A Report on

"Investigating soil deformation characteristics in railway embankment through plate load tests"

Submitted in partial fulfilment of the requirements for the award of the degree of

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Do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

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ABSTRACT

This project investigates the soil deformation characteristics in railway embankments using the Ev2 plate load test, a critical method for assessing the bearing capacity, stiffness, and compaction quality of soil layers. Conducted across multiple test sites, the study focuses on the natural ground, subgrade, and ballast layers. The Ev2 plate load test, known for its reliability and effectiveness, provided accurate in-situ measurements of soil stiffness and load-bearing capacity. The results indicated that all tested points met or exceeded the minimum specifications outlined in the railway guideline RDSO/2020/GE. The empirical correlations between Ev2 values and CBR values demonstrated that the soils at the test sites possess adequate bearing capacity and load-bearing characteristics.The findings confirm the reliability and effectiveness of the Ev2 test in evaluating soil deformation characteristics and compaction quality in railway embankments. The study concludes that the Ev2 plate load test is a highly reliable and effective method for assessing soil deformation characteristics, providing consistent and accurate measurements crucial for ensuring the stability and safety of railway infrastructure. The test's in-situ nature, economic efficiency, and time-saving attributes make it advantageous for large-scale railway projects. Future research should explore the long-term performance of compacted layers under dynamic loading conditions and the impact of varying moisture content on Ev2 values. The findings of this study can inform the design and construction of railway embankments, ensuring they meet the required standards for safety and stability, and contribute to the overall improvement of infrastructure quality.

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INTRODUCTION

1.1 BACKGROUND

Compaction involves the application of mechanical energy to soil, which can be accomplished through various methods such as rolling, tamping, or vibrating. The mechanical energy causes soil particles to rearrange themselves into a denser configuration, reducing the volume of void spaces (pores) between them. The reduction of air within the soil pores leads to a decrease in the overall volume of the soil. As the soil particles are pressed closer together, the soil becomes more compact and less compressible. The primary outcome of compaction is an increase in the soil's dry density. Dry density is defined as the mass of soil particles per unit volume of soil, excluding the volume of water and air. A higher dry density indicates a more compact and stable soil structure. The effectiveness of compaction is highly dependent on the moisture content of the soil. There is an optimal moisture content at which soil achieves its maximum density under a given compactive effort. This is because water acts as a lubricant, helping soil particles slide past each other and rearrange into a denser configuration. Too little moisture makes the soil difficult to compact, while too much moisture can lead to pore pressure buildup and reduced effectiveness of compaction.

1.1.2 IMPORTANCE OF COMPACTION

1. Enhanced Load-Bearing Capacity:

Foundation Stability: Compacted soil provides a stable base for foundations, preventing excessive settlement and differential movement that could damage structures.

Infrastructure Support: Roads, highways, runways, and railways rely on compacted subgrades to distribute loads effectively and prevent deformation under traffic loads.

2. Reduced Settlement:

Long-Term Stability: Proper compaction minimizes both immediate and long-term settlement. This ensures that structures remain level and safe over their lifetime, reducing maintenance costs and enhancing safety.

Uniformity: Uniform compaction prevents differential settlement, which can lead to structural issues such as cracks and misalignment in buildings, pavements, and bridges.

3. Increased Shear Strength:
Soil Stability: Compaction increases the shear strength of soil, making it more resistant to forces that could cause sliding or slumping. This is particularly important in slopes, retaining walls, and embankments.
Safety: Enhanced shear strength reduces the risk of landslides and slope failures, protecting both structures and human lives.

4. Lower Permeability:
Water Control: Compacted soil has fewer voids, reducing its permeability and thus controlling the movement of water. This is vital in preventing water infiltration that can weaken soil and cause erosion.
Foundation Protection: By minimizing water ingress, compaction protects foundations from being undermined by erosion or swelling clays, which can expand and contract with moisture changes.

5. Minimization of Volume Changes:
Consistency: Compaction reduces the potential for soil to swell when wet and shrink when dry, maintaining a consistent volume. This is critical in regions with expansive soils that can cause significant structural damage.
Structural Integrity: Buildings and infrastructure built on compacted soil are less likely to experience cracking or tilting due to changes in soil volume.

6. Improved Durability:
Long-Lasting Construction: Structures built on well-compacted soil are more durable and have a longer lifespan, reducing the need for frequent repairs and reconstructions.
Cost-Effectiveness: Investing in proper compaction during construction reduces future costs related to maintenance, repairs, and potential failure mitigation.

7. Environmental Impact:
Erosion Control: Compaction helps in controlling erosion by creating a denser soil structure that resists being washed away by water or blown away by wind.
Sustainable Construction: Effective compaction contributes to sustainable construction practices by ensuring that structures are built to last, reducing the environmental impact of frequent rebuilding.

8. Performance of Pavements and Embankments:
Pavement Life: Compacted subgrades and base courses extend the life of pavements by providing a stable and resilient foundation, preventing issues like rutting, cracking, and pothole formation.
Embankment Stability: For road and railway embankments, compaction ensures stability and load-bearing capacity, reducing the risk of settlement and failure.

1.1.3 METHODS OF COMPACTION

The choice of method depends on the type of soil, the project requirements, and the available equipment. Here are the primary methods of compaction:

1. Static Compaction:

- Description: This method involves the application of a steady, continuous pressure to the soil. Heavy machinery, such as smooth-wheel rollers, is used to press down on the soil surface.
- Application: Suitable for compacting cohesive soils, such as clay, and for finishing operations to create a smooth surface.
- Equipment: Smooth-wheel rollers, sheep-foot rollers.
- Advantages: Effective for achieving a high degree of compaction in fine-grained soils. It creates a smooth, level surface.
- Limitations: Not as effective for granular soils and may require multiple passes to achieve the desired density.

2. Dynamic Compaction:

- Description: This method uses impact forces to compact soil. A heavy weight is dropped repeatedly from a height onto the soil surface.
- Application: Effective for deep compaction of granular soils and loose fills.
- Equipment: Drop hammers, heavy weights (5-40 tons).
- Advantages: Can compact soil to significant depths, improving the stability of deep fills and loose deposits.
- Limitations: Generates significant vibrations, which can affect nearby structures and require careful control and monitoring.

3. Vibratory Compaction:

- Description: This method utilizes vibrations to rearrange soil particles into a denser configuration. Vibratory rollers or plates induce vibrations in the soil, causing particles to settle closer together.
- Application: Ideal for granular soils, such as sand and gravel, which respond well to vibration.
- Equipment: Vibratory rollers, vibratory plates, and vibratory probes.
- Advantages: Highly effective for compacting granular soils. Quick and efficient, with the ability to achieve high densities.
- Limitations: Less effective for cohesive soils like clay. Vibrations can affect sensitive structures and underground utilities.

4. Kneading Compaction:

- Description: This method applies shear forces to soil through the use of rollers with protruding feet or pads. The soil is manipulated and compacted by kneading action.
- Application: Suitable for compacting cohesive and mixed soils, such as clay and clayey sands.
- Equipment: Sheep-foot rollers, pad-foot rollers.
- Advantages: Effective for breaking down soil clumps and achieving uniform compaction. Enhances the bonding between soil particles.
- Limitations: Requires multiple passes and careful control to achieve uniform compaction. Less effective for granular soils.

5. Tamping Compaction:

- Description: This method uses a series of blows or impacts from tamping equipment to compact soil. Tamping rammers or pneumatic tampers deliver repeated impacts to the soil surface.
- Application: Effective for compacting cohesive and semi-cohesive soils in confined areas, such as trenches and around foundations.
- Equipment: Tamping rammers, pneumatic tampers.
- Advantages: Provides localized compaction in tight or confined spaces. Effective for achieving high densities in small areas.
- Limitations: Labor-intensive and time-consuming for large areas. May require significant effort to achieve desired compaction levels.

6. Rolling Compaction:

- Description: Rolling compaction uses various types of rollers to compress soil. Rollers can be static, vibratory, or have special features like sheep-foot or pad-foot designs.
- Application: Used for compacting large areas, such as roadbeds, airfields, and embankments.
- Equipment: Smooth-wheel rollers, pneumatic-tire rollers, sheep-foot rollers, pad-foot rollers, and vibratory rollers.
- Advantages: Efficient for large-scale projects. Versatile equipment can be adapted to different soil types and project needs.
- Limitations: Requires large, heavy machinery, which may not be suitable for all sites. May need multiple passes for optimal compaction.

7. Jetting and Flooding Compaction:

- Description: These methods involve using water to assist in compaction. Jetting uses high-pressure water jets to compact soil, while flooding saturates the soil and allows natural settlement.
- Application: Suitable for sandy and granular soils, as well as for filling and compacting voids in loose fills.
- Equipment: Water jets, hoses, and pumping equipment.
- Advantages: Can reach areas that are difficult to compact with mechanical methods. Effective for saturating and compacting loose, granular soils.

- Limitations: Requires significant water resources. The process can be slow and may lead to uneven compaction if not properly controlled.

1.1.4 METHODS TO CHECK COMPACTION

Various methods are employed to check the effectiveness of compaction, each with its unique applications and benefits.

1. The **Standard Proctor Test and Modified Proctor Test** are fundamental laboratory tests used to determine the optimal moisture content (OMC) and maximum dry density (MDD) of a soil sample. These tests provide a benchmark for evaluating field compaction efforts. By understanding the relationship between moisture content and soil density, engineers can establish the ideal conditions for soil compaction. While these tests are conducted in a controlled environment, they are essential for setting the compaction standards to be met during field operations.

2. The **Nuclear Density Gauge** is a widely used field test that measures the in-place density and moisture content of soil through nuclear radiation. This method is highly valued for its ability to provide immediate results, making it possible to quickly assess the effectiveness of compaction efforts on-site. The gauge is non-destructive and portable, allowing for rapid and accurate field measurements. However, it requires specialized equipment and trained personnel to operate, and there are regulatory and safety concerns due to the use of nuclear material.

3. **Sand Cone Method** is used to determine the in-place density of soil. This method involves excavating a small hole in the compacted soil, collecting the soil removed, and measuring the volume of the hole by filling it with sand of known density. The weight of the excavated soil and the volume of the hole are used to calculate the soil density. This method is straightforward and provides reliable results, but it is more time-consuming and labor-intensive compared to the nuclear density gauge.

4. The **Drive Cylinder Method** is also employed for field density testing. In this method, a cylindrical metal tube is driven into the soil to extract a core sample. The soil within

the cylinder is then weighed and its volume measured, allowing for the calculation of soil density. This method is effective for cohesive soils and provides accurate density measurements, but it can be challenging to use in hard or rocky soils.

5. **Rubber Balloon Method** involves inserting a rubber balloon into a hole excavated in the soil and filling it with water to measure the volume of the hole. The weight of the soil removed from the hole is then used along with the volume measurement to calculate the soil density. This method is useful for soils that are difficult to handle or measure using other techniques.

6. **Ev2 Test** (also known as the second load plate test) is a specialized method used to evaluate the bearing capacity and compaction quality of soil in the field. This test involves placing a circular plate on the compacted soil surface and applying incremental loads while measuring the settlement of the plate. The test provides valuable information on the soil's load-bearing capacity and deformation characteristics, making it particularly useful for assessing the suitability of soil for supporting structures. The Ev2 test is highly regarded for its ability to provide a direct measure of soil performance under load, but it requires careful execution and interpretation by experienced personnel.

1.2 RAILWAY PAVEMENT

1.2.1 VARIOUS LAYERS IN RAILWAY PAVEMENT

Railway pavement is composed of multiple layers designed to support the weight of trains and ensure the smooth and safe operation of the track system.

1. **SUBGRADE**

The first layer, known as the subgrade, forms the natural ground or prepared earth surface upon which all other layers are built. It plays a foundational role by bearing the load from passing trains and providing stability to the track. The subgrade must have sufficient load-bearing capacity to resist deformation and settle evenly under the dynamic loads imposed by trains.

Proper drainage is also crucial to prevent water accumulation, which can weaken the subgrade over time.

2. SUB-BALLAST

Above the subgrade lies the subballast layer, consisting of coarse aggregate material such as crushed stone or gravel. This layer serves to enhance the distribution of loads from the track and improve drainage. By allowing water to flow freely through its porous structure, subballast helps maintain the stability and integrity of the railway pavement. It acts as a buffer between the subgrade and the ballast layer, providing additional support and preventing the loss of fine particles from the subgrade.

3. BALLAST

The ballast layer is arguably one of the most critical components of railway pavement. It consists of uniformly sized crushed stone or gravel that is packed tightly around the railway ties or sleepers. The primary functions of ballast include distributing the loads from the ties and rails evenly to the underlying layers, providing lateral stability to the track, and facilitating efficient drainage. Properly maintained ballast helps in maintaining the correct alignment and gauge of the railway track, reducing the risk of track misalignment and derailments.

4. RAILWAY TIES

Railway ties (or sleepers) are rectangular or trapezoidal structures made of wood, concrete, or steel, placed horizontally perpendicular to the rails. They serve as a base for supporting the rails and transmitting loads to the ballast layer below. Ties play a crucial role in maintaining the spacing (gauge) between the rails and ensuring the overall stability of the track. They are strategically spaced along the track and securely anchored to the ballast to prevent movement and maintain track alignment.

5. RAILS

Rails are long steel beams that form the continuous track along which train wheels run. Rails must withstand heavy dynamic loads from passing trains without deformation or failure. They provide a smooth riding surface for train wheels to minimize wear and reduce rolling resistance. Rails are carefully aligned and fixed to the ties with fasteners to maintain the correct gauge and ensure safe and efficient train operation.

Collectively, these layers from the subgrade up to the top of the rails form the track bed, which supports the entire railway track system. Each layer plays a crucial role in the overall performance and longevity of the track infrastructure. Proper design, construction, and maintenance of these layers are essential for ensuring the safety, reliability, and efficiency of railway operations. Engineers and maintenance crews regularly monitor and inspect these layers to identify any issues and implement necessary repairs or adjustments to maintain optimal track performance.

1.2.2 IMPORTANCE OF COMPACTION IN RAILWAYS

Compaction plays a crucial role in railway engineering as it directly influences the stability, longevity, and operational efficiency of railway tracks. Here's an elaborate discussion on the importance of compaction in railways:

Railway tracks are subjected to immense dynamic loads from passing trains, which can lead to deformation and settlement of the underlying layers if not properly managed. Compaction refers to the process of mechanically compressing and consolidating soil or aggregate layers to achieve specified density and strength. This process is essential in railway construction and maintenance for several key reasons:

1. **Load Distribution and Bearing Capacity:** Properly compacted layers distribute the heavy loads from trains evenly across the track bed. This reduces localized stress concentrations and prevents differential settlement, which can lead to track misalignment and potential derailments. Compaction ensures that the subgrade, subballast, and ballast layers can withstand the repetitive loading without excessive deformation.
2. **Stability and Alignment:** Compaction enhances the stability of railway tracks by minimizing the risk of settlement and maintaining proper alignment. Stable track alignment is crucial for safe and smooth train operation, reducing wear on rolling stock

and infrastructure components. It also ensures that switches and crossings function correctly without misalignment issues.

3. **Drainage and Track Resilience:** Compacted layers improve the drainage characteristics of the track bed by reducing permeability and promoting efficient water runoff. This helps in preventing water-induced damage such as erosion, softening of subgrade, and ballast degradation. Proper drainage also enhances the resilience of the track during adverse weather conditions, reducing the risk of track bed instability and mud pumping.
4. **Longevity and Maintenance Costs:** Well-compacted layers contribute to the longevity of railway infrastructure by minimizing deformation and structural failures over time. This reduces the frequency and costs associated with maintenance and repairs. A stable and durable track bed requires fewer interventions, leading to increased operational efficiency and reduced downtime for maintenance activities.
5. **Safety and Operational Efficiency:** Compaction directly impacts the safety and operational efficiency of railways. By maintaining uniform density and strength throughout the track bed, compaction helps in achieving consistent track geometry and surface smoothness. This results in reduced wear on rolling stock, improved ride quality for passengers and freight, and enhanced overall operational reliability.
6. **Environmental Considerations:** Proper compaction practices also have environmental benefits. By ensuring the structural integrity of the track bed, compaction reduces the need for excessive material usage and minimizes construction-related impacts on surrounding ecosystems. Efficient drainage systems associated with well-compacted layers also help in mitigating environmental risks such as erosion and water pollution.

1.3 Ev2 (Static Deformation Modulus test)

The Ev2 test, also known as the second load modulus test, is an essential geotechnical method for evaluating the stiffness and bearing capacity of soil, particularly in the context of compaction assessment. The test is conducted using a plate load apparatus, which applies a series of loads to the soil surface through a rigid circular plate. The deformation of the soil under these loads is measured, and the stiffness modulus (Ev2) is calculated. This modulus reflects the soil's ability to resist deformation and is a critical indicator of the soil's compaction quality and strength.

Principle of the Ev2 Test The principle of the Ev2 test is based on the application of two sequential loading stages. Initially, a load is applied to the soil through the plate, and the resulting settlement or deformation is measured. This first load application helps to establish a baseline deformation response. After unloading, a second load, typically twice the magnitude of the first load, is applied, and the deformation is measured again. The stiffness modulus (Ev2) is then calculated using the relationship between the applied load and the resulting deformation.

The resulting Ev2 value provides a quantitative measure of the soil's stiffness and its capacity to support loads without excessive deformation.

1.3.1 STIFFNESS MODULUS

The stiffness modulus (E) is typically expressed as the ratio of stress to strain within the elastic range of the material's stress-strain curve.

In the context of the Ev2 test, the stiffness modulus is specifically referred to as the second load modulus (Ev2) and is calculated based on the soil's response to loading and unloading cycles.

Importance of Stiffness Modulus in Soil Mechanics

The stiffness modulus is a critical parameter in soil mechanics for several reasons:

1. **Load-Bearing Capacity**: It indicates the soil's ability to support structural loads without undergoing significant deformation. Soils with higher stiffness moduli can bear greater loads, making them suitable for supporting heavy structures such as buildings, bridges, and railway tracks.
2. **Deformation and Settlement**: It helps predict the extent of soil deformation and settlement under applied loads. Accurate estimation of soil settlement is essential for designing stable and durable structures.
3. **Elastic Behavior**: It provides insights into the elastic behavior of soil, which is the soil's ability to return to its original shape after the removal of loads. This property is crucial for assessing soil resilience and long-term performance under cyclic loading conditions, such as those experienced by railway tracks.

4. **Design and Analysis**: It is used in various geotechnical design and analysis procedures, including the design of foundations, embankments, and pavements. It helps engineers determine appropriate soil compaction levels and select suitable construction materials.

Factors Affecting Stiffness Modulus

Several factors influence the stiffness modulus of soil, including:

1. **Soil Type**: Different types of soil (e.g., clay, sand, gravel) have varying stiffness moduli. For instance, sandy soils typically have higher stiffness moduli compared to clayey soils due to their granular structure.
2. **Moisture Content**: The water content in the soil affects its stiffness. Generally, higher moisture content reduces soil stiffness, as water acts as a lubricant between soil particles, leading to increased deformation.
3. **Compaction Level**: Well-compacted soils have higher stiffness moduli due to the reduced void spaces between soil particles, resulting in greater resistance to deformation.
4. **Stress History**: The previous loading history of the soil can impact its stiffness. Soils that have been pre-loaded or subjected to repeated loading may exhibit increased stiffness due to strain hardening.
5. **Temperature**: Temperature changes can affect soil stiffness, particularly for fine-grained soils. Freeze-thaw cycles, for instance, can alter soil structure and reduce stiffness.

Measurement of Stiffness Modulus

The stiffness modulus of soil can be measured using various laboratory and field tests, including:

1. **Plate Load Test**: The Ev2 test, a type of plate load test, measures the soil's stiffness modulus by applying a series of loads to the soil surface and recording the resulting deformations.
2. **Triaxial Test**: This laboratory test involves applying controlled loads to a soil sample and measuring its deformation response under different confining pressures.

3. **Oedometer Test**: This test measures the compressibility of soil under one-dimensional loading conditions, providing data to calculate the stiffness modulus.
4. **In-situ Testing**: Field tests such as the Standard Penetration Test (SPT), Cone Penetration Test (CPT), and Pressuremeter Test provide indirect estimates of soil stiffness modulus based on soil resistance to penetration or expansion.

1.3.2 PREFERABILITY OF EV2 TEST IN RAILWAYS

Accuracy and Reliability

The Ev2 test is known for its high accuracy and reliability in measuring the stiffness modulus of soil. This attribute is critical in railway applications where precise soil properties are essential for designing durable and stable tracks. The stiffness modulus provided by the Ev2 test is a direct indicator of the soil's ability to support the loads imposed by passing trains, making it an invaluable tool in railway engineering.

In-situ Testing

One of the major advantages of the Ev2 test is its in-situ nature. Unlike laboratory tests that might not accurately reflect field conditions, the Ev2 test measures the soil properties directly at the construction site. This ensures that the test results are representative of the actual conditions that the railway pavement will experience, leading to better-informed design decisions and enhanced performance of the railway tracks.

Correlation with Load-Bearing Capacity

The Ev2 test results have a well-established correlation with the load-bearing capacity of the soil. This correlation is particularly useful in railway construction, where understanding the soil's capacity to support the heavy loads from trains is paramount. The stiffness modulus obtained from the Ev2 test helps engineers design railway pavements that can withstand these loads, thereby ensuring the safety and stability of the railway infrastructure.

Standardization and Acceptance

The Ev2 test is widely recognized and standardized in many railway construction guidelines. Its acceptance by regulatory bodies and inclusion in construction standards underscores its reliability and effectiveness. This standardization facilitates consistent and comparable results across different projects, enhancing the overall quality of railway construction.

Economic and Time Efficiency

The Ev2 test is not only accurate but also economically and time-efficient. It requires relatively simple equipment and can be conducted quickly, making it suitable for large-scale railway projects where time and budget constraints are critical. This efficiency allows for rapid assessment and timely decision-making during the construction process.

1.4 OBJECTIVE OF THE STUDY

The objective of this study is to

1. Understand the methodology of the Ev2 test and its relevance in the railway department.
2. To perform the Ev2 test at various sites of railway pavement construction.
3. To correlate the Ev2 value with other parameters like CBR value and degree of compaction.
4. To understand if the Ev2 value is as reliable as other parameters.

1.5 STRUCTURE OF THE PROJECT

This comprises of six chapters. Chapter one deals with the background and objective of the study. Chapter two gives the literature review on various papers related this topic. Chapter three gives an overview on the methodology applied to perform the test and also calculations and data collection. Chapter four gives the results and discussions. Chapter five gives the conclusion of the study. Chapter six deals with the references.

CHAPTER 2
LITERATURE REVIEW

2.1 PAPERS ON COMPACTION

1. **Kean Thai Chhun, Su-Hyung Lee, Yeong-tae Choi and Chan-Young Yune (2018)** this paper presents present a laboratory investigation on the effect of compaction on the behavior of the long-term settlement of the embankment for high-speed railways. The experiment was conducted on reconstructed soil specimens using a one-dimensional compression chamber. The soil specimen was mixed with water and compacted in three layers in the compression chamber and then, two steps of long-term constant loading were applied. Test results showed that the final settlement decreased as the load was increased while the coefficient of secondary compression index ($C\alpha$) increased. This paper also concluded the long-term settlement in high-speed railways is significant because the predicted long-term settlement based on the test results exceeds the operational limit for the residual settlement of high-speed railways.

2. **Nilo C. Consoli, Michele D. T. Casagrande, Pedro D. M. Prietto and Antonio Thome (2003)** This paper discusses the load–settlement response from two steel plate load tests (0.3 m diameter, 25 mm thick) carried out on a thick homogeneous stratum of compacted sandy soil, reinforced with polypropylene fibers, as well as on the same soil without the reinforcement. laboratory triaxial compression tests were performed to determine the static stress–strain response of the compacted sandy soil reinforced with randomly distributed polypropylene fibers. The laboratory test results showed that the reinforcement changed dramatically the stress–strain behavior at very large strains. The strength was found to increase continuously at a constant rate, regardless of the confining pressure applied, not reaching an asymptotic upper limit, even at axial strains as large as 25%.

3. **A. Tarantino and E. De col (2008)** This paper presents an experimental study of the compaction behaviour of non-active clay. One-dimensional static compaction tests were

carried out at high and medium water content with matric suction monitoring using Trento high-capacity tensiometers. At lower water contents, a transistor psychrometer was used to measure post-compaction suction. Samples were compacted on the dry side of optimum to cover a wide range of compaction water contents and vertical stresses. Three water content regions were identified in the compaction plane depending on whether post-compaction suction increased, decreased or remained constant as the degree of saturation was increased at constant water content. Postcompaction states of samples compacted on the dry side of optimum over a wide range of water contents and vertical stresses have been investigated, and three water content regions were identified. Irreversible hydraulic 'wetting' paths were modelled by a boundary surface in the space suction, void ratio, and degree of saturation. The model correctly simulated the positive slope of contours of post-compaction suction and its decrease as the compaction water content decreases. The pore size frequency distribution was shown to remain bimodal with significant intra-aggregate pore volume in the same range of water contents where compaction behaviour could be modelled using a single set of parameters.

4. **T. Batey (2009)** This paper concentrates on the impact of soil compaction on practical soil management issues, an area not previously reviewed. Compact soils can also be found under natural conditions without human or animal involvement. Compaction alters many soil properties and adverse effects are mostly linked to a reduction in permeability to air, water and roots. Many methods can be used to measure the changes. In practical situations, the use of visual and tactile methods directly in the field is recommended. The worst problems tend to occur when root crops and vegetables are harvested from soils at or wetter than field capacity. By contrast, rendzinas and other calcareous soils growing mainly cereals are comparatively free of compaction problems. The effect of a given level of compaction is related to both weather and climate; where soil moisture deficits are large, a restriction in root depth may have severe effects but the same level of compaction may have a negligible effect where moisture deficits are small. Topsoil compaction in sloping landscapes enhances runoff and may induce erosion particularly along wheel tracks, with consequent off-farm environmental impacts. Indirect effects of compaction include denitrification which is likely to lead to nitrogen deficiency in crops. The effects of heavy tractors and harvesters can to some extent be compensated for by a reduction in tyre pressures although there is concern that

deep-seated compaction may occur. Techniques for loosening compaction up to depths of 45 cm are well established but to correct deeper problems presents difficulties. Several authors recommend that monitoring of soil physical conditions, including compaction, should be part of routine soil management.

5. **Sandra l. Houston, William n. Houston, Claudia e. Zapata and Chris Lawrence** in their paper, Geotechnical engineering practice for collapsible soils, discuss the the challenges and methodologies associated with identifying, characterizing, and mitigating collapsible soils, particularly in arid and semi-arid climates where urbanization can significantly increase soil moisture content. Key points include:

   - **Mechanisms and Sensitivity**: Collapsible soils, formed through debris flows, rapid alluvial deposits, and wind-blown deposits (loess), are sensitive to moisture increases, leading to volume reduction or collapse.
   - **Urbanization Impact**: Development in arid regions often increases soil moisture through landscape irrigation, broken water lines, and other means, exacerbating the risk of soil collapse.
   - **Identification and Characterization**: Engineers must identify potential collapsible soil sites, estimate the extent of wetting, predict collapse strains and settlements, and select appropriate mitigation strategies. Geological reconnaissance and laboratory testing are critical for accurate site characterization.
   - **Laboratory and Field Testing**: Laboratory tests, such as one-dimensional response-to-wetting tests using consolidation equipment, are common. Field tests, including plate load tests, help identify and characterize collapsible soils, providing practical data for engineering assessments.
   - **Mitigation Techniques**: Effective mitigation requires understanding the collapse potential and implementing design strategies to manage increased soil moisture, such as improving drainage or soil compaction methods.

