2 - 1.5)]}{0.40 + [1094/(\mathrm{SN} + 1)^{5.19}]} + 2.32 \log_{10} M_r - 8.07 \quad (20.13)$$

where

W_{18} = predicted number of 18,000-lb (80 kN) single-axle load applications

Z_R = standard normal deviation for a given reliability

S_o = overall standard deviation

SN = structural number indicative of the total pavement thickness

$\Delta\mathrm{PSI} = p_i - p_t$

p_i = initial serviceability index

p_t = terminal serviceability index

M_r = resilient modulus in lb/in.^{2}

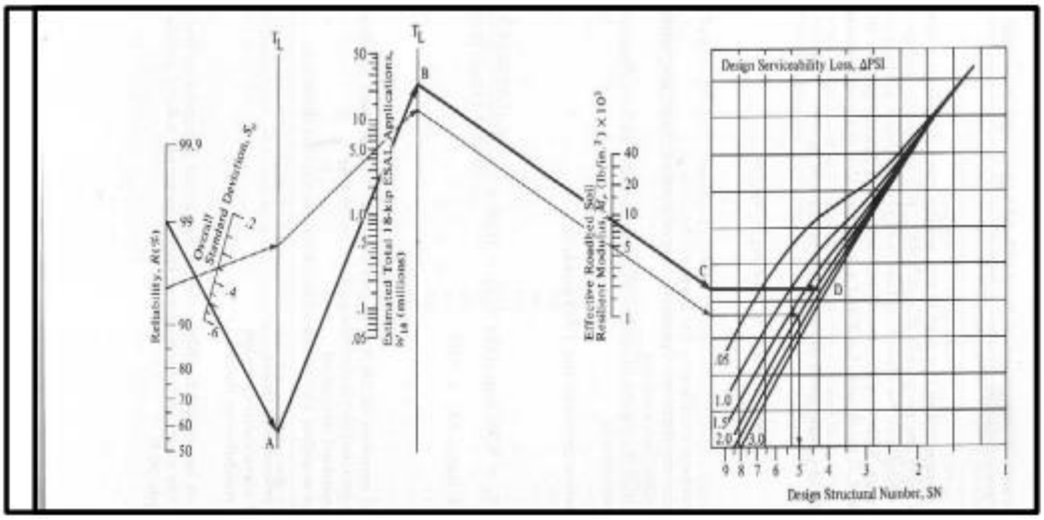


Figure 5-9 Design Chart for Flexible Pavements Based on Using Mean Values for Each Input

ESAL = 2×10^6

Mr for asphalt = 450000 lb/in^2

CBR of basecourse = 100 , Mr = 31000 lb/in^2

CBR of subbase = 22 , Mr = 13500 lb/in^2

CBR of subgrade = 6

---

* Mr of subgrade = 6×1500 = **9000 lb/in^2**
* R = 99% (from table 5.11)
* S_o = 0.49
* P_i = 4.5
* P_t = 2.5

