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A case history of the problems of determining the ground parameters of 300 sites in 6 months in Indonesia

L'histoire des problèmes entraînés en déterminant les paramètres du sol sur 300 endroits, en 6 mois, en Indonésie

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ABSTRACT: A survey for determining the ground parameters of 300 different sites along approximately 500 kilometre of railway track, was executed in Indonesia. The number of sites and different ground types opened an excellent opportunity to assess and compare the potentials of field and laboratory testing procedures. A lower bound relation between plasticity index and the ground parameters cohesion and angle of internal friction is presented.

RESUMÉ: On a fait des analyses du sol, en Indonésie, pour déterminer les paramètres du sol sur 300 endroits différents le long de 500 kilomètres de voie ferrée. Le nombre des endroits et leurs différents types de sol offrirent un occasion excellent pour justifier les problèmes et les possibilités des méthodes de recherche aux sites et dans les laboratoires de procédures d'essai. Une relation de limite basse entre l'Indice de Plasticité et les paramètres du sol, comme la cohésion et l'angle de frottement interne, est présentée.

1 INTRODUCTION

The region of South-East Asia shows a rapidly increasing economic activity. One of the countries in the region which is particularly affected by this economic revival is Indonesia. To be able to fully profit of the economic developments the infrastructure of roads and railways has to be modernized and expanded. The Indonesian Government designed a major schedule to upgrade and renovate the railway lines in Indonesia. The Netherlands Government was prepared to finance part of this upgrading as well as the survey to establish the scope of work. This paper describes the investigation for the upgrading of the bridges of five railway lines on the islands Java and Sumatra, Indonesia (fig. 1). The lines were built starting at the turn of the century up to the worldwide recession between the two world-wars.

The railway lines have to be made suitable for heavier train loads and higher train speeds. This embraces in addition to the upgrade of embankments also the upgrade and renovation of bridges. The five railway lines incorporate 289 bridges crossing mainly rivers and canals. Span lengths are up to 85 metres.

The existing steel super-structures of the bridges are not suitable because the 'life' loads (train loads) will be increased by 62 to 116 %, and 'fatigue' had lowered the strength of the steel structures. Further, corrosion of the steel had severely weakened the structures of some of the bridges. The steel structures have to be replaced by new and heavier designed structures and have to be installed on existing abutments and piers to minimize costs.

To assess the state of maintenance and the suitability of the existing abutments and piers for the new loads a survey was carried out during 1988 and 1989. The actual field survey took approximately 6 months while the subsequent interpretation of the field data, calculation of safety factors, formulation of renovation schemes and design of steel super-structures took another 6 months.

2 BRIDGE SURVEY

The five railway lines incorporate 289 bridges along railway lines with a length of 498 km. Investigating 289 bridge locations in a reasonable amount of time requires a very proper and efficient set up of the investigation scheme. To minimize logistics a permanent project office was

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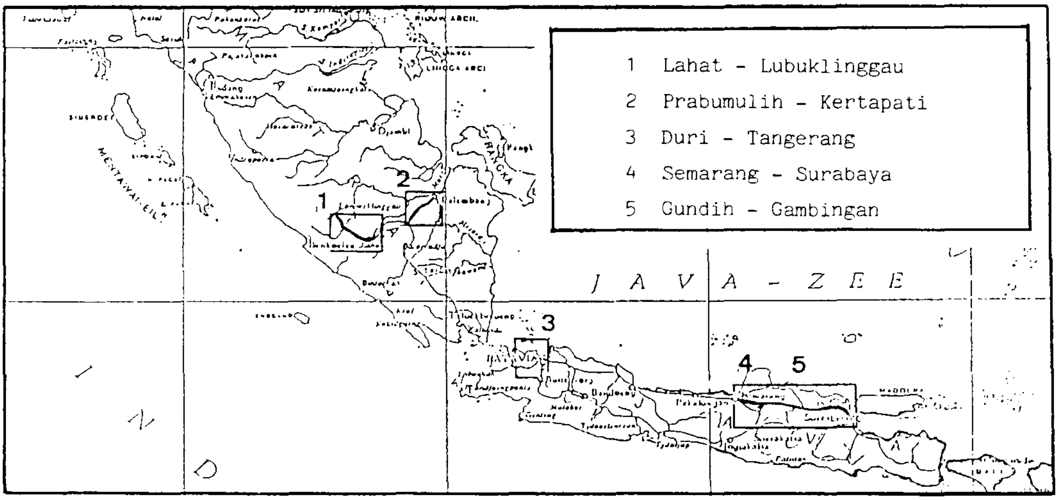

Figure 1. Locations of railway lines

established in Bandung to maintain the contacts with the Indonesian State Railways (PJKA) and testing laboratories while temporary site offices with site laboratories were erected at various locations along the railway lines.