   Overall, the paper emphasizes the importance of recognizing and addressing collapsible soils in engineering practices to ensure safe and sustainable urban development in arid regions.

2.2PAPERS ON RAILWAY PAVEMENT AND Ev2 TEST

6. The paper "A Comparison of Railway Track Foundation Design Methods" by **Dr. M.P.N. Burrow, Dr. D. Bowness, and Dr. G.S. Ghataora** examines different methodologies for designing railway track foundations, focusing on the trackbed layers which distribute forces to protect the subgrade. It compares five design procedures from the USA, UK, Europe, and Japan, revealing significant variations in recommended thicknesses due to differing assumptions and factors considered, such as subgrade conditions and traffic loads. The study highlights the need for a deeper understanding of each method's scientific basis and calls for further research to address gaps in knowledge, particularly in material properties and behavior under repeated loading conditions.
7. This research by **Pardeep Puri, Pardeep Singh, Parshant Garg, Mandeep Singh** named “Effect of Sand on Strain Modulus (Ev2) Property of Clayey Soil” investigates the impact of mixing sandy soil with clayey soil on the strain modulus (Ev2) of the clayey soil. The study was motivated by the need to utilize surplus clayey soil from the Nabha Thermal Plant for infrastructure projects, such as railway embankments, by blending it with locally available sandy soil. The primary objective was to enhance the engineering properties of the clayey soil to make it suitable for construction purposes.
   Key Findings:
   - Material Properties: The clayey soil was classified as CH (clay of high compressibility) with a high liquid limit and plasticity index, while the sandy soil was non-plastic and classified as SP (poorly graded sand).
   - Testing Methodology: Field tests were conducted on trial beds of varying thicknesses (150 mm, 300 mm, and 450 mm) for both virgin clayey soil and a mixture of clayey soil and sandy soil in a 60:40 ratio. The strain modulus (Ev2) was determined using the plate load test as per DIN 18134 standards.
   - Results: The strain modulus (Ev2) values increased with the addition of sandy soil. For the mixed soil, the Ev2 values were 74.9 MPa, 56.86 MPa, and 52.13 MPa for layer thicknesses of 150 mm, 300 mm, and 450 mm, respectively. These values represented an improvement of 15.46%, 14.29%, and 12.85% over the virgin clayey soil.
   - Conclusion: Blending sandy soil with clayey soil significantly improves the strain modulus (Ev2), enhancing the load-bearing capacity and reducing

settlement. This makes the mixed soil more suitable for use in construction projects, particularly for embankments and foundations.

8. EMPERICAL CORRELATIONS WITH Ev2

a) **Weingart's Formula (1998)**

Details: Weingart proposed an empirical correlation between the deformation modulus (Ev2) and the CBR value for cohesive and non-cohesive soils:

$$\mathbf{Ev2=7.5\ X\ CBR^{0.75}}$$

Significance: This formula suggests that the deformation modulus is related to the CBR value raised to the power of 0.75 and multiplied by a factor of 7.5. This relationship has been widely used in practice to estimate the bearing capacity of soils based on CBR values.

b) **Razouki et al. (2018)**

Details: Razouki et al. examined the correlation between the ultimate bearing capacity (qu) and the CBR value. They provided a linear regression equation:

$$\mathbf{qu=(172.6 \times CBR)-601\ for\ \ CBR>5\%}$$

Significance: This equation indicates a strong correlation (R = 0.944) between the ultimate bearing capacity and the CBR value, highlighting the reliability of CBR as an indicator of soil strength.

9. This paper by **Nielson et al.** “Determination of Modulus of Soil Reaction from Standard Soil Tests explores the relationship between the modulus of soil reaction (E') and various standard soil tests, including the California Bearing Ratio (CBR) test, Hveem's stabilometer test, and other soil properties like density, compaction, moisture content, and plasticity index. The study aims to provide a practical means for determining E' for design purposes, particularly in the context of flexible pavement construction. The authors employ the theory of elasticity to derive the relationship between E' and the CBR value, presenting a regression equation that allows for the estimation of E' based on CBR test results. The findings indicate a strong correlation between E' and CBR

values, which can be used to estimate soil stiffness in the field. The paper also discusses the influence of soil density, moisture content, and plasticity index on the modulus of soil reaction, highlighting the importance of these factors in evaluating soil properties. The study concludes that the empirical correlations and regression equations developed provide reliable methods for estimating the modulus of soil reaction, contributing to more accurate and effective soil evaluation and pavement design.

10. **A. Gomes Correia's** paper ," Basic Concepts of Soil Behaviour "provides a comprehensive overview of the fundamental principles of soil mechanics, focusing on soil stiffness and the strain modulus (Ev). The paper discusses the factors influencing soil behavior, such as soil type, compaction, moisture content, and loading conditions. Correia presents empirical correlations for estimating the strain modulus of different soil types, based on extensive field and laboratory data. The paper emphasizes the importance of soil compaction in enhancing soil stiffness and load-bearing capacity, and the role of moisture content in affecting soil behavior. The author also examines the impact of loading conditions on soil stiffness, highlighting the need to consider these factors in geotechnical design. The empirical correlations and target values provided offer practical tools for geotechnical engineers to estimate soil stiffness and design stable geotechnical structures. The paper contributes to a deeper understanding of soil mechanics and its applications in geotechnical engineering, emphasizing the importance of accurate soil evaluation for the safety and stability of geotechnical systems.

11. **Binod Sharma's** manual "Calculation of Deformation Modulus of Soil Ev2" provides a detailed procedure for calculating the deformation modulus (Ev2) of soil, emphasizing the importance of accurate field observations and graphical presentations of load vs. settlement curves. The manual outlines the step-by-step process for conducting the plate load test, which involves applying incremental loads to a circular plate placed on the soil surface and measuring the resulting settlements. The graphical method for calculating Ev2 is explained, with examples of load vs. settlement curves for different soil types. The manual also discusses the influence of soil type and compaction on the deformation modulus, highlighting the need for well-compacted soils with low moisture content to achieve higher Ev2 values. Additionally, the manual explores other methods for determining the deformation modulus, such as the pressuremeter test and the

dilatometer test, comparing their results with the plate load test. The insights provided contribute to a deeper understanding of soil behavior and its applications in geotechnical engineering, offering practical tools for geotechnical engineers to calculate Ev2 values accurately.

12. The paper "Comparison and Evaluation of Railway Subgrade Quality Detection Methods" by **Ru-song Nie et al.** investigates various methods to assess the quality of railway subgrades, which are crucial for providing a stable platform for railway tracks. The study aims to identify reliable indicators for evaluating the compaction and mechanical performance of subgrades. The authors focus on several key indicators, including compaction degree (K), porosity (n), modulus of subgrade reaction (K_{30}), basic bearing capacity (σ_0), strain moduli (Ev), dynamic modulus of deformation (Evd), and light dynamic penetration (N_{10}).The research involves laboratory tests on four soil models with different compaction degrees (K values of 0.85, 0.90, 0.95, and 0.98). The tests measure K30, Ev, Evd, σ0, and N10, and the shear strengths of the compacted soils are determined using direct shear tests. The results indicate a linear correlation between K and n, and a good correlation among K30, Ev, and Evd. The study recommends using K as the controlling indicator for compaction performance, and Ev2 and Evd for evaluating railway subgrade stiffness.The findings highlight the importance of accurate and reliable indicators for ensuring the stability and performance of railway systems. The authors suggest that bearing capacity indicators should be included in quality detection for heavy-haul railway construction. The study provides valuable insights into the quality detection methods for railway subgrades, emphasizing the need for comprehensive evaluation to prevent issues such as excessive deformation and shear failure.

13. The paper "Experiences in Compaction Control of Secondary Building Materials in Germany" by **S. Huber, E. Birle, and D. Heyer** examines the relationship between the Ev2/Ev1 ratio and the degree of compaction (DPr) for secondary building materials (SBM). The degree of compaction (DPr) is defined as the ratio between the dry density determined in the field and the Proctor density determined in the laboratory, expressed as a percentage. The Ev2/Ev1 ratio is used as an indicator of soil stiffness and compaction quality.The German earthworks regulations (ZTV E-StB 17) specify that

for a degree of compaction DPr ≥ 100%, the maximum permissible Ev2/Ev1 ratio is 2.3, and for DPr ≥ 98%, the ratio is 2.5. These ratios ensure that the soil has achieved sufficient compaction and stiffness. The study presents laboratory and field test results showing that the Ev2/Ev1 ratio increases with the degree of compaction (DPr). For SBM of soil groups GW, GI, GU, SU, and SE, the linear regression lines indicate Ev2/Ev1 ratios between 3.1 and 6.5 at a degree of compaction of DPr = 100%, which exceeds the permissible ratio specified by ZTV E-StB 17. The findings suggest that while SBM can achieve high degrees of compaction, their unique properties may result in higher Ev2/Ev1 ratios compared to primary building materials. The authors recommend conducting calibration tests to establish specific correlations between the Ev2/Ev1 ratio and DPr for different materials, rather than relying solely on standard guideline values. In conclusion, the relationship between the Ev2/Ev1 ratio and the degree of compaction (DPr) is crucial for assessing the compaction quality of secondary building materials. Tailored calibration tests are necessary to ensure that SBM meet the required compaction standards and contribute to the stability and long-term performance of earthworks.

14. The paper "Guidelines for Authors Preparing Manuscripts for Track Subballast" by **A. Kalliainen et al.** examines the importance of density and compaction in the mechanical properties of granular materials used in railway substructures. The study, conducted by Tampere University of Technology and the Finnish Transport Agency, involved building full-scale test embankments to assess the effects of subgrade conditions, material grading, layer thickness, and construction methods on compaction. Key findings indicate that grading and moisture content significantly influence the required compaction for achieving sufficient density and bearing capacity. The study utilized the plate loading test (PLT) to measure the deformation modulus (Ev2) and the ratio Ev2/Ev1, with Finnish requirements being Ev2 ≥ 160 MPa and Ev2/Ev1 ≤ 3 for insulation layers, and Ev2 ≥ 180 MPa and Ev2/Ev1 ≤ 2 for intermediate layers. The results highlight the challenges in meeting these standards, particularly for the Ev2/Ev1 ratio, emphasizing the need for proper compaction practices and quality control to ensure the stability and performance of railway substructures.

15. The paper "In Situ Characterization of an Old Railway Platform with DCP" by **E. Fortunato et al.** investigates the use of the Dynamic Cone Penetrometer (DCP) and Plate Load Test (PLT) to assess the stiffness of an old railway platform in Portugal. The study highlights the advantages of DCP, including its cost-effectiveness and simplicity compared to the more expensive and time-consuming PLT. The research presents correlations between the DCP index (DCPI) and the deformation modulus (Ev2) obtained from PLT for both coarse-grained and fine-grained soils. The findings suggest that DCPI values averaged over a depth equal to the plate diameter of the PLT provide the best correlation with Ev2, making DCP a viable alternative for in situ characterization of railway subgrades.

16. The paper "The Dynamic Cone Penetration Test: A Review of Its Correlations and Applications" by **Abdulrahman M. Hamid** provides a comprehensive review of the Dynamic Cone Penetration Test (DCPT) and its correlations with various soil properties. The DCPT is widely used for field quality assessment of soils due to its simplicity, cost-effectiveness, and ability to provide continuous records of soil strength with depth. The paper discusses the development of correlations between the DCPT index (DCPI) and soil parameters such as resilient modulus, relative density, California Bearing Ratio (CBR), unconfined compressive strength, and shear strength. It also explores the use of DCPT in quality control of compaction and performance evaluation of pavement layers. Additionally, the paper highlights the relationship between DCPT and other instruments like the Falling Weight Deflectometer (FWD), nuclear gauge, soil stiffness gauge, and Plate Load Test (PLT). The study emphasizes the effectiveness of DCPT in assessing compaction quality and its potential applications in various geotechnical engineering projects.

CHAPTER-3

METHODOLOGY

3.1 INTRODUCTION

The work of performing Ev2 test on various sites under NFR Rangia Division was awarded to RELIANT ENGINEERS Sun-Polo Colony, Byelane - Dipar Boro Path, Near Ayursundra Superspecialty Hospital, Ahomgaon, GARCHUK Guwahati-781035.

3.2 SCOPE OF WORK:

The scope of work provided to us for this project was limited to the following:-

- Mobilizing necessary plant, equipments and personnel to the project site, setting up the equipment, carrying out the field investigations on land and demobilization on completion of work.
- Conducting Ev2 tests in regular intervals per specifications / instructions of Engineer-in-Charge.
- Recording the value of the stiffness modulus and preparing a report for the client.

3.3 EQUIPMENTS USED FOR THE TEST

1. Reaction loading system:

   The reaction loading system shall produce a reaction load which is at least 10 kN greater than the maximum test load required. It may be a loaded truck or roller or any other object of sufficient mass. In our case, the client provided us with a loaded dumper.

Fig 3.1 Reaction loading system

2. Loading plates

Loading plates shall be made of grade S355 J9 steel to DIN EN 19925-1 They shall be machined so as to have the flatness and roughness tolerances in accordance. Loading plates with a diameter of 300 mm shall have a minimum thickness of 25 mm.

Fig 3.2 300 mm loading plate with measuring tunnel

3. Loading system

The loading system consists of a hydraulic pump connected to a hydraulic jack via a high-pressure hose with a minimum length of 2 m. The system shall be capable of applying and releasing the load in stages.

For the pressure to be properly applied, the hydraulic jack shall be hinged on both sides and secured against tilting. The pressure piston shall act through at least 150 mm.

The height of the plate loading apparatus during operation should not exceed 600 mm. In order to compensate for differences in the heights of the vehicles used as reaction loads, elements shall be provided that allow the initial length of the hydraulic jack to be increased to at least 1000 mm. Suitable means shall be provided to prevent buckling of these elements.

Fig3.3 Loading system

4. Force-measuring apparatus

   A mechanical or electrical force transducer shall be fitted between the loading plate and the hydraulic jack. It shall measure the load on the plate with a maximum permissible error of 1 % of the maximum test load.

5. Settlement-measuring device

   The settlement measuring device shall consist of:

   a. a frame supported at three points
   b. a vertically adjustable, torsion-proof, rigid contact arm
   c. a displacement transducer or dial gauge

The distance from the centre of the loading plate to the centreline of the support shall be at least 1.5 m and shall not be greater than 1.6 m.

Fig 3.4 A frame supported at three points with contact arm

Fig 3.5 A digital displacement transducer or dial gauge

3.4 PROCEDURE OF THE PLATE LOAD TEST

1. Test Site Preparation
   - Ground Preparation: Level the testing ground and remove any loose material. If there are undulations, level the ground with sand.
   - Placement of Bearing Plate: Position the bearing plate on the prepared surface and ensure it is level using a spirit level.
2. Setting Up the Equipment
   - Hydraulic Jack Setup: Place the hydraulic jack over the bearing plate. Use compensating cylinders to adjust the height between the jack and the plate.
   - Measurement Bridge Setup: Position the measurement bridge at a distance of 1.5 meters from the center of the bearing plate. Fix the displacement sensors on the bridge, ensuring they are centered and vertical over the plate.
3. First Loading Cycle
   - Preload Application: Apply a preload of 10 kN/m^2 and wait for 30 seconds.
   - Incremental Loading: Apply the first load increment of 80 kN/m^2 and wait for 60 seconds.
   - Continue applying load increments up to a specified maximum load (e.g., 500 kN/m^2), recording the settlement at each increment.
4. Unloading
   - After reaching the maximum load, unload the plate in decrements of 50% of the previous load value.
5. Second Loading Cycle
   - Incremental Loading: Repeat the loading process up to a specified load (e.g., 420 kN/m^2).
   - Measure and record the settlement values at each load increment.
   - Unloading: Unload the plate in decrements similar to the first cycle.
6. Data Recording and Analysis
   - Settlement Measurement: Record the settlement values using the displacement sensors connected to the digital measuring box.
7. Calculation of Deformation Modulus:
   - Calculate the deformation modulus values (Ev1 and Ev2) and Determine the ratio Ev2/Ev1 to assess the degree of compaction.

Fig 3.6 Hydraulic jack setup

Fig: 3.7 Measurement bridge setup

Fig: 3.8 Pre loading of 10 kN/m²

Fig: 3.8 First loading cycle

Fig 3.9 First loading of 80 kN/m².

Fig 3.10 Recording Data

3.5 CALCULATIONS

Calculation of the strain modulus, Ev, from the first and of the second loading cycle shall be based on load settlement fitting curves. These shall be calculated by means of a second-degree polynomial according to Equation

$$\mathbf{s = a_0 + a_1 . \sigma_0 + a_2 . \sigma_0^2}$$

σ_0=is the average normal stress below the plate, in MN/m^2.

s= settlement of the loading plate in mm.

a_0,a_1,a_2= constants of the second degree polynomial.

Then the value of strain modulus Ev is calculated as,

$$\mathbf{E_v = 1 \cdot 5 \times r \times \frac{1}{a_1 + a_2 \cdot \sigma_{0max}}}$$

where,

Ev is the strain modulus in Mpa

r is the radius of the loading plate in mm

σ_{0max} is the the maximum average normal stress below the loading plate in the loading cycle, in MN/m^2

CHAPTER-3

RESULTS AND DISCUSSION

Following meticulous reconnaissance and site assessment, Ev2 tests were conducted at 12 specified chainage points identified by the client. These tests encompassed evaluations of the natural ground, subgrade layer, and ballast layer. The outcomes were then scrutinized in accordance with the railway guideline RDSO/2020/GE (With ACS 01 Dated 16.12.2021), which outlines essential minimum specifications for each component of the embankment formation. This comparison serves to ensure compliance with prescribed standards.

Fig 4.0: Example of a test site chainage and bridge number

The objective of this study are as follows:

1. To ascertain the Ev values at all designated test sites.
2. To empirically derive the CBR values based on the Ev2 measurements.
3. To compare the obtained values with the specifications outlined in the relevant guideline
4. To explore the feasibility of determining the degree of compaction using the Ev values

1. Point no. 01

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0	First Loading
0.158	0.14	First Loading
0.238	0.54	First Loading
0.319	0.66	First Loading
0.4	0.72	First Loading
0.449	0.87	First Loading
0.5	1.25	First Loading
0.25	1.25	Unloading
0.125	1.12	Unloading
0	1.1	Unloading
0	1.1	Second Loading
0.079	1.25	Second Loading
0.158	1.44	Second Loading
0.238	2.26	Second Loading
0.319	2.3	Second Loading
0.4	2.78	Second Loading
0.449	3.42	Second Loading

Table 4.1: stress vs settlement values of GL point 1

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.155	2.148	0.84	87.61	0.49
Second loading	0.449	1.068	2.364	5.844	42.56	

Table 4.2: Calculation of constants and Ev values

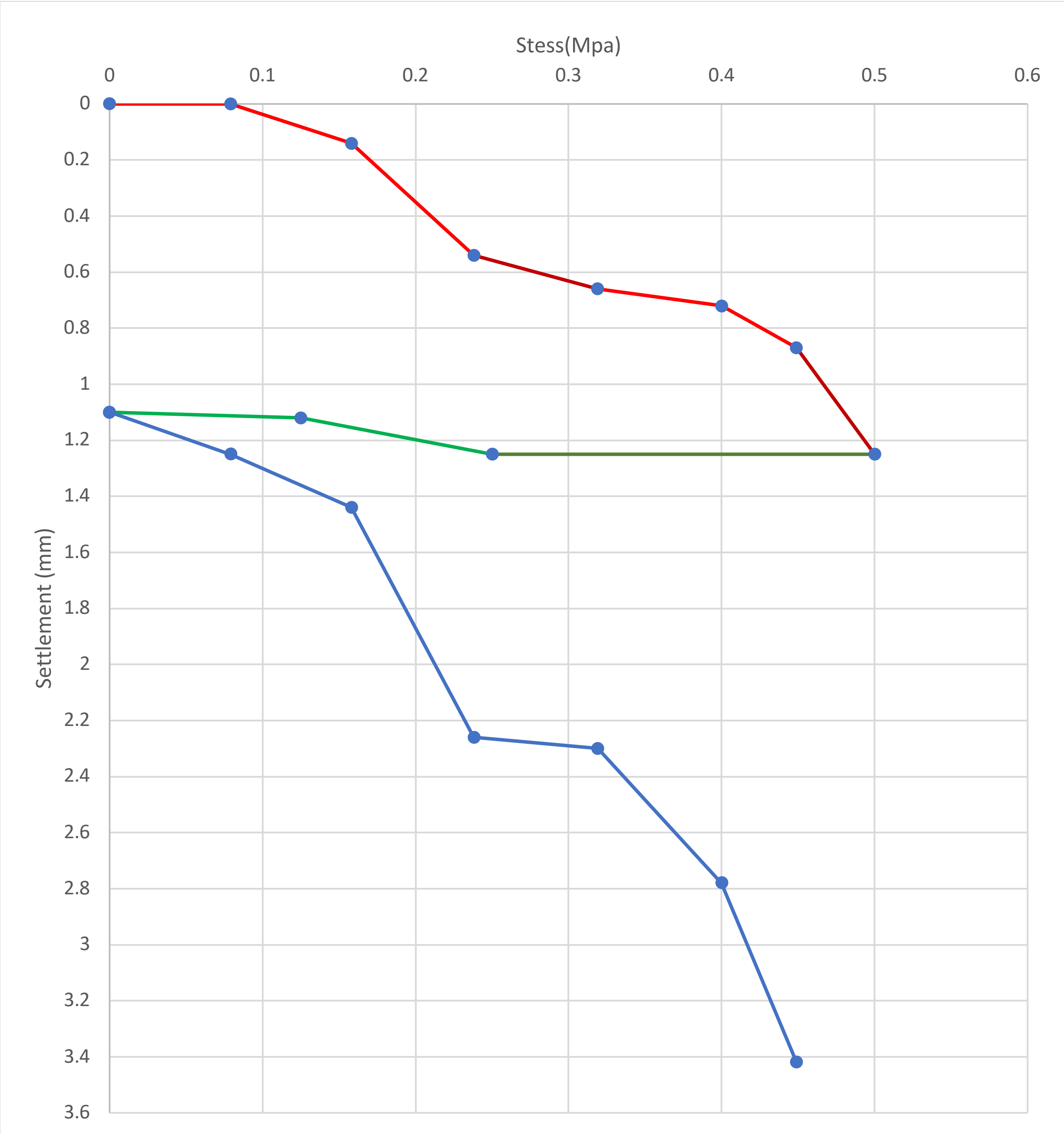

Fig 4.1 Stress vs Settlement curve (pt 1, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	1.25	First Loading
0.158	1.26	First Loading
0.238	1.32	First Loading
0.319	1.66	First Loading
0.4	1.87	First Loading
0.449	1.9	First Loading
0.5	2.3	First Loading
0.25	2.3	Unloading
0.125	2.3	Unloading
0	2.25	Unloading
0	2.25	Second Loading
0.079	2.44	Second Loading
0.158	2.5	Second Loading
0.238	2.54	Second Loading
0.319	3	Second Loading
0.4	3.22	Second Loading
0.449	3.46	Second Loading

Table 4.3: stress vs settlement values of sub grade point 1

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	1.269	-0.853	5.669	113.57	0.7
Second loading	0.449	2.292	0.501	4.664	79.43	

Table 4.4: Calculation of constants and Ev values

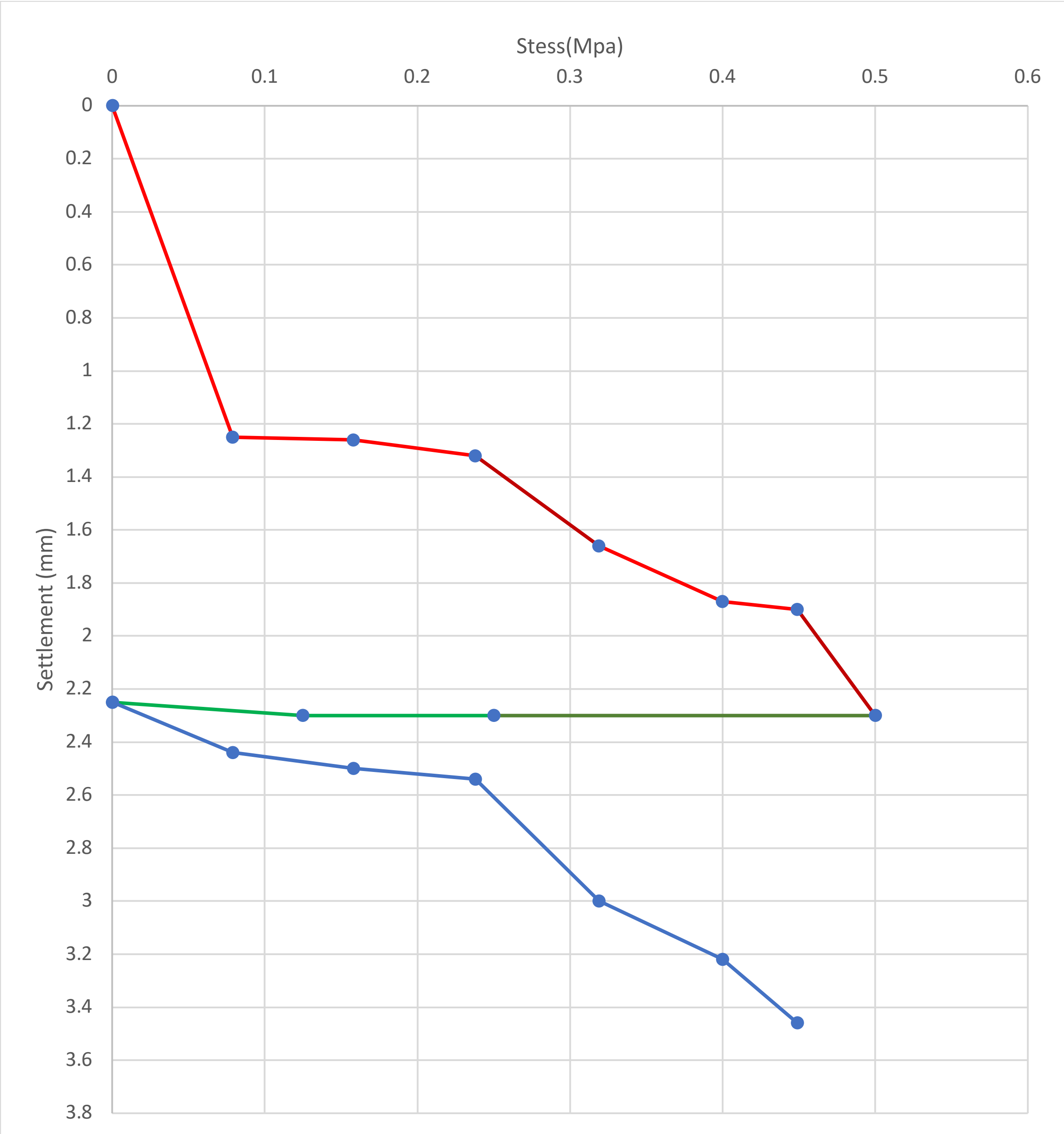

Fig 4.2 Stress vs Settlement curve (pt 1, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.2	First Loading
0.158	0.31	First Loading
0.238	0.46	First Loading
0.319	0.56	First Loading
0.4	0.72	First Loading
0.449	0.87	First Loading
0.5	1.25	First Loading
0.25	1.25	Unloading
0.125	1.22	Unloading
0	1.2	Unloading
0	1.2	Second Loading
0.079	1.2	Second Loading
0.158	1.32	Second Loading
0.238	1.44	Second Loading
0.319	1.54	Second Loading
0.4	1.72	Second Loading
0.444	2	Second Loading

