SIMULATION OF PAVEMENT DEFORMATIONS FOR DIFFERENT APPROACH SLABS CONCEPT CONSTRUCTED ON BATU PAHAT SOFT CLAY (BPSC)

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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

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This dissertation is submitted as a fulfilment of the requirements for the award of
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JUDUL: **SIMULATION OF PAVEMENT DEFORMATION FOR DIFFERENT APPROACH SLABS CONCEPT CONSTRUCTED ON BATU PAHAT SOFT CLAY**

SESI PENGAJIAN: **2006/2007**

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Special dedication to my beloved father and mother,
Mr. Mohd Daud Kayat and Mrs. Hamsah Sandir, all family members and friends. Thanks for all your valuable contributions, patience and love.

May Allah S.W.T, The Almighty bless our every living days, Insyallah...

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ABSTRACT

Depression or bump that occurs between end of bridge approach slab and road pavement interface always arises a great concern among motorists. The occurrence of the bump that motorist feel as they leaves or approaches the bridge is caused by the differential settlement problem. This problem becomes more apparent particularly over soft soil condition such in Batu Pahat district. Currently, there is no guideline and specification provided by the Public Work Department in designing a proper bridge approach model, which has exceptional transition toward road pavement. The current conventional model used in many projects was reported to be less effective since the problem is still noticeable and it requires regular maintenance work when the problem reappears recurrently. Practically, it is clear that the problem is still unresolved and this is due to the complexity of the design problem itself that merge the structural and geotechnical perspectives in design. The studies on simulation modelling for approach slab and road pavement design also have been rare. It is essential since such design analysis, which is based on numerical analysis, could have advantages in providing preliminary expected outcomes for the modelling purpose. In conjunction to this matter, the modelling of several approach slab and road pavement concepts have been successfully conducted to verify the result expectancies using this approach in order to provide better understanding on the recurrent problem.

Keywords: bump, bridge approach slab, differential settlement, soft soil, simulation modelling

ABSTRAK

Ketidakseragaman permukaan atau 'bonggol' yang berlaku di antara muka hujung papak julur bagi jambatan dan jalan raya kerap kali mengundang kebimbangan pengguna jalan raya. Kejadian tersebut yang dirasai oleh pengguna jalan raya apabila menuju atau melewati jambatan adalah diakibatkan oleh masalah prerbezaan pemendapan yang berlaku. Masalah tersebut menjadi lebih jelas apabila melibatkan pembinaan di kawasan tanah lembut seperti di daerah Batu Pahat. Pada ketika ini tiada garis panduan mahupun spesifikasi yang disediakan oleh Jabatan Kerja Raya dalam mereka bentuk papak julur yang mampu menangani permasalahan tersebut. Model konvensional yang digunapakai pada ketika ini dilaporkan kurang efektif kerana permasalahan ini masih berulang serta memerlukan kerja penyelenggaraan yang kerap. Secara praktikalnya adalah jelas bahawa permasalahan ini masih belum dapat diselesaikan dan ini adalah disebabakan oleh kesukaran yang dialami ketika mereka bentuk model di mana ia melibatkan gabungan pemahaman daripada sudut kejuruteraan struktur dan geoteknik. Manakala kajian kaedah simulasi dalam hal ini adalah jarang dilakukan dan tidak meluas. Analisis seperti ini yang melibatkan analisis elemen terhingga adalah berguna dan mempunyai kelebihan dalam menyediakan platfom rekabentuk awal. Berikutan ini, rekabentuk beberapa konsep papak julur bagi jambatan dan seksyen jalan raya telah dijalankan dengan jayanya dalam penyelidikan simulasi ini bagi menjelaskan jangkaan keputusan terhadap kajian, seterusnya memperolehi pemahaman yang lebih terhadap permasalahan yang berulang ini.

Kata kunci: bonggol, papak julur bagi jambatan, perbezaan mendapan, tanah lembut, simulasi

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LIST OF SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
CBR	California Bearing Ratio
CD	Consolidated Drained Test
CU	Consolidated Undrained Test
DVL	Digital Video Logger
FWD	Falling Weight Deflectometer
EPS	Expanded Polystyrene
ESAL	Equivalent Standard Load
GCL	Geosynthetic Clay Liner
GPR	Ground Penetrating Radar
HPU	Highway Planning Unit
LaDOTD	Louisiana Department of Transportation Development
NDT	Non-Destructive Test
NYDOT	New York Department of Transportation
PSI	Present Serviceability Index
PWD	Public Work Department
σ	normal stress
σ'	effective normal stress
σ_3	confining pressure
E	modulus of elasticity
ϕ	friction angle
$\Delta\sigma$	deviator stress
u	pore pressure
C	cohesion
C_c	coefficient of consolidation
C_α	coefficient of secondary comporession

f	yield function
$\bar{f}$	function of the stress state
κ^*	modified swelling/ recompression index
λ^*	modified compression index
P_p	pre-consolidation stress
t_0	time at which creep is assumed to commence
t_1	time
e_0	initial void ratio
e_1	void ratio
s	shear stress
μ^*	modified creep index
v	Poission Ratio
ψ	dilatancy angle

CHAPTER I

INTRODUCTION

1.1 Problem Statement

The concrete bridge found in Parit Karjo, Batu Pahat is constructed on deep foundation pile which is structurally stable and sound. Construction of pavement and bridge under soft soil circumstance is always linked to the differential settlement problems between bridge abutments and roadway ends. Though, bridge approach slab is provided to span across any difference in level due to settlement between the bridge approach and the roadway ends. The long span concrete slab certainly will provide smoother transition at the end of the roadways to the approach bridge. Thus, providing better comfortability and rideability to commuters and road-users.

The occurrence of settlement for road pavements-bridge interface sections will be noticeably when there is a sudden change of joint level between the ends of paved roadway and constructed bridge approach slab. Undoubtedly, this will affect the rideability quality or factor of the roadway in the long run. This complaint involves a 'bump' that motorists feel as they are leaving or approaching the bridge. The only alternative available now is rehabilitation or remedial work that is to increase the serviceability of the pavement before the same deformation problem reappears gradually. According to Azman and Masirin (2000), about 20% to 30% of total rural road in Batu Pahat district experienced varieties types of failure. Noticeably some damage problem such as deformation of pavement creates uncomfortable manner and also rise of worries of safety among the road users. Thus, it will raise the cost of maintenance as additional maintenance work must be carried out after some period of serviceability.

Above all the matters, it is important for engineers to provide better design and concept of approach slab thus will benefit many similar construction projects in the future. Cai et al. (2005) summarized approach slab design directly affects the safety and economy of the transportation infrastructure. Modification in design of approach slab is important in order to identify better solution for this problem. Though, other researchers such as Wong and Small (1994) in their laboratory scale test indicated that greater sloping angle of approach slab then 10° did not show any significant effect on pavement deformation. Alternatively, performance of designed approach slabs can be examined trough simulation modelling using computer software. In this study some of the conceptual design of approach slabs will be proposed to be evaluated. All required data to be used as inputs in modelling process can be obtained from various laboratory tests.

1.2 Objective of Study

This study is mainly to examine the effect of various formations and concept of approach slab on pavement deformation. The study focuses on Parit Raja rural road that is currently having severe deformation problem on its bridge connection between roadway end and bridge approach slab. Thus, the objectives of this study are as follows:

- To simulate the effect of various formation and concept of approach slab on pavement deformation using PLAXIS software.

- To examine the deferential settlement behaviour of road pavement constructed in soft soil condition when interfaced with rigid bodies such as concrete bridge.

- To critically examine the performance of road pavement when interfaced with approach slab under given soft clay condition.

1.3 History and Study Area

Parit Karjo is located at wetland area of soft soil in Batu Pahat district. With the condition of high water table and weak soft soil properties, it is always being linked with engineering structures failures due to soil settlement problem. Currently, major problem of road pavement in this area is the occurrence road surface settlement with appearance of various kinds of distresses along the roadway section. In addition to that emerging problems, we had also noticed that differential settlement occurs between constructed bridge approach slab and road pavement that is apparently more problematic. It is well-known problem but unfortunately not yet to be resolved appropriately as claimed by the statement of Public Work Department authority.

Cai, et. al, (2005), summarized the embankment settlement is contributed by many factor accumulated all together such as subsoil conditions, materials, construction techniques, drainage provisions, and quality control methods during construction. The study on causes of the problem had been conducted commonly for many years. Some of researcher such as Wong and Small (1994) had studied on the effect of orientation of approach slab model. Not merely restricted to the bridge construction alone, very similar structure such as culvert also shares the same interference problem. In this regard, Gue, S. S. et. al (2002) recommended the use of oversize culvert without end bearing piles to provide smooth riding comfort.

According to the initial field observation, deformations of road surface were severe. Rideability of pavement was so poor and rehabilitation action must be done as soon as possible to prevent more consequent damage and any safety threat to the road users. Plane view of study area is shown as follow:

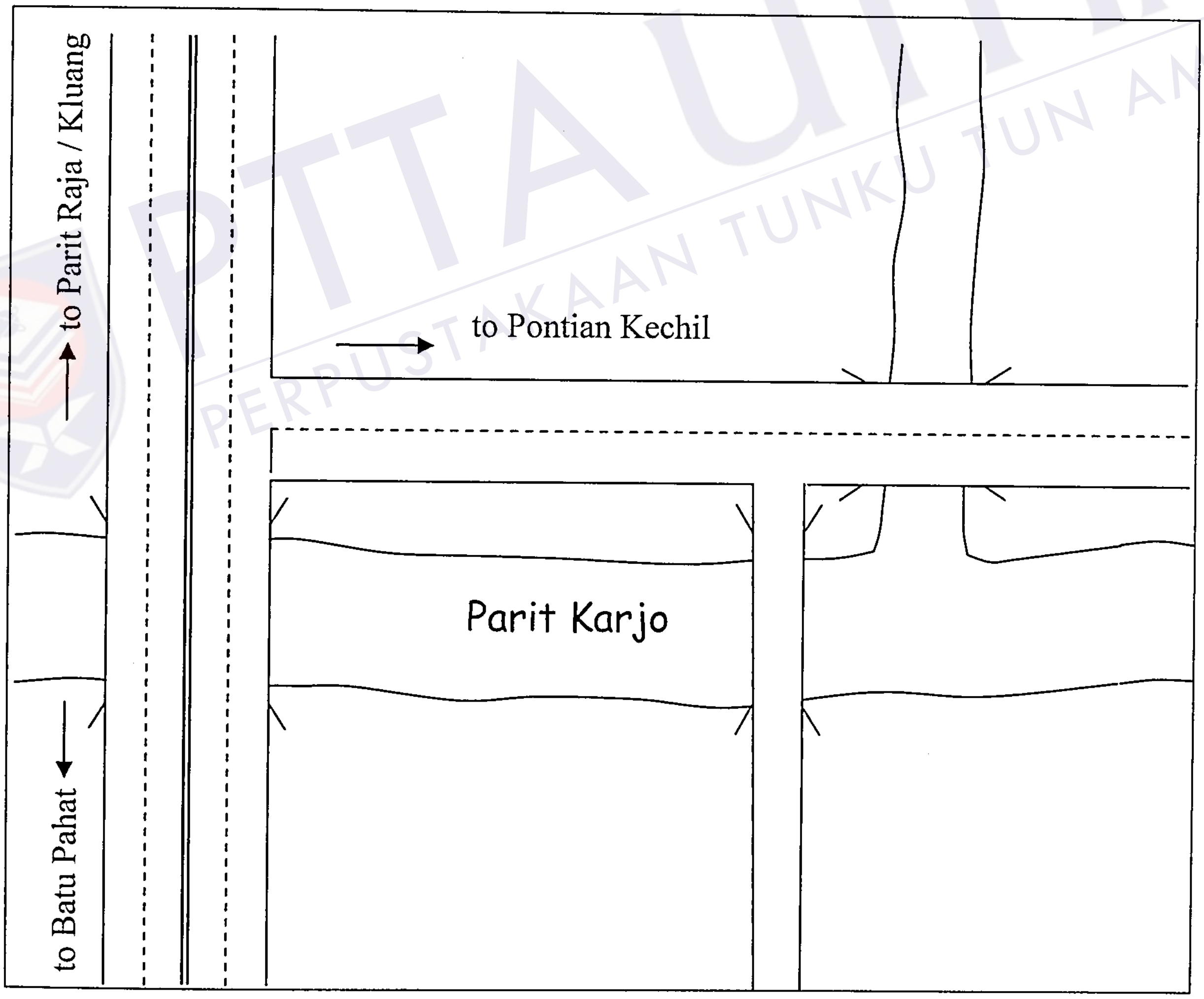

Figure 1.1: Plan View of Study Area

1.4 Scope and Limitation of Research

Research scope will concern on simulation analysis of some concept and modification of approach slabs based on the given condition of soft soil using finite element method. PLAXIS Version 8 will be used in this regard with the ability to perform two dimensional analyses. Soil properties will be obtained from various literatures of previous researchers who doing research in this field. Modelling on the concrete bridge will be based on the actual drawing obtained from the consultant firm who was responsible in this project design. In modelling of soil material itself, established Mohr-Coulomb model will be used for this purpose of study.

Parit Karjo rural road and bridge found near to the T-junction of Kluang – Batu Pahat state road has been used as a research tool. Field observation and laboratory testing has been carried out to identify the required data and properties to be used in this simulation study. However, existing road-bridge in Parit Katjo only used as. Under the limitation of PLAXIS software, deformation analysis was based on static loads at selected point. PLAXIS V8 with capability of 2-dimensional modelling was used to perform the simulation analysis of deformation and stability of geotechnical structures.

1.5 Hypothesis

Several hypotheses have be made based on the expected out comes of the research. Generally, modification in design especially beyond the end of provided approach slab would result in change of load transition behaviour. This was based on the explanation that any change in material stiffness between end of roadway and much stiffer material of approach slab would cause of smoother deformation profile. Thus, hypothesis of the research could be explained as follows:

- Conventional horizontal slab could provide better and smoother surface transition toward end of pavement if compared with the one, which was not provided with any transition of approach slab. Though, small depression of deformation beyond the end of constructed approach slab will noticeably exist. In long term effect especially under soft soil circumstance, surface deformation of pavement may become more severe if no rehabilitation work would be carried out.

- By providing some modifications on design models, performance at transition region between approach slab and road pavement might be improved and expectedly distinctive for every proposed approach slab model. Consequently, it would be able to demonstrate of how modification on the approach slab and road pavement geometry and material properties would affect on their performance against deformation.

- Interface region at connection between bridge approach slab and approaching roadbase were the critical area in which the depression of road pavement surface occurs significantly. The use of new approach slab concept with subgrade reinforcement could improve the transition behaviour at particular area.

- Modification of the approach slabs design could be extended with the use of additional reinforcement materials such as geotextile and geosynthetic clay liner that would possibly exhibit better performance particularly under soft soil condition. Such of material is widely use in numerous geotechnical and transportation engineering projects.

1.6 Research Methodology

a) Literature Review:

Literature review is an important tool in research tends to provide absolute information and study references. Apart of fundamental references from text books, references were also gathered mainly from established journals to support the current study. Other resources of literatures were also discovered from many proceeding papers, online documents, programme manuals and so forth.

b) Gathering data and information:

Initially, field observation has been conducted to investigate the current condition of the bridge-road pavement structures. This primary investigation includes the use of ground penetrating radar equipments to study the subsoil condition below the structures. Critical data items such as soil properties, road pavement specification and bridge approach slab parameters were obtained from the local authorities, literatures and previous researchers documentations.

c) Recommendation for Future Research

This study was highly expected to be success in its objective to evaluate the performance of each proposed conceptual approach models through simulation analyses. It is also recommended for possible further research work by employing some modification on design model throughout laboratory scale testing in order to provide better understanding on design concept of approach slab more critically based on approximate scaled model. Working on laboratory scale model sometimes regarded as important basis since some design parameter cannot be modelled correctly and virtually based on computer simulation due to the limitation issues of software modelling environment.

The use of new geotechnical engineering material can be introduced for designing new model of bridge approach that is supposed to be economically affordable, safe and comfortable design, and high durability with acceptance of minimum maintenance cost. Essentially it can be extended for full testing in probable future research under doctorate programme. By this means approved design of bridge approach can be accomplished throughout proper research programme and long term field monitoring of full testing research.

1.7 Flow Chart of Research Project

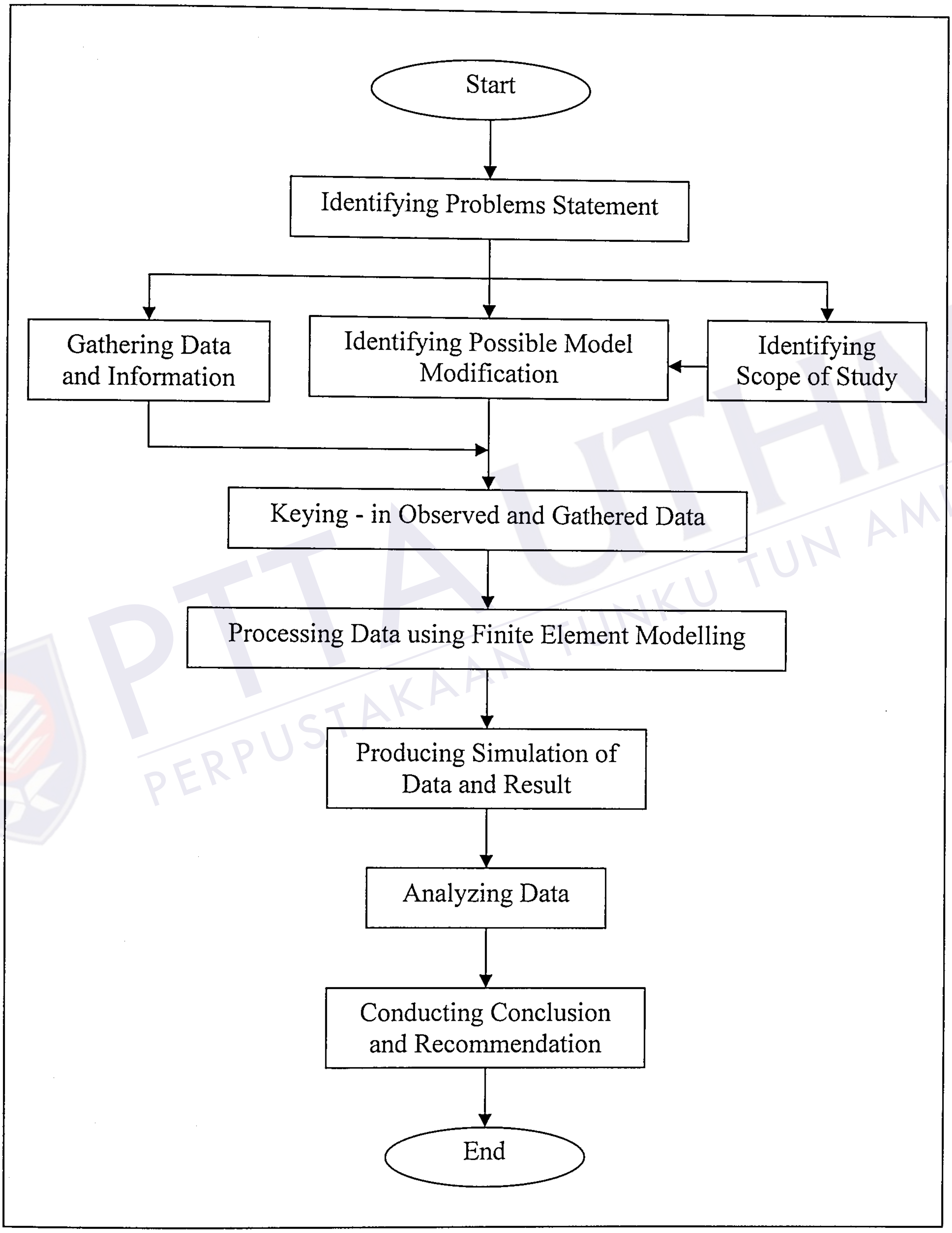

Figure 1.2: Flow Chart of Research Project

CHAPTER II

ROAD PAVEMENT-APPROACH SLAB CONSTRUCTION AND FAILURES

2.1 Introduction

A general review on literatures of this research study is primarily important in order to gain understanding on current situation that had to be discovered at the end of the study. However, this research will emphasizes on the soft clay condition in Batu Pahat area, which covers the scope of this study in basis. Other vital components in this review are the road pavement design and bridge approach determination. This chapter reviews the road pavement and approach slab construction, properties, characteristics, and design which in turn contribute towards failures at interface section. Further discussion is necessary in order to have better understanding on study conducted and as mentioned in Chapter I, Section 1.4 (Scope and Limitation of Study), and to achieve the designated objectives as mentioned (see Section 1.2). Further discussions by focusing on selected case studies were conducted as summarised in Chapter III. These will enable the author to understand the contributory factors to road-bridge interface section failures.