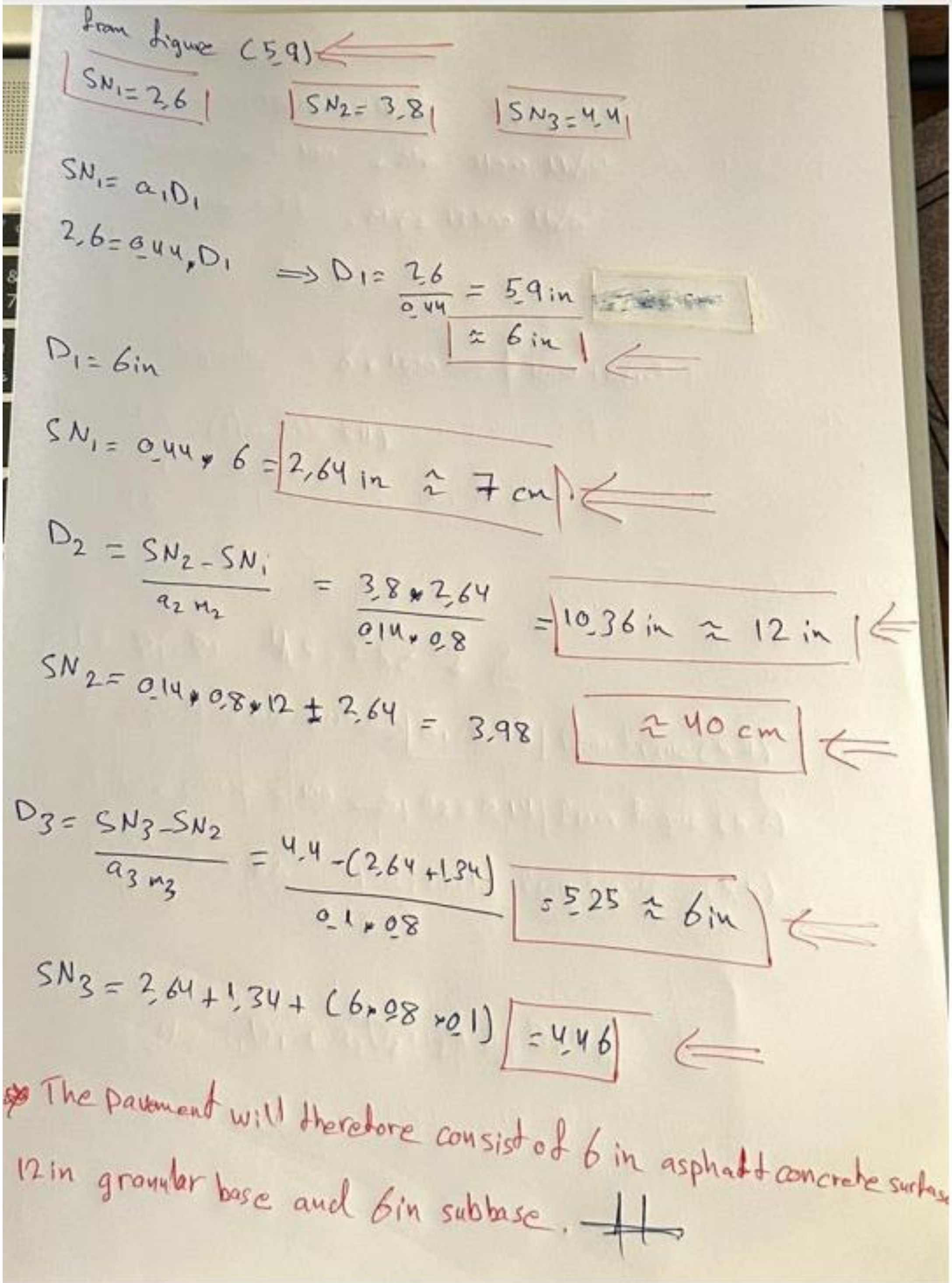
$\Delta PSI = P_i - P_t = 4.5 - 2.5 = 2$

Mr for asphalt = 450000 ⟹ $a_1 = 0.44$ from figure (5.7)

CBR of base course = 100 ⟹ $a_2 = 0.14$ from figure (5.6)

CBR of subbase = 22 ⟹ $a_3 = 0.1$ from figure (5.5)

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$



from figure (5.9)

$SN_1 = 2.6$ $SN_2 = 3.8$ $SN_3 = 4.4$

$SN_1 = a_1 D_1$

$2.6 = 0.44 D_1 \Rightarrow D_1 = \frac{2.6}{0.44} = 5.9\,in \approx 6\,in$

$D_1 = 6\,in$

$SN_1 = 0.44 * 6 = 2.64\,in \approx 7\,cm$

$D_2 = \frac{SN_2 - SN_1}{a_2 m_2} = \frac{3.8 - 2.64}{0.14 * 0.8} = 10.36\,in \approx 12\,in$

$SN_2 = 0.14 * 0.8 * 12 \pm 2.64 = 3.98$ $\approx 40\,cm$

$D_3 = \frac{SN_3 - SN_2}{a_3 m_3} = \frac{4.4 - (2.64 + 1.34)}{0.1 * 0.8} = 5.25 \approx 6\,in$

$SN_3 = 2.64 + 1.34 + (6 * 0.8 * 0.1) = 4.46$

The pavement will therefore consist of 6 in asphalt concrete surface, 12 in granular base and 6 in subbase. //

Figure 5-10 Calculate Pavement Structural

CHAPTER 6 RESULTS & RECOMMENDATUIONS

6.1 Introduction .

6.2 Results .

6.3 Recommendations

6.1 Introduction

This chapter discusses and contains the set of findings reached in the design process for this road, along with recommendations that will provide a good impression when implementing this project and assist in other ways.