Table 4.5: stress vs settlement values of ballast layer point 1

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.251	-0.538	4.731	123.14	0.97
Second loading	0.444	1.204	-0.101	3.984	119	

Table 4.6: Calculation of constants and Ev values

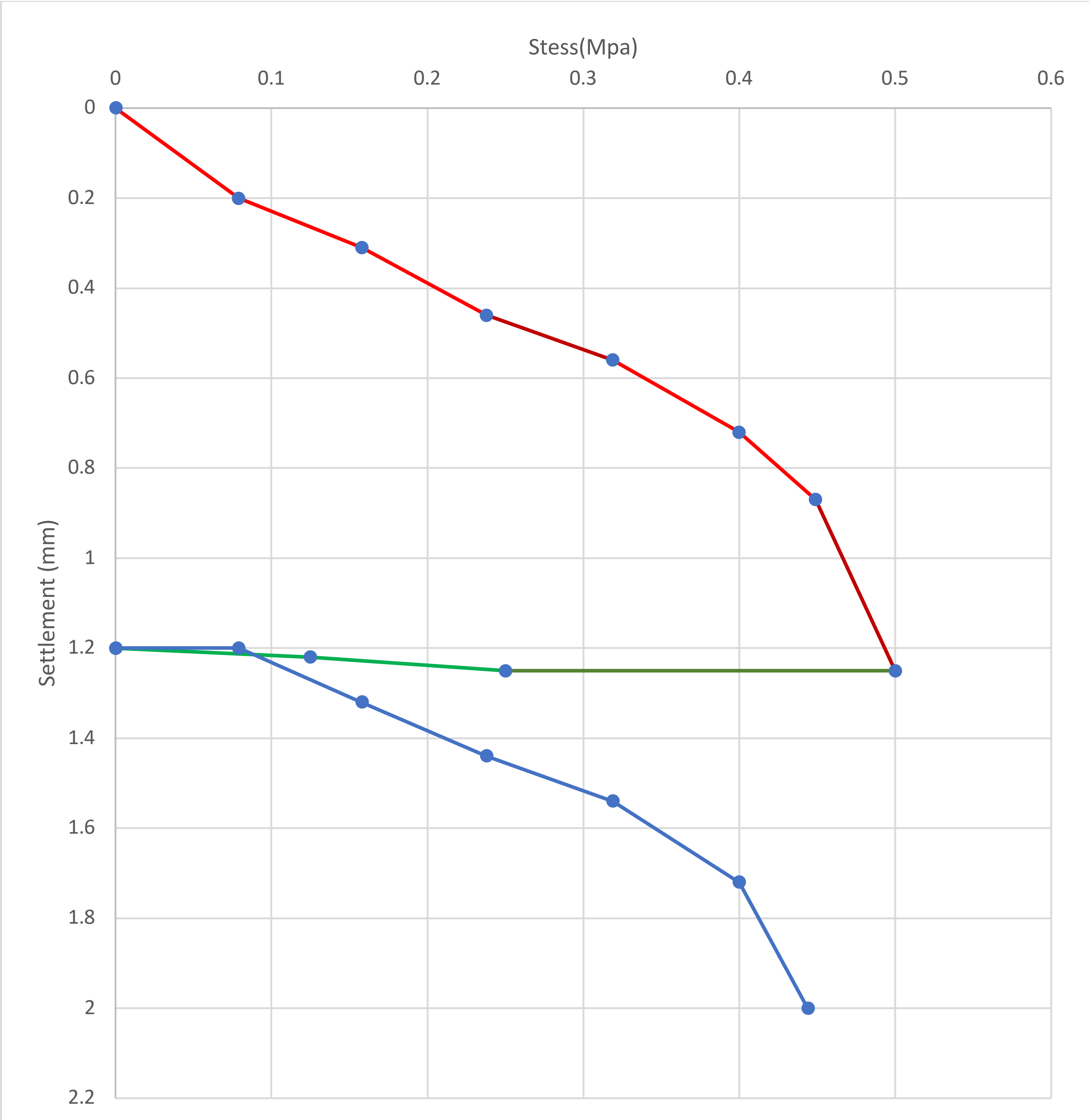

Fig 4.3 Stress vs Settlement curve (pt 1, ballast layer)

1. Point no. 02

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.43	First Loading
0.158	0.62	First Loading
0.238	1.24	First Loading
0.319	1.46	First Loading
0.4	2.24	First Loading
0.449	2.53	First Loading
0.5	2.77	First Loading
0.25	2.77	Unloading
0.125	2.77	Unloading
0	2.77	Unloading
0	2.77	Second Loading
0.079	2.88	Second Loading
0.158	2.98	Second Loading
0.238	3.01	Second Loading
0.319	3.24	Second Loading
0.4	4.42	Second Loading
0.449	4.63	Second Loading

Table 4.7: stress vs settlement values of GL point 2

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.106	3.271	4.47	40.86	1.16
Second loading	0.449	2.891	-2.817	15.158	47.25	

Table 4.8: Calculation of constants and Ev values

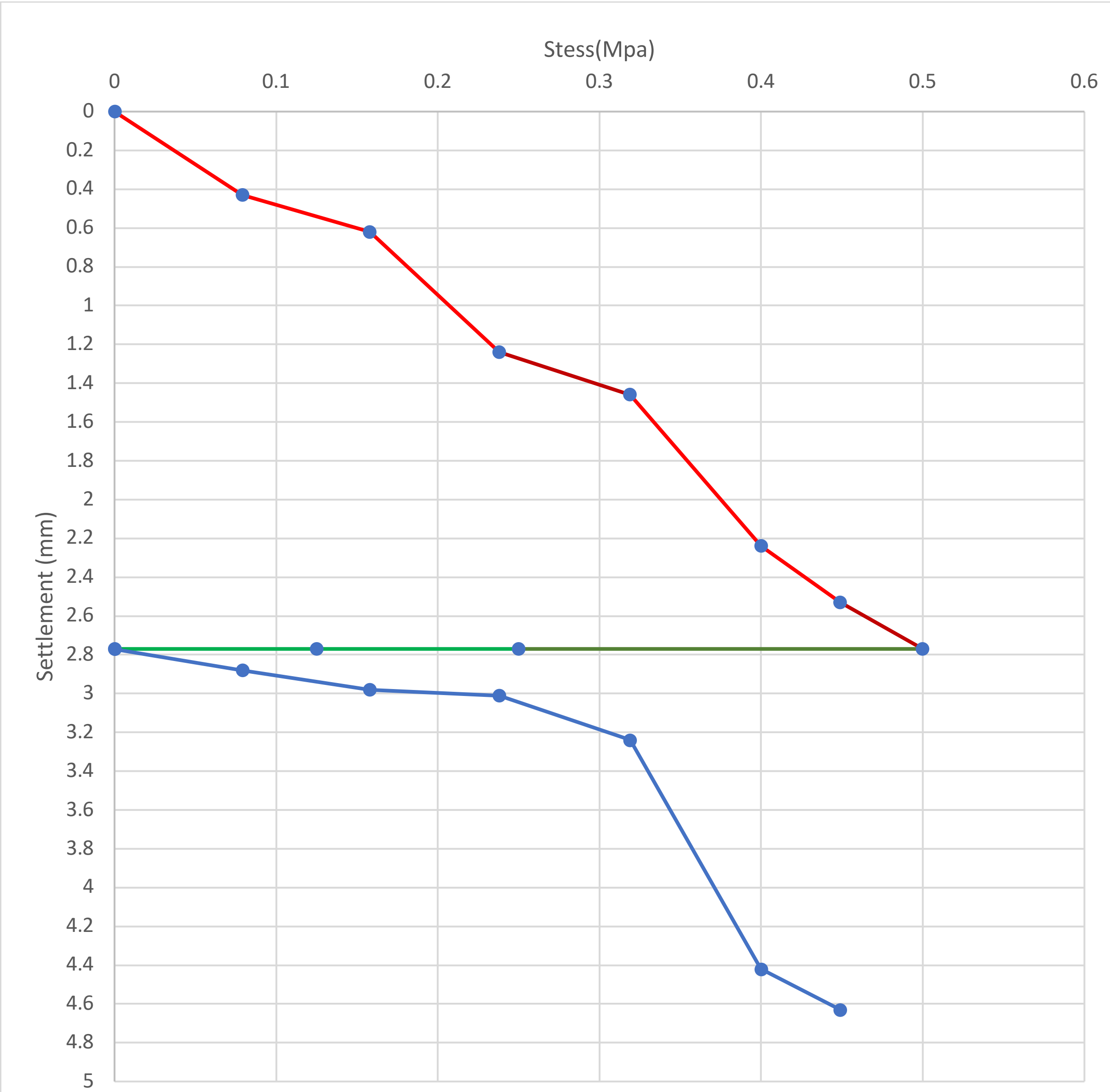

Fig 4.4 Stress vs Settlement curve (pt 2, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.3	First Loading
0.158	0.36	First Loading
0.238	0.47	First Loading
0.319	0.57	First Loading
0.4	0.68	First Loading
0.449	1.2	First Loading
0.5	1.34	First Loading
0.25	1.34	Unloading
0.125	1.34	Unloading
0	1.32	Unloading
0	1.32	Second Loading
0.079	1.32	Second Loading
0.158	1.39	Second Loading
0.238	1.55	Second Loading
0.319	1.67	Second Loading
0.4	2.01	Second Loading
0.449	2.51	Second Loading

Table 4.9: stress vs settlement values of sub grade point 2

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.448	-1.955	7.467	126.52	0.64
Second loading	0.449	1.358	-1.372	8.26	81.58	

Table 4.10: Calculation of constants and Ev values

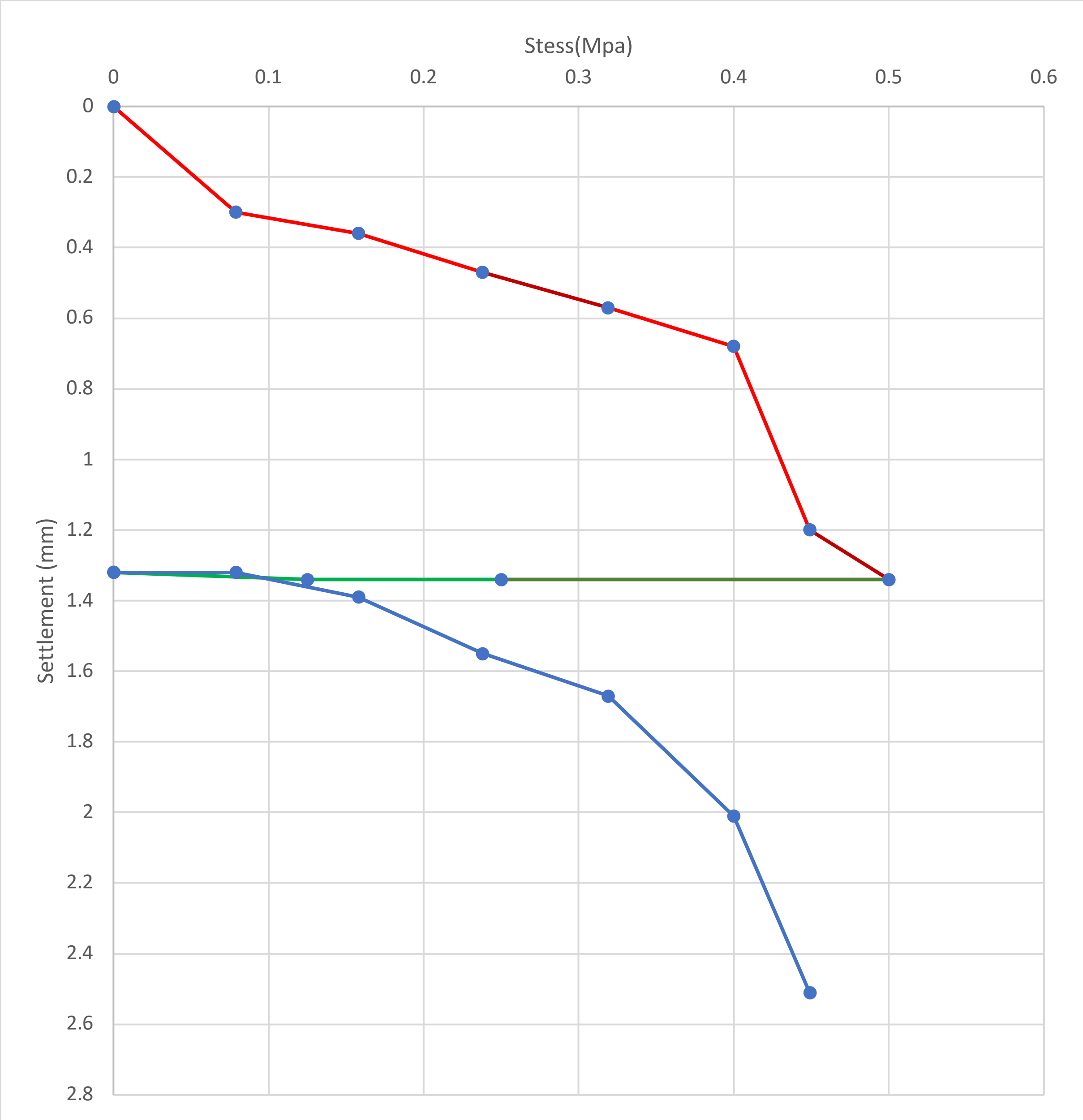

Fig 4.5 Stress vs Settlement curve (pt 2, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.1	First Loading
0.158	0.14	First Loading
0.238	0.34	First Loading
0.319	0.62	First Loading
0.4	0.75	First Loading
0.449	0.81	First Loading
0.5	1.13	First Loading
0.25	1.13	Unloading
0.125	1.13	Unloading
0	1.12	Unloading
0	1.12	Second Loading
0.079	1.12	Second Loading
0.158	1.44	Second Loading
0.238	1.51	Second Loading
0.319	1.75	Second Loading
0.4	1.82	Second Loading
0.444	1.96	Second Loading

Table 4.11: stress vs settlement values of ballast layer point 2

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.005	0.815	2.781	102.02	1.11
Second loading	0.444	1.071	1.965	0.043	113.3	

Table 4.12: Calculation of constants and Ev values

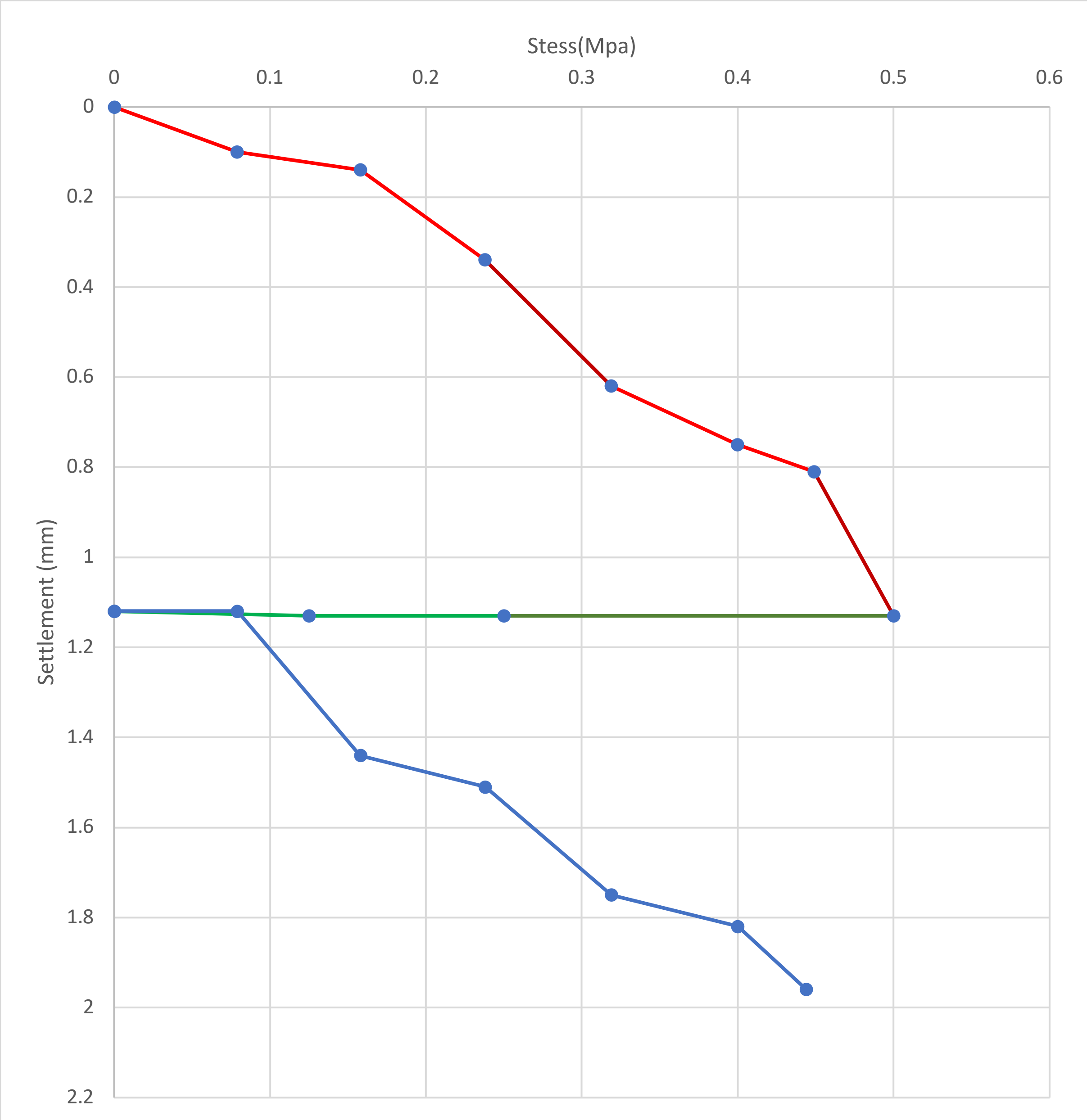

Fig 4.6 Stress vs Settlement curve (pt 2, ballast layer)

3. Point no. 03

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0	First Loading
0.158	0.86	First Loading
0.238	1.26	First Loading
0.319	1.28	First Loading
0.4	2.24	First Loading
0.449	2.42	First Loading
0.5	3	First Loading
0.25	3	Unloading
0.125	2.84	Unloading
0	2.84	Unloading
0	2.84	Second Loading
0.079	2.84	Second Loading
0.158	2.98	Second Loading
0.238	3.68	Second Loading
0.319	4.01	Second Loading
0.4	4.23	Second Loading
0.449	5.23	Second Loading

Table 4.13: stress vs settlement values of GL point 3

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	4.928	2.654	35.97	-0.227	1.14
Second loading	2.818	0.134	10.678	41.11	2.818	

Table 4.14: Calculation of constants and Ev values

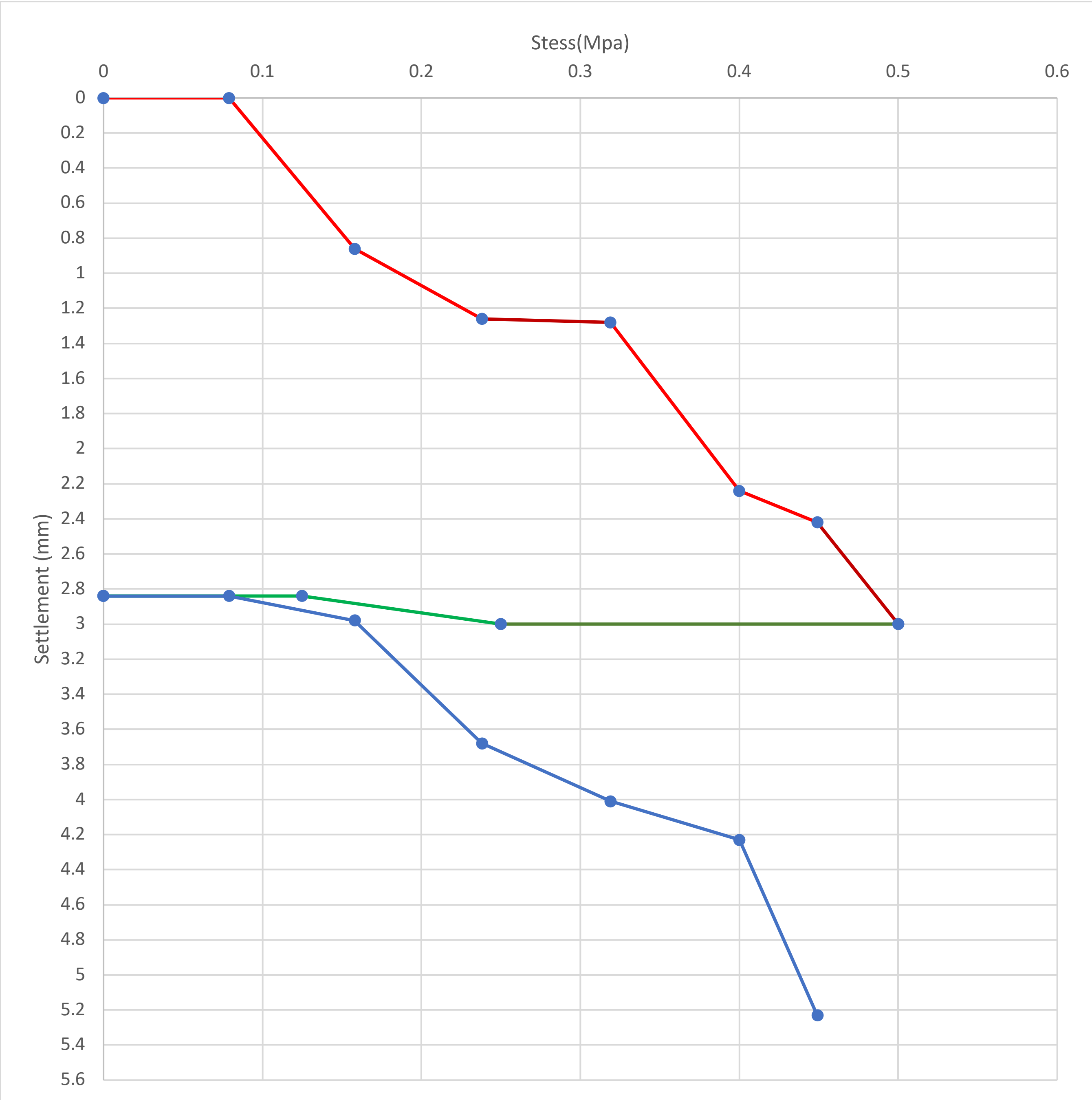

Fig 4.7 Stress vs Settlement curve (pt 3, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.25	First Loading
0.158	0.28	First Loading
0.238	0.43	First Loading
0.319	0.98	First Loading
0.4	1.01	First Loading
0.449	1.12	First Loading
0.5	1.12	First Loading
0.25	1.12	Unloading
0.125	1.12	Unloading
0	1.12	Unloading
0	1.12	Second Loading
0.079	1.12	Second Loading
0.158	1.46	Second Loading
0.238	1.76	Second Loading
0.319	1.87	Second Loading
0.4	2.1	Second Loading
0.449	2.3	Second Loading

Table 4.15: stress vs settlement values of sub grade point 3

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.067	3.004	-0.932	88.65	0.9
Second loading	0.449	1.057	2.329	0.96	80.09	

Table 4.16: Calculation of constants and Ev values

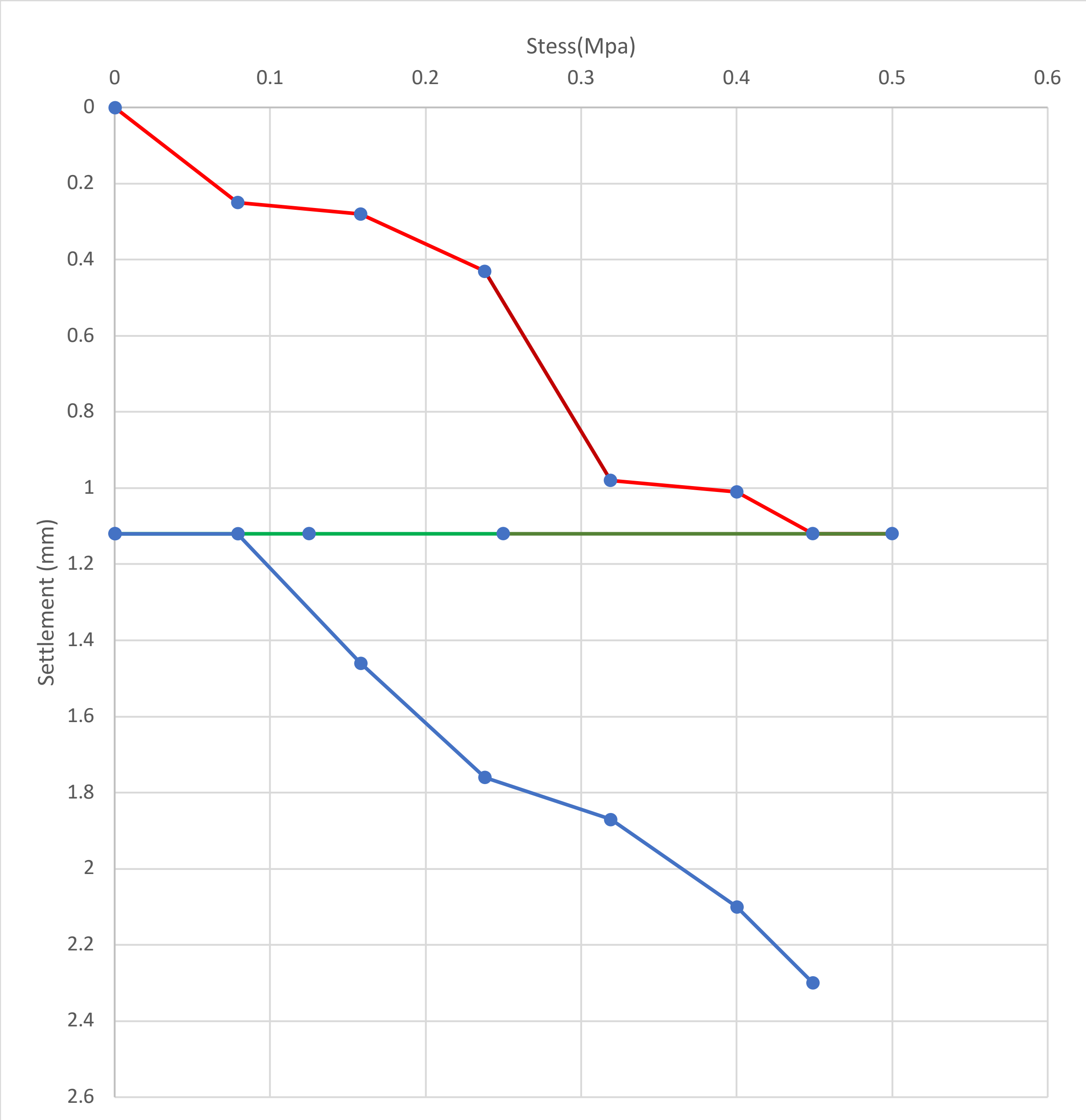

Fig 4.8 Stress vs Settlement curve (pt 3, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.07	First Loading
0.158	0.1	First Loading
0.238	0.18	First Loading
0.319	0.46	First Loading
0.4	0.62	First Loading
0.449	0.87	First Loading
0.5	0.92	First Loading
0.25	0.92	Unloading
0.125	0.92	Unloading
0	0.92	Unloading
0	0.92	Second Loading
0.079	0.92	Second Loading
0.158	1.12	Second Loading
0.238	1	Second Loading
0.319	1.4	Second Loading
0.4	1.6	Second Loading
0.444	1.76	Second Loading