The following aspects were included in the survey:

1. A survey of all existing historical and present-day data, eg. as-built drawings of the existing bridges, river levels and rainfall data, records of the Indonesian State Railways, etc..

2. A ground-investigation survey to assess the stability of the foundations of the existing abutments and piers.

3. A hydrological survey to determine maximum river water levels and to assess maximum water pressures on abutments.

4. A survey of the strength and state of maintenance of the existing abutments and piers.

5. A survey of the steel super-structures.

This paper describes the ground-investigation survey only. The other aspects of the survey will be reported upon in different papers.

3 GEOLOGY

The islands Java and Sumatra belong to an island arc of volcanic and orogenic origin. They form the boundary of the Euro-Asian plate in the north and the Indo-Australian plate in the south. Present and past tectonic movements and abundant volcanic activity govern present day geology. The results of this geological setting are encountered during the survey. Two of the five railway lines are located in rock areas where the bridges are founded on weak tufaceous rock. The three remaining railway lines are located in coastal areas where the formations consist of marine and alluvial clays, marine and alluvial volcanic ash clays and limestone muds and sands. The marine and alluvial clays contain varying amounts of silt and carbonate.

4 CALCULATION SAFETY FACTORS

The aim of the survey was the determination of the safety of each bridge after renewal of the steel super-structure and with the new loading scheme applied. A major aspect in the safety of a bridge is the stability of its foundations. The stability depends on: the loads on the foundation level, the type of foundation and the ground parameters of the foundation layers.

4.1 Loads on the foundation level

The loads on the foundation of an abutment or pier can be divided into dead and life loads. The dead loads are the loads caused by the weight of the abutment or pier, steel super-structure and passive and active ground pressures. The live loads are loads caused by a passing train, their influence on the water pressures at the active side of the abutment, wind and river-water pressures and earthquake loads. A train which comes to a stand-still on a bridge is regarded as a permanent load although the time the train will be on the bridge is small compared to the other permanent loads.

4.2 Type of foundation

As-built drawings of the foundations and revision data with drawings were available for the majority of the bridges. During the survey the as-built and revised drawings of abutments and piers proved to be accurate so that details about the foundations (depth, area, etc.) and type of foundation (raft, piles, ground improvement, etc.) were known.

4.3 Ground-parameters

The foundation analyses of the existing bridges consisted of analyses of ultimate bearing capacity according to Brinch-Hansen, overturning, sliding and slope stability. To calculate these failure mechanisms the following ground parameters have to be determined: dry and wet unit density, angle of internal friction, cohesion, layer thickness, and ground-water tables.

Under the new loading scheme only the load of the train will be increased. (The weight of the new steel super-structures is only marginally higher than the weight of the old structures.) Settlement of the bridges should have been completed in the 50 years the bridges were already in position and additional settlement due to the increase of the train load will be minimal. Extra settlement has, therefore, not been evaluated.

For the evaluation of ground parameters the available ground information from the time the bridges were built has also been used. This was available for a few of the bridges. The data have been compared with the information obtained during the survey and no significant differences were found.

Revised bridge drawings and data indicated whether problems with particular bridges on a particular foundation had been experienced in the past and probably could be expected in the future for other similar bridges with similar foundations.

5 GROUND-INVESTIGATION SET-UP

To determine the ground parameters the following two approaches are possible:

1. Extensive ground survey
An extensive ground-investigation for each bridge. This would have resulted in very high costs and would have taken a considerable amount of time to execute.

2. Cost-limited ground survey
The determination of ground parameters for a particular bridge by correlating and interpolating ground parameters determined along the railway lines, without executing a whole set of tests at each bridge. This lowers the accuracy, but speeds up the investigation and therefore lowers the costs considerable.

The cost-limited approach (2) was chosen because of the following reasons:

1. Available data
The type of foundation was known and the available ground data from the time the bridges were built was reasonably accurate.

2. Required accuracy
The accuracy of the survey did not have to comply with the standards necessary for building completely new bridges.

Secondary arguments for a cost-limited ground survey were the available time and the budget. The budget for the survey was based upon a field investigation with a duration of approximately six months. An extensive ground survey would have severely extended the time necessary and thus would have required a larger budget.

