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Evaluation of Modulus of Subgrade Reaction (k-value) at a Barrage Site across an Indian River

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Abstract: *The modulus of subgrade reaction (k-value) is a critical parameter in the design of hydraulic structures such as barrages, where foundation stability and settlement control are paramount. It represents the soil's stiffness by establishing a relationship between the applied pressure and the corresponding settlement. Accurate determination of the k-value using field and laboratory investigations is essential for ensuring structural safety, economic design, and long-term performance. This paper explores the significance of the modulus of subgrade reaction in barrage design, focusing on its influence on foundation selection, load distribution, and settlement management. A detailed review of the plate load test method, as per IS: 9214-1979, is presented to illustrate its application in determining the k-value. As per the code the test was carried out at three selected locations on an Indian River. The finding of the test shows a variation of modulus of subgrade reaction (k-value). The findings emphasize the importance of reliable soil investigation data in optimizing barrage foundation design and ensuring the safety and longevity of barrage.*

Keywords: *modulus of subgrade reaction, k-value, barrage design, plate bearing test*

I. Introduction:

Barrages are large hydraulic structures built to control river water flow, facilitate irrigation, and prevent flooding. Their foundation design is a critical factor in ensuring long-term stability and operational efficiency. The modulus of subgrade reaction, a measure of soil stiffness, provides engineers with essential data to predict settlement behaviour under applied loads. Accurate assessment of the k-value enables safer and more resilient barrage construction, particularly in regions with variable soil conditions like alluvial plains. This paper focuses on understanding the importance of k-value determination, using IS: 9214-1979 methods and applying findings to real-world barrage design projects.

II. Modulus of Subgrade Reaction:

The 'Modulus of Subgrade Reaction Test' usually known as K-value test is essentially a plate bearing test. This test is used for the design of pavement structures and raft foundations. Modulus of sub grade reaction is the ratio of load per unit area of horizontal surface of a mass of soil to corresponding settlement of the surface. It is determined as the slope of the secant drawn between the point corresponding to zero settlement and the point of 1.25 mm settlement of a load-settlement curve obtained from a plate load test on a soil using a 750 mm diameter or smaller loading plate with corrections for size of plate used.

K-value is taken as the slope of the line passing through the origin and the point on the curve corresponding to 1.25 mm settlement.