Table 4.17: stress vs settlement values of ballast layer point 3

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.012	0.121	3.636	116.06	0.89
Second loading	0.444	0.927	-0.241	4.834	103.41	

Table 4.18: Calculation of constants and Ev values

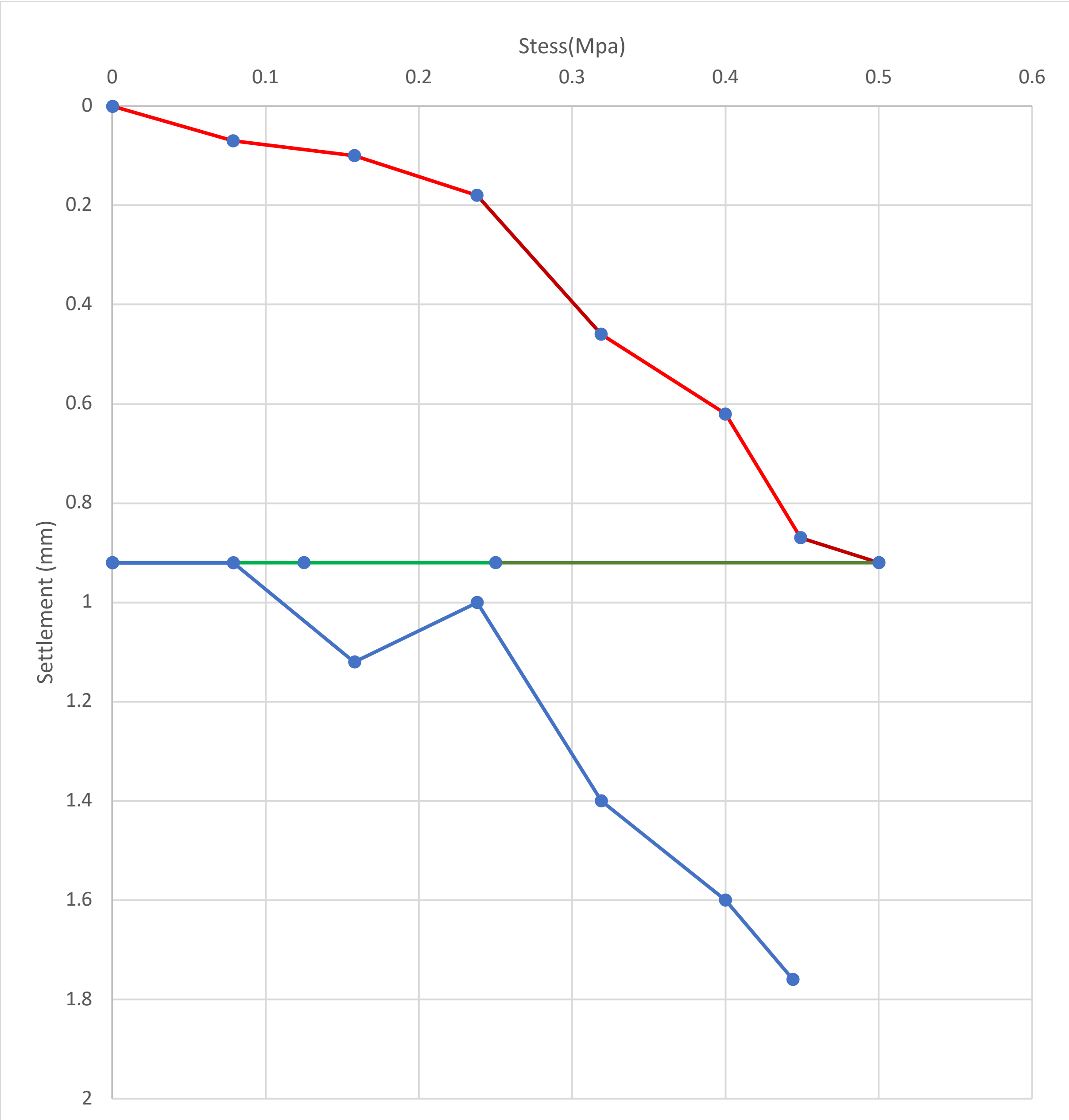

Fig 4.9 Stress vs Settlement curve (pt 3, ballast layer)

4. Point no. 04

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.14	First Loading
0.158	0.34	First Loading
0.238	1.26	First Loading
0.319	1.26	First Loading
0.4	1.98	First Loading
0.449	2.24	First Loading
0.5	2.98	First Loading
0.25	2.98	Unloading
0.125	2.82	Unloading
0	2.82	Unloading
0	2.82	Second Loading
0.079	2.82	Second Loading
0.158	3.1	Second Loading
0.238	3.46	Second Loading
0.319	3.84	Second Loading
0.4	4.51	Second Loading
0.449	4.88	Second Loading

Table 4.19: stress vs settlement values of GL point 4

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	-0.129	3.004	5.852	37.94	1.15
Second loading	2.818	2.804	0.292	9.736	43.61	

Table 4.20: Calculation of constants and Ev values

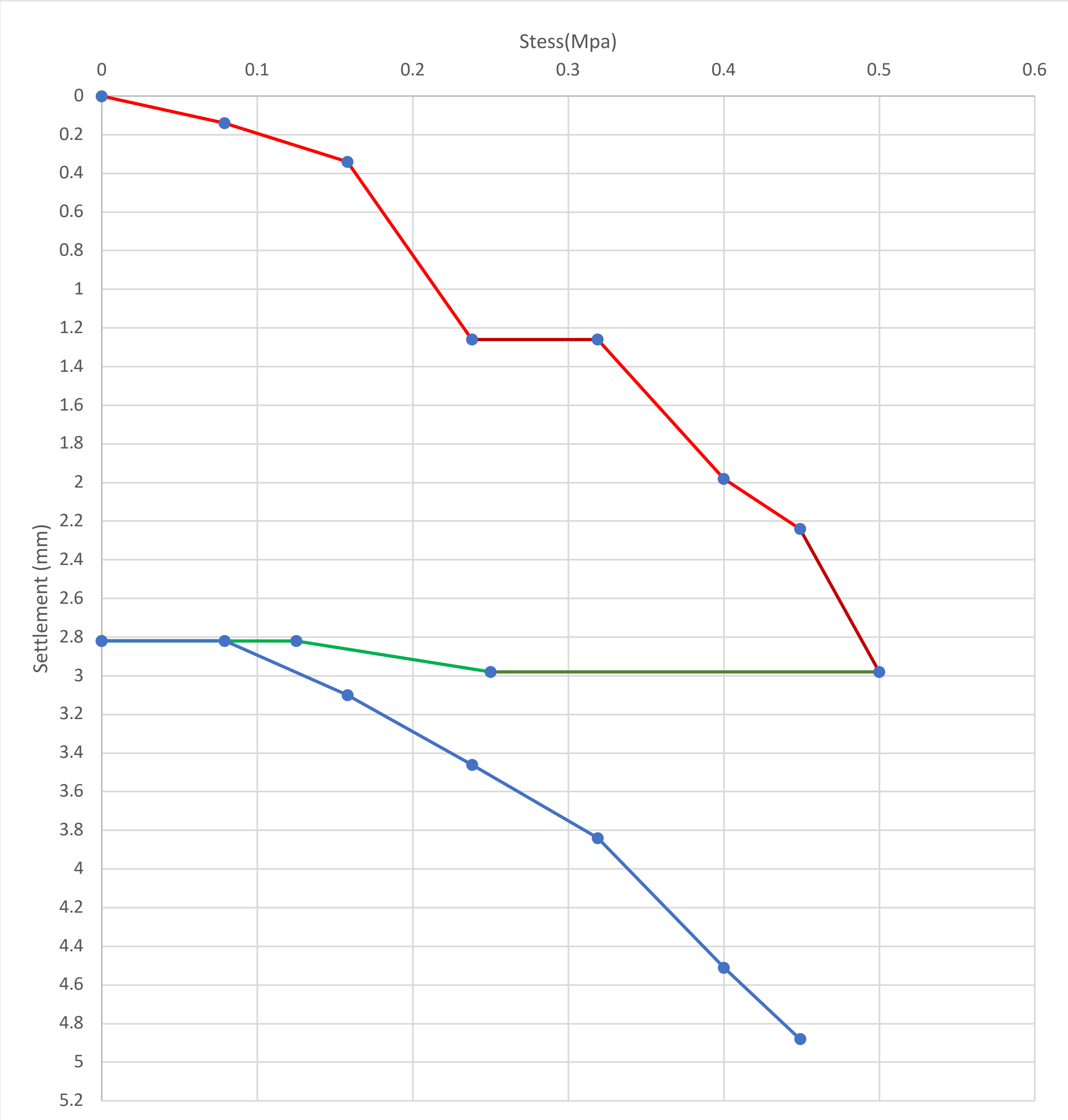

Fig 4.10 Stress vs Settlement curve (pt 4, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.15	First Loading
0.158	0.18	First Loading
0.238	0.31	First Loading
0.319	0.43	First Loading
0.4	0.56	First Loading
0.449	0.8	First Loading
0.5	1.16	First Loading
0.25	1.16	Unloading
0.125	1.16	Unloading
0	1.16	Unloading
0	1.16	Second Loading
0.079	1.2	Second Loading
0.158	1.46	Second Loading
0.238	1.5	Second Loading
0.319	1.66	Second Loading
0.4	2.1	Second Loading
0.449	2.22	Second Loading

Table 4.21: stress vs settlement values of sub grade point 4

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.277	-1.757	6.766	138.33	0.63
Second loading	0.449	1.173	0.526	4.101	87.3	

Table 4.22: Calculation of constants and Ev values

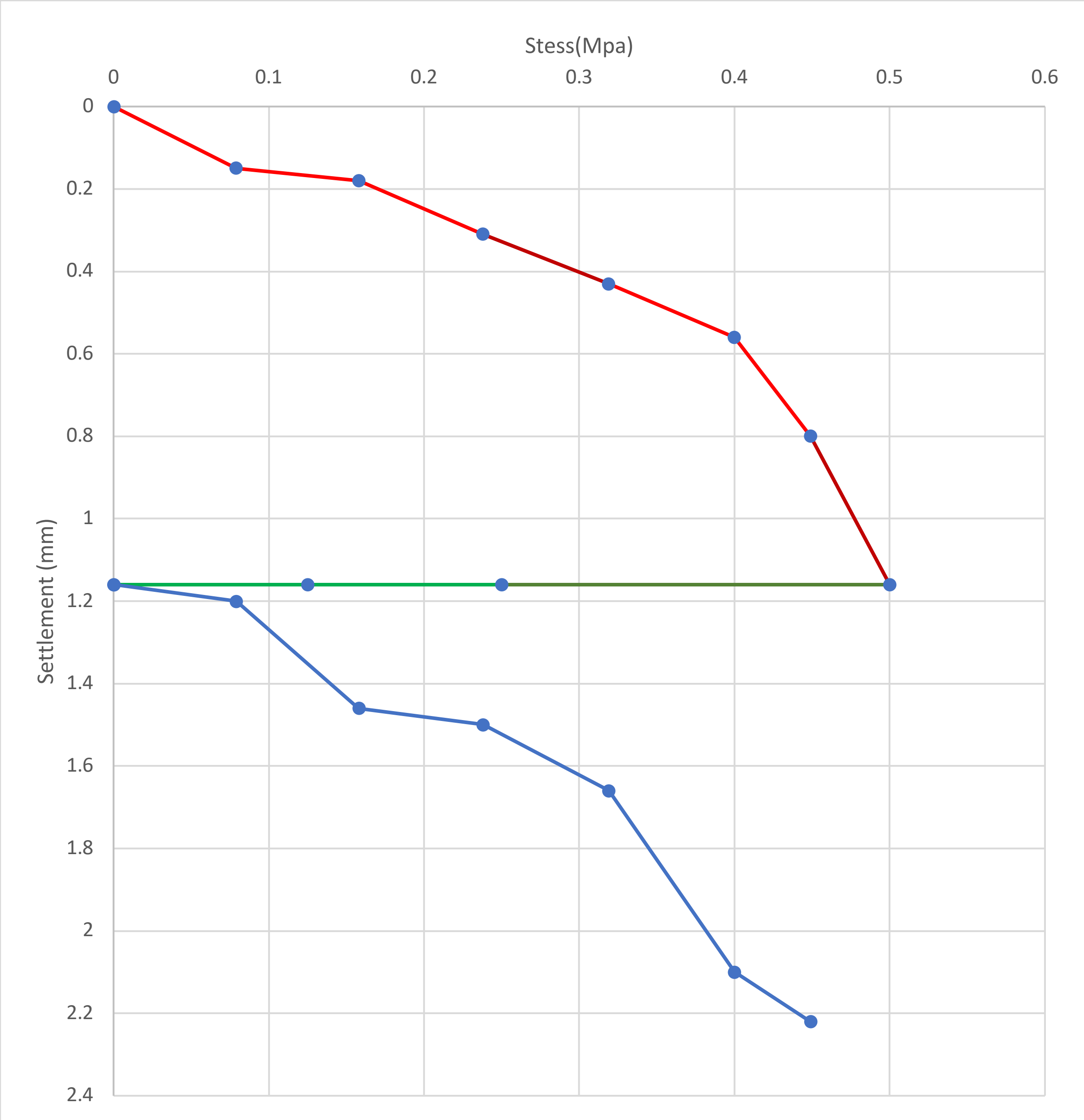

Fig 4.11 Stress vs Settlement curve (pt 4, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.05	First Loading
0.158	0.18	First Loading
0.238	0.31	First Loading
0.319	0.43	First Loading
0.4	0.76	First Loading
0.449	0.8	First Loading
0.5	0.87	First Loading
0.25	0.87	Unloading
0.125	0.87	Unloading
0	0.87	Unloading
0	0.87	Second Loading
0.079	0.87	Second Loading
0.158	1.08	Second Loading
0.238	1.36	Second Loading
0.319	1.62	Second Loading
0.4	1.66	Second Loading
0.449	1.74	Second Loading

Table 4.23: stress vs settlement values of ballast layer point 4

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.085	1.488	1.031	112.31	0.9
Second loading	0.444	0.791	2.263	-0.063	100.82	

Table 4.24: Calculation of constants and Ev values

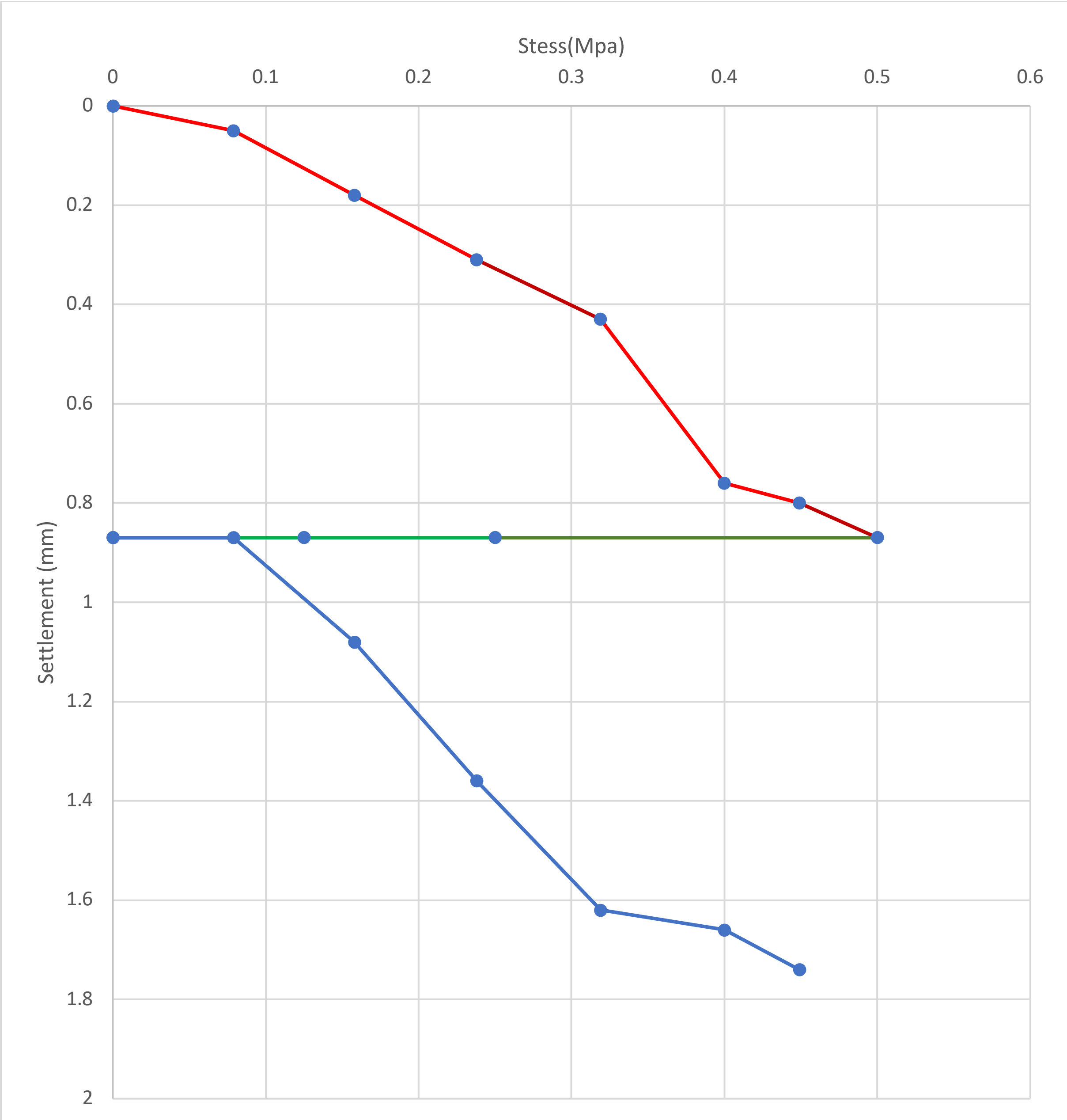

Fig 4.12 Stress vs Settlement curve (pt 4, ballast layer)

5. Point no. 05

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.18	First Loading
0.158	0.23	First Loading
0.238	0.46	First Loading
0.319	0.66	First Loading
0.4	0.86	First Loading
0.449	1.37	First Loading
0.5	1.87	First Loading
0.25	1.75	Unloading
0.125	1.62	Unloading
0	1.62	Unloading
0	1.62	Second Loading
0.079	1.75	Second Loading
0.158	2	Second Loading
0.238	2.68	Second Loading
0.319	2.98	Second Loading
0.4	3.5	Second Loading
0.449	4.01	Second Loading

Table 4.25: stress vs settlement values of GL point 5

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	0.374	-2.751	11.131	79.94	0.5
Second loading	2.818	1.576	2.295	6.774	39.6	

Table 4.26: Calculation of constants and Ev values

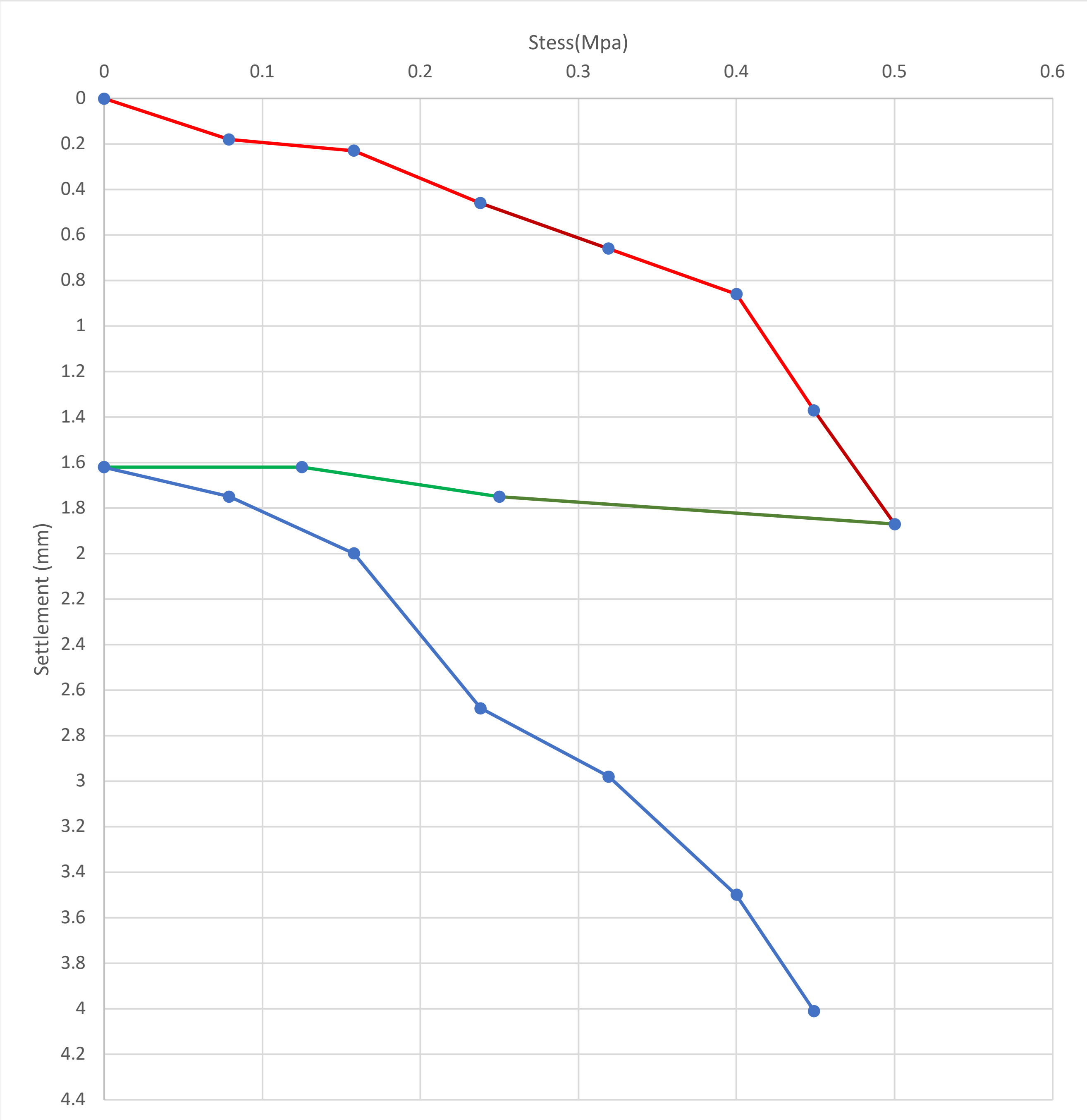

Fig 4.13 Stress vs Settlement curve (pt 5, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.15	First Loading
0.158	0.2	First Loading
0.238	0.87	First Loading
0.319	0.98	First Loading
0.4	1.26	First Loading
0.449	1.62	First Loading
0.5	1.88	First Loading
0.25	1.88	Unloading
0.125	1.88	Unloading
0	1.88	Unloading
0	1.88	Second Loading
0.079	1.88	Second Loading
0.158	1.98	Second Loading
0.238	2.42	Second Loading
0.319	2.46	Second Loading
0.4	3.02	Second Loading
0.449	3.1	Second Loading

Table 4.27: stress vs settlement values of sub grade point 5

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.128	2.773	2.429	56.42	1.24
Second loading	0.449	1.854	0.477	5.478	69.96	

Table 4.28: Calculation of constants and Ev values

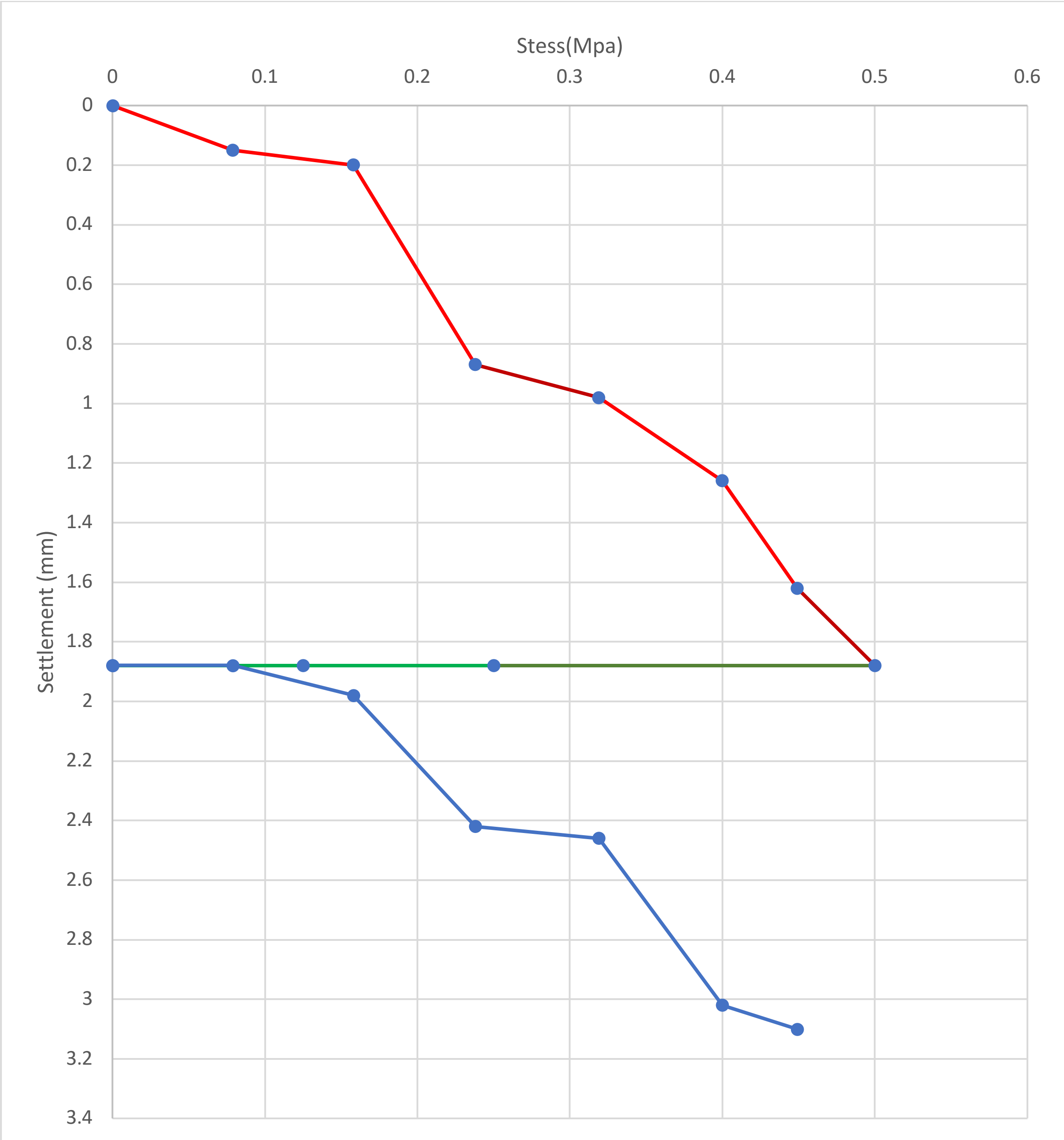

Fig 4.14 Stress vs Settlement curve (pt 5, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.07	First Loading
0.158	0.34	First Loading
0.238	0.37	First Loading
0.319	0.46	First Loading
0.4	0.76	First Loading
0.449	1.2	First Loading
0.5	1.44	First Loading
0.25	1.44	Unloading
0.125	1.44	Unloading
0	1.38	Unloading
0	1.38	Second Loading
0.079	1.38	Second Loading
0.158	1.48	Second Loading
0.238	1.5	Second Loading
0.319	1.72	Second Loading
0.4	1.87	Second Loading
0.449	2.03	Second Loading