2.1.1 Batu Pahat Soft Clay

Batu Pahat district is located at west coast of the Peninsular Malaysia. Vast economic development has encouraging requirement for new infrastructures development and increase of economic activities. Apparently, this area is located at wetland region of which has significant traverse soft soil deposite of marine or coastal alluvium (Masirin, 2005). Very soft and soft deposit of river alluvium and marine deposit are common in west cost of the Peninsular Malaysia, which also currently gain rapid economic development for over centuries. The river alluvium and marine deposit normally consist of clay, silty clay and occasionally with intermittent of sand lenses especially near a major delta (Gue, S. S. et. al, 2002). Soil deposit of soft clay geologically can reach up to between 20 m to 30 m.

The plasticity index value ranging from 35% to 60% for the upper layer and for the lower clay layer is about 15% to 35%. Bulky density of the upper clay is slightly lower than the bottom clay (Malaysian Highway Authority, 1989). With the high annual rainfall around 200mm to 250 mm in average, constitution of liquid limit is high up to 60% to 90% and even higher soil moisture content. The level of water table is approximately around 0.5m to 0.65m from ground level. However, it may rise significantly during raining season (Jestin, 2006). Weak properties of soft clay and seasonal high water level may significantly lead to design failure on any structures build on this soft clay soil. Differential settlement problem on engineering structures such as building, bridge settlement and severe distresses on road pavement structures are quiet common.

2.1.2 Road Pavement

Road pavement generally can be divided into two categories; flexible pavement and rigid pavement (Wright, P. H., 1996). Though composition of both asphalt (flexible pavement) and portland cement concrete (rigid pavement) in pavement design might be considered in third category that is composite pavement. In Malaysia, flexible pavement is a major type of road pavement that is spreading throughout the country. Flexible pavements are constructed of bituminous and granular materials, thus considered to be more economical in term of construction and maintenance cost.

Conceptually, flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low (Huang, Y. H., 2000). Important criteria in design of flexible pavement are design thickness, traffic loading, environment condition and material characteristics. Another type of pavement certainly is rigid pavement or so called concrete pavement. Structural design such as reinforcement design and joints connection in concrete pavement is critically important.

In Malaysia, flexible pavement is a predominant and very common, which is linking rural and urban area effectively. Additionally, it is a kind of cost effective option available with all materials used in construction can be obtained locally. Local agency such as Public Work Department also provides specific guidelines for design purposes. There are two broad classifications of road in Malaysia, namely Federal Roads and State Roads. According to Public Work Department statistic in 2006, a total of 59,761 kilometers of roads make up the whole road network of the country, with 24.4% of the network being Federal Roads, while the remaining 75.6% forms the State Roads. Federal Roads are all roads declared under the Federal Roads Ordinance (1959). Despite of mass construction of flexible pavements, concrete pavements also constructed in Malaysian road with comparatively in a small scale compared to the former option.

2.1.3 Bridge Approach

Obviously, bridge is a vital for the transportation means when two location is separated by the river or trench. In Malaysia, it is estimated that there are about 4500 road bridges in the country, out of which about 2800 numbers are located on the Federal Roads. Presently the Public Works Department Malaysia has compiled an inventory for 2546 bridges on the Federal Roads in Peninsular Malaysia (Public Work Department, 2006). In state of Johor alone, it is about 469 bridges found and this bulk number of bridges defined that this state consists the most compared to others state. With this amount it represents how important of the bridge to link the peoples and goods.

Despite of bridge construction, bridge approach is also provided in bridge design as a transition medium between rigid body of bridge abutment and road pavement section. In many bridge designs, it is constructed to provide smooth ride of the traffics as they approach or leave the bridge in consequence. Occasionally, bridges approach is composed of load transition medium such as reinforced concrete, transition piles, light weight fill materials and many other design approaches. The function of all these materials is to provide a smooth transition between the bridge deck and the roadway pavement. For instance, bridge approach such in approach slab is designed as a simply-supported beam between abutment and approaching road pavement (Cai et. al, 2005). Design guidelines may vary from a location or state to another. For instance, NYDOT Bridge Manual (2006) stated that the required length of the slab could be in between of 3 m to 8 m and the end of approach slab may be designed as an integral abutment bridge structure or simply supported beam.

The bridge approach also can be designed incorporated with transition piles. This option is often more costly but may essential in some road construction project. Yang, (2004) in his study of using expanded polystyrene (EPS) for bridge approach found that the beneficial effect of using the EPS material can reduce vertical pressure to the subground and also lateral pressure against bridge abutment. Some other researchers integrated the use of geosynthetic material to improve the transition soil medium in bridge approach.

2.2 Flexible Pavement: Design and Construction

2.2.1 Design Methods

Flexible pavement design can be distinguished by the numerous method of design approach such as empirical method, limiting on deflection or shearing failure, design method based on mechanistic approach and so on. Empirical method of design, which is used by AASHTO, is the most popular method based on observation of pavement performance through road test procedures. Empirical method adopted by AASHTO based solely on performance of road test developed using pavement serviceability concept and equation relating the number of load repetitions (Croney, 1991). The disadvantage of empirical method is that it can be applied only to a given set of environmental, material, and loading condition since it is developed for certain geographical condition (Huang, Y. H., 2000). The use of mechanistic method should be more appropriate since the design is based on the mechanics of material that relates an input, such as a wheel load, to an output or pavement response, such as stress or strain.

2.2.2 Design Factors

According to Huang (2001), there are four categories of design factors; traffic and loading, environment, materials and failure criteria. Four important measures under traffic and loading factor are about the parameter of axle loads, number of load repetitions, contact area of load itself and also the vehicle speed. The environment factors that influence pavement design include temperature and precipitation. Basically, both parameters will affecting the elastic moduli of the pavement layers. The precipitation of rain will affects the subgrade through infiltration of surface water and also from groundwater table. Another important factor is the material of pavement itself. Materials used in every layer of pavement must be complying with standard of design. The subsequent of all these factors consequently affect another factor of failure criteria. In flexible pavement, it is well agreed that fatigue cracking and rutting are the two principle types of distress to be considered in designing.

2.2.2.1 Traffic Loading

Traffic loading is one of the primary important input in road pavement design. In this regard, the subgrade has to be protected form the loading imposed by traffic so that the pavement structure is able to withstand a large numbers of load repetition during its design life. This is more apparent when road pavement is constructed on weak foundation of soft soil. In flexible pavement design, important loading factors are magnitude of axle loads, volume and composition of axle loads, and contact area (Wright, 1996).

Empirical method in design has been widely perceived in road pavement design which was established by AASHTO based on their road test in 1960. Our local agency such as Malaysian Public Work Department also employed the similar approach which was taken directly from AASHTO practice. It requires input from projected or estimated traffic data of which converted to the total number of equivalent standard axle loads that is 80kN according to AASHTO design method. In mechanistic design approach, number of repetitions is another important remark that has to be considered in design. Since the empirical nature in flexible design that is currently being practised, the application is restricted for flexible pavement design (Huang, 2000). However, with the use of computerised calculation, it is actual has no problem to consider the number of load repetitions in designing purpose.

The magnitude of traffic loadings is control by local agency and traffic survey is conducted to establish appropriate informational data from current traffic movement. As Malaysia faces a tremendous increase in the vehicle registration during the last decade for the period of 1977 to 1994, the total number of registered vehicle has increased from 1.78 million vehicles in 1977 to 7.21 million vehicles in 1994 respectively. This increase is equivalent with an average growth rate of 7.4% per annum. In recent year, percentage of motorcycles represents about 24.5% for Federal Roads and 38.9% for State Roads, which is covering the major traffic volume. Traffic survey is conducted by The Highway Planning Unit (HPU) with the assistance of the State Public Work Departments, District Engineers and Local Authorities. Traffic data are recorded and analysed for the planning of new roads, upgrading of existing road network and the design of highways and traffic control devices.

2.2.2.2 Material Characteristics

Material characteristics used in design are depending on the nature of design procedure. Among desirable material characteristics are surfacing layer, base and subbase layers, treated or stabilized layers and also subgrade layer (Wright, 1996). The desired properties of materials was covered extensively in AASHTO and other agency such as ASTM, Shell Institute and many others.

For the subgrade material, reinforcement on weak soil foundation has been widespread with the use of reinforcement form synthetic materials. Geosynthetics are used in all layers of road structures, exhibiting the following major functions: separation, reinforcement, filtration, drainage, and moisture barrier. Furthermore, geoform that is usually made up from block-moulded EPS has proved suitable as lightweight fill material on soft ground, for soil exchange beneath the sub-base and for temperature isolation to prevent freezing-thawing damages. The use of geosynthetics to reinforce soft subgrade or subsoil or to separate cohesive ground from granular road structures is a wide application area which has been extensively investigated theoretically and practically world- wide (Brandl, H. and Adam, D., 2000).

2.2.2.3 Failure Criteria

According to empirical method of AASHTO, failure criterion is based on present serviceability index (PSI) and road pavement reliability. In contrast, other design method such as mechanistic –empirical method requires establishment of specific types of distress from a number of failure criteria. Generally, it is agreed that fatigue cracking, rutting and low temperature are the three principal of distress (Huang 2000).

In flexible pavement, rutting is one of the important criteria of road pavement failure. In order to control the occurrence of rutting, two designs method are used by limiting vertical compressive strain and limiting the rutting to specific amount. For the first method, by assuming quality of road surface and base course is appropriately controlled, the tolerable amount of rutting in design can be achieved by limiting the vertical compressive strain on the subgrade.

2.2.3 Road Pavement Design in Malaysia

In Malaysia, Arahan Teknik Jalan that is a manual published by Malaysian Department of Public Work was decreed to be used in road design through out the country. This manual is based on empirical design method developed by AASHTO. According to the manual, the thickness design of the pavement shall be based on the design CBR (California Bearing Ratio) of the subgrade and the total number of 8.16 tonnes standard axle applications for a specific design period.

Roads in Malaysia are classified according to their locality, function, design or authority/management jurisdiction. In this regard, all road pavements in Malaysia have been classified into 5 categories (Meor et. al, 2001). This category is given in Table 2.1 for reference. Road pavement categories found in Batu Pahat district is also shown in Figure 2.1. In order to control the traffic design and cost of maintenance, The Weight Restriction (Federal Roads) Order 1989, which came into force on the 1st. January 1990, specifies the limits of vehicle weight on Federal Roads. In this order, Federal Roads are categorised under seven load classes with a schedule of the roads in each load class provided. This category is necessary not merely due to difference in bridge design criteria but rather to road geometric considerations. The maximum permissible Gross Vehicle Weight (GVW) specified for each load class depends on the number of axles, axle configuration and vehicle dimensions. It ranges from 8 tonnes for a 2-axle rigid vehicle to 38 tonnes for a 6-axle articulated vehicle with a wheelbase of at least 13.1 metres.

Table 2.1: Roads Categories in Malaysia (Meor, et. al, 2001)

Index	Type of roads	Road ordnance	Jurisdiction	Financial
1	Expressway	Federal Road Ordnance (1959)	Consortium	Consortium
2	Federal roads	Federal Road Ordnance (1959)	Federal Government	Provide by Federal Government
3	State roads	State Road Ordnance (1959)	State Government	Provide by State Government
4	Urban road	State Road Ordnance (1959)	State Government	Provide by State Government
5	Rural roads	State Public Work Department	District Office	Public Work Department

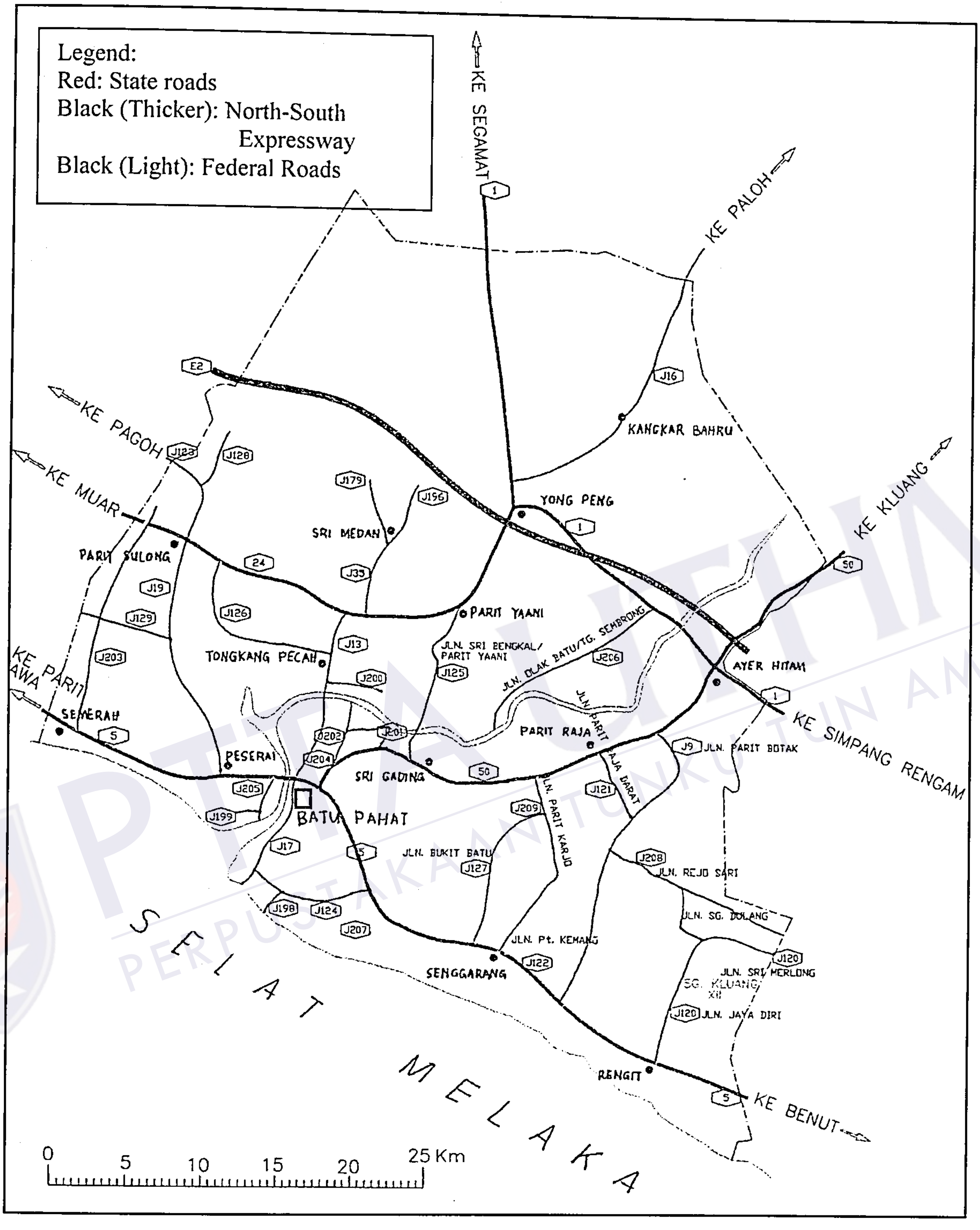

Figure 2.1: State Roads in Batu Pahat District (Batu Pahat PWD, 2004)

2.2.4 Construction under Soft Clay Condition

Development and construction of road pavement in soft clay region such in Batu Pahat district is a great challenge for engineers. Subsurface investigation is one of primary important component in designing of road pavement under soft ground condition (Gue, et. al., 2002). For higher class of road categories, such as federal or state road, the requirement of additional parameter in design is very common since more traffic volumes is projected during their design life expectancy. Under soft ground condition, ground treatment is significantly important in order to minimise possible failure on road structures and increase expectancy of design life. In contrast, construction of rural road is not provided with critical components in design. Typical cross section of road pavement for rural road provided by Public Work Department of Malaysia is shown in Figure 2.2. Basically, the design of road pavement shown in the figure is used on all soil condition for rural road in Batu Pahat district.

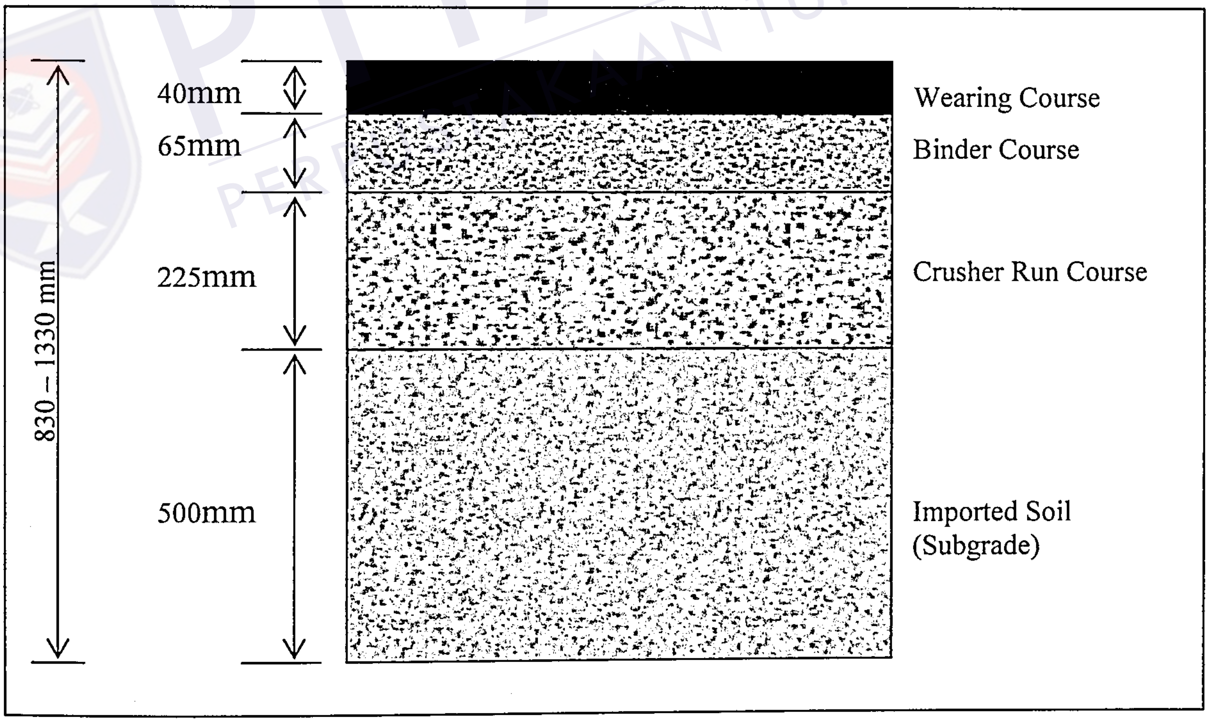

Figure 2.2: Typical Cross Section of Rural Road Pavement in Batu Pahat District (Public Work Department, 2001)

Design parameter for state road may varies from one place to another. For example, road pavement that is designed for state road of Parit Karjo is shown in Figure 2.3. In practice of road pavement design, Public Work Department only provides design parameter and standard requirement but the whole modelling and designing process will be undertaken by consultancy agency. Additionally, local Public Work Department only monitoring the construction project to run smoothly and also provide some technical support if desired.