$$K = \frac{p}{0.125} MPa/cm = \frac{10p}{0.125} kgf/cm^2/cm$$

where,
p = load intensity corresponding to settlement of plate on 1.25 mm

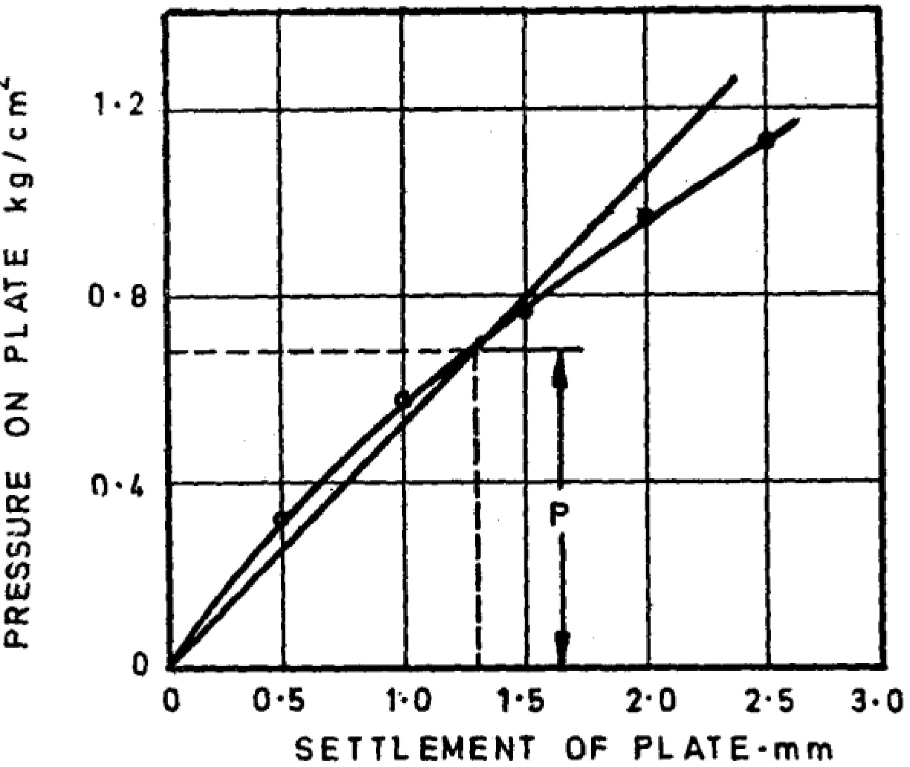

Figure-1: Result of Plate Bearing Test on Natural Subgrade (IS: 9214)

III. Assembly (Test Setup)

The Modulus of subgrade reaction test was conducted on a 750 mm diameter and 25 mm thick circular plate in accordance with IS: 9214-1979.The size of the pit was five times the size of the bearing plate. Stiffening plates of 600 mm, 450 mm and 300 mm were placed above 750 mm diameter test plate. Around 400 number of sand filled gunny bags, each of approximately 35 kgs weight were placed on the platform as kentledge to provide a reaction of 20 ton. This whole assembly was to act as a reaction pad for performing the test.

For measuring settlement, three digital Dial gauges of 0.001 mm least count and 25 mm travel were used, and these were fixed on the periphery of 750 mm diameter bearing plate at an angular spacing of 120° supported on an independent datum bar.

At test location, an area of about 800 mm diameter was stripped off, filled with a thin layer of sand and levelled again. The bearing plate of 750 mm diameter was then centrally placed at prepared area. Three circular plates of sizes 600 mm, 450 mm and 300 mm were placed centrally, one above another, on the bearing plate and the levelling and centering of the system ensured at each stage. A hydraulic jack of 15 ton capacity was then placed centrally on these plates. A ball and socket arrangement was placed over the jack to keep the direction of loading vertically throughout the test. The gap between the main girder and the ball and socket arrangement was filled with solid cylindrical spacers and plates of suitable thickness. The centering and levelling of the whole system was rechecked by using the plumb bob and sprit level.