Table 4.29: stress vs settlement values of ballast layer point 5

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.222	-1.363	7.547	93.37	1.47
Second loading	0.444	1.393	-0.254	3.777	137.65	

Table 4.30: Calculation of constants and Ev values

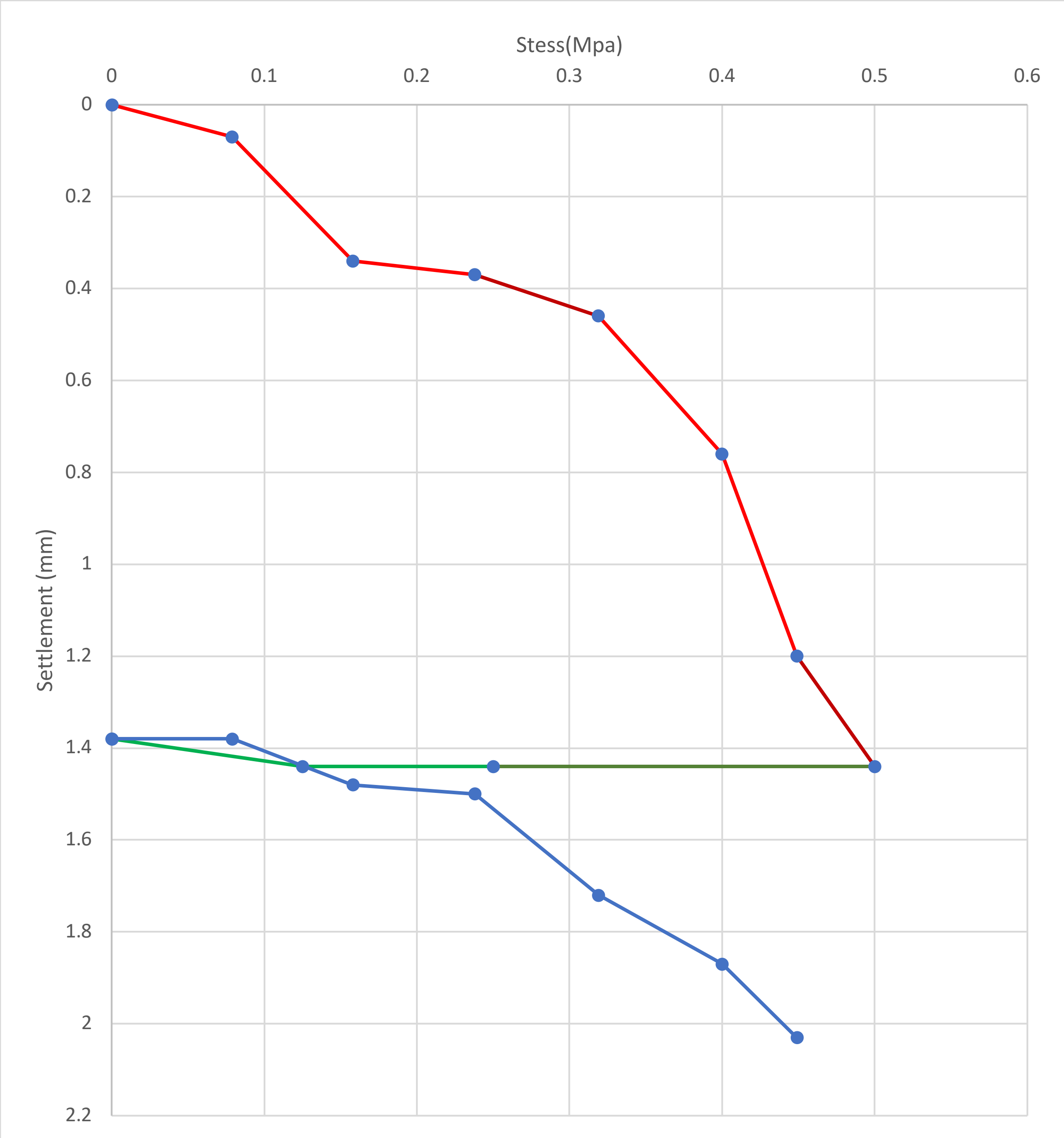

Fig 4.15 Stress vs Settlement curve (pt 5, ballast layer)

6. Point no. 06

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.03	First Loading
0.158	0.23	First Loading
0.238	0.31	First Loading
0.319	0.46	First Loading
0.4	0.8	First Loading
0.449	1.25	First Loading
0.5	1.87	First Loading
0.25	1.72	Unloading
0.125	1.72	Unloading
0	1.65	Unloading
0	1.65	Second Loading
0.079	1.65	Second Loading
0.158	2.07	Second Loading
0.238	2.44	Second Loading
0.319	2.85	Second Loading
0.4	3.4	Second Loading
0.449	4.01	Second Loading

Table 4.31: stress vs settlement values of GL point 6

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	0.366	-3.724	12.984	81.28	0.49
Second loading	2.818	1.63	0.859	9.547	39.94	

Table 4.32: Calculation of constants and Ev values

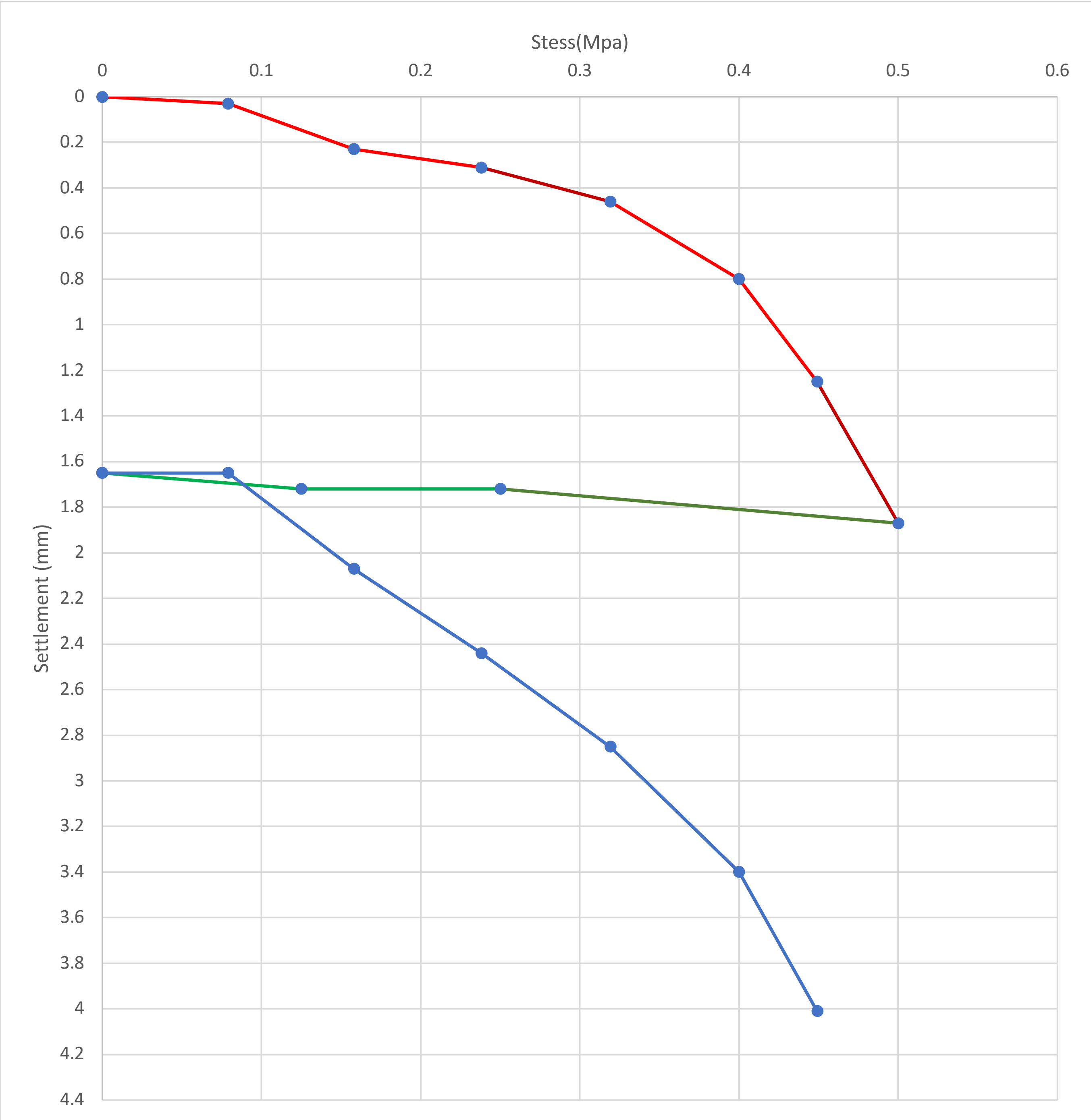

Fig 4.16 Stress vs Settlement curve (pt 6, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.15	First Loading
0.158	0.2	First Loading
0.238	0.31	First Loading
0.319	0.62	First Loading
0.4	0.81	First Loading
0.449	0.94	First Loading
0.5	1.38	First Loading
0.25	1.38	Unloading
0.125	1.38	Unloading
0	1.32	Unloading
0	1.32	Second Loading
0.079	1.44	Second Loading
0.158	1.62	Second Loading
0.238	1.86	Second Loading
0.319	2.02	Second Loading
0.4	2.32	Second Loading
0.449	2.44	Second Loading

Table 4.33: stress vs settlement values of sub grade point 6

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.198	-0.961	6.403	100.41	0.85
Second loading	0.449	1.307	1.814	1.664	85.02	

Table 4.34: Calculation of constants and Ev values

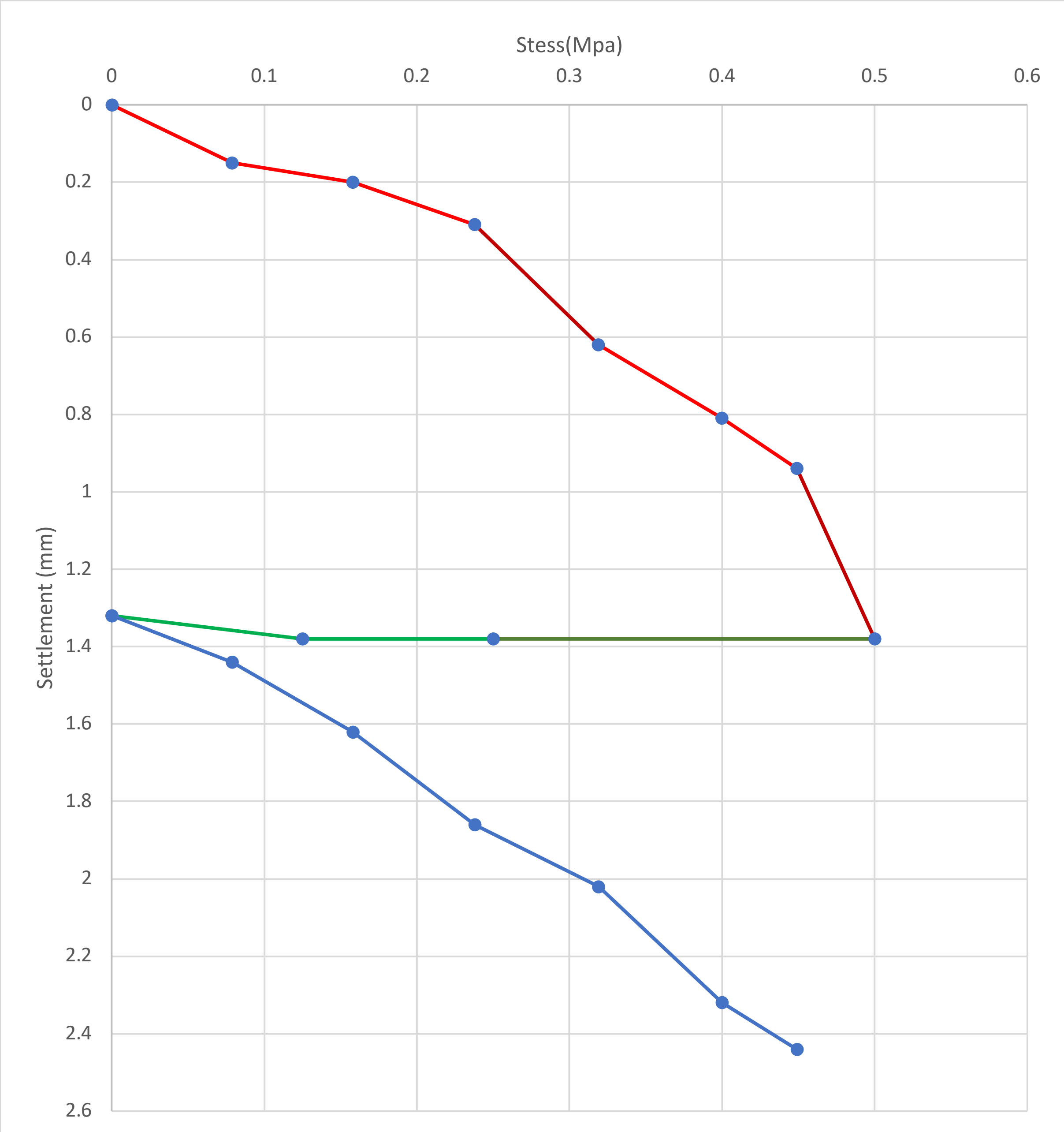

Fig 4.17 Stress vs Settlement curve (pt 6, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.05	First Loading
0.158	0.18	First Loading
0.238	0.3	First Loading
0.319	0.37	First Loading
0.4	0.62	First Loading
0.449	0.98	First Loading
0.5	1.24	First Loading
0.25	1.24	Unloading
0.125	1.2	Unloading
0	1.2	Unloading
0	1.2	Second Loading
0.079	1.2	Second Loading
0.158	1.24	Second Loading
0.238	1.54	Second Loading
0.319	1.66	Second Loading
0.4	1.82	Second Loading
0.444	1.9	Second Loading

Table 4.35: stress vs settlement values of ballast layer point 6

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.175	-1.476	7.119	108.01	1.11
Second loading	0.444	1.157	0.806	2.143	119.81	

Table 4.36: Calculation of constants and Ev values

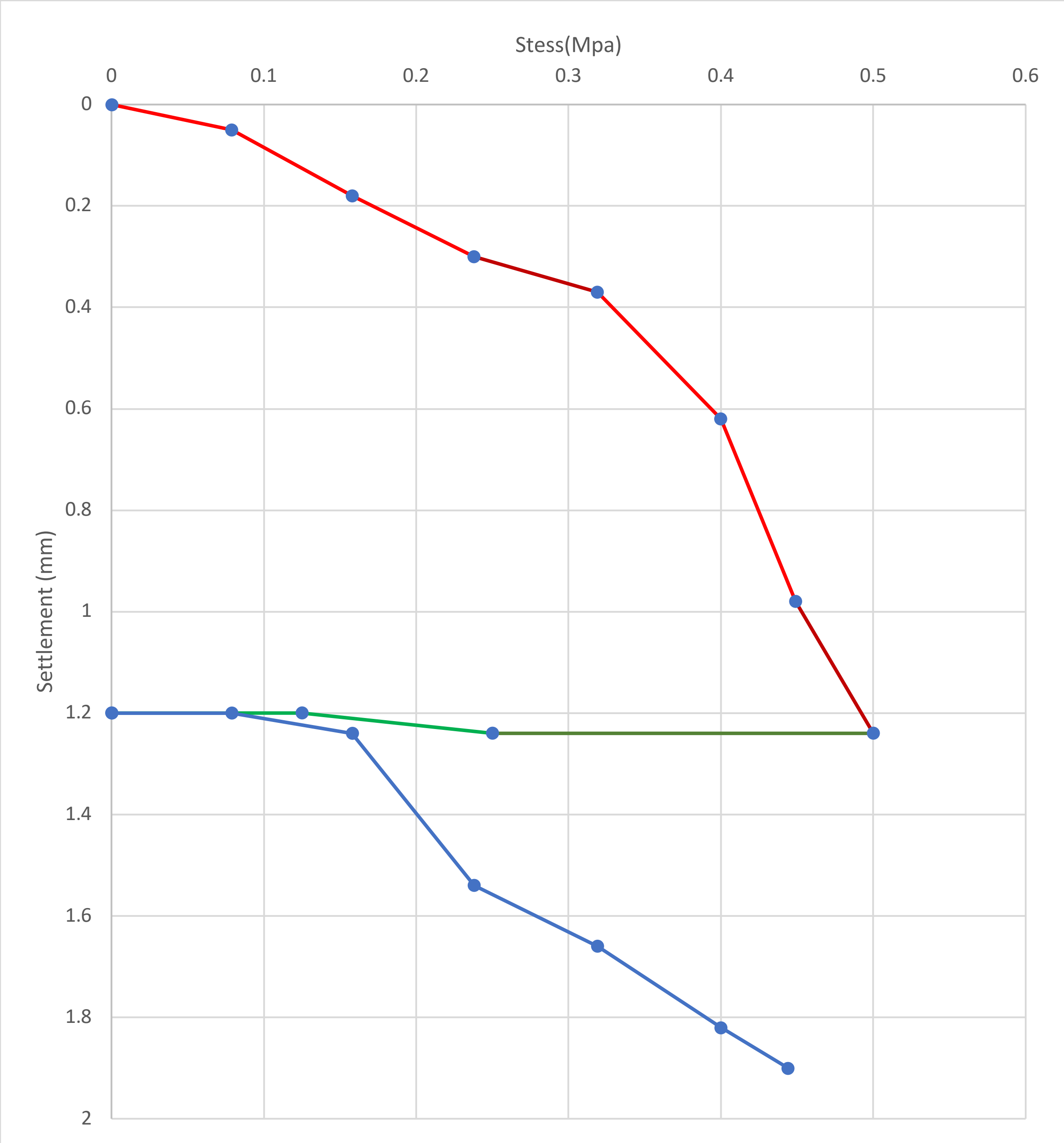

Fig 4.18 Stress vs Settlement curve (pt 6, ballast layer)

7. Point no. 07

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.34	First Loading
0.158	0.68	First Loading
0.238	1.22	First Loading
0.319	1.4	First Loading
0.4	1.66	First Loading
0.449	1.98	First Loading
0.5	2.24	First Loading
0.25	2.24	Unloading
0.125	2.24	Unloading
0	2.22	Unloading
0	2.22	Second Loading
0.079	2.22	Second Loading
0.158	2.42	Second Loading
0.238	2.54	Second Loading
0.319	3.22	Second Loading
0.4	3.98	Second Loading
0.449	4.42	Second Loading

Table 4.37: stress vs settlement values of GL point 7

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	-0.023	4.822	-0.803	50.9	0.78
Second loading	2.818	2.242	-1.73	14.816	39.63	

Table 4.38: Calculation of constants and Ev values

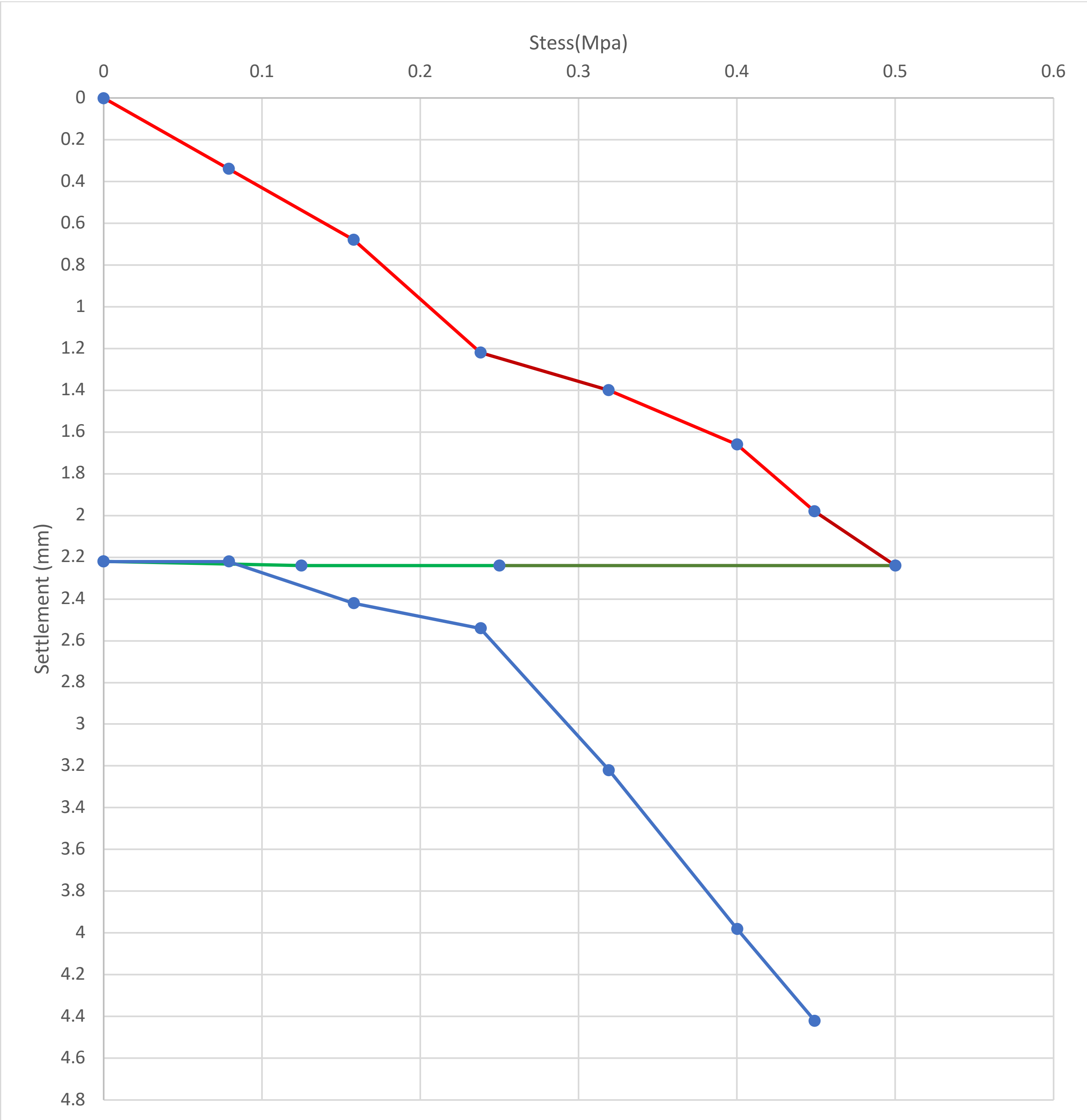

Fig 4.19 Stress vs Settlement curve (pt 7, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.14	First Loading
0.158	0.2	First Loading
0.238	0.28	First Loading
0.319	0.62	First Loading
0.4	0.82	First Loading
0.449	0.92	First Loading
0.5	1.38	First Loading
0.25	1.38	Unloading
0.125	1.38	Unloading
0	1	Unloading
0	1	Second Loading
0.079	1.4	Second Loading
0.158	1.5	Second Loading
0.238	1.86	Second Loading
0.319	2	Second Loading
0.4	2.22	Second Loading
0.449	2.44	Second Loading

Table 4.39: stress vs settlement values of sub grade point 7

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.183	-0.944	6.403	99.67	0.77
Second loading	0.449	1.055	3.405	-0.94	76.65	

Table 4.40: Calculation of constants and Ev values

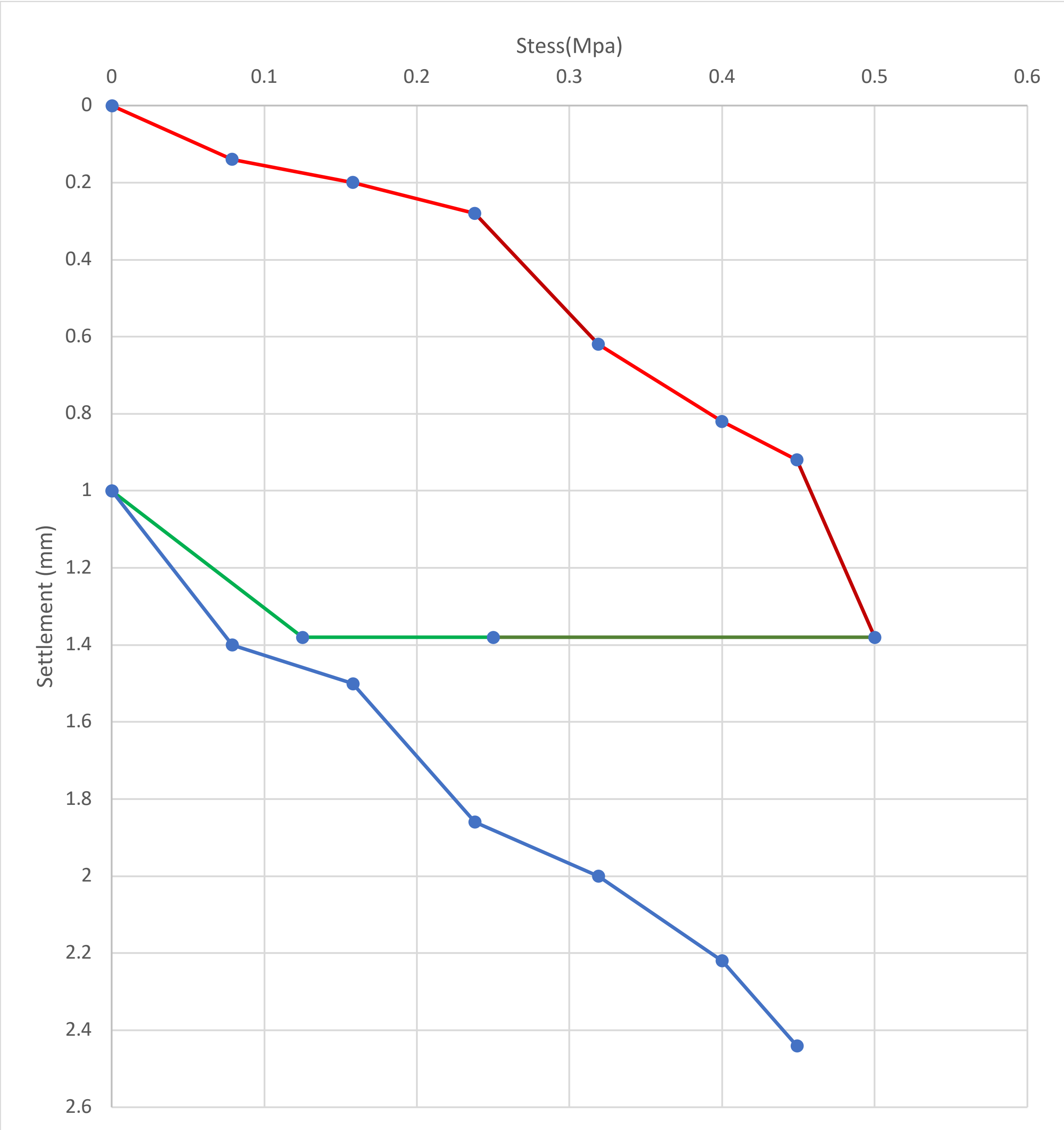

Fig 4.20 Stress vs Settlement curve (pt 7, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.15	First Loading
0.158	0.18	First Loading
0.238	0.28	First Loading
0.319	0.34	First Loading
0.4	0.5	First Loading
0.449	0.8	First Loading
0.5	1.16	First Loading
0.25	1.14	Unloading
0.125	1.14	Unloading
0	1.14	Unloading
0	1.14	Second Loading
0.079	1.14	Second Loading
0.158	1.14	Second Loading
0.238	1.44	Second Loading
0.319	1.72	Second Loading
0.4	1.86	Second Loading
0.444	1.9	Second Loading