Although the cost-limited ground survey was selected, all incoming data from the survey were carefully checked, so that it was discovered during the course of the work whether the cost-limited ground survey was unsuitable for a particular bridge and the survey had to be extended. If this happened for many bridges the time and budget restrictions would obviously have had to be re-assessed.

During the survey it was observed that:

1. Field data obtained during the survey indicated that correlation of ground-parameters over long distances was possible.

2. The majority of the bridges are still standing-up without any signs which could indicate failure of the foundations. This implies that the safety factor for these bridges under the old loading scheme had to be at least 1 at the time of the investigation. Abutments which showed possible failure of the foundations, for example: tilting, should have a safety factor of less than 1 at the time of investigation. Safety factors

calculated under the old loading scheme with ground-parameters obtained by correlation and interpolation according to the cost-limited ground survey gave results which confirmed these values.

Both points above proved that a cost-limited ground survey was suitable for this investigation.

6 GROUND INVESTIGATION METHODS

Correlation and interpretation of ground data over long distances and the short time available to execute the survey has led to a special set-up of the testing program. A series of tests were executed with emphasis to use the results for correlation of parameters.

6.1 Field tests

1. Visual Inspection

All bridges and surroundings were inspected by an engineering-geologist or geotechnical engineer. Emphasis was placed on the recording of geological and geomorphological features of the foundation layers. Secondly the abutments were inspected for damage possibly caused by failure of the foundations. The as-built drawings were compared with the particulars found in the field.

2. Dutch Cone Penetration Test (CPT)

A Dutch Cone Penetration test was necessary for each bridge as this was the main tool for correlating the ground layers. For larger bridges two or more CPTs were made. For a series of bridges CPTs were made available by the Indonesian State Railways but for the majority of bridges a CPT test was executed during the survey. The CPT test included the measurement of local friction so that a better indication of the ground parameters was obtained. To keep data handling errors to a minimum the measurements were recorded with a hydraulic/electronic measuring device on the top of the CPT rods and were plotted by a computer. To decrease the execution time the CPT equipment was mounted on a flat train-wagon which was loaded with a ballast of 12 ton. The advantages of this set-up were that it was possible to execute the CPT tests in a very short time which allowed these tests to be executed in-between the normal (very busy) train schedule. Also this set-up allowed the execution of the CPTs directly behind the rear of an abutment, so that soil-information over the full depth of the abutment, including the track embankments, could be recorded.

On locations where a CPT test from the track was not possible, eg. besides piers, a 2.5 ton CPT was carried out. The readings were obtained by means of hydraulic pressure gauges.

The CPT testing set-up proved to be very efficient. Approximately 325 CPTs were executed along the railway lines within a tight train schedule. Although the data obtained by CPT tests was not directly applicable to calculate drained ground parameters, it was an excellent tool for correlation purposes.

3. Boreholes

Based upon the geological information available, boreholes were drilled at regular intervals along the railway lines to obtain stratigraphic information and samples for laboratory testing. Boreholes where especially drilled at locations where changes in foundation formations were expected. Two types of drilling were executed: machine drilling with Standard Penetration Tests (SPT) up to a depth of maximum 25 m and hand drilling for obtaining samples from shallow depths and from the track embankments.

Machine drilling was executed with a rotary drilling machine. All boreholes were fully sampled. A flight auger was used in soft none-cohesive soils to obtain re-moulded samples. Shelby tube samples were taken from soft to firm cohesive soils and double and triple tube core barrels were used in firm to hard cohesive soils and in rock.

Hand drilling was executed with a flight auger in none-cohesive soils and Shelby tubes were taken in cohesive soils.

All boreholes were described according British Standard for Engineering purposes by a trained engineering geologist at the drilling location.

The borehole information was necessary for correlation and for test samples although the drilling itself was cumbersome. The quality of available equipment was often marginal and handling of borehole cores was rough. Although this later improved during the survey. Another related problem was the availability of trained engineering geologists.

6.2 Laboratory testing

The following tests were executed on samples obtained from boreholes:

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1. Consolidated un-drained triaxial tests with water-pressure measurement
2. Determination of bulk, dry and wet unit weights.
3. Unconfined Compressive Strength (UCS)
4. Pocket Vane test
5. Pocket Penetrometer
6. Water content
7. Grain size analyses
8. Hydrometer analyses
9. Attenberg Limits (Liquid Limit and Plasticity Limit)
10. Specific Gravity.

The triaxial tests were executed in Bandung while the other tests were executed in field laboratories.