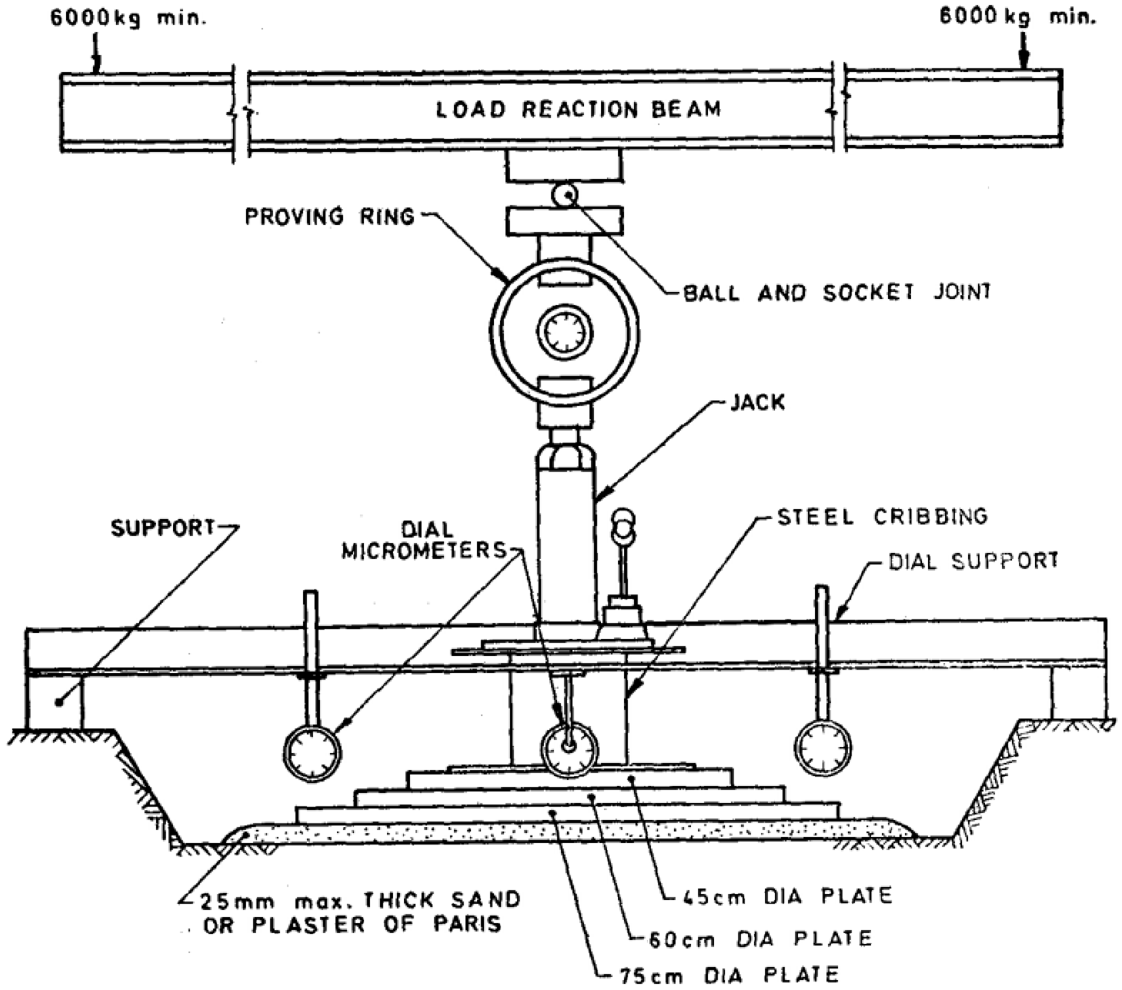

Figure-2: Schematic Diagram for Plate Bearing Test (IS: 9214)

IV. Procedure

A seating load of 310 kg was first applied over the plates and kept for 15 minutes or until practically complete deformation had taken place. At this time, reading in all the three dial gauges was recorded. Then without releasing the seating load, an additional load of 3.1 ton was applied for at least 15 minutes or until the rate of settlement of the plate was less than 0.0002 cm/min. Then the load was increased in the increment of 1.55 ton to a maximum of 9.30 ton and each load was kept for a minimum duration of 15 minutes or until the rate of settlement of the plate was less than 0.0002 cm/min. At the end of test the pressure was released to zero and all test accessories from pit were removed.

1. Modulus of Subgrade Reaction k-value test on the banks of an Indian River

1.1 Location-1: The Modulus of subgrade reaction (K-Value) test was carried out at the designated location. Load was applied in equal increments (after applying seating load 310 kg). Load vs settlement readings of dial gauges were recorded and same are presented in Pressure vs settlement curve, Figure-3.