Table 4.41: stress vs settlement values of ballast layer point 7

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.354	-2.638	8.271	150.22	0.7
Second loading	0.444	1.102	0.585	3.129	104.68	

Table 4.42: Calculation of constants and Ev values

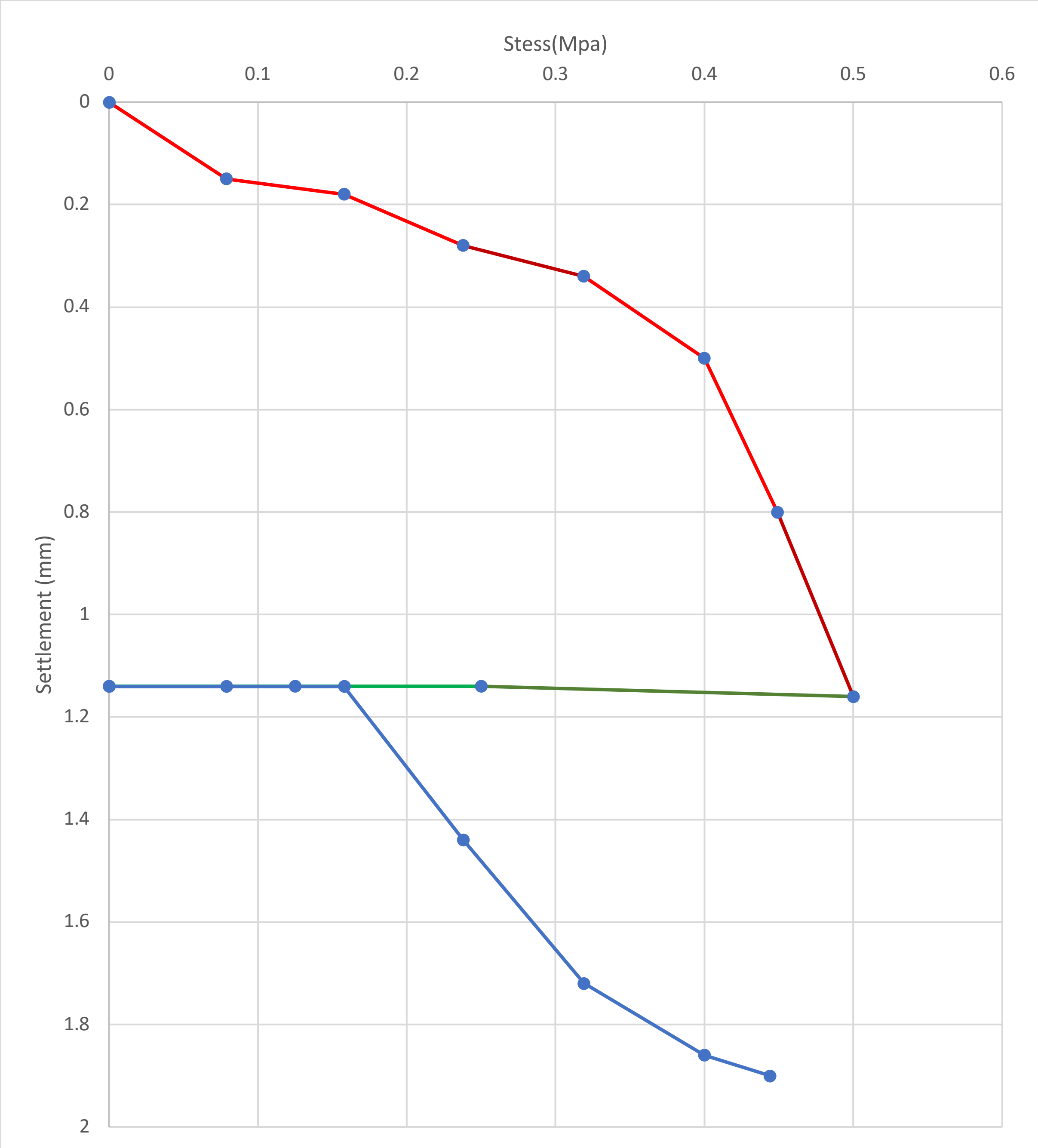

Fig 4.21 Stress vs Settlement curve (pt 7, ballast layer)

8. Point no. 08

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.31	First Loading
0.158	0.54	First Loading
0.238	0.98	First Loading
0.319	1.25	First Loading
0.4	1.66	First Loading
0.449	2.46	First Loading
0.5	2.84	First Loading
0.25	2.84	Unloading
0.125	2.68	Unloading
0	2.46	Unloading
0	2.46	Second Loading
0.079	2.84	Second Loading
0.158	2.92	Second Loading
0.238	3.44	Second Loading
0.319	4.38	Second Loading
0.4	5	Second Loading
0.444	5.55	Second Loading

Table 4.43: stress vs settlement values of GL point 8

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	-0.227	0.317	-0.422	10.962	44.47	0.67
Second loading	2.818	2.506	1.433	12.275	29.72	

Table 4.44: Calculation of constants and Ev values

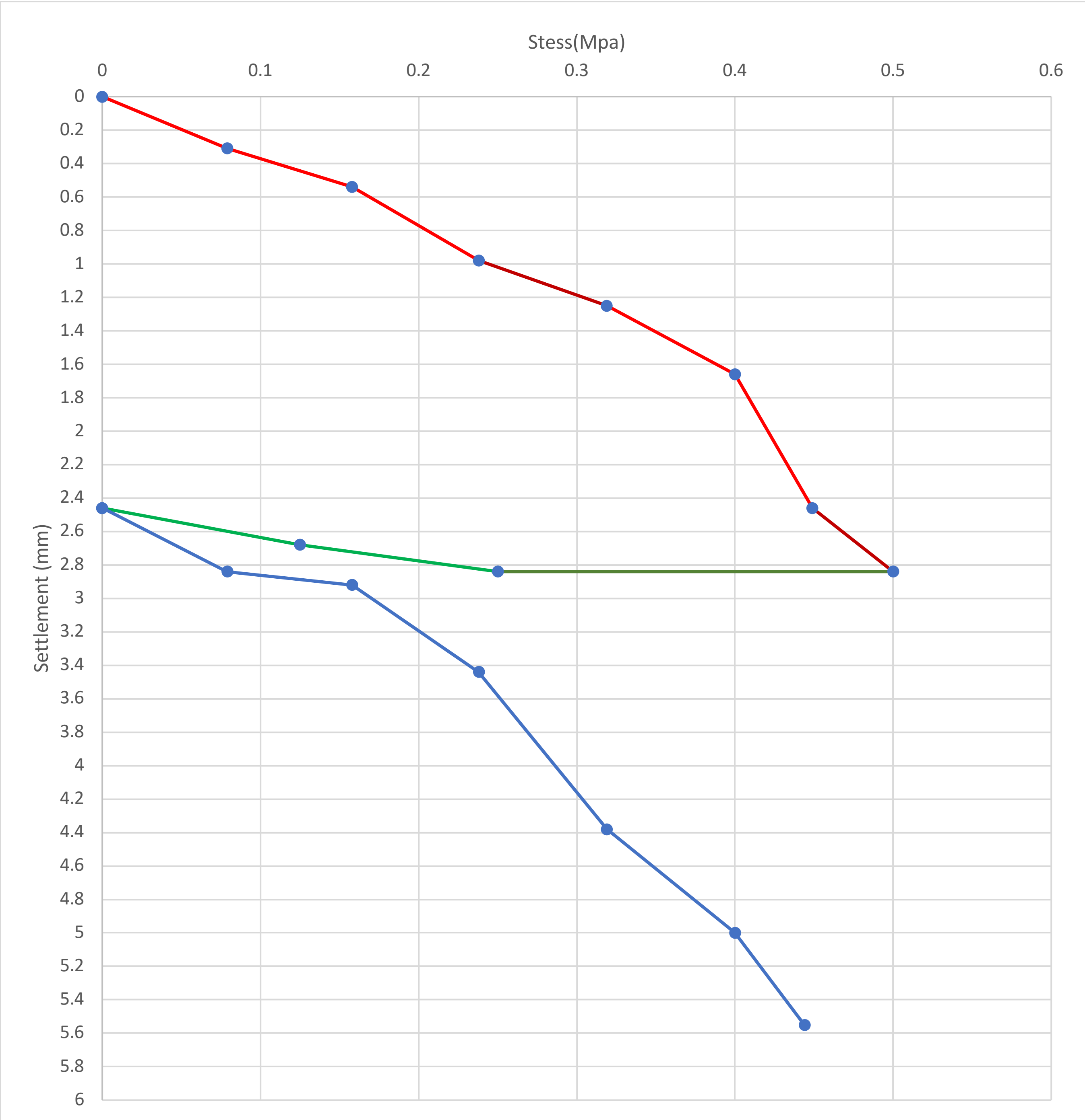

Fig 4.22 Stress vs Settlement curve (pt 8, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.23	First Loading
0.158	0.36	First Loading
0.238	0.56	First Loading
0.319	0.68	First Loading
0.4	1.24	First Loading
0.449	1.84	First Loading
0.5	2.7	First Loading
0.25	2.7	Unloading
0.125	2.53	Unloading
0	2.53	Unloading
0	2.53	Second Loading
0.079	2.53	Second Loading
0.158	2.6	Second Loading
0.238	2.82	Second Loading
0.319	3.2	Second Loading
0.4	3.52	Second Loading
0.444	3.68	Second Loading

Table 4.45: stress vs settlement values of sub grade point 8

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.695	-5.915	19.317	60.11	1.21
Second loading	0.444	2.517	-0.137	6.464	72.71	

Table 4.46: Calculation of constants and Ev values

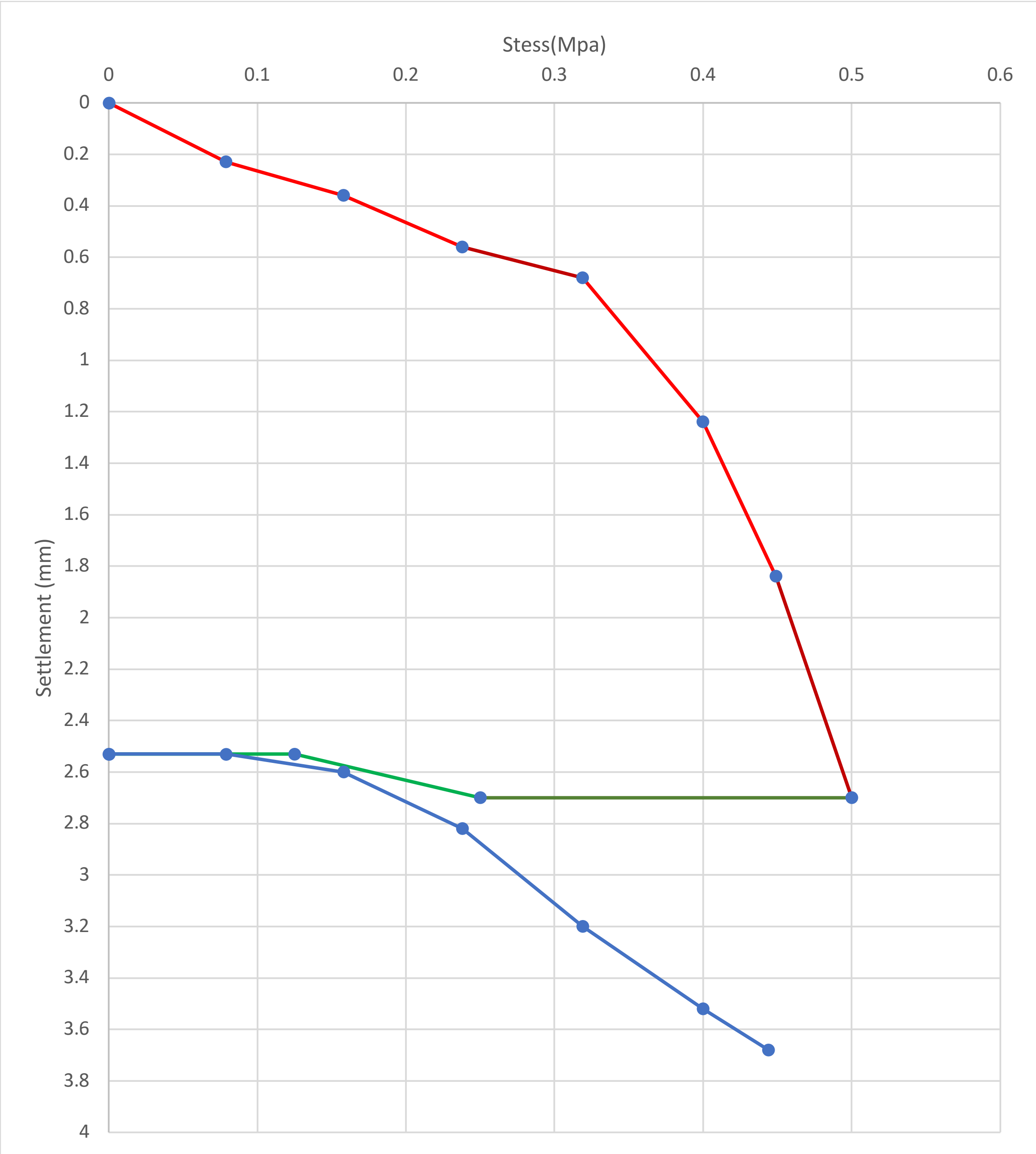

Fig 4.23 Stress vs Settlement curve (pt 8, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.28	First Loading
0.158	0.4	First Loading
0.238	0.43	First Loading
0.319	0.62	First Loading
0.4	0.76	First Loading
0.449	0.8	First Loading
0.5	1.4	First Loading
0.25	1.4	Unloading
0.125	1.38	Unloading
0	1.38	Unloading
0	1.38	Second Loading
0.079	1.38	Second Loading
0.158	1.38	Second Loading
0.238	1.44	Second Loading
0.319	1.62	Second Loading
0.4	1.87	Second Loading
0.444	2.3	Second Loading

Table 4.47: stress vs settlement values of ballast layer point 8

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.447	-1.831	6.907	138.73	0.74
Second loading	0.444	1.441	-1.962	8.292	103.01	

Table 4.48: Calculation of constants and Ev values

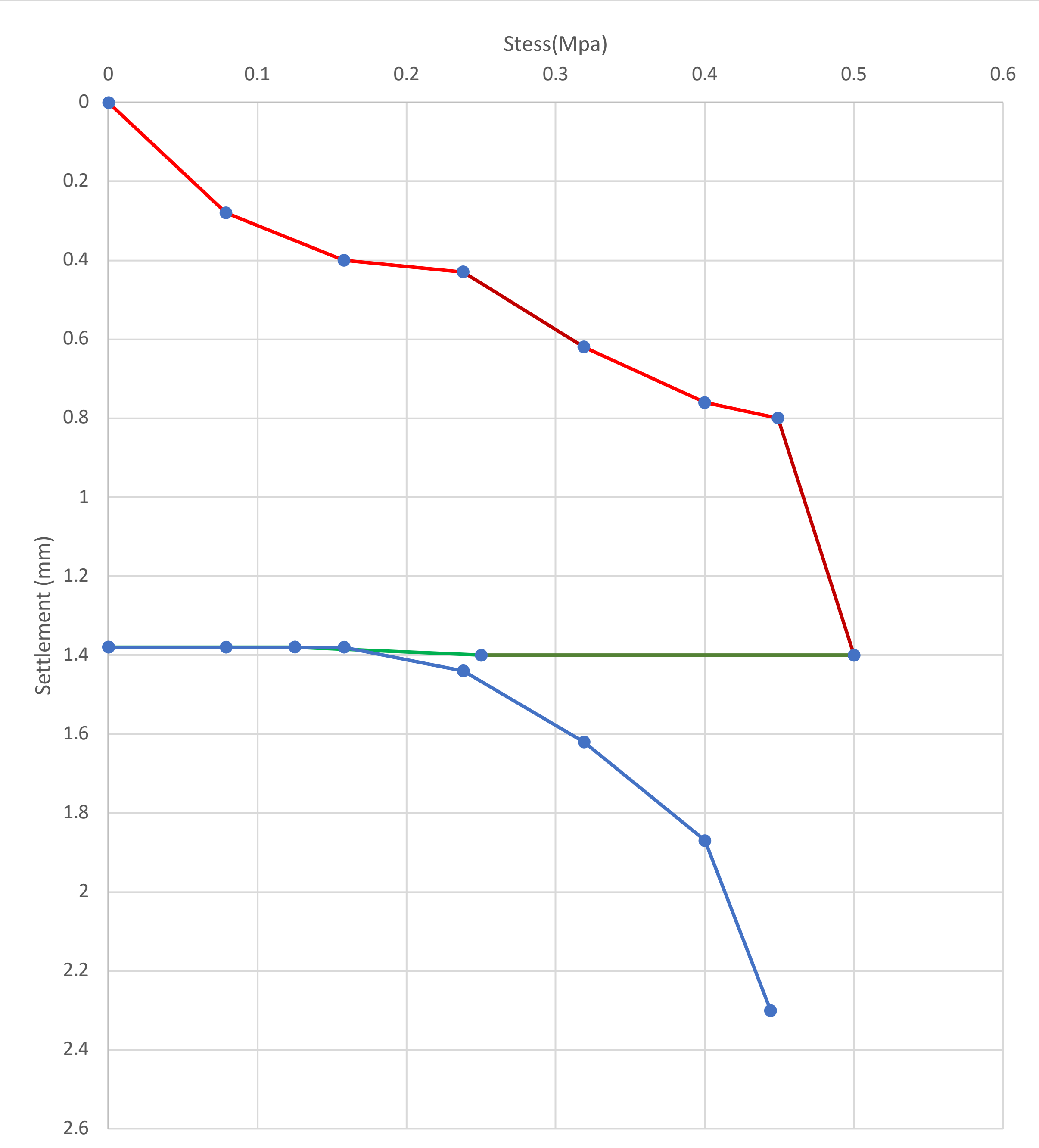

Fig 4.24 Stress vs Settlement curve (pt 8, ballast layer)

9. Point no. 09

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.2	First Loading
0.158	0.62	First Loading
0.238	0.98	First Loading
0.319	1.24	First Loading
0.4	1.62	First Loading
0.449	1.84	First Loading
0.5	2	First Loading
0.25	2	Unloading
0.125	2	Unloading
0	1.9	Unloading
0	1.9	Second Loading
0.079	2.52	Second Loading
0.158	2.84	Second Loading
0.238	3.16	Second Loading
0.319	3.68	Second Loading
0.4	3.98	Second Loading
0.444	4.26	Second Loading

Table 4.49: stress vs settlement values of GL point 9

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.15	4.907	-1.134	51.85	0.87
Second loading	0.444	1.975	5.696	-1.433	45.19	

Table 4.50: Calculation of constants and Ev values

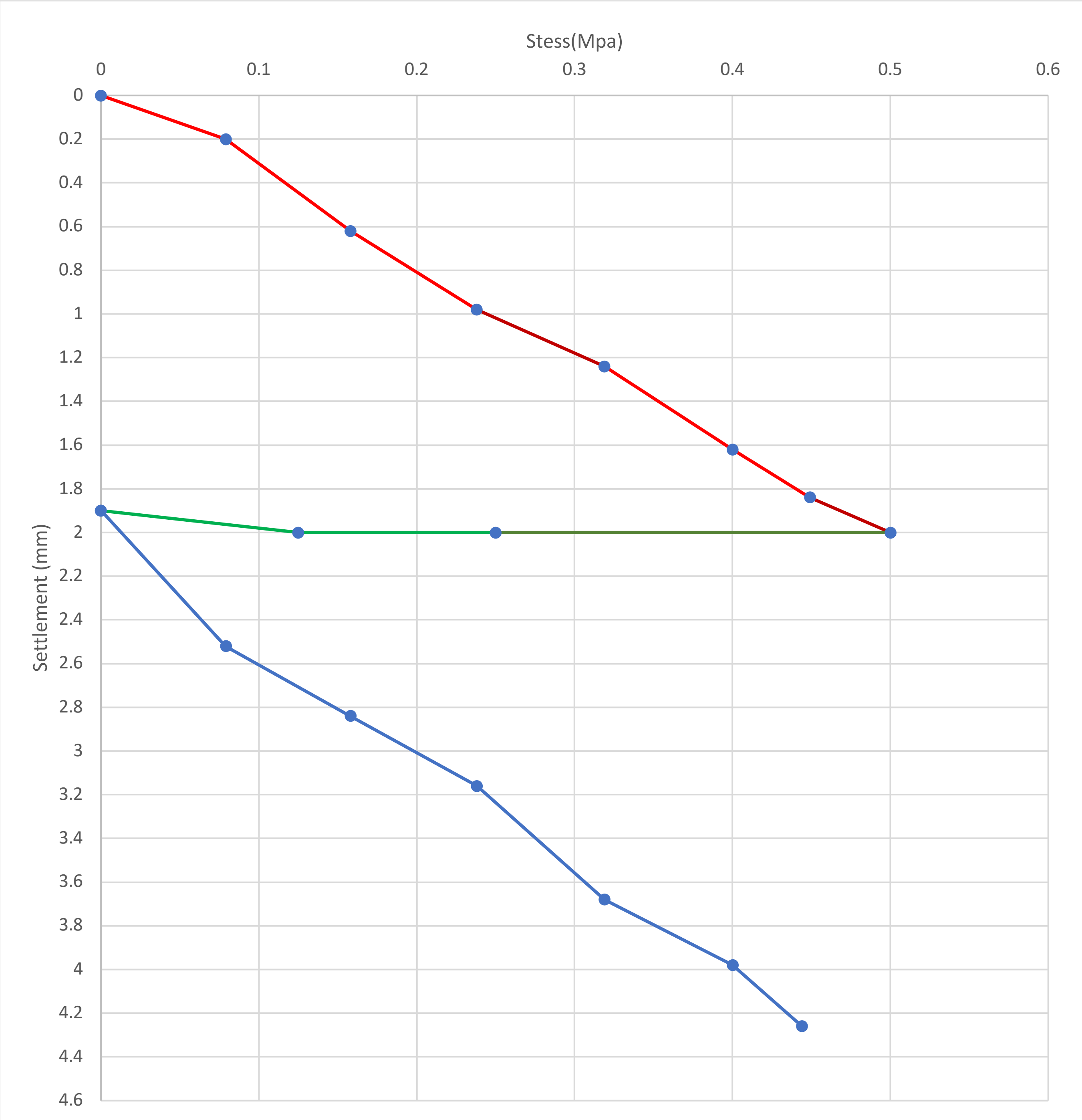

Fig 4.25 Stress vs Settlement curve (pt 9, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.34	First Loading
0.158	0.4	First Loading
0.238	0.54	First Loading
0.319	0.68	First Loading
0.4	1.2	First Loading
0.449	1.5	First Loading
0.5	2.78	First Loading
0.25	2.78	Unloading
0.125	2.42	Unloading
0	2.42	Unloading
0	2.42	Second Loading
0.079	2.42	Second Loading
0.158	2.59	Second Loading
0.238	2.98	Second Loading
0.319	3.42	Second Loading
0.4	3.52	Second Loading
0.444	3.7	Second Loading

Table 4.51: stress vs settlement values of sub grade point 9

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.952	-7.664	21.578	72.01	0.93
Second loading	0.444	2.334	1.932	2.852	67.01	