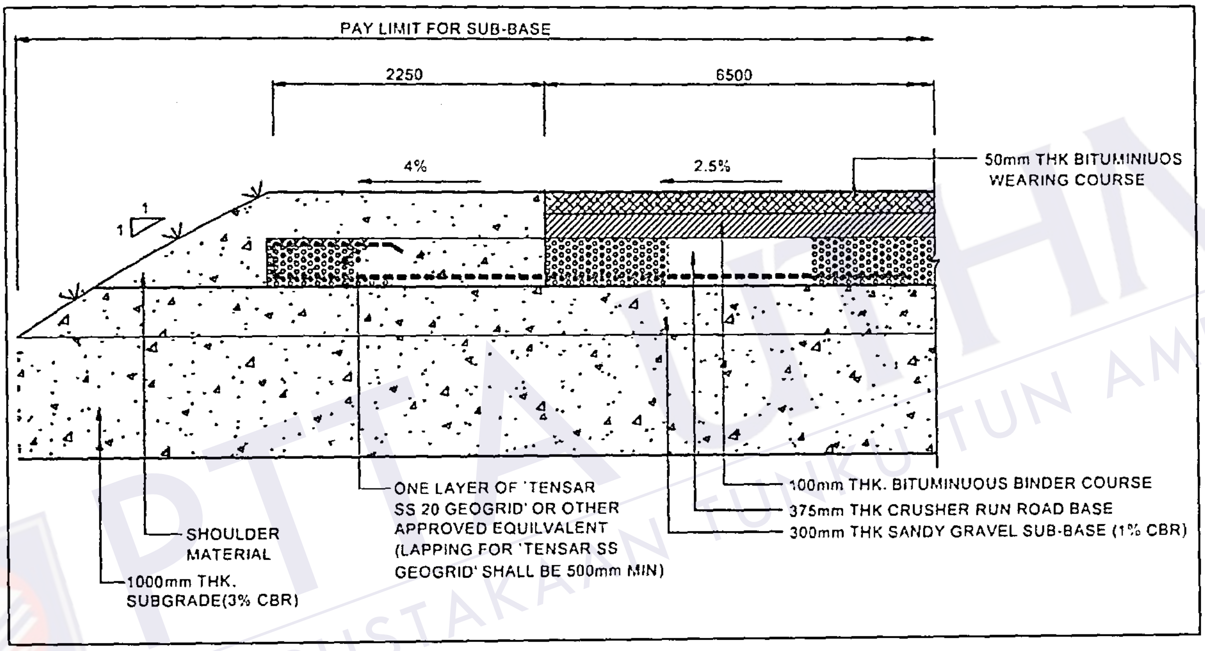

Figure 2.3: Typical Pavement Section Constructed on Parit Karjo State Road (State Public Work Department, 2006)

2.3 Bridge Approach Slab: Design and Construction

2.3.1 Bridge Abutment and Approach Slab

Abutments function as both earth retaining structures and as vertical load carrying components in bridge structure. In general, bridge abutment is design either using integral abutment or non-integral abutment. The use of integral abutment eliminates the need for deck joints and expansion bearings (Roman, et. al., 2002). Integral abutment design is also often referred to jointless bridges. The objectives of design are to provide desirable long-term serviceability, minimise maintenance requirements, cut construction cost and improve aesthetics and safety (Indiana Department of Transportation Bridge Manual).

Bridge abutments were constructed in the past with and without approach slabs. Typically, bridges without approach slabs are located on secondary road. Traffic movement near to the connection of abutment and roadway end has caused the fill behind the abutment to shift and compacted. Apparently this often cause settlement of the pavement directly adjacent to the abutment and result in a bump to develop consequently. Approach slab is normally designed as reinforced concrete slab and designed as simply supported beam attached to the bridge abutment at one end and another one is overlaid on the supported ground surface. Generally there are two types of slabs to be considered; flat slab and flat plate in which the choice of slab type to be used rely on many factors such as design load, required spans, serviceability and strength requirement. The design approach between these two types of beamless slab is usually a matter of loading and span (Park, R. and Gamble, W. L., 2000).

2.3.2 Design Method

In practice, approach slabs are often but not always effective in providing ride characteristics at bridge approaches. The design approach of slab may varies form one agency to others. According to many agencies in U.S, approach is suggested to have the length vary from a minimum of 3.0m to a maximum that is based on the intercept of a 1.0 on 1.5 line from the bottom of the abutment excavation to the top of the highway pavement. This length is to be measured along the centreline of roadway (Bridge Design Manuals of New Jersey DOT & North Carolina DOT). Additionally, the end support is assumed to be a uniform soil reaction with a bearing length that is approximately 1/3 the length of the approach slab (25/3 = 8 feet). In the United State, the bridge approach slab is designed as a slab in accordance with Section 4.6 of the AASHTO LRFD Bridge Design Specifications – U.S. Units, Second Edition 1998. However, according to the agency no details on how the approach slab should be designed specifically. Though, in accordance with WSDOT Design Manual Chapter 1120, the State Geotechnical Engineer will include a recommendation in the geotechnical report for a bridge on whether or not bridge approach slabs should be used at the bridge site.

In Malaysia, BS5400 and BS8110 are primarily important guidelines used in designing bridge structures. Both are design manuals for bridge and concrete structures which is employed for local design. Similarly, no specific guideline is provided to design appropriate approach slab structure. Most probably, it is due to the lack understanding and input from both structural engineering and highway or geotechnical engineering practitioner or designer. Certainly, our local Public Work Department do not provide any design criteria that has to be adopted for local environment design.

2.3.3 Construction of Approach Slab

Basically, approach slabs are constructed to provide a smooth transition and span the problematic region on interface between road pavement and bridge decks. Typically, there are two main types of approach slab; one type is tied or cantilevered to the abutment. Another type has an expansion joint between the bridge deck and the approach slab (NJDOT, 1998). Wingwall is might be constructed together with approach slab and abutment. There are many types of wingwall preferabley, U-wall, in-lined wingwall, stand-alone wingwall, cantilevered wingwall and others.

Essentially, approach slab is not tied to the wingwall, instead polyethylene may be provided to allow free movement of approach slab vertically.

Approach slab with expansion joint must be provided with polyethylene sheeting of 2 layers or about 4 mm thick to avoid bounding on connection between abutment and approach slab structure. According to design manual for bridges and structures of NJDOT, for bridge lengths 50 m or less, provision for expansion at the approach slab ends shall not be required if interfaced with flexible pavement. For bridge length over 50m and up to 100 m, provisions shall be made for expansion at the end of each approach slab by installation of additional sleeper slab. However, bridge lengths over 140 m are not recommended for integral type of abutment.

2.4 Flexible Pavement and Approach Slab Performance

2.4.1 Flexible Pavement Failures

There are many definitions are being used in determination of road pavement distresses or failures. Table 2.2 shows some determination of road failure by several researchers. However, a typical type of road deterioration in flexible pavement is rutting. The phenomenon develops in rapid consequence during first few years after construction. Rutting develops surface depression on the wheel paths as shown in Figure 2.4. In many cases, depression of rutting occurs apparently after rainfall. Fatigue cracking is a crocodile shape-like of road pavement distress.

Secondly is fatigue cracking and somewhat also known as alligator or crocodile cracking. It happens after some considerable amount of loading is imposed on the road pavement and then becomes severe rapidly after that (Huang, 2000). Intrusion of water into developed cracks and continuous traffic loadings will lead to more severe deterioration and shortening the expectancy of the entire design life. Graphically, the development of fatigue or crocodile cracking can be shown in Figure 2.5.

Table 2.2: Pavement Failures According to Several Researchers (Jestin, 2006)

Index	According to	Pavement Failure categories
1	Woods and Adcox (2002) in Smith (2004),	**Structural** - loss of load carrying capability, where the pavement is no longer able to absorb and transmit the wheel loading through the fabric of the road without causing further deterioration. **Functional** - Loss of any function of the pavement such as skid resistance, structural capacity, and serviceability or passenger comfort. **Materials failure**- occurs due to the disintegration or loss of material characteristics of any of the component materials. **Combination of these types.**
2	Yoder and Witczak (1975))	**Structural** – includes a collapse of the pavement structure or a breakdown of one or more of the pavement component of such magnitude to make the payment incapable of sustaining the loads imposed upon its surface **Functional** – may or not be accompanied by structural failure but is such that pavement will not carry out its intended function without causing discomfort to passengers or without causing high stress in the plane or vehicle that passes over it, due to its roughness.
3	Austroads (2000a) in Smith (2004)	**Deformation failures** - include corrugations, depressions, potholes, rutting and shoving. These failures may be due to either traffic (load associated) or environmental (non load associated) influences. It may also reflect serious underlying structural or material problems that may lead to cracking. **Surface texture failures** - include bleeding and flushing, cracking, polishing, stripping and ravelling. These failures indicate that while the road pavement may still be structurally sound, the surface no longer performs the function it was designed to do, which is normally to provide skid resistance, a smooth running surface and water tightness.

Depression by definition is a type of distress occurs on road surface when localized pavement surface having elevation slightly lower than surrounding area. Longitudinal and transverse cracking is another type of distresses that occurs on asphalt pavement which are develops parallel and across the pavement centreline. Other type of distress such as swell is characterized by an upward bulge on the pavement surface. Some other minor consequences of road failures are caused by lane or shoulder dropoff, block cracking, bleeding, corrugation, potholes, slippage cracking, patch deterioration and many more.

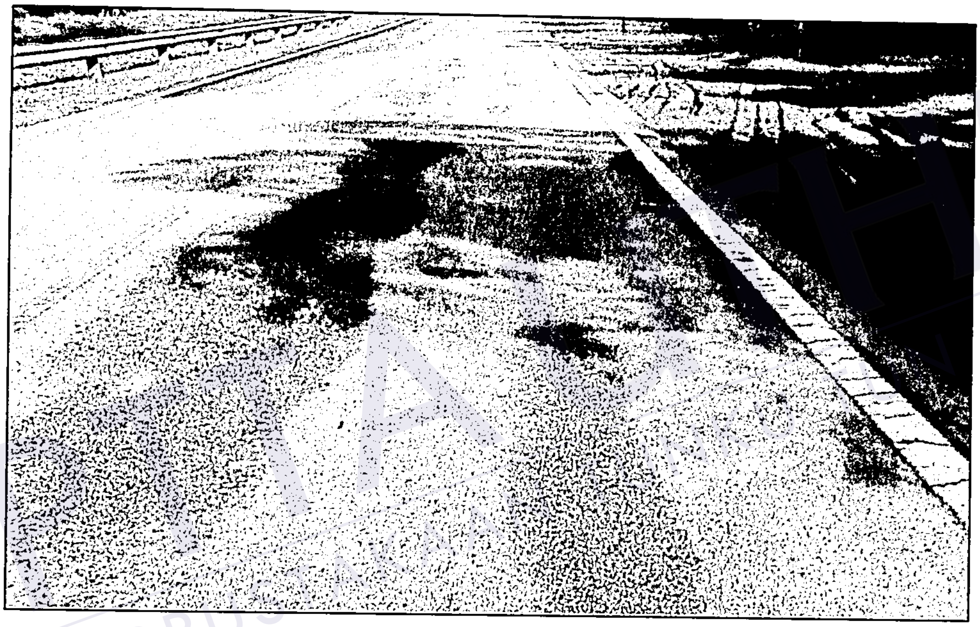

Figure 2.4: Typical Rut on Flexible Road Pavement

Figure 2.5: Typical Fatigue Cracking on Road Pavement Surface (Jestin, 2006)

2.4.2 Causes of Road Pavement Failures

Road pavement failures are due to the many mechanism acts individually or in combination of different causes. In Jestin 2006, the problem might be caused by moistures, loads, material, construction and design-related problems. Structural performance of road pavement is mainly control directly by these important parameters. Typically, the permanent deformation of any pavement layer or subgrade layer due to consolidation or lateral movement of these layers causes major distress problem on structural performance such as rutting (Huang, 2000). Since rutting is important in design criteria, significant occurrence of rutting may lead to major structural failures.

Degrading on road pavement performance is also due to the fatigue cracking that is caused by the fatigue failure of asphalt surface or stabilized base under repeated traffic loadings. It happens in consequent since the highest impacted of load is under a wheel path. It is considered as a major structural distress in flexible road pavement but do not occurs in asphalt overlay over concrete pavement. Usually this type of distress develops along wheel path and propagates longitudinally as parallel cracks.

Longitudinal and transverse cracking may develop from the occurrence of reflective cracks below the asphalt surface. Meanwhile, depression of road pavement can be caused by the settlement of foundation soil or can be developed incidentally during construction. Depression is also common in approaching section of road pavement to the approach slab structure. Other type of failure such as swell is primarily caused by the swelling soil beneath the road pavement.

2.4.3 Problem on Connection between Approach Slab and Approaching Road Pavement Section.

Bump which is occurs on connection between approach slab ends and approaching road pavement structure can also be referred to the occurrence of depression happen in road pavement. Though, this occurrence is mainly due to the differential settlement problem between two structures with different stiffness properties. In this consequent problem, it is apparent that approach slab structure is slightly more rigid than interfacing flexible road pavement.

It is known that the bump, resulting from bridge approach settlement, contributes to add expense and repair time, added risk to maintenance workers, reduction in transportation agency's public image, distraction to drivers, reduced steering control, damage to vehicles, and damage to bridge decks (W., David, 2005). According to Public Work Department, the need of an effective and economically design of approach slab is critical since this reoccurrence of the problem especially on construction under soft soil condition rises cost of regular maintenance work.

In Malaysia there are no preferable guidelines for designing of approach slab provided by local authorities since the design of bridge and approach slab is solely based on British practice. The design of bridge structure is carried out separately by structural engineers and the important function of geotechnical experts is always misled in design input. This problem actually is a very common and not merely unique and restricted to local issue. Recent study by Cai et. al (2005) found that an appropriate approach slab design directly affects the safety and economy of the transportation infrastructure.

Some others researchers have carried out several comprehensive studies on the performance of approach slabs in order to identify the causes of the problem. According to Steward in 1985, he identified that the original subgrade subsidence and fill settlement as primary causes of approach maintenance problems. Mahmood (1990) also indicated that the type of abutment affects the magnitude of settlement and thus, recommended the use of various ground improvement techniques, including wick drains and surcharging to mitigate the soil settlement.

CHAPTER III

CASE STUDIES OF ROAD-BRIDGE INTERFACE PERFORMANCE

3.1 Introduction

In this chapter, some of previous studies regarding the road – bridge interface performance are discussed and summarised. The design performance of approach slab and road pavement, and some conceptual designs of previous research were being reviewed. It is essential to understand previous researchers' works which were conducted in order to provide a firm understanding and support for the research work. Discussions about these literatures were being reviewed at the end of the chapter. Comparisons were done to review the various factors contributing towards road–bridge interface failure. With these facts, some parameters were identified to be used in the research methodology chapter (see Chapter VI). The usage of PLAXIS software (see Chapter IV) is to analyse the geo-structural effect to the simulation process of this research work. Similar work conducted by Cai et. al, (2005), employed ANSYS as a tool to analyses the bridge approach slab structure only.

3.2.1 Structural Performance of Bridge Approach Slabs under Given Embankment Settlement

3.2.1 Introduction

Bridge approaches in Louisiana are normally constructed with reinforced concrete slabs that connect the bridge deck with the adjacent paved roadway. Their function is to provide a smooth transition between the bridge deck and the roadway pavement. However, complaints about the ride quality of bridge approach slabs still need to be resolved. The complaints usually involve a "bump" that motorists feel when they approach or leave bridges. Field observations indicated that either faulting near the slab and the pavement joint or a sudden change in the slope grade of the approach slab causes this bump. Concrete approach slabs can lose their contact and support from soils due to the settlement of embankment soil on which the slabs are built. When settlement occurs, load and the self-weight of the slab will redistribute to the ends of the slab, resulting in vertical faulting or a bump across the roadway. Eventually, the rideability of the bridge approach slabs will deteriorate.

Although the bump-related problems have been commonly recognized and the causes identified, no unified engineering solutions have emerged, primarily because of the complexity of the problem. Typically, the embankment settlement reflects an accumulated effect of many factors such as subsoil conditions, materials, construction techniques, drainage provisions, and quality control methods during construction.

3.2.2 Objectives of Study

There were three main objective of the study. All of the objectives are describe as follows:

- The objective is to find a feasible solution that allows the approach slabs to be stiff enough to lose a portion of their contact support without detrimental deflection.

- This paper is also intent to perform a three dimensional finite element analysis that investigate the approach slab performance under a given embankment settlement. These results were used to check the structural design of the approach slab currently used by LaDOTD, and will eventually be used to systematically evaluate the effectiveness of approach slabs and to develop guidelines for their structural design.

- This information will also help determine when settlement controls are necessary for an economical approach slab design. Figure 3.1 shows a sketch of a typical approach slab. Since the left end of the slab sits on the pile-supported abutment whereas the right end is on embankment soil, a differential movement occurs between the two ends of the slab, resulting in a gap between the slab and the embankment soil.

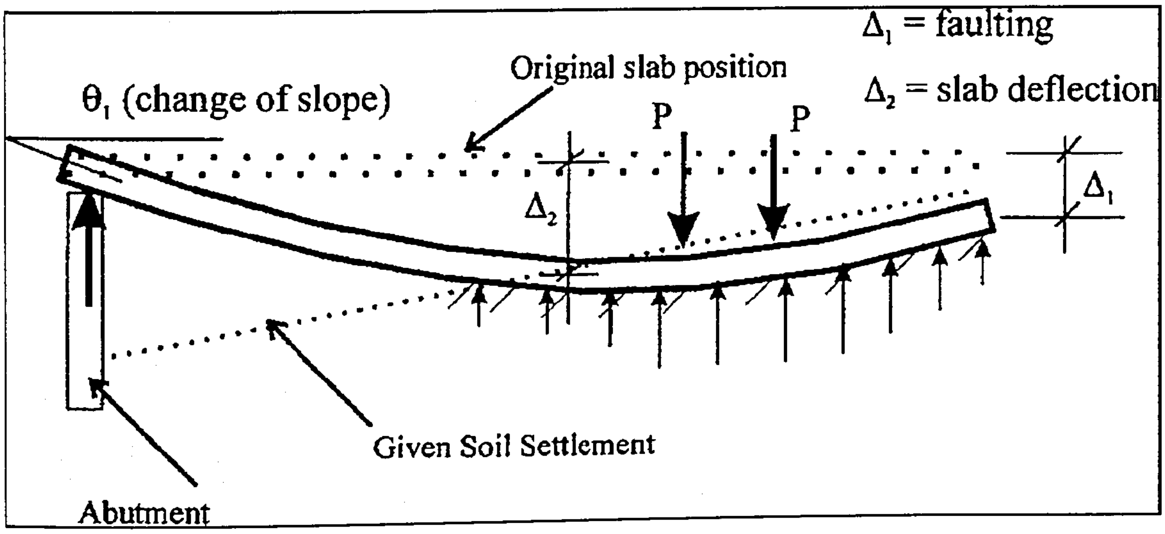

Figure 3.1: Illustration of Slab Interaction with Soil (Cai, et. al., 2005)

3.2.3 Research Methodology

3.2.3.1 Finite Element Modeling

Louisiana is currently using approach slabs with a length of either 6,096 mm or 12,195 mm depending on whether it is a cut or filled embankment (LaDOTD 2002). For the demonstration purpose of analysis, an approach slab with 12,195 mm (40 ft) in span length, 305 mm (12 in) in thickness was chosen with a 1,220 mm (4 ft) wide sleeper slab. Consequently, a 3D finite element model was established, where eight-node hexahedron elements (*ANSYS*, Canonsburg, Pa., Solid 45) were used to form the finite element mesh. In addition to the dead load of the slab, two AASHTO (2002) HS20 truck loads were applied on the slab. The two HS20 truck loads were moved along the slab length to produce the worst loading scenario for the slab deflection and internal bending moments, the same way as in the bridge live load analysis. These predicted internal moments provide information for the structural evaluation and design of the approach slabs by selecting appropriate slab reinforcement, section dimensions and length. The current LaDOTD bridge design manual (LaDOTD 2002)

Specifies the same reinforcement for both 6,096 and 12,195 mm span length approach slabs. The soil profile under the approach slab consisted of compacted embankment and silty clay subgrade soil that are very common in Louisiana. A contact and target pair surface element available in the *ANSYS* element library was used to simulate the interaction between the soil and the slab. This surface element is compressive only and can thus model the contacting and separating process between the slab and soil. When the soil is in tension, the slab and soil separate automatically. The Drucker–Prager model was used to define the yield criteria for both embankment soil and subgrade soil. Table 3.1 lists the material parameters used in the finite element analysis of the present study.