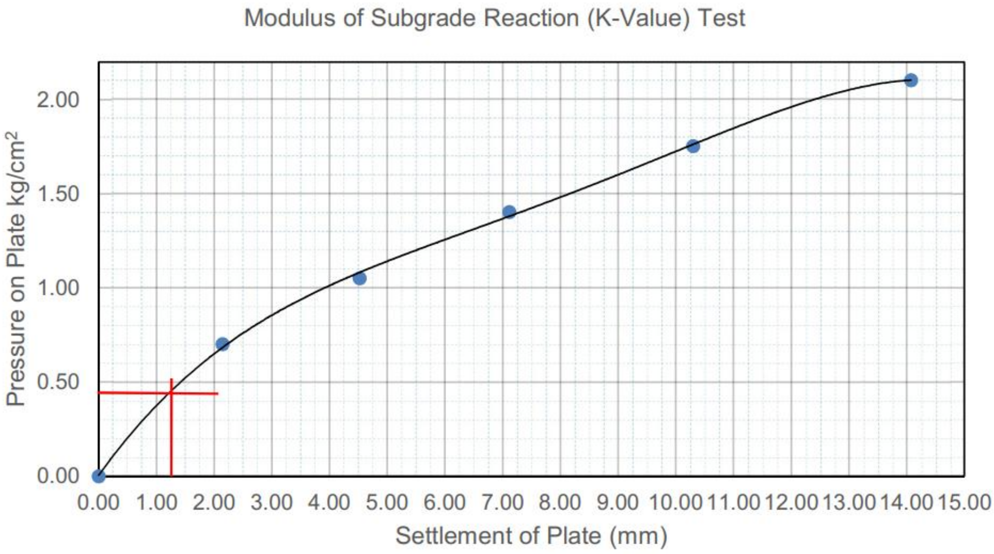

Figure-3: Pressure vs Settlement Curve) at Location-1

1.1.1 Modulus of Subgrade Reaction (k-value) obtained at Location-1: The value of modulus of subgrade reaction obtained at the Location-1 after applying all the corrections is = 3.46 kg/cm^2/cm)

1.1.2 Laboratory Test Results

a. **Mechanical Analysis and Atterberg Limits:** The soil sample collected from the test pit was subjected to Mechanical Analysis and Atterberg Limits test for classification of soil. The grain size analysis of the tested material indicates that the soil sample from the test pit location possess predominantly silt sizes size followed by clay and fine sand. Based on the results of grain size distribution and Atterberg limits tests, the soil samples from the pit at Location-1 falls under clay of intermediate compressibility (CI) group as per Bureau of Indian Standard Soil classification system.

b. In-situ Density and Natural Moisture Content: The in-situ dry density and natural moisture content was determined for the sample collected from the test pit. The value of in-situ dry density and natural moisture content of the tested soil samples varied from 1.42 g/cc while natural moisture content is 19.8 %.

1.2 Location-2: The Modulus of subgrade reaction (K-Value) test was carried out at the designated location. Load was applied in equal increments (after applying seating load 310 kg). Load vs settlement readings of dial gauges were recorded and same are presented in Pressure vs settlement curve, Figure-4.

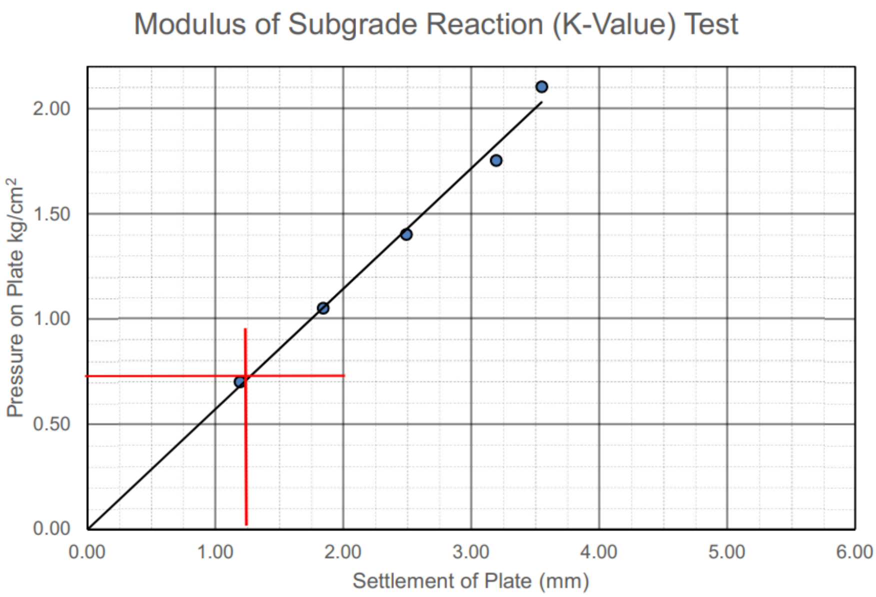

Figure-4: Pressure vs Settlement Curve) at Location-2

1.2.1 Modulus of Subgrade Reaction (k-value) obtained at Location-2: The value of modulus of subgrade reaction obtained at Locatipn-after applying all the corrections is = 4.42 kg/cm^2/cm.