6.2 Results After completing the comprehensive monitoring process and designing this road, several results were achieved:

1. The entire road was elevated, and detailed plans were obtained.
2. All horizontal and vertical designs, along with the necessary information for signing, were prepared, and corresponding maps were created.
3. Implementing this method is crucial as it saves time and effort for the user.
4. The importance of studying road design and integrating it with other fields of knowledge was highlighted.
5. The final design was based on AASHTO 2011 specifications, with a design speed of 50 km/h.
6. The results of the layers, after performing all necessary calculations, were as follows:
    - Asphalt layer: 7 cm
    - Base Course layer: 40 cm
7. The design was created using the D3 Civil program, and the results were displayed on the attached drawings.

6.3 Recommendations

1. The asphalt layer should be paved in a stage with a thickness of 7 cm according to specifications.
2. The base layer should be spread and compacted in two layers, each 20 cm thick, according to specifications.
3. Vehicles should be prohibited from driving on the asphalt layer for 24 hours after it has been spread to prevent collapse.
4. Consider the amount of excavation and backfilling resulting from the project to minimize costs.
5. Encourage the university to continuously communicate with governmental and non-governmental institutions to enhance the overall level for graduates and suitable projects.
6. Invite the university to conduct training courses for students to achieve a higher level, especially from a technological perspective and with modern programs.
7. Ensure the existence of joint projects between the various departments in the College of Engineering to achieve integration.