Table 3.1: Material Parameters (Cai, et. al., 2005)

Soil type	Elastic modulus E MPa (psi)	Poisson ratio μ	Cohesion c kPa (psi)	Friction angle φ (degrees)	Density γ kg/m^3(pcf)
Embankment	260 (37,700)	0.3	80 (11.6)	30	2,000 (127.4)
Natural	30 (4,360)	0.3	50 (7.25)	30	1,500 (95.6)

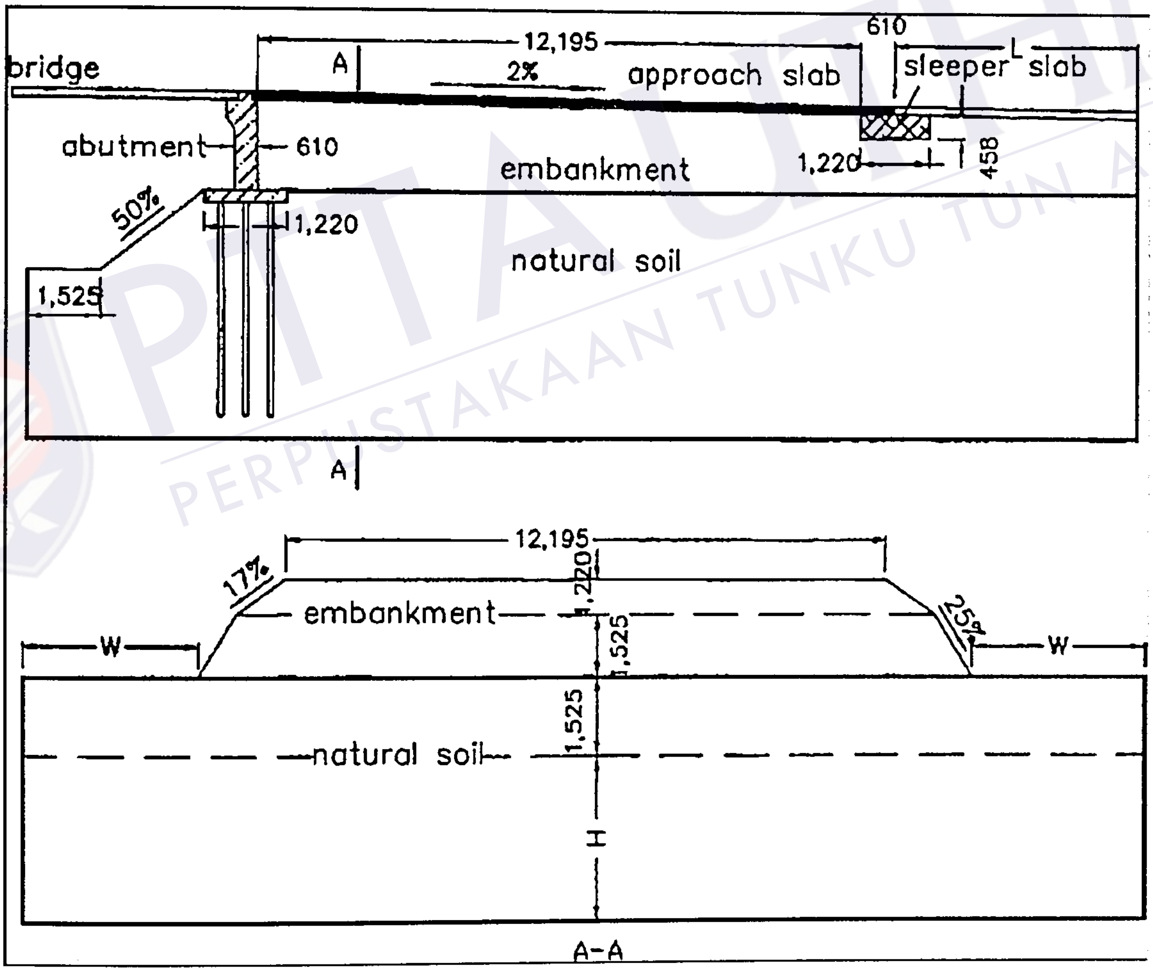

Figure 3.2: Sketch of Materials Arrangement (Cai, et. al., 2005)

3.2.3.2 Determination of Boundary Conditions

The soil underneath the approach span is theoretically semi infinite. Sensitivity analysis was conducted to determine how much soil, laterally, vertically, and longitudinally, should be included in the finite element model. Three parameters, *W*, *L*, and *H* shown in Fig. 2 were investigated in the sensitivity study as follows:

1. *W* was varied from 1,524, 3,049, 4,573, 6,098, 7,622, 9,146, to 13,720 mm (5, 10, 15, 20, 25, 30, to 45 ft) for the fixed *L*=9,146 mm s30 ftd and *H*=9,146 mm (30 ft);

2. *L* was varied from 3,049, 6,098, 9,146, 12,195, 15,244, to 36,585 mm (10, 20, 30, 40, 50, to 120 ft) for the fixed *H* =9,146 mm (30 ft) and *W*=7,622 mm (25 ft)

3. *H* was varied from 1,524, 3,049, 6,098, 9,146, 10,671, 12,195, 15,244, 18,293, 30,488, to 60,976 mm (5, 10, 20, 30, 35, 40, 50, 60, 100, to 200 ft) for the fixed *W*=7,622 mm (25 ft) and *L*=9,146 mm (30 ft).

3.2.3.3 Effects of Embankment Settlements on Slab Performance

With the dimensions of the finite element model determined above, a parametric study was conducted to examine the mechanism of interaction between the embankment soils and the approach slab under different embankment settlements. The maximum deflections and internal moments of the approach slab under different settlements were obtained by moving the truck loads along the slab. In the finite element analysis for a given embankment settlement, the dead load (DL) was applied first; then the dead load and live loads (DL+LL) were applied together. The live load effects (LL) were then calculated from the total load effect minus the dead load effect, i.e., (DL+LL)−DL. This procedure was necessary since the loading sequence affects the contacting and separating process between the slab and the soil. Therefore, the live load could not be applied independently without including the dead load for a proper solution

3.2.3.4 Test Result

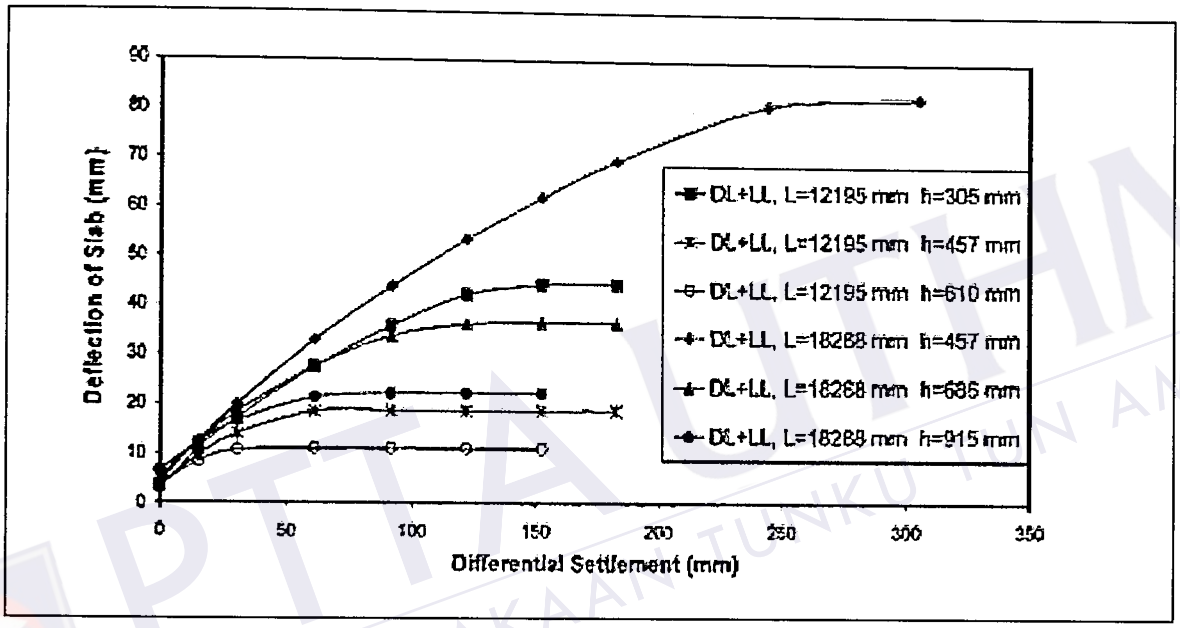

Figure 3.3: Deflection of Slab against Differential Settlement (Cai, et. al., 2005)

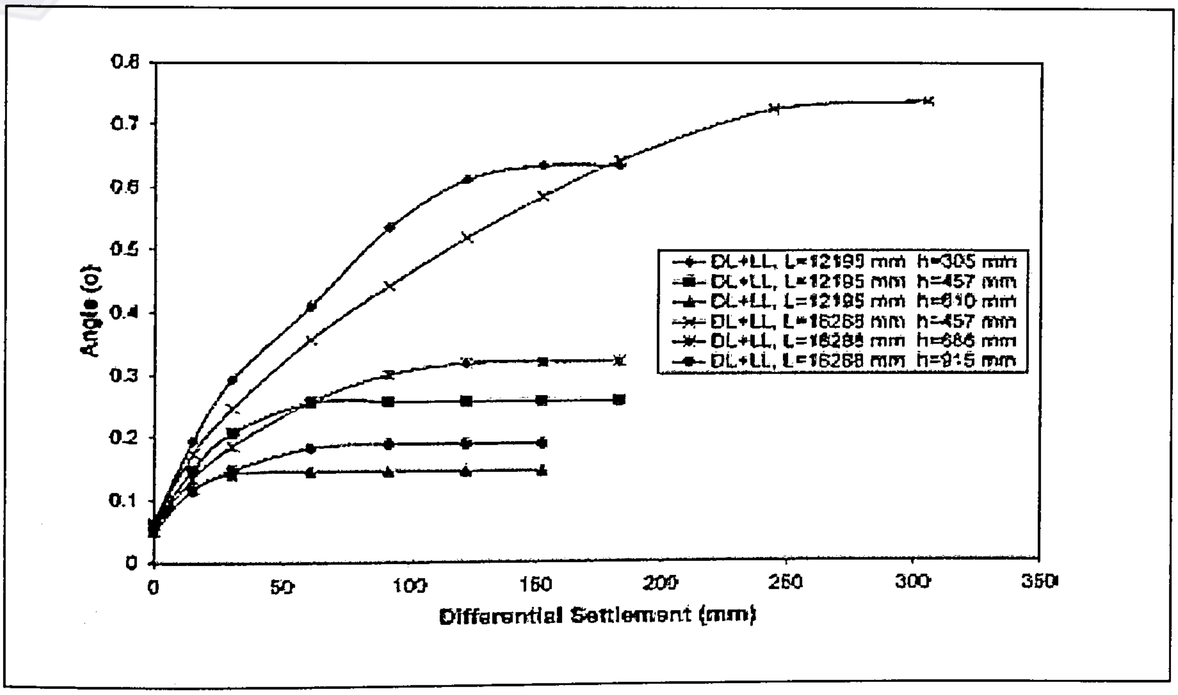

Figure 3.4: Rotation of Slab against Differential Settlement (Cai, et. al., 2005)

3.2.4 Conclusion

An appropriate approach slab design directly affects the safety and economy of the transportation infrastructure. A rational design is necessary not only for the serviceability requirement of the transition approach slab, but also for the life expectancy of the whole highway system including bridges and pavements. As the bump problem has existed for years, the design of the approach slab is still more an art than a science. Engineering calculations of the approach slab are typically not conducted or the approach slab is simply designed as a simply-supported beam since the information about the interaction of the approach slab and the embankment settlement is unknown for a routine office design.

There are no AASHTO guidelines for designing approach slabs considering a given embankment settlement. The present study investigated the effect of embankment settlement on the structural performance of the approach slab. Deflections and internal moments of the slab and stresses of the embankment soil were predicted with finite element modeling; they increased with the increase of the embankment settlement. For the particular example used in the present study, when the settlement increased to 152 mm (6.0 in.), the approach slab became a simply-supported beam. Predicted results indicated that LaDOTD's current slab design is good for cases without embankment settlement, but the ultimate strength is not adequate if settlement greater than 15 mm is considered, implying that more reinforcement, thicker slab section, or settlement control are needed to satisfy the AASHTO structural design requirement. Similar issues may exist in other states and modifications of concrete slab design may be warranted.

This research shows how finite element procedures can help design approach slabs for a given embankment settlement. Parametric studies were then conducted to develop a simpler design procedure so that engineers do not need to use complicated finite element analysis in a routine design. Instead, the developed coefficients can be multiplied with the corresponding simple beam response to consider the interaction of the embankment soil and slab under a given embankment settlement. The more rational design considering a given settlement will eventually lead to a more reliable practice in using approach slabs. LaDOTD has initiated a large effort under the Louisiana Quality Initiative program to resolve the bump problems related to approach spans, and this study is one of the components necessary to eventually resolve this issue.

3.3 Effect Of Orientation Of Approach Slabs On Pavement Deformation

3.3.1 Introduction

The use of approach slabs in bridge embankments is quite common, with slabs mainly used to reduce differential settlement between the bridge and the embankment. The construction procedure usually involves placing a horizontal concrete slab on a prepared section of level ground on the approach embankment, with one end of the slab connected to the bridge abutment. With this arrangement, part of the roadbase is replaced by a much stiffer concrete slab. As a result of the difference in material stiffnesses the pavement beyond the end of the slab will experience more severe deformation when subjected to traffic loading. This usually leads to the formation of a small depression or "bump," which may cause driver discomfort, damage to the pavement, and possible damage to vehicles.

By allowing the approach slab to be placed at an angle to the horizontal, the change in material stiffness will not be as abrupt, and the resulting deformation profile should have a smoother, more uniform change of gradient. To test this hypothesis, a series of tests was carried out to investigate the effect of the orientation of the approach slab on the deformation behavior of model pavements.

In this paper, the test track that was used for the tests is described, and the pavement materials and their placement are discussed. The effect of the approach slab in controlling the formation of a bump adjacent to the bridge abutment is also discussed.

3.3.2 Objectives of Study

The main objectives of the study for this laboratory scale test are mentioned as follows:

- The objective is to understand the cost of bump problem of the road surface near to the approach slab. It is either caused by the soil underlying the embankment consolidates or because the pavement and embankment materials are compressible and the bridge deck is essentially rigid.

- This paper is also intent to identify if any orientation of slab arrangement could significantly affect the behaviour of deformation profile between approach slab end and road way. This is done with modeling the approach slab and road pavement in laboratory scale test.

3.3.3 Research Methodology

3.3.3.1 Approach Slab

To study the effects of slab orientation on pavement deformation response, tests need to be carried out with the slab at various angles to the horizontal. One way of achieving this is to construct slabs at different orientations. This was considered not versatile enough as the angles of inclination are fixed. The option adopted was a connection system designed such that the slab could be set at different orientations. The upper and lower connection plates were designed so that the slab would either lie flat, or at 5° or 10° to the horizontal. These angles were chosen so that the slab did not reach the "critical depth" too close to the abutment. For the control mechanism in this test, conventional horizontal slab was used for the purpose of test comparison. Arrangement of these slabs are shown in Figure 3.5 through Figure 3.6 respectively.

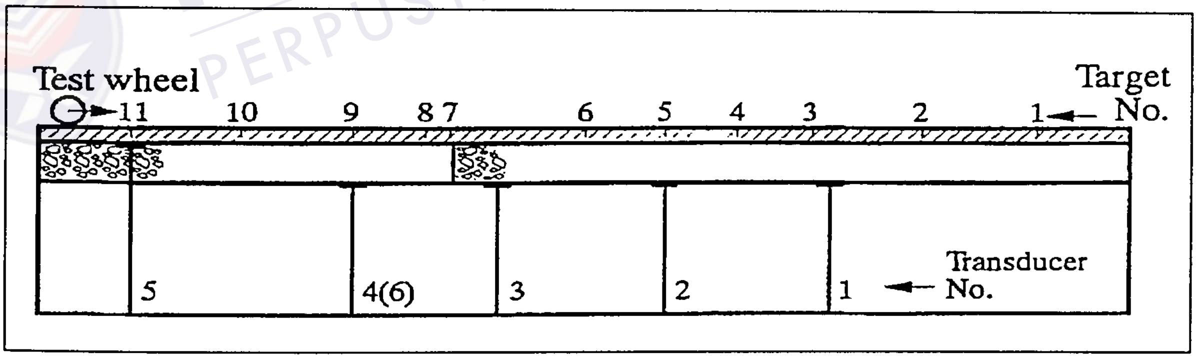

Figure 3.5: Test Section of the Control Horizontal Slab (Wong, et. al., 1995)

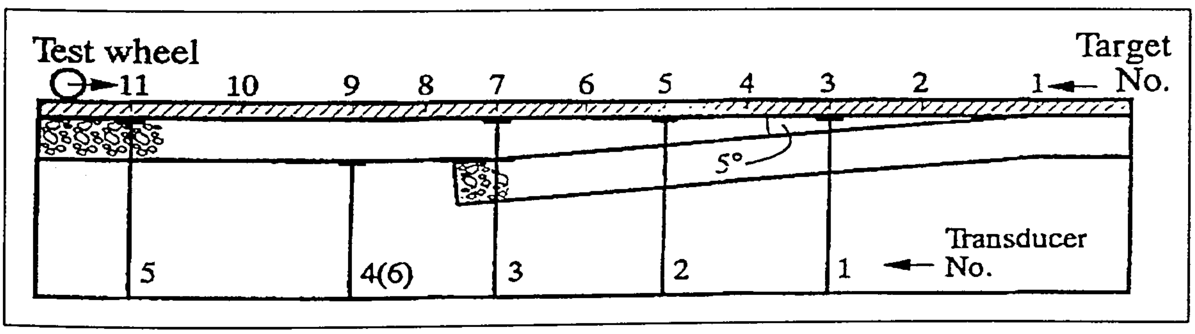

Figure 3.6: Test Section of the Slab at 5° to Horizontal (Wong, et. al., 1995)

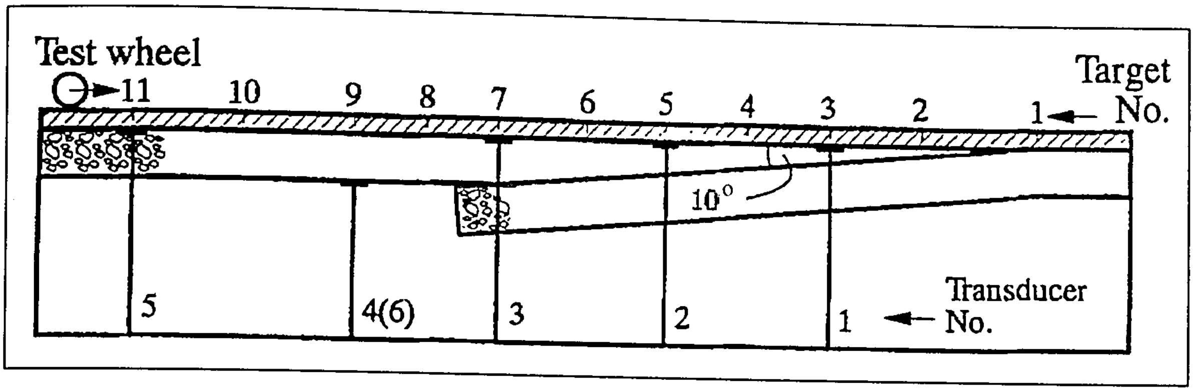

Figure 3.7: Test Section of the Slab at 10° to Horizontal (Wong, et. al., 1995)

3.3.3.2 Measurement of Deformation

Several different methods were used to monitor deformation of the pavements such as surface deformation, horizontal movement and subsoil deformation. Measurements of the movement of the surface of the pavement could be made in three mutually perpendicular directions and subsoil deformations could be measured in the vertical direction.