1.2.2 Laboratory Test Results

a. **Mechanical Analysis and Atterberg Limits:** The soil sample collected from the test pit was subjected to Mechanical Analysis and Atterberg Limits test for classification of soil. The grain size analysis of the tested material indicates that the soil sample from the test pit location possess predominantly silt sizes size followed by clay and fine sand. Based on the results of grain size distribution and Atterberg limits tests, the soil sample falls under clay of intermediate compressibility (CI) group as per Bureau of Indian Standard Soil classification system.

b. In-situ Density and Natural Moisture Content: The in-situ dry density and natural moisture content was determined for the sample collected from the test pit. The value of in-situ dry density and natural moisture content of the tested soil samples varied from 1.75 g/cc while natural moisture content is 14.0 %.

1.3 Location-3: The Modulus of subgrade reaction (K-Value) test was carried out at the designated location. Load was applied in equal increments (after applying seating load 310 kg). Load vs settlement readings of dial gauges were recorded and same are presented in Pressure vs settlement curve, Figure-5.

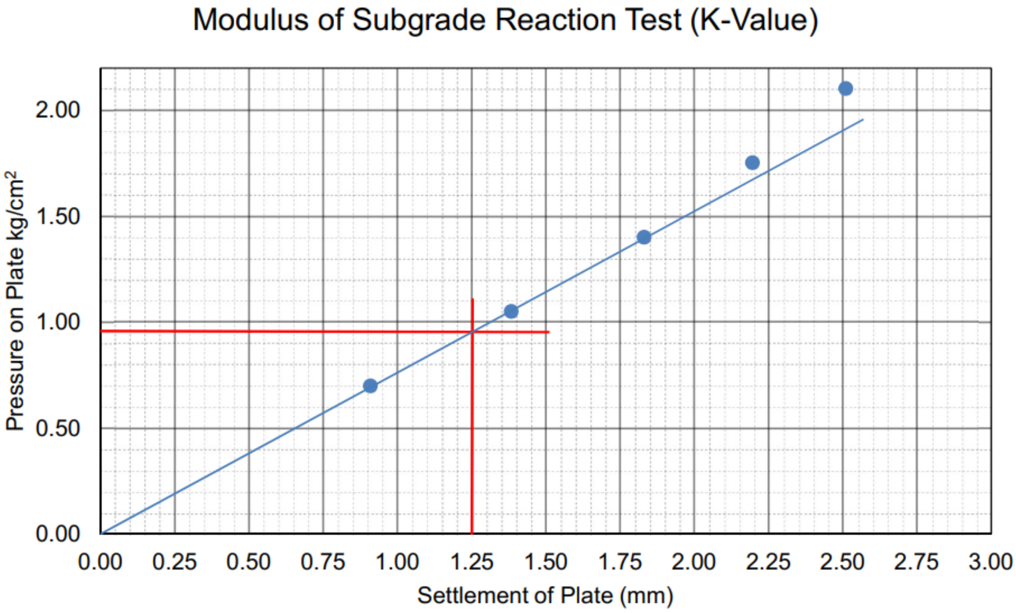

Figure-5: Pressure vs Settlement Curve) at Location-3

1.3.1 Modulus of Subgrade Reaction (k-value) obtained at Location-3: The value of modulus of subgrade reaction obtained at Locatipn-3 after applying all the corrections is = 5.04 kg/cm^2/cm.