APPENDIX

AGISOFT REPORT

AIN NONQUR STREET

Processing Report

02 January 2025

Survey Data

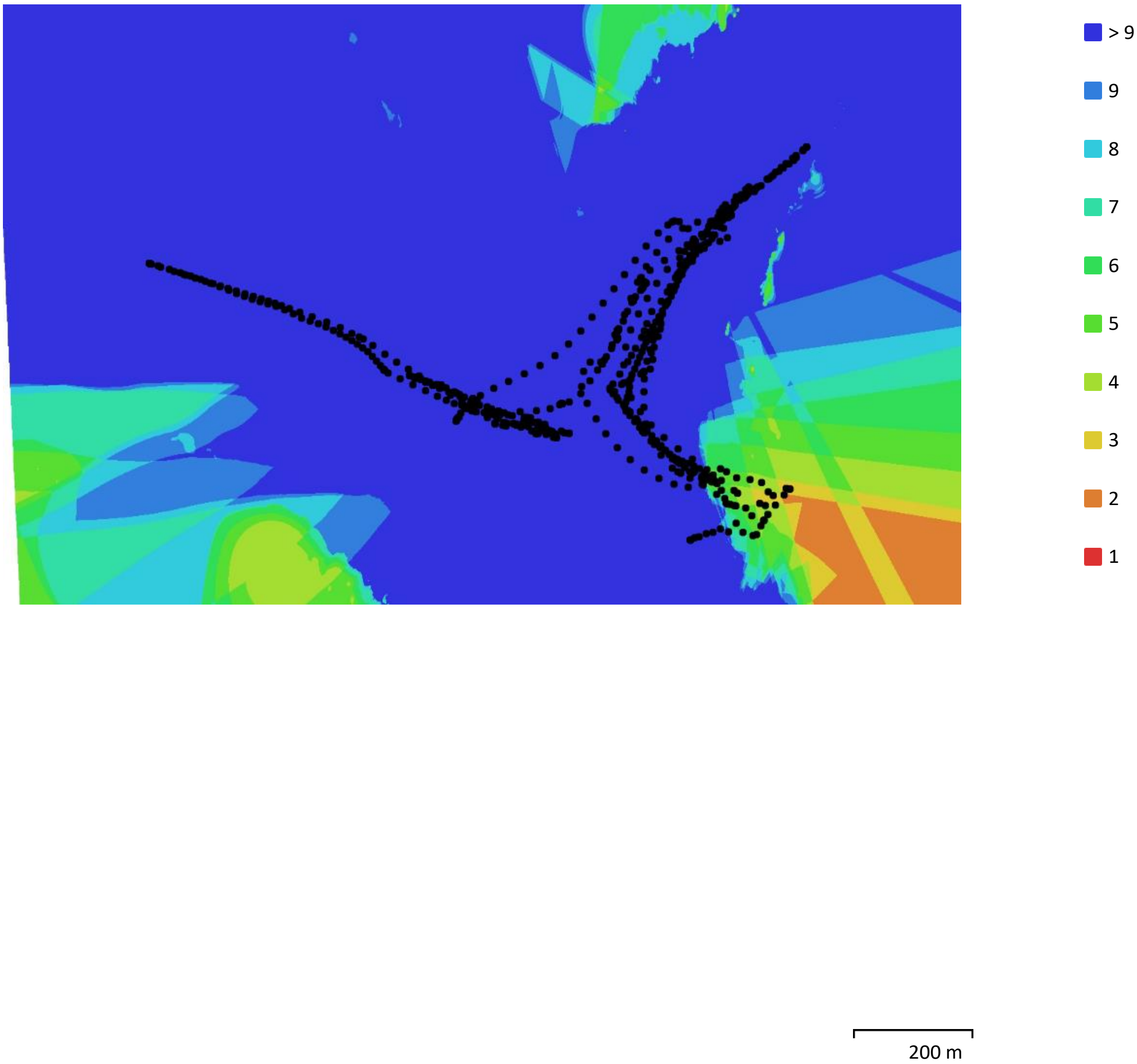


Fig. 1. Camera locations and image overlap.

Number of images:	733	Camera stations:	733
Flying altitude:	61.4 m	Tie points:	518,300
Ground resolution:	1.98 cm/pix	Projections:	2,249,293
Coverage area:	1.5 km²	Reprojection error:	0.991 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
L2D-20c (12.29mm)	5280 x 3956	12.29 mm	3.36 x 3.36 μm	No

Table 1. Cameras.

Camera Calibration

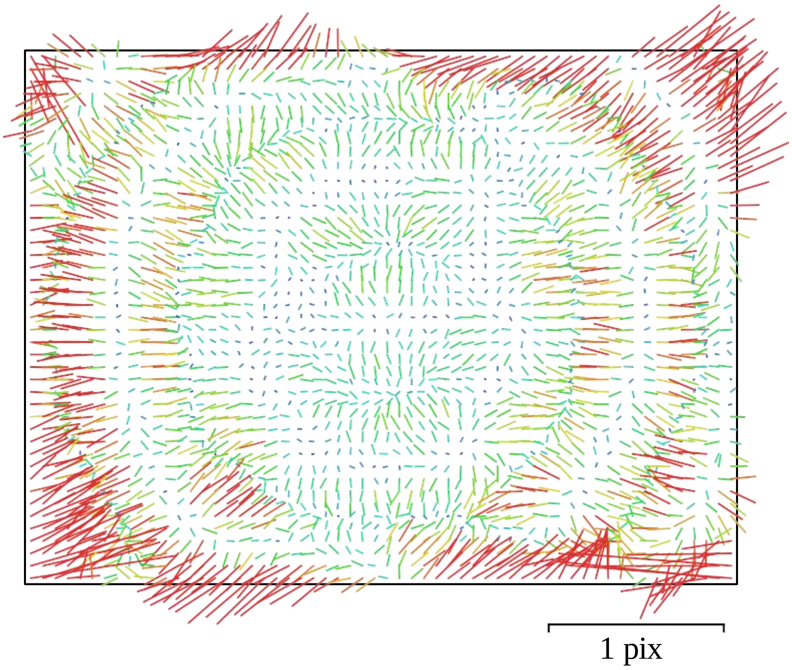


Fig. 2. Image residuals for L2D-20c (12.29mm).

L2D-20c (12.29mm)

733 images, additional corrections

Type	Resolution	Focal Length	Pixel Size
Frame	**5280 x 3956**	**12.29 mm**	**3.36 x 3.36 µm**

	Value	Error	F	Cx	Cy	B1	B2	K1	K2	K3	K4	P1	P2
F	**3740.97**	0.59	1.00	0.10	0.03	-0.28	0.02	-0.99	0.98	-0.96	0.93	0.13	0.03
Cx	**-45.8278**	0.13		1.00	0.01	-0.30	0.28	-0.10	0.10	-0.10	0.10	0.98	-0.00
Cy	**41.9858**	0.12			1.00	-0.17	-0.32	-0.04	0.04	-0.04	0.04	-0.00	0.97
B1	**-1.78368**	0.019				1.00	-0.01	0.30	-0.31	0.30	-0.29	-0.30	-0.15
B2	**1.59771**	0.014					1.00	-0.02	0.02	-0.02	0.01	0.27	-0.33
K1	**-0.0245443**	0.0013						1.00	-1.00	0.98	-0.96	-0.13	-0.03
K2	**0.0148656**	0.004							1.00	-0.99	0.98	0.13	0.03
K3	**0.123713**	0.0054								1.00	-0.99	-0.13	-0.03
K4	**-0.123768**	0.0027									1.00	0.12	0.03
P1	**-0.00287579**	2e-05										1.00	-0.01
P2	**0.00174209**	1.9e-05											1.00

Table 2. Calibration coefficients and correlation matrix.