3.3.3.3 Test Result

To determine if a sloping approach slab would be effective in eliminating bumps at the end of bridge decks, tests were carried out using a horizontal slab, a slab inclined at 5° to the horizontal, and one inclined at 10° In addition a test was done with no slab to assess the behavior of the pavement alone. The slab was designed to be of about one-quarter scale to be in keeping with the scale of the tire and the aggregates used. The length and thickness of the slab were chosen to be 740 mm and 50 mm, respectively. The slab length and inclination needs to be chosen so that the slab does not lie too far beneath the surface of the pavement or it will not be effective in controlling surface deflections. For all of the tests conducted, the rut that was formed by passage of the wheel was due to distortion of the surface of the pavement rather than due to cracking. For the tests conducted with slabs at an angle to the horizontal, the rut formed could be seen to make a smooth transition from its maximum depth to almost zero at the abutment. Figure 3.8 through Figure 3.10 shows the deformation profile against distance for each slab arrangement.

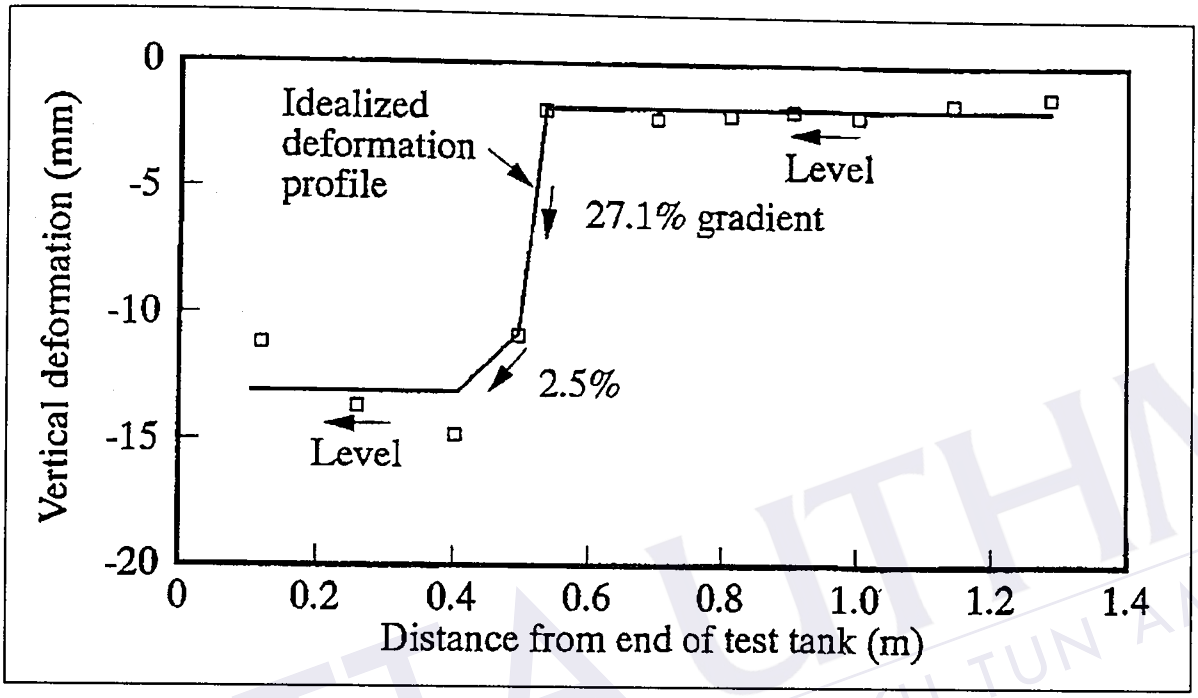

Figure 3.8: Deformation Profile of the Control Horizontal Slab (Wong, et. al., 1995)

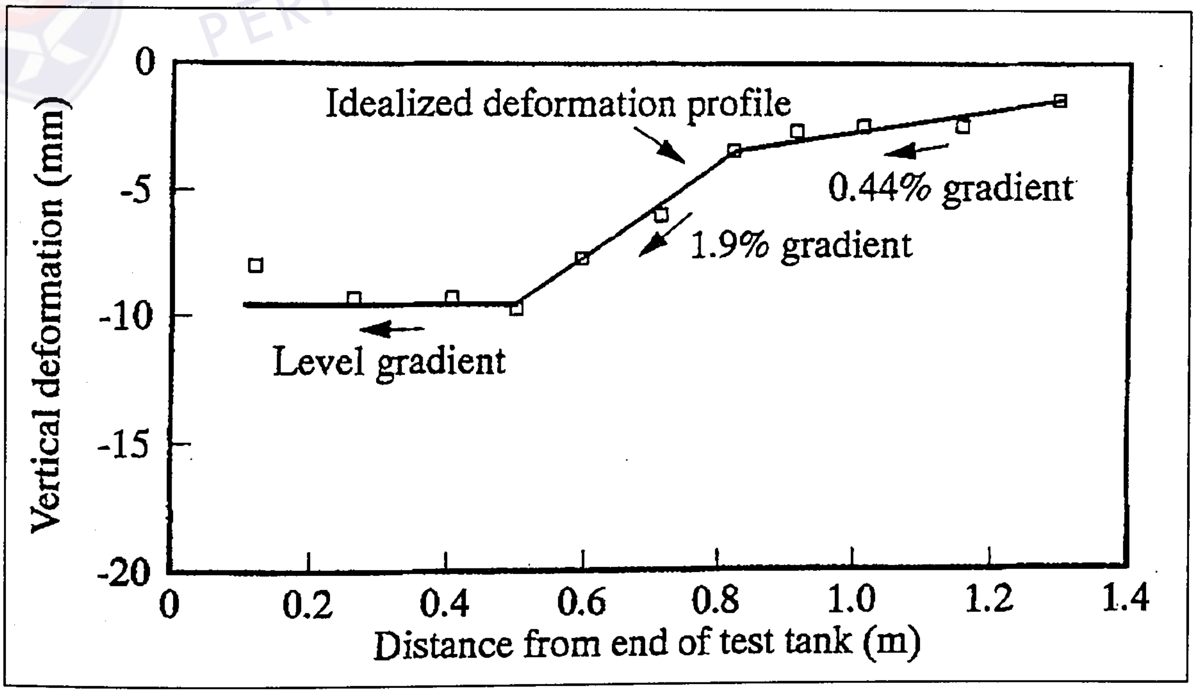

Figure 3.9: Deformation Profile of the Slab at 5° to Horizontal (Wong, et. al., 1995)

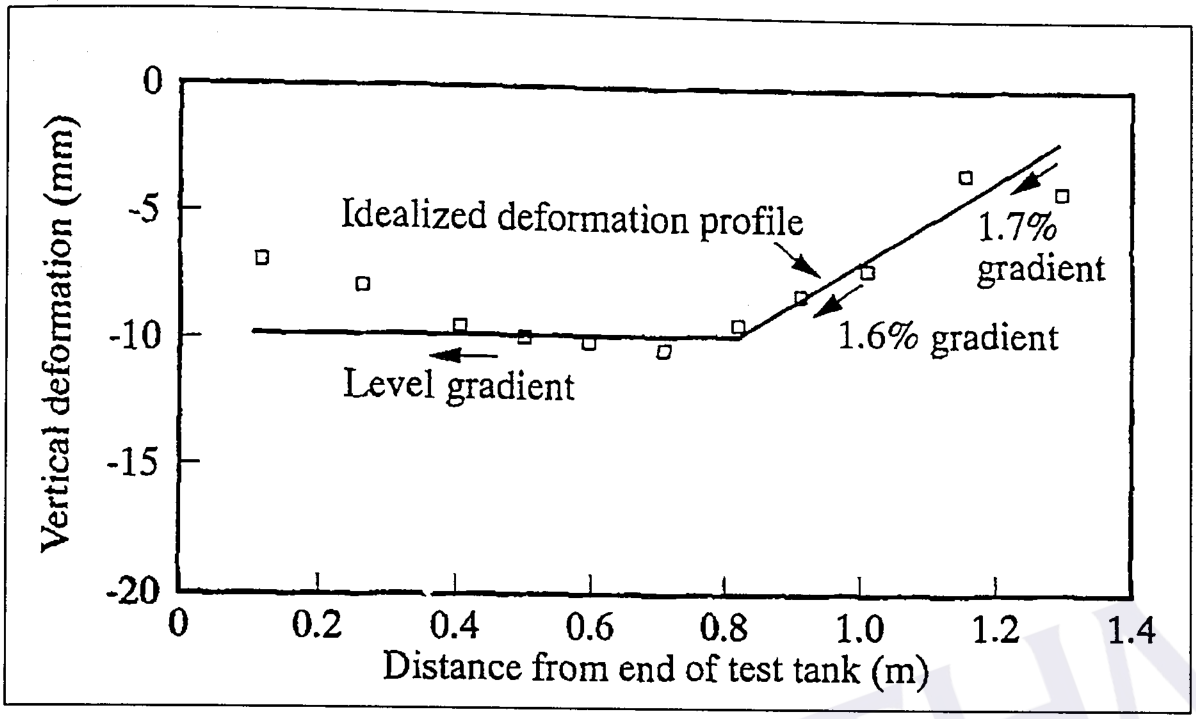

Figure 3.10: Deformation Profile of the Slab at 10° to Horizontal (Wong, et. al., 1995)

3.3.4 Conclusion

Tests on model pavements were carried out to assess the effects of using approach slabs constructed at an angle to the horizontal so that they slope down beneath the pavement. It was found that if the slab is constructed in a horizontal position, an abrupt change or gradient (or "bump") will form at the leading edge of the slab in much the same way that a bump forms at the bridge abutment, and therefore the construction of the slab contributes little to solving the problem.

However, by constructing the slab at an angle to the horizontal so that it slopes down beneath the pavement, the surface deformations are more gradual, reflecting the increasing depth of material between the slab and the wearing surface. The rate of change of surface gradient is reduced and smoother riding characteristics are produced at the abutment.

The tests also showed that the sloping slab has little effect on the surface deformation once the slab is deeper than a certain critical depth where vertical deformation of the pavement becomes small. That part of a slab at depths greater than the critical depth does not contribute to reducing vertical deformations and so slab lengths should be limited so that they do not protrude much beyond the critical depth.

Further work with full-scale abutments and different pavement types will be necessary to determine how inclined slabs will behave in practice. However, the model testing carried out by the writers does indicate that the method shows promise for eliminating problems caused by differential movements and the bump this creates at bridge abutments.

3.4 Performance of Geocomposite Membrane in Pavement Systems

3.4.1 Introduction

Modern traffic with greater number of vehicles and increased truck tires pressures and axial loads has detrimental effect on pavement systems. Although traditional material performed satisfactorily on a wide range of the road in the past, recent dramatic failures have attracted the attention of public and media to the status of current transportation infrastructure. Most of newly developed materials and techniques were empirical based on field experiences. Hence, the contribution of this new method to the pavement or bridge system has not been fully understood. Among the new materials utilized to improved pavement and bridge deck performance are geosynthetics. As with any polymeric materials, geosynthetics properties are not only functions of temperature and loading times that reflect their viscoelastic behaviour, but they are also highly dependent on their chemical and topologic composition. This paper illustrates the initiation of a new project that will reduce the gap between in-situ performance of geocomposite membrane and its properties and behavior mechanism. Preliminary data collected at the Virginia Smart Road illustrates the potential use of this material in pavement systems.

3.4.2 Objectives

The objectives of the study could be described as follows:

- To evaluate the performance of geocomposite material in pavement systems based on full-scale research for Intelligent Transportation Systems (ITS) in Southwest Virginia.

- To examine the effectiveness of the use of geocomposite in twelve flexible pavement sections with different designs, wearing surfaces, and drainage capabilities.

- To study the use of geocomposite membrane as moisture barrier and capability of reinforcement over their application at different roadbase layer.

- To define the development of deformation profiles of each road pavement design using field instrumentations and study about the behavior of the structures empirically.

3.4.3 Methodology

This research was conducted in a full-scale research in Southwest Virginia which the constructed road sections was named as Virginia Smart Road. This facility of the Smart Road test includes twelve different flexible pavement sections. Each section is approximately 100 m long. Seven of the 12 sections are located on a fill, while the remaining five sections are located in a cut. Different layers are used in each section designated in accordance with Virginia Department of Transportation specification.

The construction of road pavement is divided into 2 section namely section J and section K. In section J, geocomposite membrane was installed underneath an asphalt treated drainage layer to test its effectiveness as a moisture barrier. In section K, the geocomposite was installed underneath the surface mix to investigate its capability to relief stress. Figure 3.11 shows a schematic of the layered system of each section.

Installation of geosynthetic in pavements is a major source of damage for the material and, hence, may impact its potential effectivness. The installation procedure used at the Smart Road was newly developed due to the lack of familiarity with the installation of such materials in roadways.

In order to evaluate the informational data from the test, two tests were carried out; Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR). FWD tests were conducted before and after installation and also periodically after the construction. It was use used to investigate the effectiveness of the geocomposite membrane in construction. While, GPR is periodically used to monitor water movement in the pavement sections at the Smart Road and to identify any significant changes in the pavement system profile.

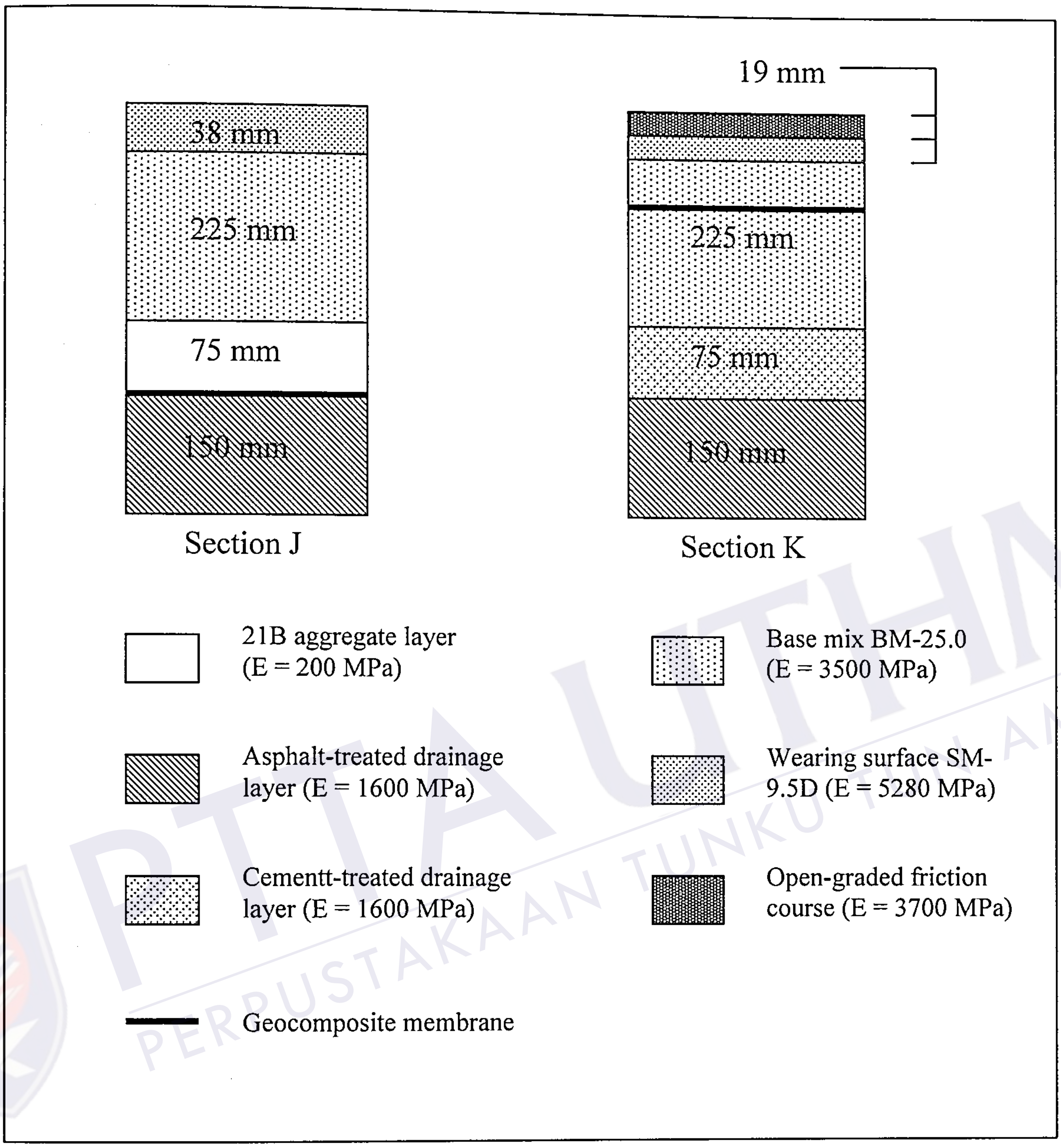

Figure 3.11: Pavement Design (Section J and K) (Brandl, H. and Adam, D., 2000)

3.4.4 Conclusion

To develop a fundamental understanding of how geosynthetics may contribute to the performance of flexible pavements under environmental and vehicular loadings, a full-scale instrumented facility mat provide significant information as to the in-situ behavior of the paving materials and geosynthetic contribution. In addition, allow the verification of any theoretical analysis. This paper presents preliminary results as to the effectiveness of geocomposite membranes used in roads for the first time and tested at the Virginia Test Road:

- Initial analysis of the collected data from embedded instruments showed the ability of the geocomposite membrane to significantly reduce the transversal tensile strain in the supporting layer due to its strain energy absorption capability.

- The FWD results indicate the ability of the geocomposite membrane to enhance the performance of a pavement system by allowing for greater recoverable deformation.

- The GPR results showed the ability of this type of geocomposite membrane to effectively enhance draining the water out of the pavement system laterally to the drainage system when installed underneath an open-graded drainage layer.

3.5 Discussions

From the first study case that has been reviewed in this chapter, it was clear that conducting research on this approach slab performance was greatly significant since the problem of dispersion or bump remains unresolved technically. Details on specification and design manual about the approach slab is not provided by the local authorities because of the lack of understanding in design in which incorporating of both structural and geotechnical fundamentals. Preliminary design using finite element of numerical calculation to anticipate the behaviour of design models was also described as rare and many of the researches were only focusing on causes of problems, synthesis of practice and soil improvement. However, since research was conducted only for structural performance, the study on interaction of approach slab with approaching road pavement was not included in this paper. The research also did not conduct any new concept of approach slab design but only study on performance of existing horizontal approach slab.

Second review on new proposed approach slab modelling using inclined slab model could be an attractive approach and should be discovered correctly with introduction of some additional parameters in design. Certainly, with high-speed computer available these days, it could be redeveloped using computer modeling in which critical study could be carried out in consequent with the aid of robust numerical calculation of the software. Critical study on interface region in which the occurrence of dispersion takes place, could be conducted more extensively and seamlessly using computer simulation. Though, it was found that the deformation within interface region has demonstrated some improvement over control models but still visualized abrupt drop on development of deformation profiles. This might due to the design of approach slab in which not provided with expansion joint, but was design as cantilevered structure to abutment.

Additional design parameters in conceptual modelling such as the introduction of subgrade reinforcement on road pavement could also be used in development of new concept of approach slab design. From the previous researches, it was proven that the use of geocomposite or geosynthetic materials could show the ability to reduce the effect of deformation in supporting layers. The use of impermeable material like geosynthetic clay liner in design could make sense for the new development especially over soft soil environment with high water table effect. On the whole, the use of geosynthetic materials in geotechnical engineering are prominent and have been practice in numerous construction projects for over decades. Continuous research for new application in engineering works has also proved their intentional use and still growing rapidly over the world.