1.3.2 Laboratory Test Results

a. **`Mechanical Analysis and Atterberg Limits:** The soil sample collected from the test pit was subjected to Mechanical Analysis and Atterberg Limits test for classification of soil. The grain size analysis of the tested material indicates that the soil sample from the test pit location possess predominantly silt sizes size followed by clay and fine sand. Based on the results of grain size distribution and Atterberg limits tests, the soil sample falls under clay of intermediate compressibility (CI) group as per Bureau of Indian Standard Soil classification system.

b. In-situ Density and Natural Moisture Content: The in-situ dry density and natural moisture content was determined for the sample collected from the test pit. The value of in-situ dry density and natural moisture content of the tested soil samples varied from 1.75 g/cc while natural moisture content is 8.2 %.

2. Significance of Modulus of Subgrade Reaction in Barrage Design

The modulus of subgrade reaction (k) is a crucial parameter in the design of barrage foundations as it represents the stiffness of the soil beneath the foundation. It defines the relationship between the soil pressure and the corresponding settlement. The significance of the k value in barrage foundation design includes the following aspects:

- **Foundation Settlement Estimation:** The k value helps in predicting the settlement of the raft foundation under applied loads. A higher k value indicates stiffer soil with minimal settlement, while a lower k value suggests soft or weak soil prone to larger settlements. Settlement calculations are essential to ensure the foundation remains within permissible limits to prevent structural damage.
- **Load Distribution and Structural Response:** In barrage foundation design, the modulus of subgrade reaction directly affects the load distribution across the base width of barrage. A uniform k value results in more predictable and even load transfer, whereas variations in k lead to differential settlements and potential structural distress. For long barrages, the variation of k with depth (especially in layered soil strata) needs to be accounted for in the design.
- **Structural Rigidity and Thickness Optimization:** The selection of the k value aids in determining the thickness and reinforcement of the barrage foundation. Higher stiffness values may reduce the bending moments and shear forces within the foundation, leading to more efficient designs. In cases of non-uniform k, additional structural reinforcement may be required to mitigate the effects of differential settlement.
- **Effect on Structural Stability and Safety:** The stability of barrage foundation, particularly under seismic loads, is significantly influenced by the modulus of subgrade reaction. A lower k value in liquefiable or soft soils may compromise the safety of the structure. Appropriate geotechnical investigations, including in-situ and laboratory tests like plate load tests/(modulus of subgrade reaction (k-value) or SDMT (Seismic Dilatometer Test), are essential for determination of the k value..
- **Adjustment for Different Soil Conditions:** In heterogeneous soil conditions, the k value may vary, necessitating a differential assessment. Methods like subgrade improvement, soil stabilization, or using a compensated barrage foundation can be applied to achieve more uniform stiffness.
- **Finite Element Analysis (FEA) and Design Validation:** In modern foundation design, finite element modelling is commonly used to simulate the soil-structure interaction using the k value. It provides accurate insights into the stress distribution and foundation behaviour under various loading conditions.

V. Conclusion

The modulus of subgrade reaction (k-value) is a vital parameter in the design of barrages, influencing foundation stability, load distribution, and settlement control. Accurate determination of the k-value through field plate load tests, as outlined in IS: 9214-1979, ensures reliable predictions of soil behaviour under applied loads. The test carried out at three locations in an Indian River demonstrate how site-specific investigations provide essential data for designing appropriate foundation and minimizing may minimise failures. Further, correlating laboratory and field data aids in understanding soil characteristics and evaluating the needs for ground improvement techniques in regions with low k-values. Implementing an appropriate design based on accurate k-value assessments enhances the structural safety and longevity of barrages. In conclusion, considering the modulus of subgrade reaction during the design phase may be critical for creating cost-effective, resilient, and durable hydraulic structures resting on soil strata. Continuous monitoring and periodic re-evaluation of foundation performance are recommended to address any unforeseen settlement behaviour, ensuring the long-term stability of structures.

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