Camera Locations

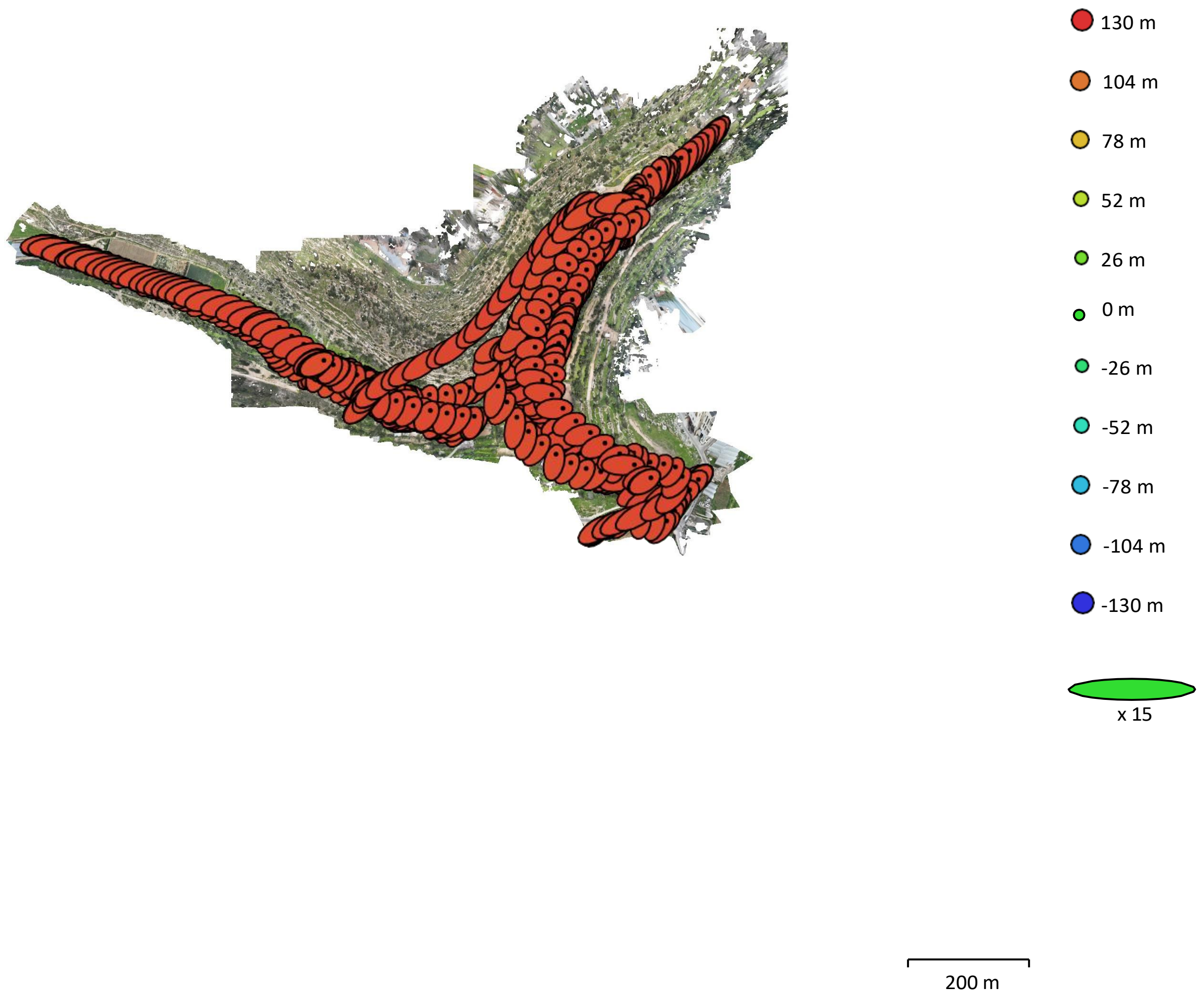


Fig. 3. Camera locations and error estimates.

Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.

Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	Z error (m)	XY error (m)	Total error (m)
1.45478	1.56971	120.781	2.14018	120.8

Table 3. Average camera location error. X - Easting, Y - Northing, Z - Altitude.

Ground Control Points

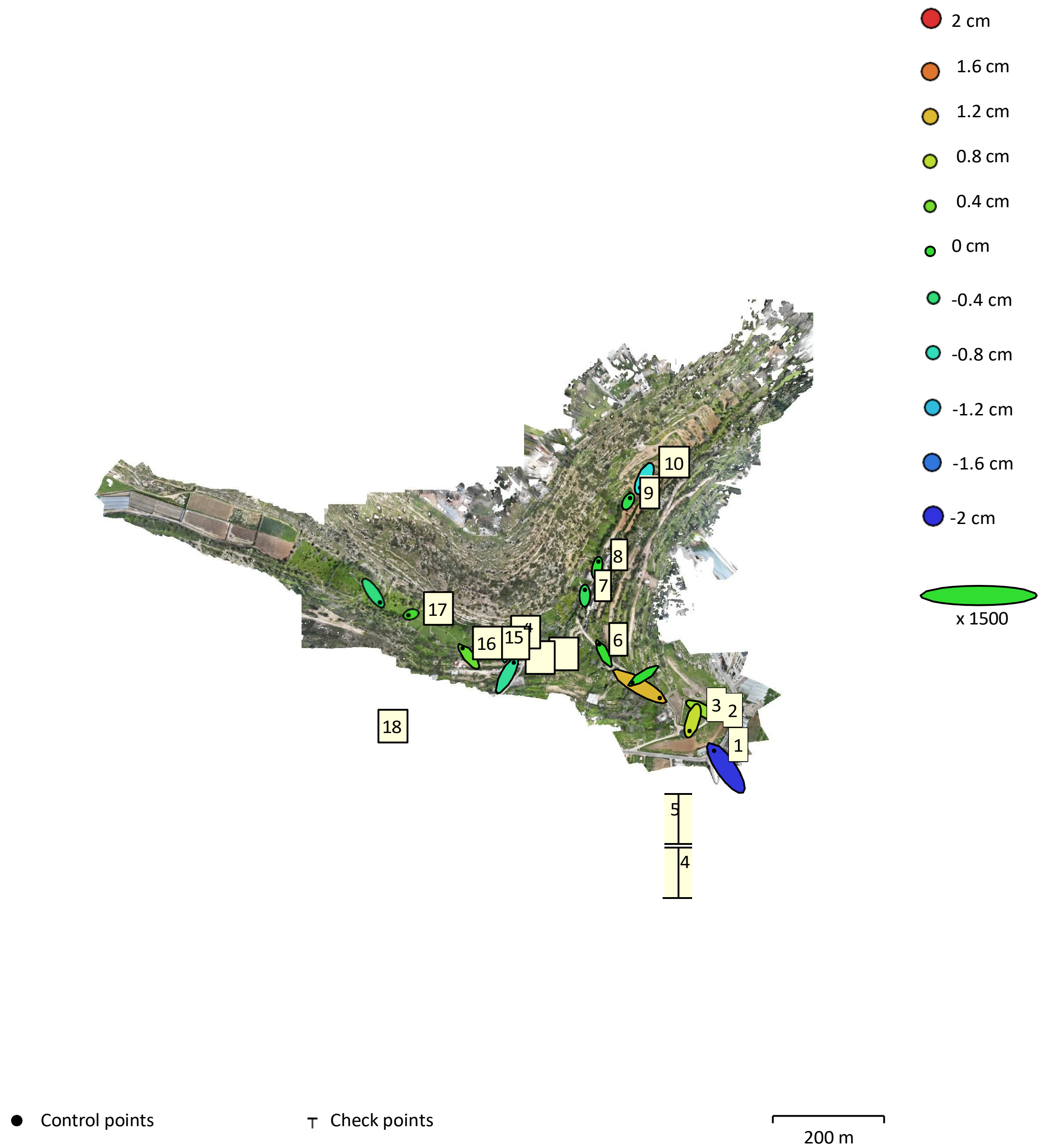


Fig. 4. GCP locations and error estimates.

Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.

Estimated GCP locations are marked with a dot or crossing.

Count	X error (cm)	Y error (cm)	Z error (cm)	XY error (cm)	Total (cm)
17	1.82197	2.05577	0.711159	2.74696	2.83752

Table 4. Control points RMSE.