CHAPTER IV

FAILURE SIMULATION USING PLAXIS

4.1 Introduction

As discussed in Chapter III, there are many contributory factors to road-bridge interface differential settlement failures. One of the common methods to analyse these factors are by using simulation with finite element programs. Finite element program is a complex mathematical solution and this software is intended to provide a tool for practical analysis to be used by geotechnical engineers who were not necessarily numerical specialists. The common use of computer programme indeed enables engineers to deal with the numerical methods of mathematics for complex calculation task compared to time consuming classical analytical methods easily. Preliminary prediction of deformation behaviour for instance can be performed effortlessly with the aid of computer programme. Prior to any construction project, we could also avoid major failures by the acquisition of soil properties information especially for soft soil under the different circumstances of road pavements and any structures (Das, 2000). Chapter V further discuses on the appropriate roles of PLAXIS as a simulation tool to determine and correlate the appropriate contributory factors to road - bridge differential settlements.

Geotechnical applications require advanced constitutive models for the simulation of the non linear, time dependent and anisotropic behaviour of soils and/ or rock. Therefore finite element is often used because one can calculate the stresses and deformation for every single nodal point of the analysed area. The finite element method also was originally developed for use in both static and dynamic calculation in structural mechanics. Finite element method of analyses is being used extensively in geotechnical engineering modelling. One of the provable finite elements modelling software is the PLAXIS developed by Technical University of Delft, The Netherlands. PLAXIS is a finite element package intended for the two-dimensional analysis of deformation and stability in geotechnical engineering. In this chapter, discussion of this simulation using PLAXIS software has been made in reference to PLAXIS Reference Manual and Material Model Manual supplied by PLAXIS and also from other additional references.

4.2 PLAXIS Finite Element Modelling in Geotechnics

PLAXIS version 8 supports two-dimensional finite element calculation for the simulation of deformation and stability analysis purposes. This two-dimensional simulation program allows for automatic generation of unstructured 2-dimensional finite element meshes with option for global and local mesh refinement (Withlow, 2001). The 2-dimensional mesh generator is a special version of the Triangle generator, which was developed by SEPRA. PLAXIS programme also able to generate high order element of 4^{th} order 15- node triangular element for deformation and stresses modelling. As an option, quadratic 6- node triangular element is also available for quick computer analysis.

Various soil models are used in modelling of soil whereas the model parameters are used to quantify the soil behaviour. Mohr-Coulomb model is a basic soil model to be used as primary modelling process. More advanced soil models are introduced in PLAXIS such as the Hardening-Soil model, Jointed Rock model, Soft-Soil model as well as Soft-Soil-Creep model.

4.2.1 Mohr–Coulomb Model

Mohr-Coulomb model in this programme can be applied in various kinds of soils including soft soil. It is an elastic plastic soil model that is extensively renowned for accurate representative in soil analysis. According to the theory developed by Coulomb, failure along plane in a material occurs by a critical combination of normal and shear stress, and not only by normal or shear stress alone (Cernica, 1995). Coulomb introduced this functional relationship as given in Eq. (4.1). The experimental result conducted by Kirkpatrick indicated that the Mohr-Coulomb criterion gives a better representation for soil.

$$s = c + \sigma \tan \o \qquad (4.1)$$

The Mohr-Coulomb model requires a total five soil parameters that are commonly known in geotechnical engineering aspect. These parameters can be obtained from basic tests onsoil samples in laboratory. They are Young's modulus (E), Poisson's ratio (v), friction angle ($\o$), cohesion (c) and dilatancy angle (ψ). All of these parameters are exceptionally essential in determination of soil behaviour within the process of calculation and can be determined by conducting laboratory triaxial test.

Cohesive soil like soft soil has cohesion value grater then zero. PLAXIS does not have any problem to perform calculation under given cohesion value found in soft soil unless in case of cohesionless sands that may result in problem on calculation performance. Friction angle is another important parameter which has to be taken into account in modelling. Higher friction angles are normally found in dense sands, and low plasticity of clay and silt soils. Though, organic soils principally have lower values of friction angle.

4.2.2 Soft-Soil Model

It is worth to mention that starting from Version 7, PLAXIS software had some changed in the soil modelling. In PLAXIS Version 7, Soft-Soil model had been excluded and emerged in more advanced Hardening-Soil model features. Now this well known soil model has reintroduced in the latest version of PLAXIS Version 8 in regard with users preferences to keep on this renowned soil model.

In the Soft-Soil model, it is assumed that there is a logarithmic relation between the volumetric strain, ε_v and the mean effective stress, σ '. This model is capable to simulate soil behaviour under general state of stress. However triaxial loading condition is restricted under which $\sigma_2' = \sigma_3'$. For such state of stress the yield function of the Soft-Soil model is defined as:

$$f = \bar{f} - P_p \tag{4.2}$$

where $\bar{f}$ is a function of the stress state and P_p is the pre-consolidation stress. Above equation describes the irreversible volumetric strain in primary compression and a perfectly-plastic Mohr-Coulomb type yield function is used to model the failure state of soft soil.

All essential soil parameters such in Mohr-Coulomb model are used consequently in this model for soft soil. Young's modulus is used in this calculation programme as the basic stiffness modulus in the elastic model apart of other stiffness moduli that is also available for alternative choice. Standard drained triaxial test may yield a significant rate of volume decrease at the very beginning of axial loading, consequently result in a low initial value of Poisson's ratio (v). Such particular unloading problems may be realistic to use a low initial value, but in the Mohr-Coulomb model, it is recommended to use high value of Poisson's ratio.

Additional soil parameters could be essentially considered to integrate the function of using this Soft-Soil model criterion. The two important parameter included in this model are modified compression index, λ^* and modified swelling/ recompression index, κ^*. Both parameters of soil can be simplified as below:

$$\lambda^* = \frac{C_c}{2.3(1+e)} \tag{4.3}$$

$$\kappa^* = \frac{2C_r}{2.3(1+e)} \tag{4.4}$$

4.2.3 Soft-Soil-Creep Model

Soft-Soil-Creep model is an advanced soft soil modelling for high degree of compressibility of soft soil behaviour. In oedometer testing, normally consolidated clay behaves 10 times softer than normally consolidated sand and certainly it illustrates the extreme compressibility behaviour of soft soils. All soil basically exhibit some creep, thus primary consolidation of compression always followed by a certain amount secondary of secondary compression. A number of factors are considered to influence the secondary compression or creep such as the principal stress ratio, load increase rate, history of loading, the layer thickness and the ambient temperature. Also, secondary compression seems to be greater in organic soils.

According to Buisman (1936), a creep law for clay could not be fully explained by classical consolidation theory. This work was based on 1-dimensional secondary compression and now had been extended to complete 3D analysis on which implemented in this modelling purpose. Some basic characteristic of this Soft-Soil-Creep model are the integration with logarithmatic compression behaviour, distinction between primary loading and unloading-preloading characteristics, and the implementation of secondary compression. Similar to others model, the Mohr-Coulomb failure criterion is used in failure behaviour modelling.

Parameters of the soil model are basically the same as Soft-Soil model. The only additional parameter in this model is modified creep index, μ^* for secondary compression behaviour of soil. Modified creep index can be obtained roughly from the relation of below equation:

$$\mu^* = \frac{C_\alpha}{2.3(1+e)} \tag{4.5}$$

4.3 PLAXIS Programmes

PLAXIS Version 8 comes with 4 functional softwares they are; Plaxis Input, Plaxis Calculation, Plaxis Output, and Plaxis Curves. For the ease of use, users can switch any program they need separately. Though, it is strictly recommended to pour a great attention on understanding soil modelling and finite element implementation in the software program itself. Some important knowledge that has to be counted for is regarding to the soil model to be used in study, material input parameters, determination of boundary condition, and limit of finite element calculation method.

4.3.1 Determination of Boundary Conditions

In finite element modelling, it is fundamentally important to determine boundary condition for proposed design work. Sensitivity analysis is conducted to determine how much soil, laterally, vertically, and longitudinally should be included in the finite element model (Cai, et. al., 2005). For two-dimensional analysis of finite element, only vertical and longitudinal boundaries are applicable to be included and determined. In PLAXIS, no specific instruction is provided, but the user must be aware the significant effect in regard with this matter in numerical calculation of finite element modelling. Without proper determination of boundary condition, the analysis may lead to error particularly at the outer boundary. Therefore, it is necessary to conduct appropriate sensitivity analysis regarding on this matter.

4.3.2 Input Parameters

The Input program contains all facilities to create and to modify a geometry model, to generate a corresponding a finite element mesh and to generate initial conditions. The generation of initial condition is done in a separate mode of the Input program (Initial condition mode). Input program consist of three main components that are geometry, loads and material input along with additional important parameter in numerical modelling that are mesh and initial condition.

4.3.2.1 Geometrical Input

Geometry input has numbers of submenu contains the basic options to compose a geometry model. In addition to a normal geometry line, the user may able to select plates, geogrids, interfaces, anchors, tunnel, hinges/rotation springs, drains and wells. Fundamentally, geometrical input parameter is an important component in PLAXIS software, which allow user-friendly interface to establish a model. Other modelling procedure certainly can not be performed if this primary procedures is not followed appropriately. Optionally, users are able to compose their desired geometrical model comfortably using typing command much like in many CAD programs. Example of geometrical input window is shown in following Figure 4.1.

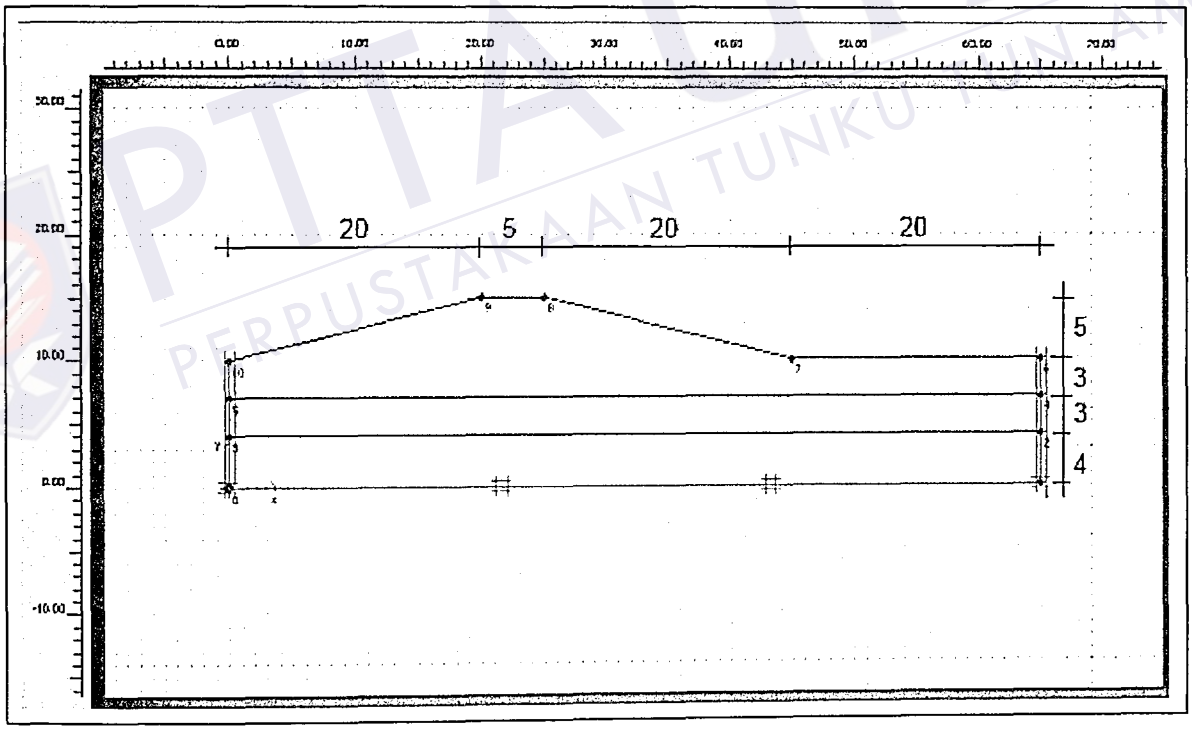

Figure 4.1: Geometry Model in Plaxis Input Program (PLAXIS Tutorial Manual, 2002)

A unique geometrical component such as plate is used as a structural object to model slender structures in ground with a significant flexural rigidity and normal stiffness. Other additional component such as geogrid is used with a normal stiffness but with no bending stiffness. Such of additional components in geometrical input is very helpful since consideration of those components in design is a vital important since geotechnical design is always merged with this critical design component all together without exception.

4.3.2.2 Loads Types

Loads types used in the Input program is all the matter of loading that imposed to the design model such as configuration of point of distribution loads types. Fixity and pre-displacement matters are included in this component accordingly. For the loadings characterization, it is not necessarily to be provided with the values because it can be done later on in calculation program.

Fixity in finite element modelling is necessary and have to be provided appropriately. It is about the characterization of the behaviour of outer boundary lines in geometrical structure. For many condition, it is allowed to provide with standard fixities in which left and right side boundary are considered to have freely movement in vertical direction whereas bottom boundary is assumed to be rigid. However, other fixities parameter can also be employed in order to provide more representative condition of boundary lines.

4.3.2.3 Material Input

Material input is another fundamental component in PLAXIS Input program. All load components that have been determined must be assigned appropriately with material properties. This facility consists of four important submenu that providing such are; soils and interfaces, plates, geogrids, and anchors. Assigning material parameter can be done after engineering properties of each material model has been performed. Material set assignment of soil material is shown in Figure 4.2 for reference.

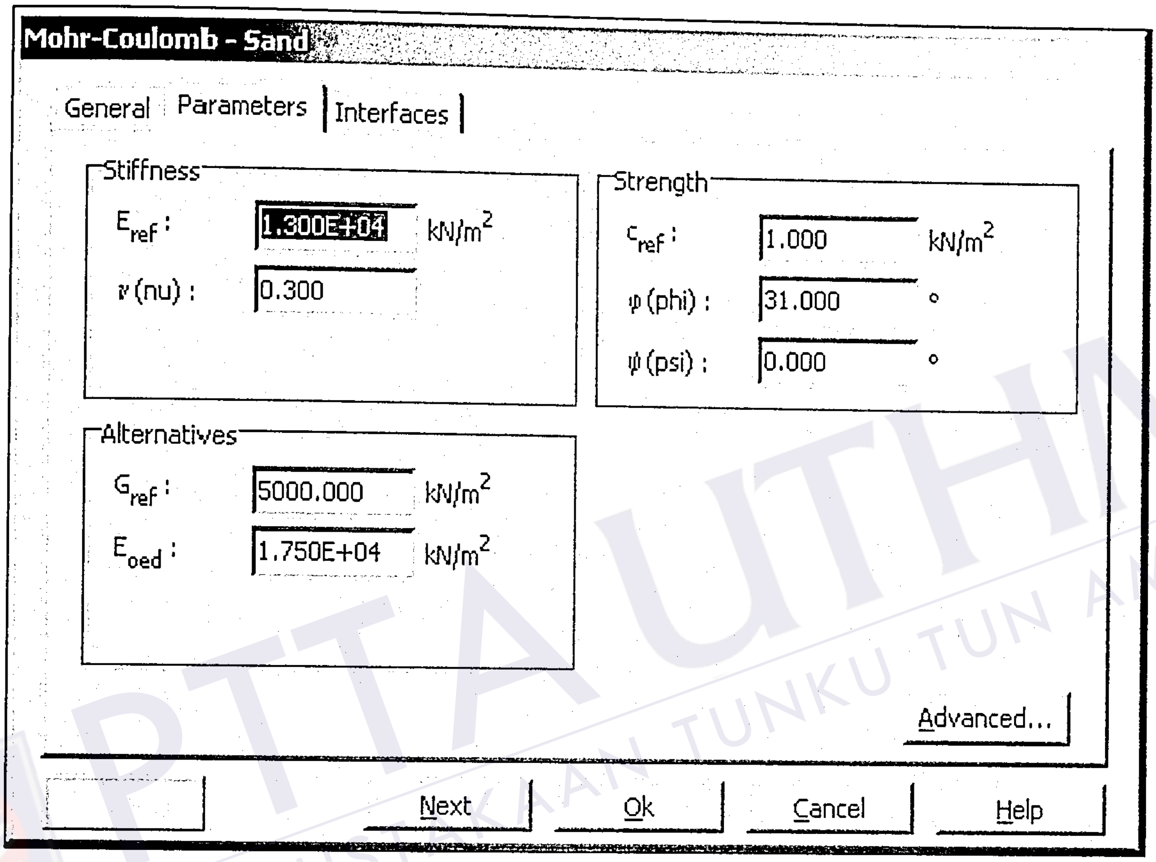

Figure 4.2: Material Set and Configuration for Soil Properties (PLAXIS Tutorial Manual, 2002)

Soil and interfaces are certainly common in this geotechnical engineering design. This parameter allows users to define their own soil properties after establishment of geometrical model. With the easy-to-use interface and material input method, the task of assigning for each material data in geometrical model becomes even easier. Additional material data input and assigning are such as plates, geogrids and anchors. Usually, plates is used if the modelling deal with other structural constitution such in structural engineering project. Geogrid is a common material in geotechnical field, thus to have it in this option is somewhat has a significant important feature.

4.3.2.4 Mesh Generation

In finite element modelling, generation of mesh is a fundamental component that have to be looked on. Even it is unnecessarily to know of what exactly happen to the numerical calculation behind the program, the mesh generation is the key of further numerical analysis. In other word, the finer the meshes are generated, the more accurate the result of final calculation. Though, the use of finer mesh may result in slower computerised numerical calculation performance in Calculation program.

For this purpose, mesh coarseness can be adjusted in global coarseness submenu. There are five element distribution can be chosen by the user from the coarser to the finest one as what they prefers in their modelling. Mesh generation can be executed by selecting refine global under the submenu of mesh. Importantly, all material set have been assigned correctly.

4.3.2.5 Initial Condition

Initial condition represents the actual condition of the modelling design of soil model without provision to additional loads of other structural components. Initial condition is an important component as regards to the additional parameter in PLAXIS design environment since some additional parameter input have to be assigned during this stage. These are including phreatic level, closed boundary for flow and consolidation parameters, generation of water pressure and initial stresses.

Water pressure generation is either generated by means of phreatic level or ground water calculation for steady state condition of water level. Generation of water level is unnecessary if the modelling does not including the water level. However, the generation of initial stresses is an important procedure in design.

Appropriate K_0 procedures or gravity weight should be followed when deal with this design component for stress development.

4.3.3 Calculation Program

After generation of all required parameter in PLAXIS Input program, the actual calculation of finite element canlculation can be executed in this program. Some necessary input such as calculation type, loadings input and point selection on what specific points should be included by later PLAXIS Curves program is assigned appropriately.

4.3.3.1 Calculation Types

In this program, there are three optional calculation types to be chosen about namely plastic, consolidation and phi-c calculation. When the calculation is preferably a plastic type which only considering plasticity properties of the material, the use of plastic type calculation is more accurate. In contrast, if the time loading is taken into consideration, consolidation type of calculation is preferable for the calculation.

4.3.3.2 Loading Input

Loading input is the matter of the loadings that has to be organized into the calculation modelling for specific given time. For instance, if stage construction is about to chose for consolidation calculation type that involves construction modelling over soft soil circumstance, specific time interval of each construction stage must be provided.

In addition, definition of load must be assigned correctly before numerical calculation is performed. Simultaneously, any material sets and other component which is available in Section 4.3.2.5 can also be reassigned desirably before or during calculation phases. Total multipliers and incremental multiplier calculation options also can be preferred if desired but these options does not accounts for time-dependent loading calculation, which is important on construction modelling over soft soil circumstance.