The consolidated un-drained triaxial tests were executed in geotechnical laboratories in Bandung because the equipment was too extensive and too sensitive to transport to the site. The results of the tests were not always very satisfactory. This was thought to be caused by sample handling, and the long distances and time involved in transporting the samples from the site to the laboratories in Bandung. Control testing was executed in The Netherlands to maintain independent control of the tests. Odd single test results were rejected if they were not confirmed by the testing in The Netherlands.

The tests executed in the site laboratory were very successful. The massive quantities of tests were executed very satisfactory.

Some of the laboratory tests were not strictly necessary for calculating the safety factors, but were executed in large quantities for correlation purposes.

7 RESULTS/INTERPRETATION

The CPT results together with the stratigraphic information and laboratory test results from the boreholes provided reasonably detailed geological profiles along the railway lines. The limestone sands/muds were distinguished from the clay formations and obviously, (weak-) rock formations were easily recognized. In many cases it was also possible to correlate boundaries within the clay formations with the available geological maps and profiles.

The strength of the limestone sands and muds and the rock formations was more than sufficient for the foundation loads and ground-parameters for limestone sands and muds and for the weak rock formations proved to be no problem and will not be discussed further.

Volcanic ash was found along all railway lines. The degree of weathering and compaction of the volcanic ashes varied from none-compacted and fresh ash to fully compacted, consolidated and weathered (ash-) clay. The fully weathered volcanic (ash-) clay is geotechnically considered as a clay. The unweathered and fresh ash was never below the foundation but at some locations the volcanic ash contributed to the active and passive soil pressures on the abutments and piers. Undisturbed sampling of volcanic ash is, in general, impossible, because the very loose structure is immediately disturbed by the sampling tools. Determination of bulk and dry densities was possible but the strength parameters had to be estimated.

Determining ground-parameters of particular clay formations in the coastal areas was difficult. Below the different approaches are described.

7.1 Bulk and Dry Density Parameters

The bulk and dry density parameters could be established from the boreholes. The variations in bulk and dry densities within the clay formations were so small that average values of bulk and dry densities could be used.

7.2 Swelling clays

Potentially swelling clays were found at a few locations. The existing bridges were only assessed at failure state and therefore the influence of the swelling clays was not evaluated. However for new bridges swelling clays will be a major design criterium.

7.3 Sensitivity of soils

Soils sensitive to earthquake vibrations were found only at a few locations and, in general, at larger depths where they had no influence on the stability of the bridges.

7.4 Phi and Cohesion Parameters

1. Searle graph

The Searle graph (Searle 1979) correlates soil type with cone resistance and local friction. For the clay formations surveyed the soil types according to Searle for cone resistance less than 1 [MPa] did not correlate at all with the borehole information. The distances between boreholes and CPTs which were compared, were small and it was reasonably certain that the same soil layers were encountered by both borehole and CPT.