X - Easting, Y - Northing, Z - Altitude.

Label	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)
12	-0.757386	0.222943	0.0336795	0.790235	1.159 (3)
13	1.62556	2.991	-0.593064	3.45547	2.373 (3)
14	0.3698	-2.25904	-0.528667	2.34937	1.107 (3)
15	-0.50747	-0.03217	-0.392724	0.64249	1.173 (3)
16	-1.49086	1.89878	0.309105	2.43384	0.779 (3)
17	-0.594027	-0.191096	0.122273	0.635875	0.670 (3)
18	1.54314	-2.2064	-0.448001	2.72951	1.075 (3)
1	-2.81496	4.06131	-1.97052	5.31989	2.861 (3)
2	2.54524	-1.31642	0.606294	2.92896	1.921 (3)
3	-0.747576	-2.4643	0.847948	2.71121	1.655 (3)
4	4.82525	-2.80838	1.22378	5.71556	1.692 (3)
5	-2.66522	-1.6268	-0.00965073	3.12249	1.663 (3)
6	-1.11913	2.21685	0.00193361	2.48332	1.541 (3)
7	0.0127542	1.38632	-0.230191	1.40535	0.867 (3)
8	0.309151	1.47624	-0.0513368	1.50913	0.814 (3)
9	0.432821	0.802971	-0.158511	0.925863	0.761 (3)
10	-0.991335	-2.17747	-0.975646	2.58379	1.291 (3)
Total	**1.82197**	**2.05577**	**0.711159**	**2.83752**	**1.496**

Table 5. Control points.

X - Easting, Y - Northing, Z - Altitude.