4.3.3.3 Calculation Phases

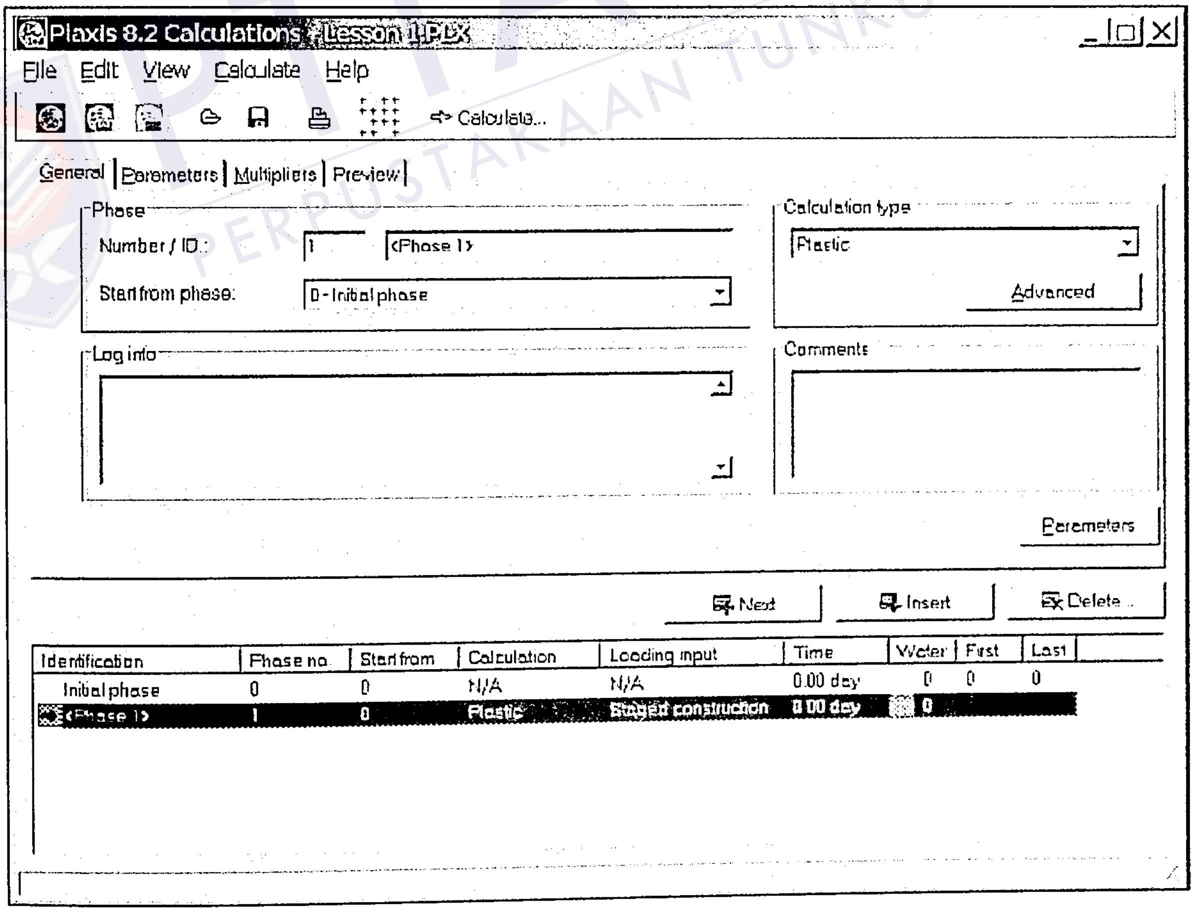

Figure 4.3: Typical Calculation Window in PALXIS Calculations Program (PLAXIS Tutorial Manual, 2002)

In engineering practice, construction works are carried out in phases due to design requirement, site condition and other limitation that may be encountered during the construction is taking place. Initial phase is represents the initial situation of the project as defined in Input program before. The introduction of new phase can be made simultaneously in this option and each assigned phase can be represented to different type of loading input if desired in design. Additional calculation phases can also be assigned independently within the existing phases and can be made after other calculation phases were calculated. Typical calculation input and calculation phases are shown in following Figure 4.3.

4.3.3.4 Selection of Points

Selection of specific points within developed nodes and stress points is compulsory before any calculation phase is allowed to be performed. It is important because generation of data output and representative curves only available for selected specific point prior to calculation stage. However, numbers of specific point allowed to be selected for analysis only a few limited to only 10 points each for both load-displacement and stress/strain curves. This procedure is only required once for any different calculation phases of a project. Selection should be made to specific point that will gives most representative outcomes since the generation of nodes or stress points may not exactly as in geometrical input stage.

4.3.4 Output Data

In PLAXIS finite element calculation, displacement at the nodes and the stresses at the stress points are the main output values. Output program is used for this purpose, which offers an extensive range of required facilities for analysis by means of PLAXIS software environment. In addition, this program also allow for various parameters for output views such as cross-sectional view, output table view for displacement stress-strain, geometrical view and other informational data, and material types are just a few. Generally this program facilitate three main option for output viewing that are geometry, deformations and stresses which also allows for multiple window view for each facility. This available option will be discussed accordingly in this section.

4.3.4.1 Graphical Output

Geometry tab facility is utilized to view basic geometrical input such as structures modelling, material and phreatic level if applicable. In addition loads parameter input such in Input program can be relocated with this option. Instead of only element view, nodes and stress points can be added if more representative view is desired. Other minor option such as numbering for elements, nodes, stress points, materials, and clusters are also available. In this view, geometrical view option has no significant important outcomes in analysis, though may provides some informational view more representatively in graphical mode.

Deformation mesh option might be very essential since it shows deformation mesh graphically from the original mesh. Instead of horizontal and vertical displacement, total displacement is available if required so. Other option such as increment and strain are also available. Meanwhile, total and increment strains are also can be viewed in Cartesian.

Stresses output data can be viewed in various options such as effective stress, total stress, plastic point, over consolidation ratio and additionally, the first two kinds of stress are also applicable to be viewed in Cartesian mode. The matters of pore pressure such as active and excess pore pressure together with groundwater head, flow field and degree of saturation are other variation that can be also considered.

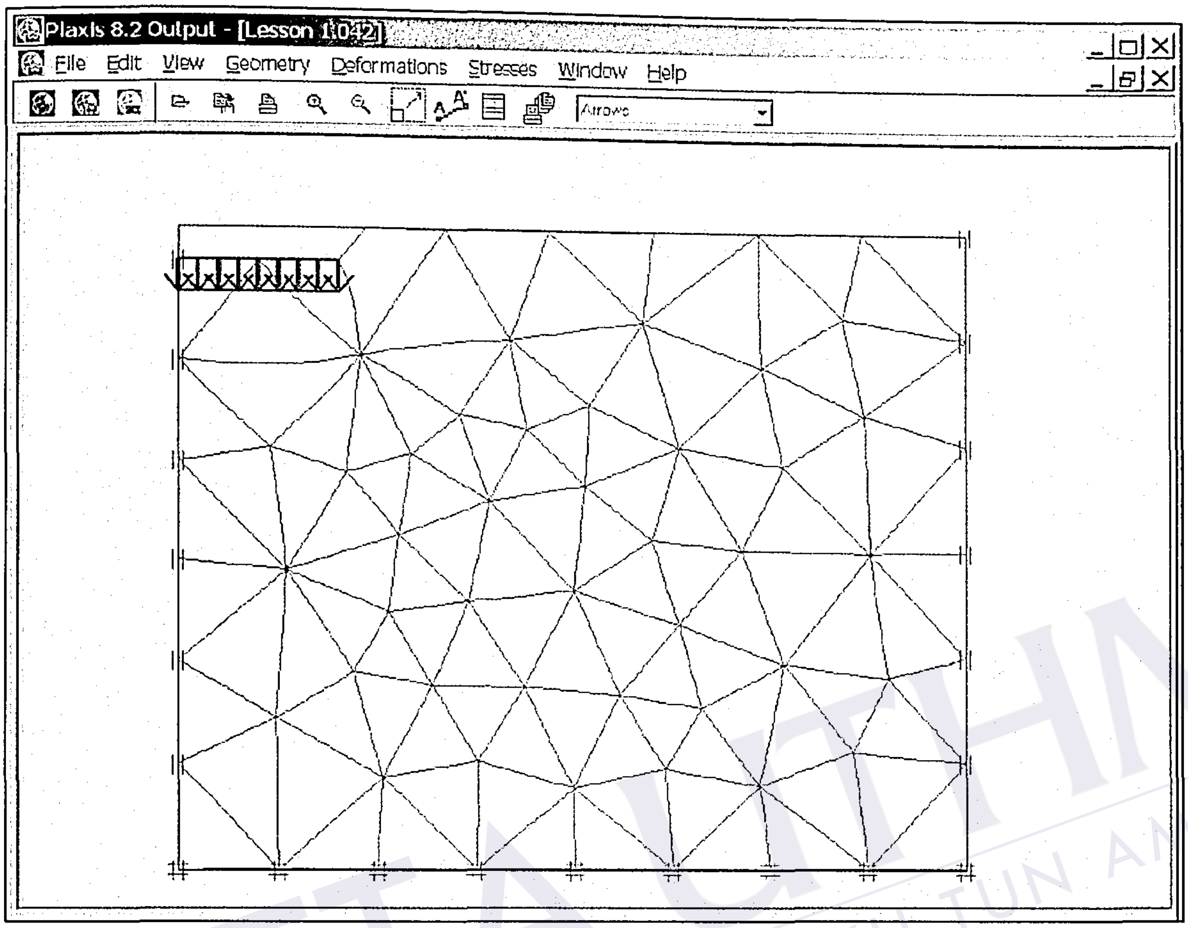

Figure 4.4: Deformed Mesh Visualised Graphically in PLAXIS Output Program (PLAXIS Tutorial Manual, 2002)

4.3.4.2 Cross-Section Output

Cross-section output data may required for certain requirement in observation of data outcomes. This option is useful in order to obtain insight in the distribution of a certain quantity in the soil. It is available for all types of stresses and displacements in the soil elements.

Additionally multiple cross-section may be drawn in the same geometry if desired. The distribution of quantities in cross-sections is obtained from interpolation of nodal data in displacement data. Extrapolation is carried out by the program from stress point to obtain strains and stresses data. However, iIt is also have to be noted that the result might be less accurate than tha values of actual stress points.

4.3.4.3 Table Output

Another flexibility of the Output program is the availability of numerical data to be observed in series of tables accurately. Mainly there are three output table view namely tables of deformations, tables of stresses and strains and tables of nodes and stress points.

Tables of displacements display component of displacement at all nodes. The total of displacements are the accumulated displacements from all previous , whereas the incremental displacements are the incremental displacement in the current step calculation phases.

Tables of stresses and strains display the Cartesian components at all stress points. When tables of stresses or strains are shown, the menu includes the submenu called geometry. This submenu contains options to view the position and numbering of the element nodes and stress points.

4.3.5 Curve Generations

Generation of curves can be accomplished after all calculation procedure and output data were established previously. The Curves program is required and has all facilities used to generate load-displacement curves, stress path and stress-strain diagrams. Curve generation can be made by selecting *New* option shortly after this program is started. Several curves are allowed to be combined in one figure seamlessly. This option is not also restricted to current project but applicable for other imported output data from other project. Essentially, various graph representation can be made using curve generation window ad shown in Figure 4.5.

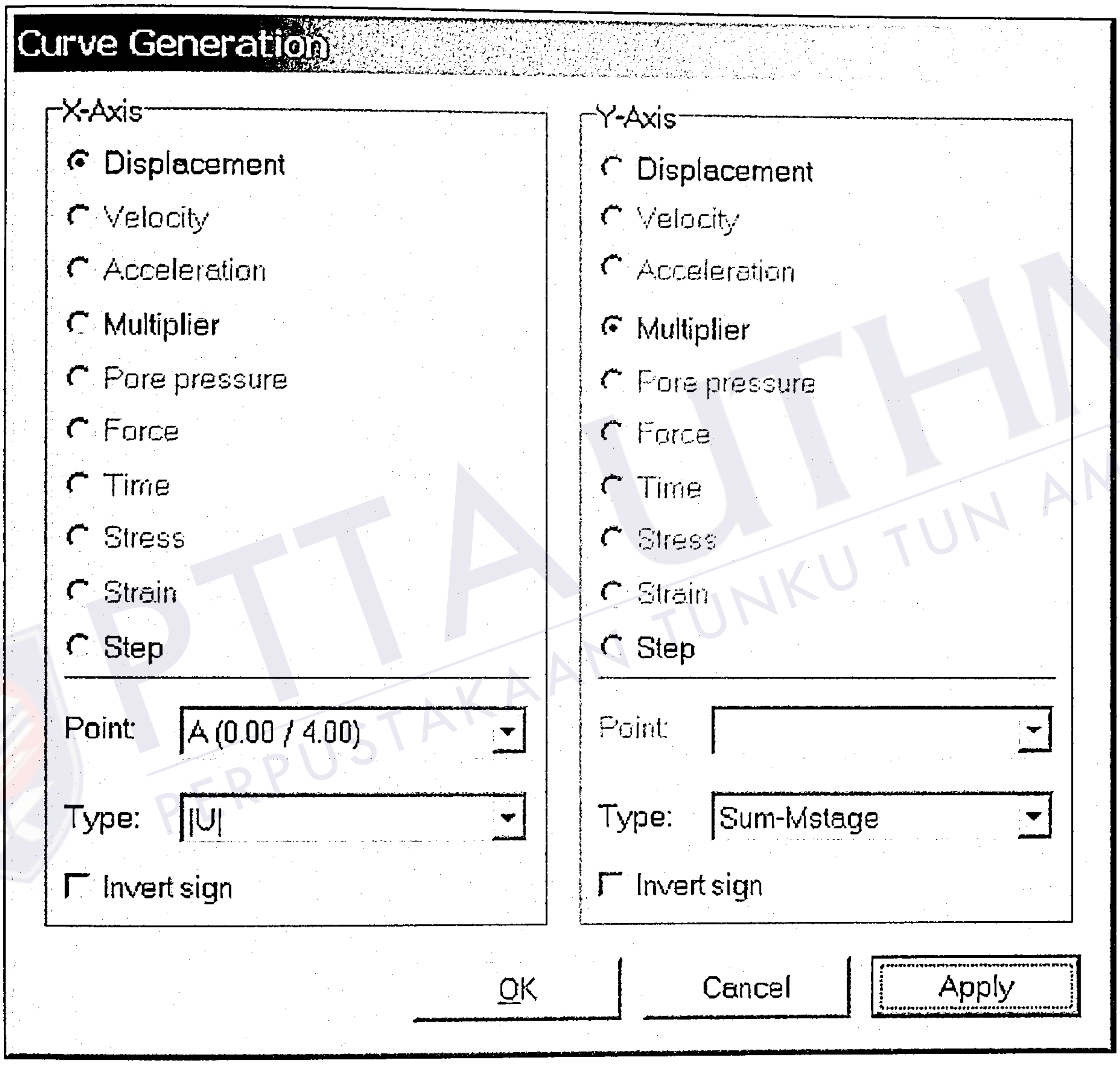

Figure 4.5: Curve Generation Window in PLAXIS Curves Program (PLAXIS Tutorial Manual, 2002)

The load-displacement curves is used in order to visualise the relationship between the applied loading that is relating to load level made in calculation phase and the resulting displacement for specific point. Typical curve generation is shown in following Figure 4.6. Additionally, time-displacement curve is another important types of curve generation that is useful to interpret the results of calculation in favour of time-dependent behaviour of soil. This program also facilitate additional formatting options if user desires to modify the look of presentation curves.

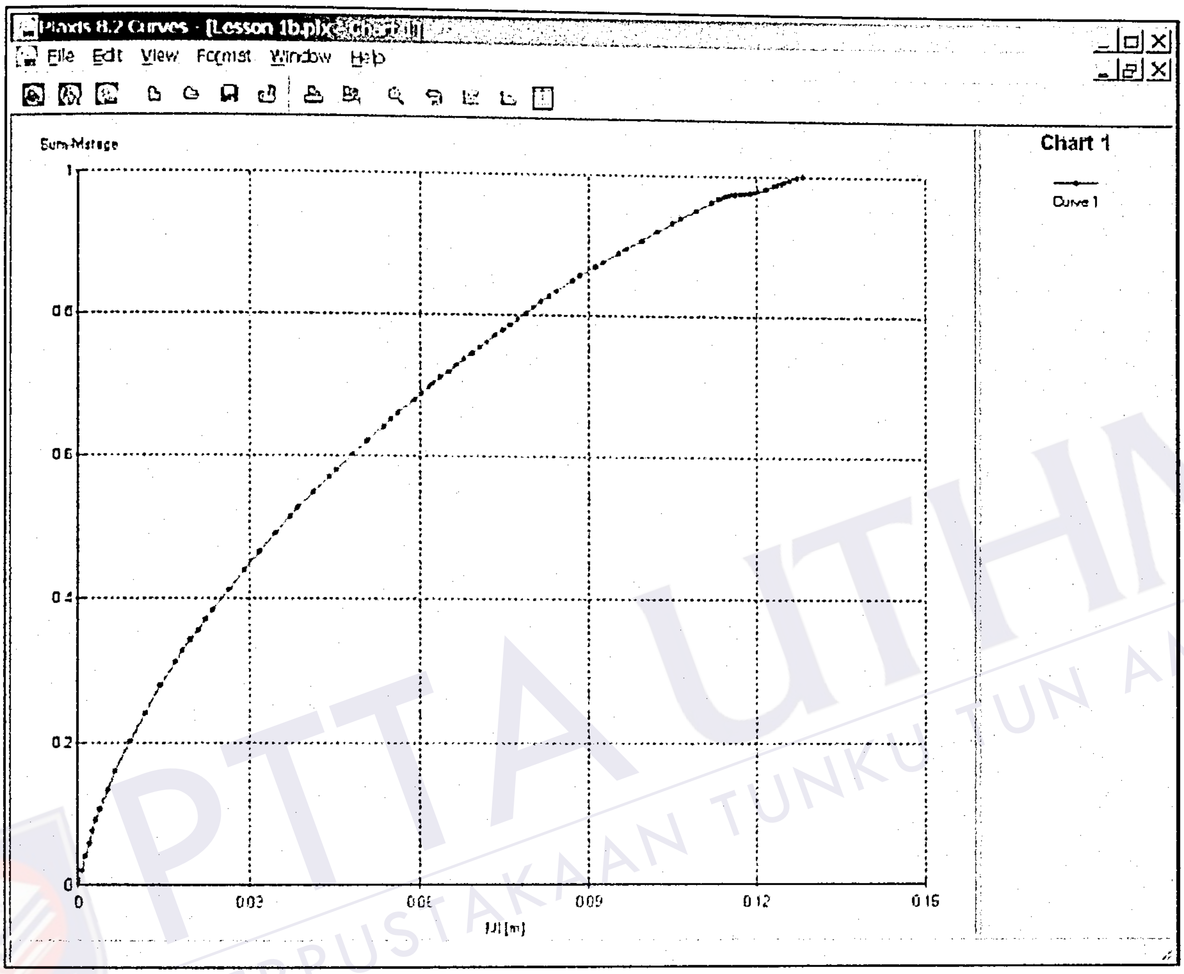

Figure 4.6: Load-Displacement Curve Generated by PLAXIS Curves Program (PLAXIS Tutorial Manual, 2002)

4.4 Failure Simulation Analysis

Failure analysis using PLAXIS software can be conducted in various forms depending on the approach of failure mechanism that being introduces in the modelling. It can be based on safety factors which requiring P/chi reduction calculation procedures. For other geotechnical construction which is related to soil modelling over soft clay condition for instance, consolidation calculation procedures should be followed accordingly.

Output data from the Output program and Curves program can be interpreted in accordance with the failure criteria that has been chosen for our design purpose. For instance, maximum deformation of subgrade layer can be used in limiting design life by considering on long-term consolidation effect. From the subsequent output data of maximum deformation or strain in specific point location, failure criteria can be employed in order to verify reliability of design models.