Table 4.52: Calculation of constants and Ev values

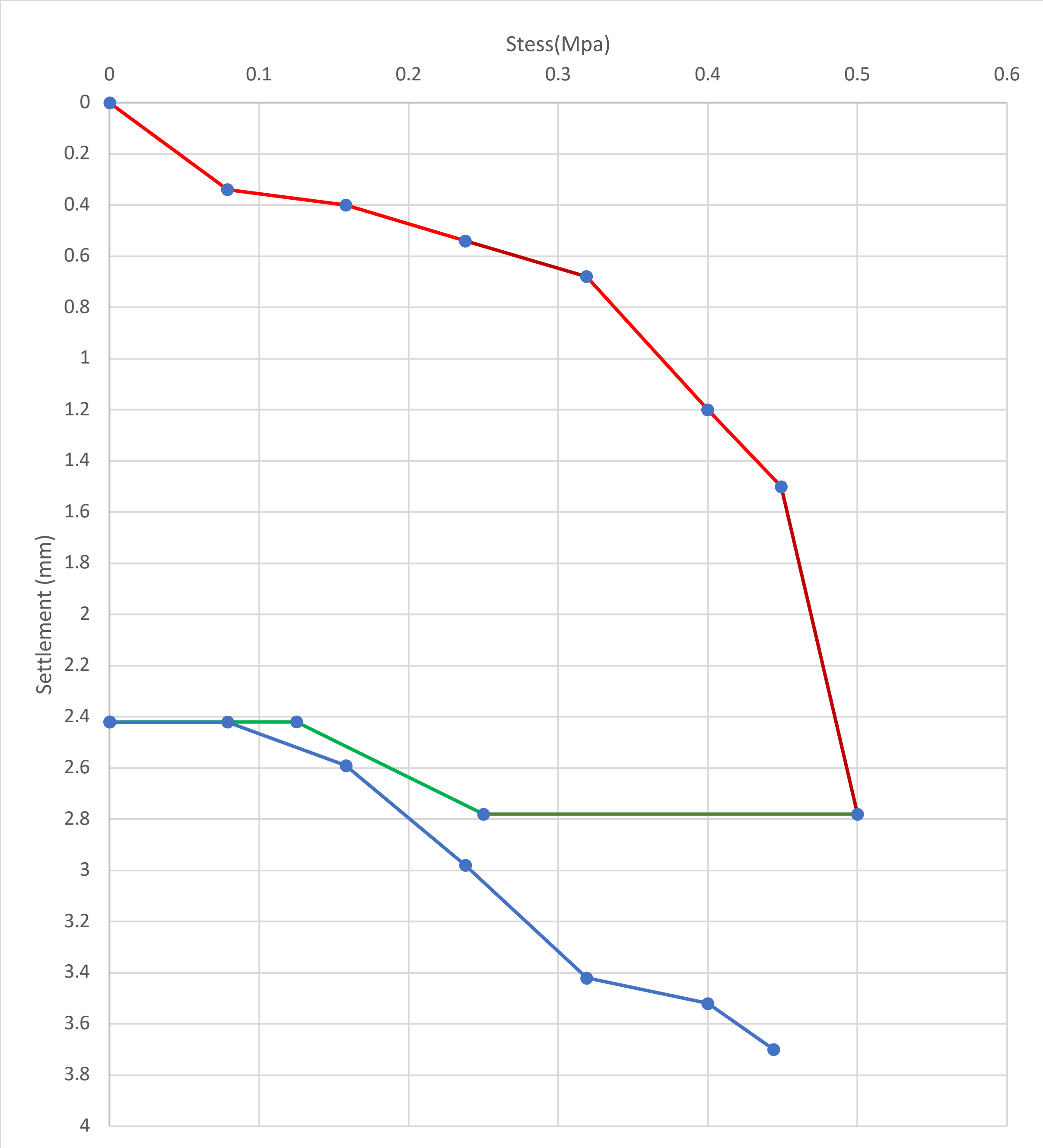

Fig 4.26 Stress vs Settlement curve (pt 9, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.23	First Loading
0.158	0.4	First Loading
0.238	0.46	First Loading
0.319	0.66	First Loading
0.4	0.76	First Loading
0.449	0.92	First Loading
0.5	1.34	First Loading
0.25	1.34	Unloading
0.125	1.26	Unloading
0	1.24	Unloading
0	1.24	Second Loading
0.079	1.25	Second Loading
0.158	1.44	Second Loading
0.238	1.5	Second Loading
0.319	1.87	Second Loading
0.4	1.9	Second Loading
0.444	2.02	Second Loading

Table 4.53: stress vs settlement values of ballast layer point 9

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.301	-0.54	4.827	120.07	0.93
Second loading	0.444	1.202	1.186	1.638	112.23	

Table 4.54: Calculation of constants and Ev values

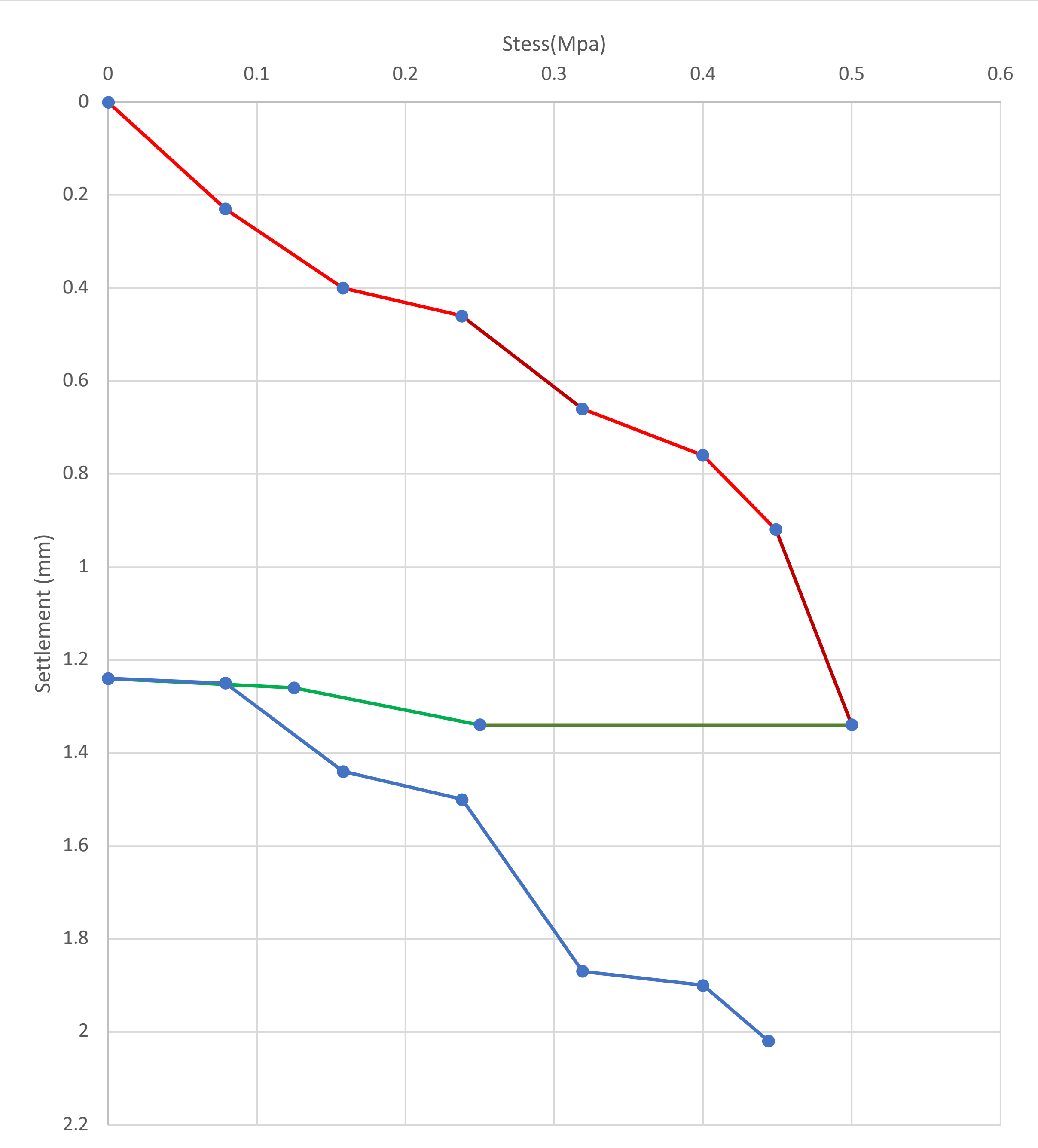

Fig 4.27 Stress vs Settlement curve (pt 9, ballast layer)

10. Point no. 10

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0	First Loading
0.158	0.23	First Loading
0.238	0.4	First Loading
0.319	0.66	First Loading
0.4	0.76	First Loading
0.449	1.24	First Loading
0.5	1.44	First Loading
0.25	1.44	Unloading
0.125	1.44	Unloading
0	1.4	Unloading
0	1.4	Second Loading
0.079	1.4	Second Loading
0.158	2.83	Second Loading
0.238	3.1	Second Loading
0.319	3.64	Second Loading
0.4	3.9	Second Loading
0.444	4.21	Second Loading

Table 4.55: stress vs settlement values of GL point 10

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.026	0.601	4.591	77.69	0.45
Second loading	0.444	1.202	9.432	-6.121	35.31	

Table 4.56: Calculation of constants and Ev values

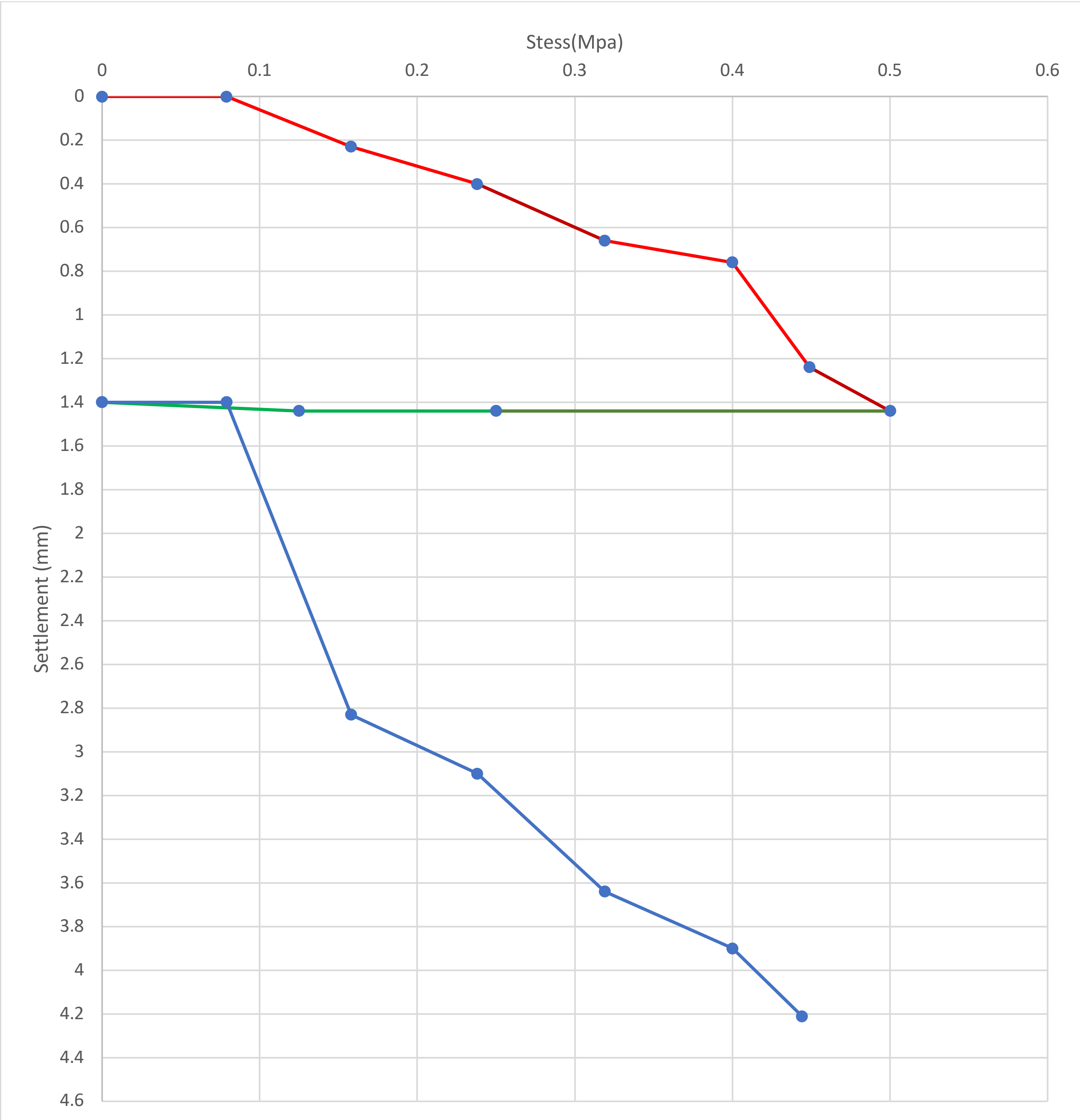

Fig 4.28 Stress vs Settlement curve (pt 10, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.2	First Loading
0.158	0.46	First Loading
0.238	0.62	First Loading
0.319	0.87	First Loading
0.4	1.12	First Loading
0.449	1.54	First Loading
0.5	2.42	First Loading
0.25	2.42	Unloading
0.125	2.42	Unloading
0	2.42	Unloading
0	2.42	Second Loading
0.079	2.42	Second Loading
0.158	2.6	Second Loading
0.238	3	Second Loading
0.319	3.42	Second Loading
0.4	3.51	Second Loading
0.444	3.7	Second Loading

Table 4.57: stress vs settlement values of sub grade point 10

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.501	-3.153	13.157	65.68	1.03
Second loading	0.444	2.331	2.115	2.414	67.72	

Table 4.58: Calculation of constants and Ev values

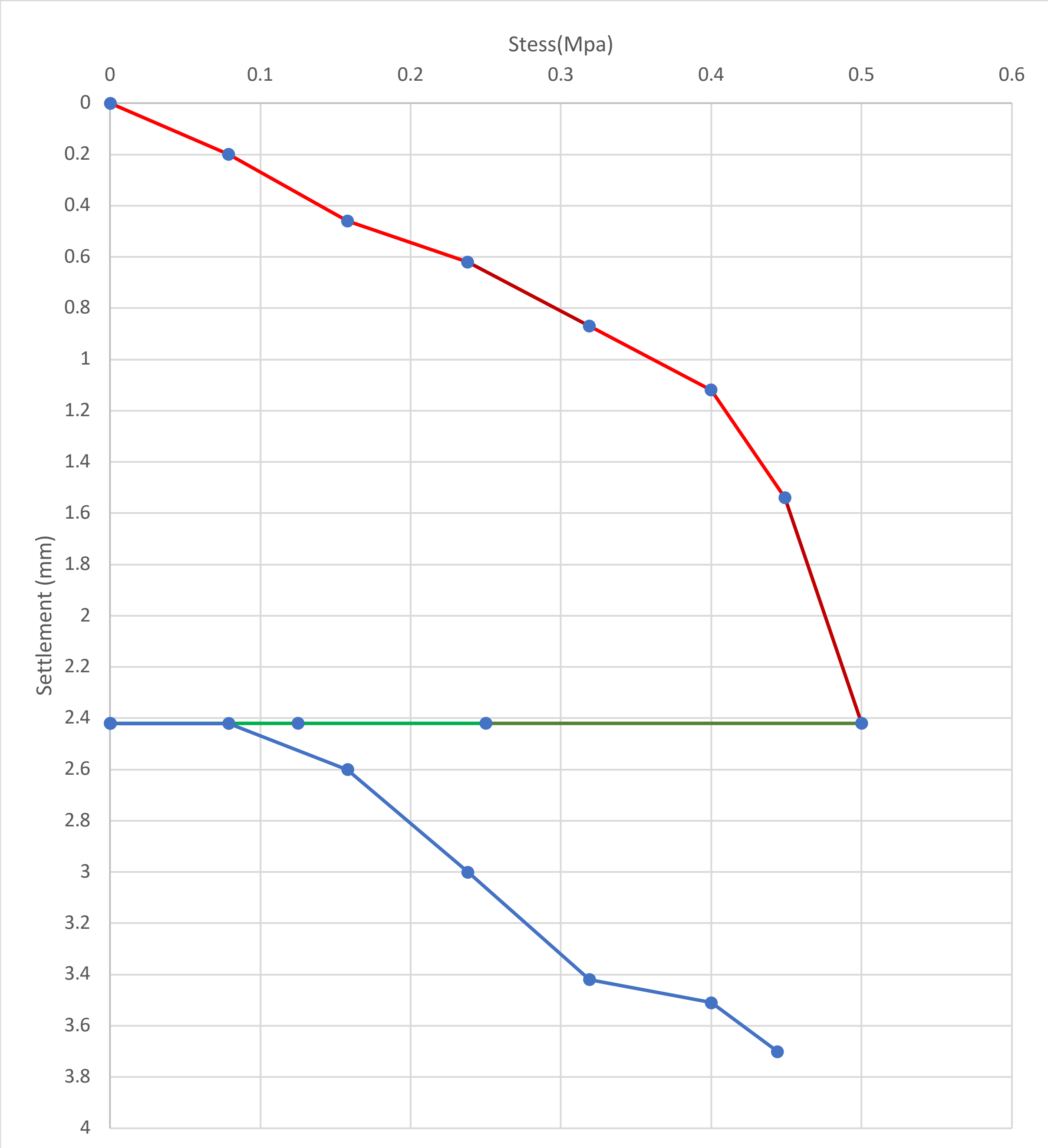

Fig 4.29 Stress vs Settlement curve (pt 10, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.3	First Loading
0.158	0.31	First Loading
0.238	0.46	First Loading
0.319	0.5	First Loading
0.4	0.62	First Loading
0.449	1.1	First Loading
0.5	1.37	First Loading
0.25	1.37	Unloading
0.125	1.25	Unloading
0	1.25	Unloading
0	1.25	Second Loading
0.079	1.26	Second Loading
0.158	1.4	Second Loading
0.238	1.44	Second Loading
0.319	1.82	Second Loading
0.4	1.88	Second Loading
0.444	1.98	Second Loading

Table 4.59: stress vs settlement values of ballast layer point 10

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.509	-2.77	8.823	137.07	0.86
Second loading	0.444	1.226	0.722	2.372	117.92	

Table 4.60: Calculation of constants and Ev values

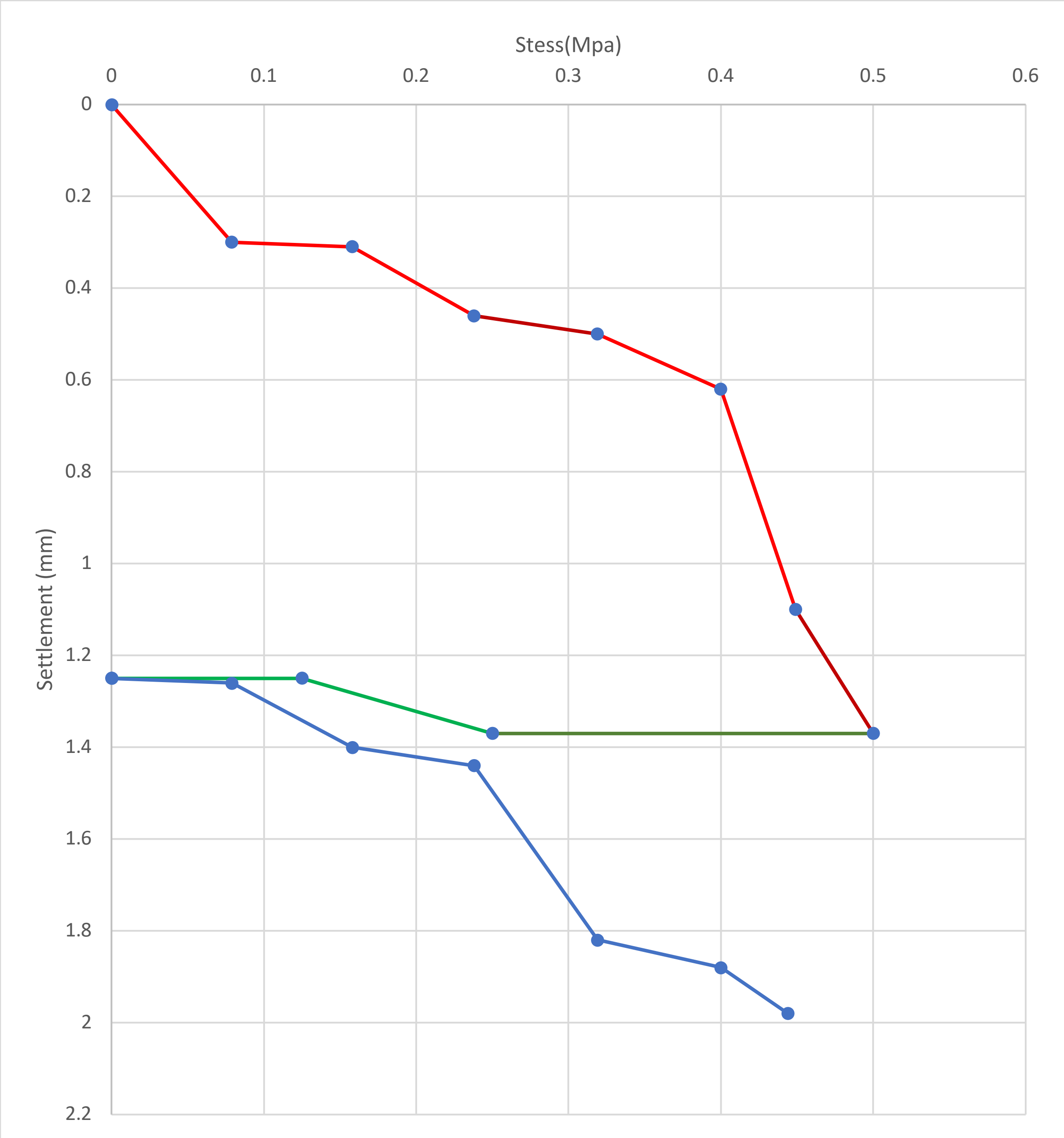

Fig 4.30 Stress vs Settlement curve (pt 10, ballast layer)

11. Point no. 11

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0	First Loading
0.158	0.1	First Loading
0.238	0.68	First Loading
0.319	0.86	First Loading
0.4	0.92	First Loading
0.449	1.12	First Loading
0.5	1.25	First Loading
0.25	1.25	Unloading
0.125	1	Unloading
0	1	Unloading
0	1	Second Loading
0.079	1.12	Second Loading
0.158	1.54	Second Loading
0.238	1.87	Second Loading
0.319	2.52	Second Loading
0.4	3.22	Second Loading
0.444	4.01	Second Loading

Table 4.61: stress vs settlement values of GL point 11

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.399	4.717	-2.935	69.24	0.45
Second loading	0.444	1.031	0.404	13.592	31.25	

Table 4.62: Calculation of constants and Ev values

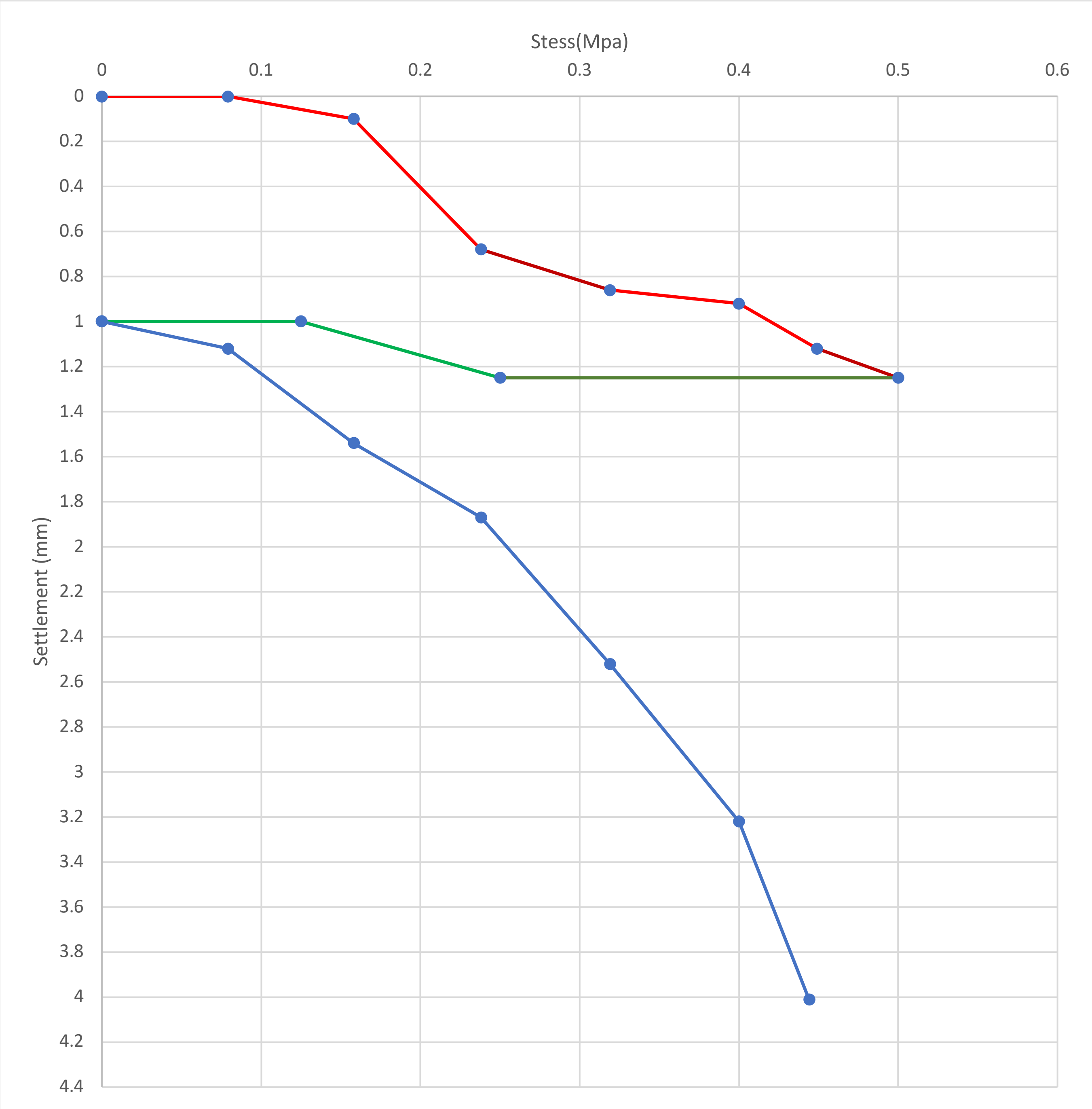

Fig 4.31 Stress vs Settlement curve (pt 11, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.4	First Loading
0.158	0.5	First Loading
0.238	0.74	First Loading
0.319	0.86	First Loading
0.4	1.22	First Loading
0.449	1.76	First Loading
0.5	2.68	First Loading
0.25	2.68	Unloading
0.125	2.68	Unloading
0	2.3	Unloading
0	2.3	Second Loading
0.079	2.5	Second Loading
0.158	2.88	Second Loading
0.238	3.1	Second Loading
0.319	3.42	Second Loading
0.4	3.68	Second Loading
0.444	3.76	Second Loading

Table 4.63: stress vs settlement values of sub grade point 11

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.851	-5.487	17.527	68.67	0.97
Second loading	0.444	2.28	3.73	-0.71	66.66	