Digital Elevation Model

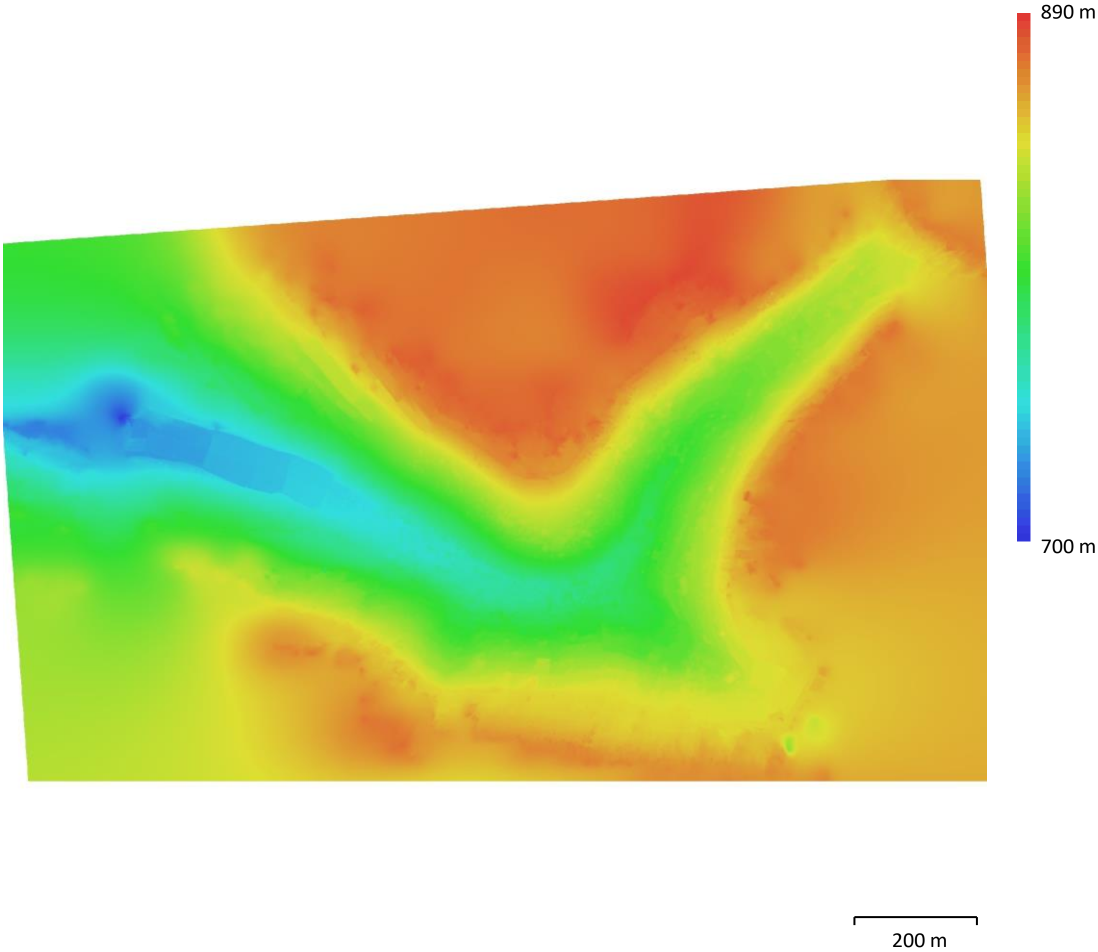


Fig. 5. Reconstructed digital elevation model.

Resolution:	3.95 cm/pix
Point density:	640 points/m²

Processing Parameters

General

Cameras	733
Aligned cameras	733
Markers	17

Shapes

Point	1593
LineString	53
Coordinate system	Palestine 1923 / Palestine Grid (EPSG::28191)
Rotation angles	Yaw, Pitch, Roll

Tie Points

Points	518,300 of 664,313
RMS reprojection error	0.232201 (0.991404 pix)
Max reprojection error	2.01854 (67.2286 pix)
Mean key point size	3.56921 pix
Point colors	3 bands, uint8
Key points	No
Average tie point multiplicity	4.66506

Alignment parameters

Accuracy	High
Generic preselection	Yes
Reference preselection	Source
Key point limit	40,000
Key point limit per Mpx	1,000
Tie point limit	4,000
Exclude stationary tie points	Yes
Guided image matching	No
Adaptive camera model fitting	No
Matching time	7 minutes 9 seconds
Matching memory usage	5.29 GB
Alignment time	12 minutes 47 seconds
Alignment memory usage	896.47 MB

Optimization parameters

Parameters	f, b1, b2, cx, cy, k1-k4, p1, p2
Fit additional corrections	Yes
Adaptive camera model fitting	No
Optimization time	58 seconds
Date created	2024:10:23 10:54:48
Software version	2.1.1.17803
File size	61.15 MB

Point Cloud

Points	346,591,221
Point attributes	
Color	3 bands, uint8
Normal	
Point classes	
Created (never classified)	346,591,221
Depth maps generation parameters	
Quality	High
Filtering mode	Mild
Max neighbors	16

Processing time	44 minutes 24 seconds
Memory usage	6.31 GB

Point cloud generation parameters

Processing time	1 hours 41 minutes
Memory usage	17.01 GB
Date created	2024:10:23 13:34:33
Software version	2.1.1.17803
File size	4.48 GB

Model

Faces	154,818,827
Vertices	77,802,652
Vertex colors	3 bands, uint8

Depth maps generation parameters

Quality	High
Filtering mode	Mild
Max neighbors	16
Processing time	44 minutes 24 seconds
Memory usage	6.31 GB

Point cloud generation parameters

Processing time	1 hours 41 minutes
Memory usage	17.01 GB

Reconstruction parameters

Surface type	Arbitrary
Source data	Point cloud
Interpolation	Enabled
Strict volumetric masks	No
Processing time	2 hours 32 minutes
Memory usage	21.97 GB
Date created	2024:10:28 15:10:46
Software version	2.1.1.17803
File size	3.25 GB

DEM

Size	40,769 x 24,922
Coordinate system	Palestine 1923 / Palestine Grid (EPSG::28191)

Reconstruction parameters

Source data	Point cloud
Interpolation	Enabled
Processing time	13 minutes 6 seconds
Memory usage	388.49 MB
Date created	2024:10:28 15:37:38
Software version	2.1.1.17803
File size	3.31 GB

Orthomosaic

Size	81,538 x 49,844

Coordinate system	Palestine 1923 / Palestine Grid (EPSG::28191)
Colors	3 bands, uint8
Reconstruction parameters	
Blending mode	Mosaic
Surface	DEM
Enable hole filling	Yes
Enable ghosting filter	No
Processing time	18 minutes 15 seconds
Memory usage	2.91 GB
Date created	2024:10:28 15:46:54
Software version	2.1.1.17803
File size	8.65 G

System

Software name	Agisoft Metashape Professional
Software version	2.1.1 build 17803
OS	Windows 64 bit
RAM	7.77 GB
CPU	Intel(R) Core(TM) i7-8565U CPU @ 1.80GHz
GPU(s)	NVIDIA GeForce MX130

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