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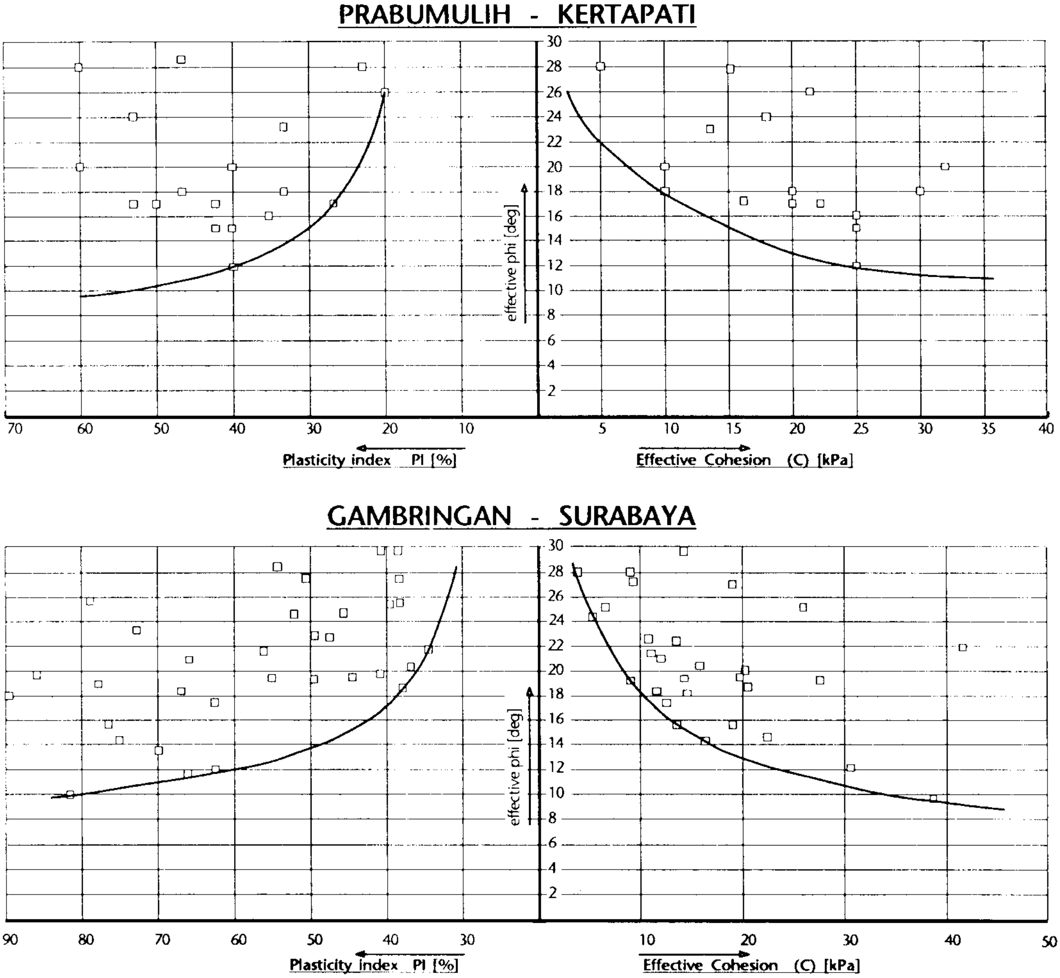

Figure 2. Examples Plasticity Index - effective phi and cohesion relation. (ch.7.4-4)

The discrepancies were most likely due to cementation between the soil grains. The Searle graph is not valid in cemented soil types.

2. Correlation between CPT cone resistance, friction and effective triaxial data

The CPT values did not correlate with the laboratory triaxial effective phi and effective cohesion values. The scattering in both sets of values was too large for a reasonable correlation.

3. Minimum effective phi and cohesion

The minimum effective phi and cohesion values measured were used in a series of calculations of the stability of the foundations. The loads on the foundations in these calculations were based on the old loading scheme. According to these calculations the majority of the bridges founded on clay worked out to be very unstable whereas the bridges in reality did not show any sign of instability. The minimum values therefore were too pessimistic for most of the bridges founded on clay.

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4. Other correlations

Correlations between Unconfined Compressive Strength, pocket penetrometer, pocket vane tests and triaxial values and CPT results were all unsuccessful.

A reasonable correlation was obtained between Plasticity Index and effective phi. This relation is described in the literature (Kenney 1959, Lambe 1979). The scattering in the diagram (fig.2) shows that the relation is not optimal but accounting for the scattering by taking the lower boundary for the phi values resulted in a workable relation.

Also it was found that a plot of triaxial laboratory effective phi and cohesion for clay formations showed a relation. All phi and cohesion values of clay and ash-clay formations lie within a particular area (fig. 2). Because of the scattering in this relation the lower boundary of the range was used.

The Plasticity Index values show a good correlation with the different types of clay and ash-clay formations. To put a PI value to a particular layer was possible and through the effective phi/cohesion - PI relation it became possible to determine the ground parameters.

Along the railway lines 4 different effective phi/cohesion - PI relations were established. Safety factors calculated according to the effective phi/cohesion - PI relations under the old loading scheme, correlated very well with the state in which the bridges were at the time of the visual investigation.

8 CONCLUSIONS

Careful examination of geological information combined with Dutch Cone Penetration tests facilitates the determination of ground parameters of foundation layers. Although the Dutch Cone Penetration test might not give a strength value which can be used directly in foundation calculations, it is a very efficient and cheap test to establish different ground layers.

The relation between effective phi and cohesion, and PI values can be very useful in assessing ground-parameters. Determining Plasticity Index values is easy and cheap in contrast with relatively expensive and cumbersome triaxial tests. The authors, however, do not claim that similar relations exist in soil types different from the clay and ash-clay formations found in the coastal areas of Sumatra and Java. Further investigations will be necessary to establish the validity of effective phi/cohesion - PI relations.

ACKNOWLEDGEMENT

The authors are grateful to the Indonesian State Railways authorities (PJKA) for their support and co-operation during the field-work.

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