Table 4.64: Calculation of constants and Ev values

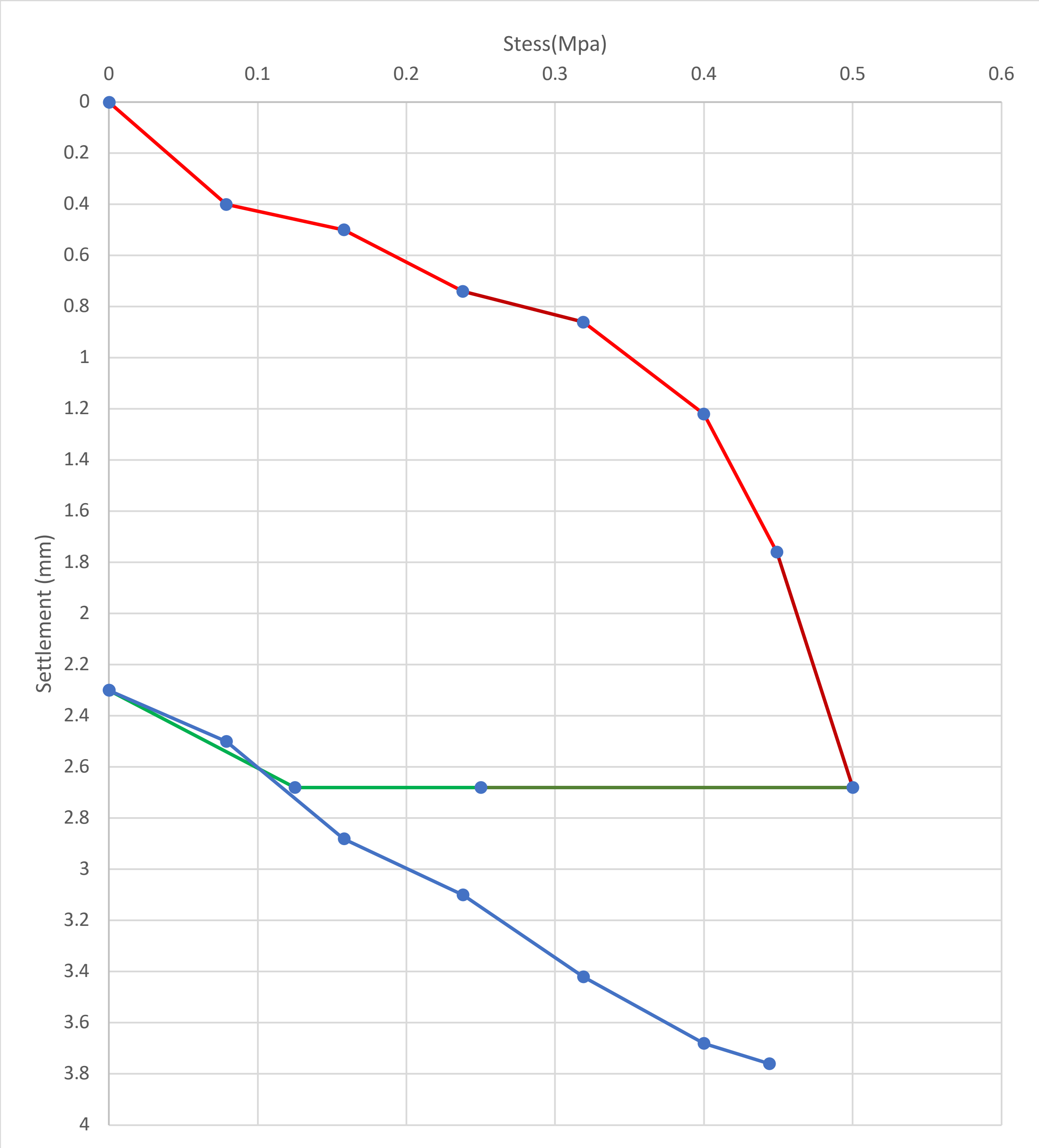

Fig 4.32 Stress vs Settlement curve (pt 11, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.1	First Loading
0.158	0.18	First Loading
0.238	0.25	First Loading
0.319	0.46	First Loading
0.4	0.62	First Loading
0.449	0.87	First Loading
0.5	0.94	First Loading
0.25	0.94	Unloading
0.125	0.94	Unloading
0	0.94	Unloading
0	0.94	Second Loading
0.079	0.94	Second Loading
0.158	1.16	Second Loading
0.238	1.44	Second Loading
0.319	1.5	Second Loading
0.4	1.76	Second Loading
0.444	1.82	Second Loading

Table 4.65: stress vs settlement values of ballast layer point 11

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.087	-0.059	3.727	124.7	0.82
Second loading	0.444	0.898	1.682	1.038	102.24	

Table 4.66: Calculation of constants and Ev values

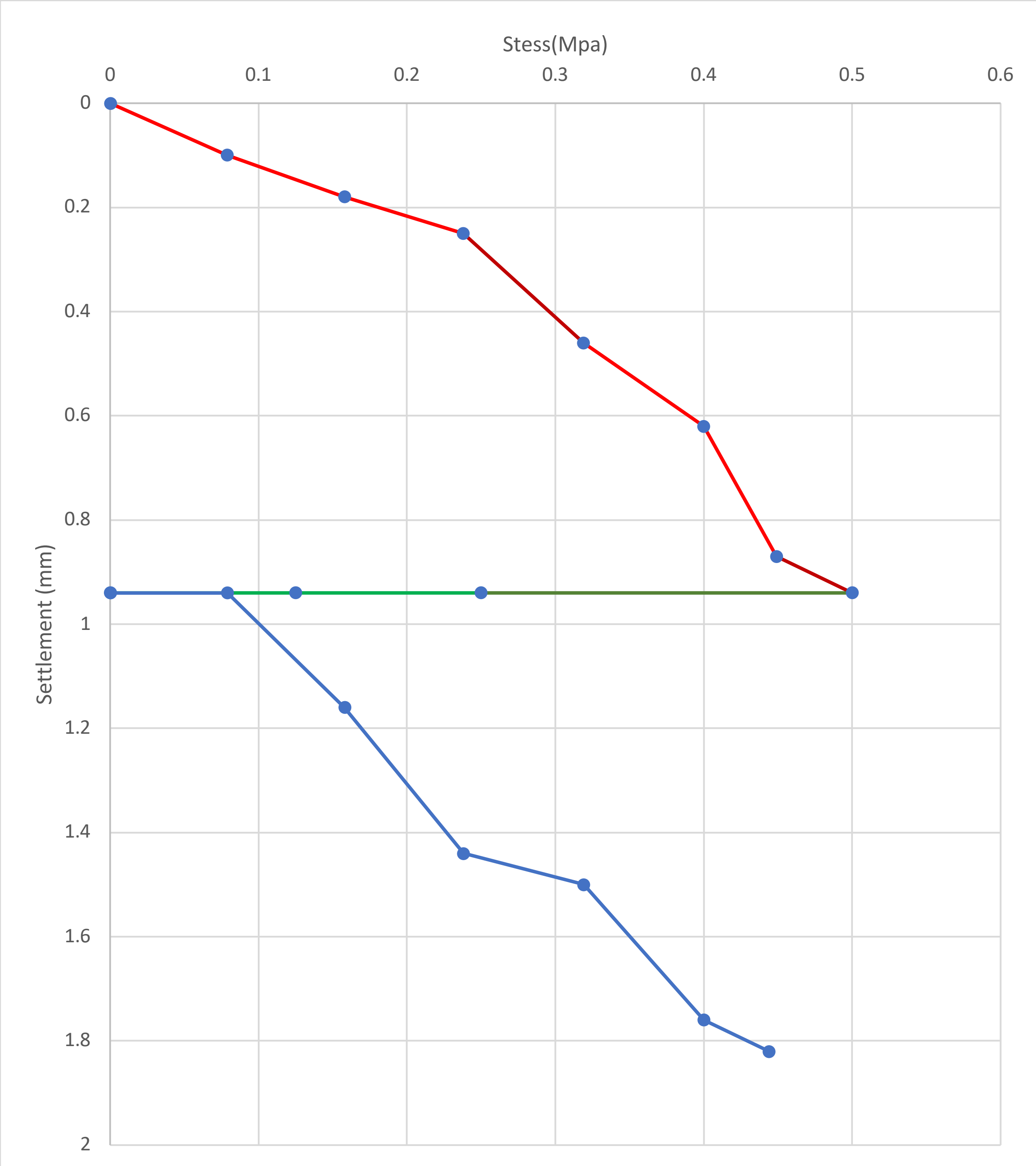

Fig 4.33 Stress vs Settlement curve (pt 11, ballast layer)

12. Point no. 12

a. Natural ground

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.02	First Loading
0.158	0.28	First Loading
0.238	0.31	First Loading
0.319	0.43	First Loading
0.4	0.86	First Loading
0.449	1.5	First Loading
0.5	1.87	First Loading
0.25	1.87	Unloading
0.125	1.54	Unloading
0	1.54	Unloading
0	1.54	Second Loading
0.079	1.54	Second Loading
0.158	1.62	Second Loading
0.238	2.24	Second Loading
0.319	3.22	Second Loading
0.4	3.64	Second Loading
0.444	4.03	Second Loading

Table 4.67: stress vs settlement values of GL point 11

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.339	-3.555	13.197	73.92	0.45
Second loading	0.444	1.459	0.453	12.604	33.31	

Table 4.68: Calculation of constants and Ev values

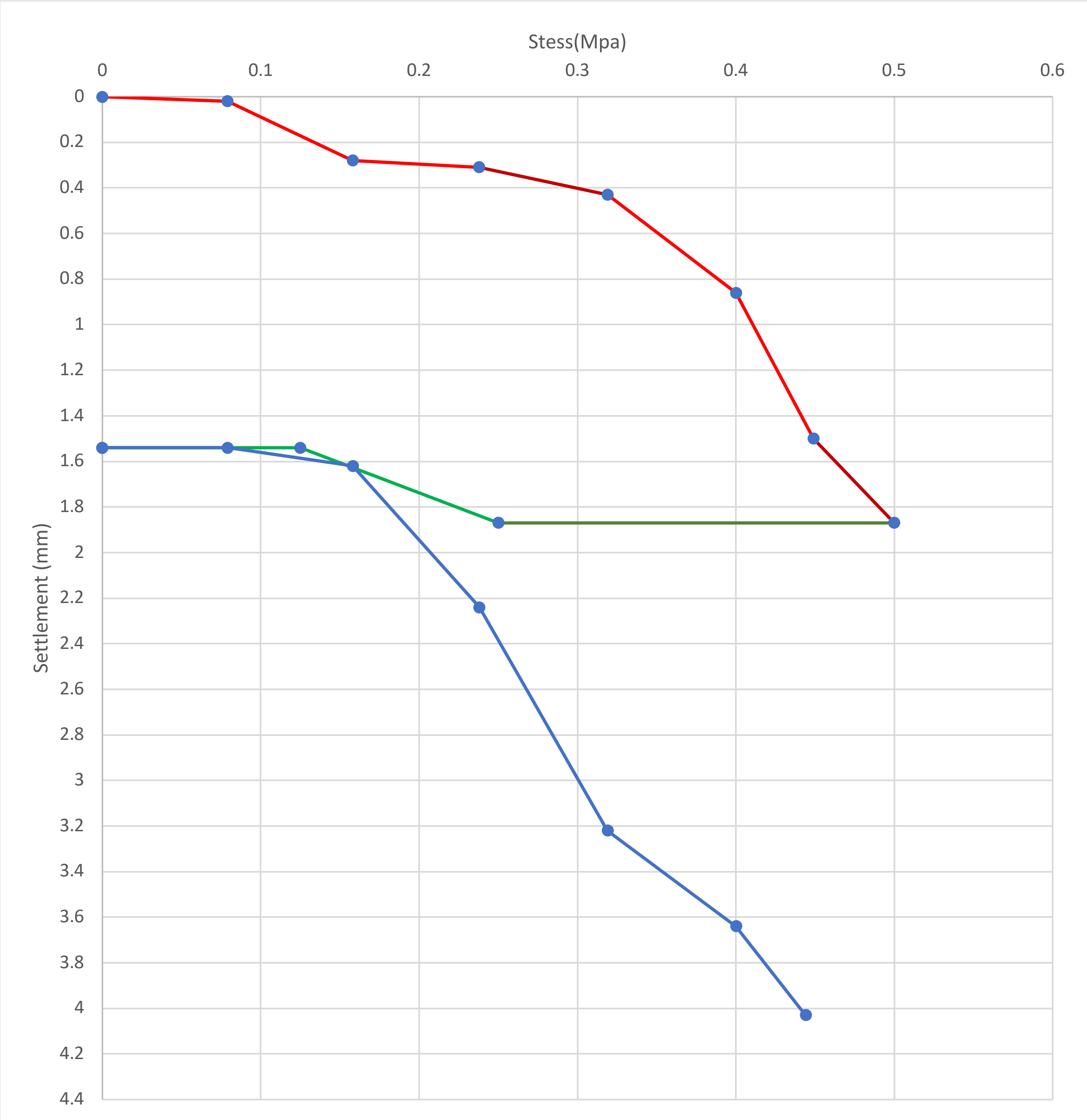

Fig 4.34 Stress vs Settlement curve (pt 12, GL)

b. Sub grade layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.1	First Loading
0.158	0.46	First Loading
0.238	0.76	First Loading
0.319	1.24	First Loading
0.4	1.86	First Loading
0.449	1.98	First Loading
0.5	2.64	First Loading
0.25	2.58	Unloading
0.125	2.58	Unloading
0	2.5	Unloading
0	2.5	Second Loading
0.079	2.5	Second Loading
0.158	2.98	Second Loading
0.238	3.42	Second Loading
0.319	3.5	Second Loading
0.4	3.75	Second Loading
0.444	3.88	Second Loading

Table 4.69: stress vs settlement values of sub grade point 12

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	-0.065	2.01	6.549	42.58	1.61
Second loading	0.444	2.401	3.98	-1.408	68.67	

Table 4.70: Calculation of constants and Ev values

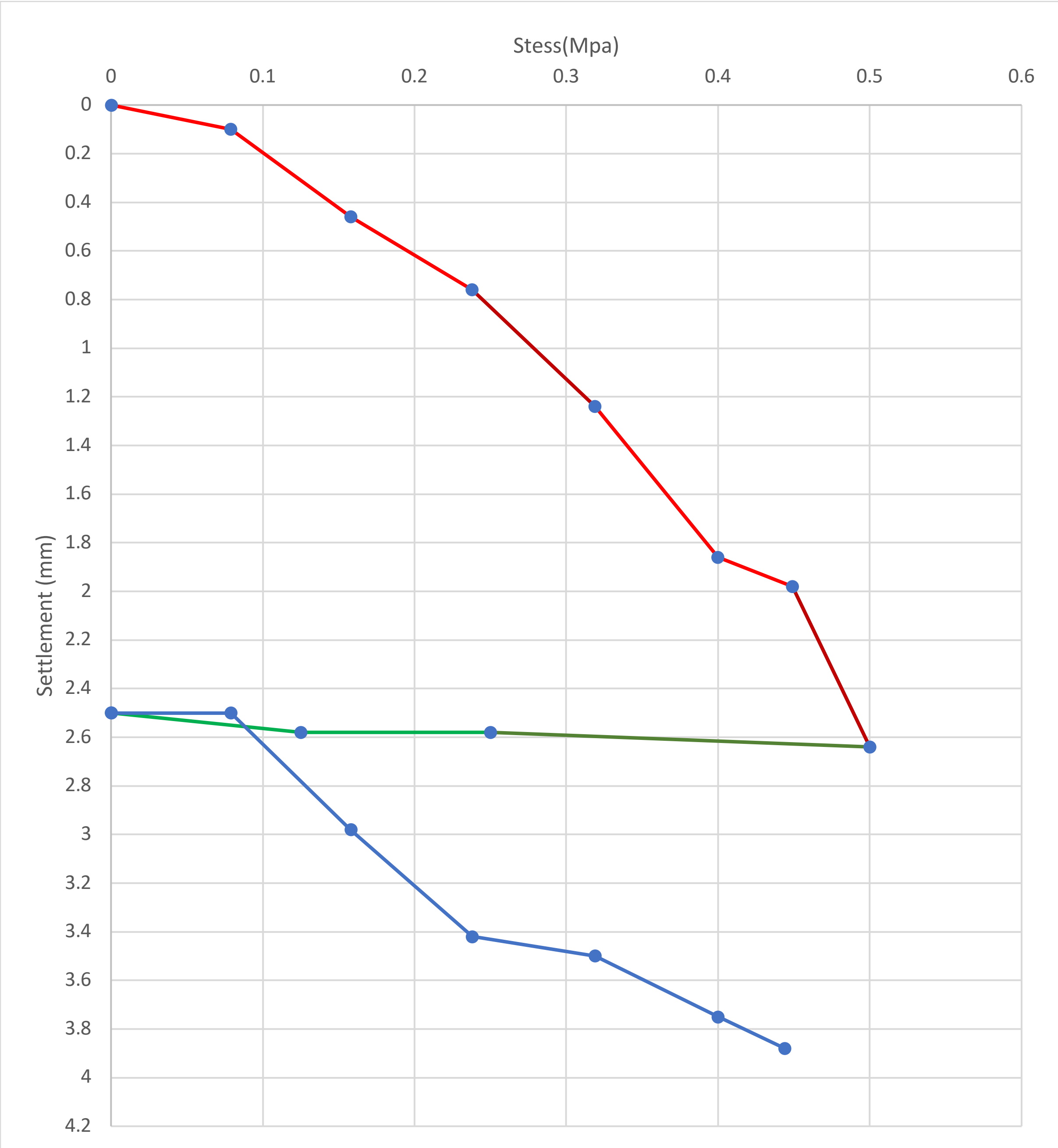

Fig 4.35 Stress vs Settlement curve (pt 12, subgrade)

c. Ballast layer

Stress (MPa)	Settlement (mm)	Series
0	0	First Loading
0.079	0.18	First Loading
0.158	0.4	First Loading
0.238	0.46	First Loading
0.319	0.56	First Loading
0.4	0.74	First Loading
0.449	0.8	First Loading
0.5	1.08	First Loading
0.25	1.02	Unloading
0.125	1.02	Unloading
0	1.02	Unloading
0	1.02	Second Loading
0.079	1.02	Second Loading
0.158	1.25	Second Loading
0.238	1.64	Second Loading
0.319	1.72	Second Loading
0.4	1.78	Second Loading
0.444	1.9	Second Loading

Table 4.71: stress vs settlement values of ballast layer point 12

No.	Maximum stress	a_0	a_1	a_2	Evi	Ev_2/Ev_1
First loading	0.5	0.172	0.645	2.08	133.54	0.79
Second loading	0.444	0.946	2.627	-1.001	105.8	

Table 4.72: Calculation of constants and Ev values

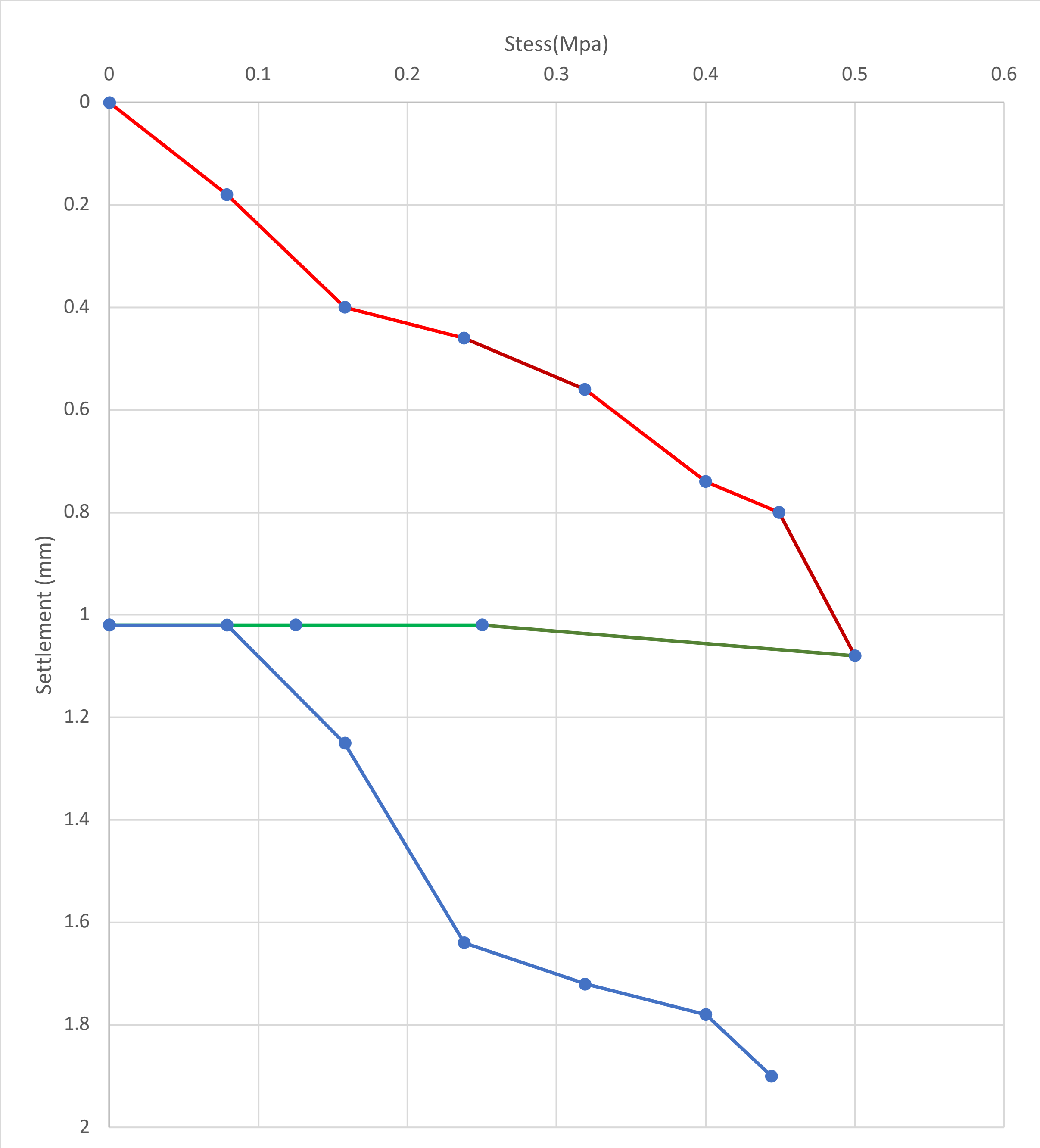

Fig 4.36 Stress vs Settlement curve (pt 12, ballast layer)

Using Weingart's empirical equation and the German earthworks regulations (ZTV E-StB 17), the CBR value and Degree of compaction (in percentage) of each of the points have been determined.
According to the regulations , for an Ev2/Ev1 value less than 2.3, the degree of compaction is approximately equal to 100% and for a value less than 2.5 it is greater than equal to 98%.

GROUND LEVEL POINTS				
Point no.	Ev2 value (in Mpa)	Ev2/Ev1	CBR Value	Degree of compaction
1	42.560	0.49	10.122	>98%
2	47.250	1.16	11.636	>98%
3	41.110	1.14	9.665	>98%
4	43.610	1.15	10.456	>98%
5	39.600	0.50	9.194	>98%
6	39.940	0.40	9.300	>98%
7	39.630	0.78	9.203	>98%
8	29.720	0.67	6.271	>98%
9	45.190	0.87	10.964	>98%
10	35.310	0.45	7.891	>98%
11	31.250	0.45	6.705	>98%
12	33.310	0.45	7.300	>98%

Table 4.73: CBR and Degree of compression values

SUB-GRADE LAYER				
Point no.	Ev2 value (in Mpa)	Ev2/Ev1	CBR Value	Degree of compaction
1	79.430	0.70	23.258	>98%
2	81.580	0.64	24.101	>98%
3	80.090	0.90	23.516	>98%
4	87.300	0.63	26.380	>98%
5	69.960	1.24	19.636	>98%
6	85.020	0.85	25.465	>98%
7	76.650	0.77	22.179	>98%
8	72.710	1.21	20.672	>98%
9	67.010	0.93	18.540	>98%
10	67.720	1.03	18.802	>98%
11	66.660	0.97	18.411	>98%
12	68.670	1.61	19.155	>98%

Table 4.74: CBR and Degree of compression values

BLANKET LAYER				
Point no.	Ev2 value (in Mpa)	Ev2/Ev1	CBR Value	Degree of compaction
1	119.0	0.970	39.870	100%
2	113.3	1.110	37.344	100%
3	103.4	0.890	33.062	100%
4	100.8	0.900	31.963	100%
5	137.7	1.470	48.412	100%
6	119.8	1.110	40.232	100%
7	104.7	0.700	33.605	100%
8	103.0	0.740	32.892	100%
9	112.2	0.930	36.875	100%
10	117.9	0.860	39.388	100%
11	102.2	0.820	32.565	100%
12	105.8	0.790	34.085	100%

Table 4.75: CBR and Degree of compression values

Now, in accordance with the railway guideline RDSO/2020/GE, the minimum specifications provided are:

Layers	Specification
1. Blanket	Minimum Ev2 = 100 MPa
	Minimum CBR value ≥ 25
	Field Compaction :Min. 100% of MDD
2.Sub-grade	Minimum Ev2 = 45 Mpa
	Minimum CBR value ≥6
	Field Compaction : Min. 98% of MDD
3.Ground soil	Minimum Ev2 = 20 Mpa

Thus, we can say the that all points in the above study are safe for construction according to the railway guidelines.

CHAPTER 5
CONCLUSION

The primary objective of this study was to investigate the soil deformation characteristics in railway embankments using the Ev2 plate load test. This research aimed to assess the bearing capacity, stiffness, and compaction quality of various soil layers, including the natural ground, subgrade, and ballast layers, at multiple test sites.

Key Findings:

1. Ev2 Values and Compaction Quality:
    - The Ev2 values obtained from the tests indicated that all tested points met or exceeded the minimum specifications outlined in the railway guideline RDSO/2020/GE.
    - The degree of compaction for all points was found to be greater than or equal to 98%, with many points achieving 100% compaction, particularly in the blanket layer.
2. Correlation with CBR Values:
    - The empirical correlations between Ev2 values and CBR values demonstrated that the soils at the test sites possess adequate bearing capacity and load-bearing characteristics.
    - The CBR values derived from the Ev2 measurements were consistent with the expected performance of well-compacted soils suitable for railway embankments.
3. Layer-Specific Observations:
    - Natural Ground: The Ev2 values for the natural ground ranged from 29.72 MPa to 47.25 MPa, indicating that the natural soil has sufficient stiffness and bearing capacity to support the railway embankment.
    - Subgrade Layer: The subgrade layer exhibited Ev2 values between 66.66 MPa and 87.30 MPa, reflecting high compaction quality and robustness to support the overlying layers.
    - Ballast Layer: The ballast layer showed the highest Ev2 values, ranging from 100.8 MPa to 137.7 MPa, confirming its critical role in distributing loads and maintaining track stability.

Conclusions:

1. Reliability and Effectiveness of the Ev2 Test:
    - The Ev2 plate load test proved to be a highly reliable and effective method for evaluating soil deformation characteristics and compaction quality in railway embankments. The test provided consistent and accurate measurements of soil stiffness and load-bearing capacity, which are crucial for ensuring the stability and safety of railway infrastructure.
    - The in-situ nature of the Ev2 test allows for direct assessment of the soil properties under actual field conditions, enhancing the reliability of the results compared to laboratory tests.

2. Advantages of the Ev2 Test:
   - The Ev2 test is economically efficient and time-saving, requiring relatively simple equipment and quick execution. This makes it suitable for large-scale railway projects where time and budget constraints are critical.
   - The test's ability to provide a direct measure of soil performance under load makes it an invaluable tool in geotechnical engineering, particularly for railway applications where precise soil properties are essential for designing durable and stable tracks.
3. Compliance with Standards:
   - The results confirm that the tested sites comply with the railway guidelines, ensuring that the soil layers are adequately compacted and possess the necessary stiffness and bearing capacity for safe and stable railway operations.
4. Recommendations for Future Research:
   - Further studies could explore the long-term performance of the compacted layers under dynamic loading conditions to assess their durability and resilience.
   - Investigating the impact of varying moisture content on the Ev2 values and soil deformation characteristics could provide a more comprehensive understanding of soil behavior in different environmental conditions.
5. Practical Implications:
   - The findings of this study can be used to inform the design and construction of railway embankments, ensuring that they meet the required standards for safety and stability.
   - The use of the Ev2 test can be extended to other geotechnical projects to assess soil compaction and bearing capacity, contributing to the overall improvement of infrastructure quality.

In conclusion, this study successfully demonstrated the applicability, reliability, and advantageousness of the Ev2 plate load test in assessing soil deformation characteristics in railway embankments. The results provide a solid foundation for ensuring the safety and stability of railway infrastructure, supporting the continued development and maintenance of efficient and reliable railway systems.

CHAPTER 6

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