In addition, failure simulation can be made representatively and visualized appropriately using provided Output program. Development of stress/strain on geometrical model can also be viewed using some attractive option available in this program. These visualizations of failure simulation are essentially important in order to provide more informational and representative data on how the displacements of soil component are developed which is in consequent will lead to the structural and functional failures.

4.5 Limitation of PLAXIS Software

PLAXIS software is used to simulate the soil behaviour using numerical calculation of finite element method. In PLAXIS version 8, only two-dimensional modelling and simulation analysis is applicable. Development code of this software has been carried out throughout a lot of testing and technical supports from various agencies world-wide. However, it still cannot be guaranteed that the PLAXIS code is free from any possible error. Additionally, the simulation modelling using finite element method might involve some inevitable numerical and modelling error during the calculation phases.

With the limitation of two-dimensional modelling, it appears that the geometrical design component is not really represented the actual condition required for accurate simulation modelling. The parameters of loadings input facilitate in Calculation program also not sounds for moving load characterized by actual traffic loadings if road pavement model is considered in design.

Other material parameter such as plates and geogrids are insufficiently integrated in design since material input for these components are still limited to only one or few material properties. For example, only one material property for plate is applicable in material set. Simplification of other structural geometry such as conversion of concrete structures to plate concept may necessary in PLAXIS modelling environment. But obviously it is not representing the actual condition of genuine design since the thickness of structure is altered unexpectedly. On the whole, geometrical components other than provided in this program are not allowed indefinitely but this sound more logical since the program is specifically developed for the used in geotechnical engineering lines.

CHAPTER V

RESEARCH METHODOLOGY AND TESTING

5.0 Introduction

This chapter describes the research methodology that has been employed during the research work. The methodology was employed to assist the author in understanding the effect of loading, time and distance from road-bridge interface on the differential settlement developed, subsequently. The selected simulation tool, that is, PLAXIS Version 8, was capable to give the author some description of the behaviour of the flexible road pavement and bridge interface but with some functional constraints in the simulation enhancement. For the simulation procedure in this study, all of the required parameters were conducted appropriately in accordance with the simulation modelling procedure in PLAXIS software environment. Further discussions on the results observed from the simulation modelling were discussed in Chapter IV (Failure Simulation using PLAXIS). Consequently, output data analyses were discussed in Chapter VI (Data Observation and Analysis) and Chapter VII (Conclusion and Recommendation). In addition, reference on figures and tables discussed in this chapter were made available in Appendix 'A' and Appendix 'B', respectively.

5.1 Gathering Data and Information

5.1.1 Literature Review

Literature review involves the fundamental understanding of soft soils. inspection of plans, description of approach slab and pavement design. specification. and the application of simulation modelling using computer software. Some review of previous researches related to this study has been described appropriately in order to prove and support the research that has been carried out.

5.1.2 Interview

Interviews were conducted during the research as important efforts to review and excess some valuable information of the study from the dependable resources. It has also used as fundamental references before further investigation could be carried out. Availability of some important data must be identified so that any limitations or obstacles during the study could be minimized considerably. Personnel interviewed among others were Batu Pahat district officers, Public Work Department officers, consultant firm, and the local communities.

According to local communities and personnel interviewed form local authorities, roadway along Parit Karjo to Pontian Kechil had been overlaid during July 2006. The recurrent work of maintenance was carried out due to deterioration of pavement performance and has to be done periodically since the problem was normally reappears after some period of time. A concrete bridge referred in this study was built in year of 2000 according to the District Public Work Department of Batu Pahat.

5.2 Field Investigation and Laboratory Testing

The writer has also conducted initial field investigation in September 2006 in order to examine any appearance of surface distresses on pointed and nearby study area. The bridge-road pavement section that had been study is located about 500 m away from the Kluang – Batu Pahat. The road suffer major deformation problem particularly on connection between ends of paved roadways and bridge approach slab. In this area, structure damage that is caused by deformation of soil is preferably known as differential settlement between the two structures constructed on different basement and soil properties. Other circumstances such as motor vehicles excess and nearby trenches were also observed at time of inspection work.

Observation of subsoil condition was carried out in early of January 2007 in order to investigate the elevation of road pavement and approach slab for the purpose of preliminary study. This observation work was also to provide rough information about the consequent of subsoil damage due to deformation problem. It was conducted using Ground Penetrating Radar (GPR) equipment supplied by Sensor and Software Inc. Further discussion about this outcome could be made to Section 5.2.3 in this chapter.

5.2.1 Geological Information of Study Area

All damage appearances and possible aspects that may cause occurrence on pavement deformation will be examined on site such as geological data, water table location, existence of nearby trenches, traffics loading, and also current condition of structural performance. This study area is located at wetland of which has significant traverse soft soil deposite of marine or coastal alluvium (Masirin, 2005). Soil deposit of soft clay geologically can reach up to between 20 m to 30 m. With the high annual rainfall around 200mm to 250 mm in average, constitution of liquid limit is high up to 60% to 90% and even higher soil moisture content. The plasticity index value ranging from 35% to 60% for the upper layer and for the lower clay layer is about 15% to 35%. Bulky density of the upper clay is slightly lower than the bottom clay (Malaysian Highway Authority, 1989). As shown in Figure A5.1 in Appendix A, there was a trench network on side of the bridge with considerably low in water table as the picture taken in dry season. Figure A5.2 in Appendix A shows the similar open channel in wet season. The water table is approximately 0.5m to 0.65m from ground level but may rise significantly during raining season (Jestin, 2006).

5.2.2 Structural Condition

It was found that surface damage of pavement might caused by the consequent deformation of soil basement. This apparently will cause the upper structure of pavement will follow to deform downward and cause subsequent damage on its surface. The bump exist at near the ends of approach slab are obviously result in differential settlement problem between the connection of the ends of pavement and approach slab. For the first site observation in September 2006, the road surface was in acceptable condition after maintenance work had conducted in July by local authority. As attached in Appendix A, Figure A5.3 shows a considerably road surface condition near to slab approach area before experiencing deterioration problem on the next few months.

Though, just after 5 month of overlay, surface deterioration was begin to reappears as it used to be particularly on connection between concrete bridge slab and approach slab and also between approach slab and roadway end. This problem is shown in Figure A5.4 and Figure A5.5 respectively. In Figure A5.6 shows a sketch of current differential settlement problem on that particular location. Those particular figures are also attached neatly in Appendix A.

5.2.3 Subground Condition

Subground soil condition has been observed using Ground Penetrating Radar (GPR) tools. Complete equipments of GPR consists of Noggin as subsurface imaging instrument, SmartCart system for easy movement and distance measurement, rechargeable battery pack, and also Digital Video Logger (DVL) used in data acquisition. All the equipments were supplied by Sensor and Software Inc. Instrumentation of this equipment has been explained in prior chapter for further information details.

Observation of the subsurface condition of the road pavement was carried out using 2-dimensional feature in GPR. It took about the whole 3 meters length of approach slab with 5 meters length of concrete bridge in one side and another 5 meters length of road pavement at another side. Depth of radar penetration set to be 5 meter with wave velocity 0.100 m/ns. The configuration of observation method is shown in Figure A5.7 in Appendix A. Figures of output data from GPR observation are also can be referred to the Figure A5.8 and Figure A5.9 respectively.

5.2.4 Soil Testing

Important soil properties that have been used in simulation design were obtained from laboratory testing. These design parameters used in soil material modelling were gathered essentially from previous research data. Consequently, established Mohr-Coulomb Model was used in this study. In general, Mohr-Coulomb requires important parameters such as Young's modulus (E), Poisson's ratio (v), friction angle (ϕ), cohesion (c) and dilatancy angle (ψ). These parameters can be obtained from basic tests on soil samples in laboratory.

Parameters such as friction angle, ϕ and cohesion, c of soil can be obtained from direct shear test or triaxial test. For weak saturated soft soil, the use of triaxial test equipment is more prominent and far superior then direct shear test since the simple equipment of direct shear test may not able to provide necessary control for the accuracy of testing.

Young's Modulus, E was obtained by means of triaxial test procedures. Since many soil testing prone to be nonlinear, this stiffness parameter requires special attention in soil testing. Generally, soil with a large linear elastic range was more realistic to use E_0 from initial slope and for normal loading soil, the use of E_{50} which taken from secant modulus at 50% strength is appropriate.

Parameter of Poisson's ratio, v is also can be obtained from triaxial test. In many cases, v values is in the range between 0.3 and 0.4..It is known that clay soils tend to have little dilatancy angle which is nearly zero. Since the study is about the modelling over soft clay circumstance, it is said to be realistic and acceptable to use the value of zero for dilatancy angle parameter (PLAXIS Material Model Manual, 2002).

5.3 Traffic Loading

Configuration of traffic loadings is one of the primary important components in design. For this purpose, loads from the traffic have been assigned appropriately in modelling so that expectancy of design life and acceptance of long-term structural performance could be achieved.

5.3.1 Type of Loading

An apparent constraint of this simulation software is its incapability to perform moving traffic loads. PLAXIS version 8 only enables to analyze and perform finite element modelling for static load due to both the dead and life loads. In this study, the traffic loading was analyzed using static loadings at selected point on the surface of pavement model. Analysis using uniformly distributed load along the road pavement was unnecessary since distance of front and rear wheels was about 4.0 m as was illustrated in following Figure 5.1. Within distance range, that their effect on stresses and strains should be considered independently (Huang, Y. H., 2001).

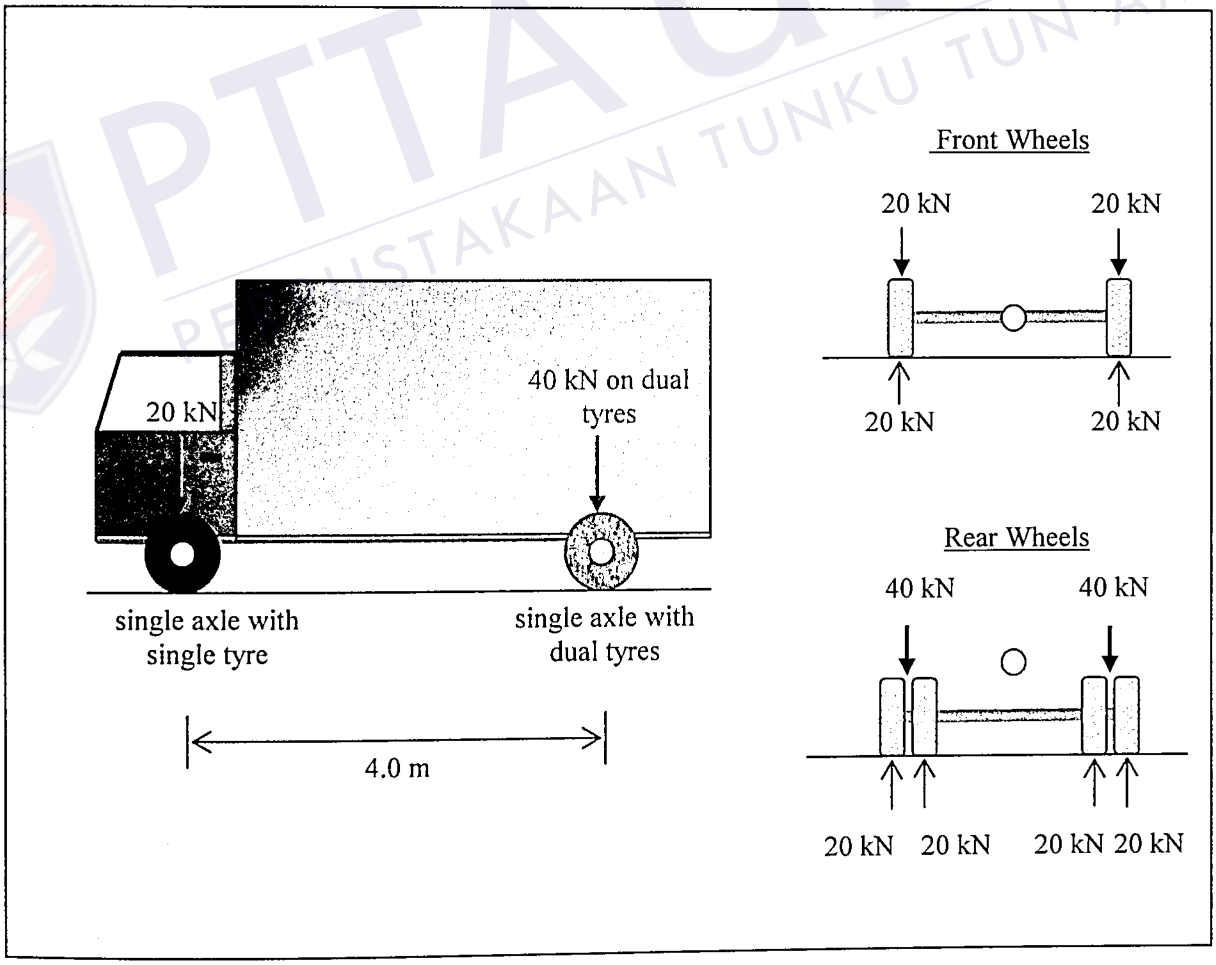

Figure 5.1: Typical Configuration of a Heavy Vehicle with Standard 18 kips (80 kN) Single Axle Dual Tyres

5.3.2 Loading Configuration

For this purpose, a load of 18 kips (80 kN) has been used in this study to represent a average maximum loadings of traffic caused by a standard 18 kips single axle truck as used in Malaysian Public Work Department of road pavement design. This standard loading configuration is based on full scale road test by AASHO at their facilities in Illinois during 1958 until 1960. As the loads is distributed over two axle consist of dual tyres of each, lead the original 80 kN load to be divided evenly to 20 kN for each tyre. Thus, 20 kN point load will be used in this sense to represent actual imposed load on the road surface.

5.4 Performing Simulation Program

Since this study was based on computer simulation, data verification for data input in PLAXIS software modelling environment was primary important in this research. The critical part was to provide the conceptual design that would be used in this simulation analysis. PLAXIS is a finite element package that has been developed specifically for the analysis of deformation and stability in geotechnical engineering projects. This software is used to provide both quick generation of complex finite element models and detail presentation of computational results. The calculation itself is fully automated and based on numerical calculation procedures.

For the purpose of research, PLAXIS version 8 has been used to generate 2-dimensional analysis of finite element modelling. This software featuring simple graphical input procedures and user has also another option to follow standard CAD feature. Further discussion and the use of this software have been made in Chapter IV. In this section, important input parameter is discussed accordingly.

5.4.4 Geometrical Parameters

Selection of design concept is always prominently important in the study in order to identify the suitability and most preferable design in the research. Currently, no specific guidelines had been clarified on the structural and conceptual design of approach slab by our local authority of Public Work Department. Indeed the design of approach slab that had been proposed by many researches are considerably more subjective in design and always be viewed as an art rather than a science (Cai et al. 2005). Though about twodesigns of approach slab models were evaluated namely conventional horizontal slab, and slab with 5° inclined plane.

5.4.4.1 Subgrade Thickness and Geosynthetic Layer

In this study, reinforced subgrades with geosynthetic layers were also conducted in order to determine its effect on deformation pavement deformation. Subgrade with two thickness of 500 mm and 1000 mm were used in this simulation study. For geosynthetic materials, two types of material were used and placed at the bottom of road embankment beneath the subgrade layer.

Generally, geometrical parameters were based on standard elevation plan as shown in following Figure A5.6 in Appendix A. It shows a simplified drawing of road pavement section that had been used for construction of rural road pavement in Batu Pahat district. Following Figure 5.2 shows modified model of standard horizontal approach slab constructed towards paved roadway end with or without provision of geosynthetic layer. Initially, the performance of roadway sections with approach slab was compared to a condition in which no approach slab was provided.

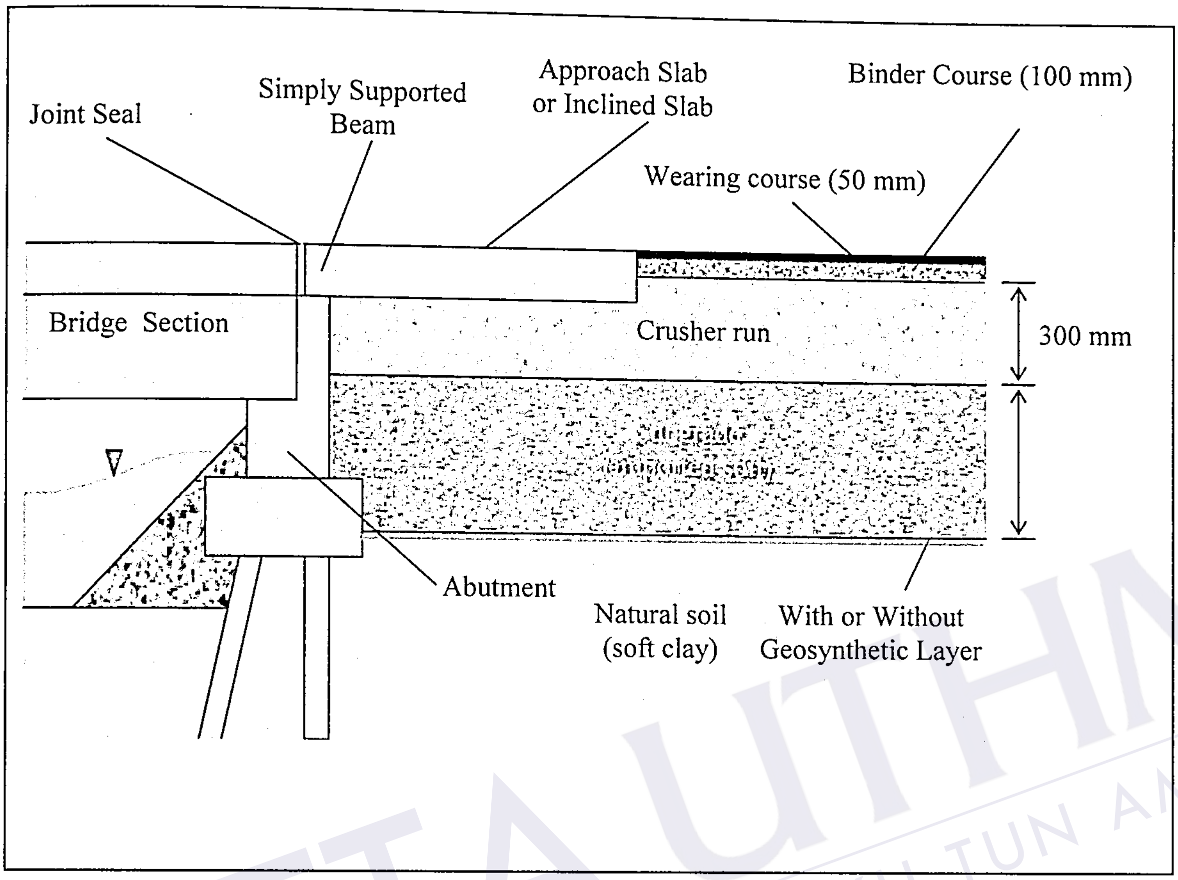

Figure 5.2: Cross Sectional View of Subsoil Layer and Approach Slab

5.4.4.2 Control Model (Horizontal Slab)

Horizontal slab model was used as control model in this research along with road section without provision of any transition medium. In above Figure 5.2, this conventional model used in current practice was about 5 m long and about 25 cm thick with considerable assumption of pin connection at its one end. This dimensional configuration was also plausible since many approach slab length was designed in range between 3.0 m to 15 m. The figure shows a basic alignment of pavement structure near to bridge deck as horizontal approach slab was introduced as a transition medium.

5.4.4.3 Slab Inclined at 5° to Horizontal

This model had been proposed by Wong et. al. (1995) trough their laboratory-scale test. From this research, it showed that orientation of approach slab design had demonstrated better performance against development of deformation profiles particularly for slab inclined at 5° to horizontal surface. Geometrical parameters employed in this study were 22.5 cm slab thick and 5 m horizontal length with 5° inclined to the horizontal surface. Following Figure 5.3 shows appropriate geometrical and material model of design.

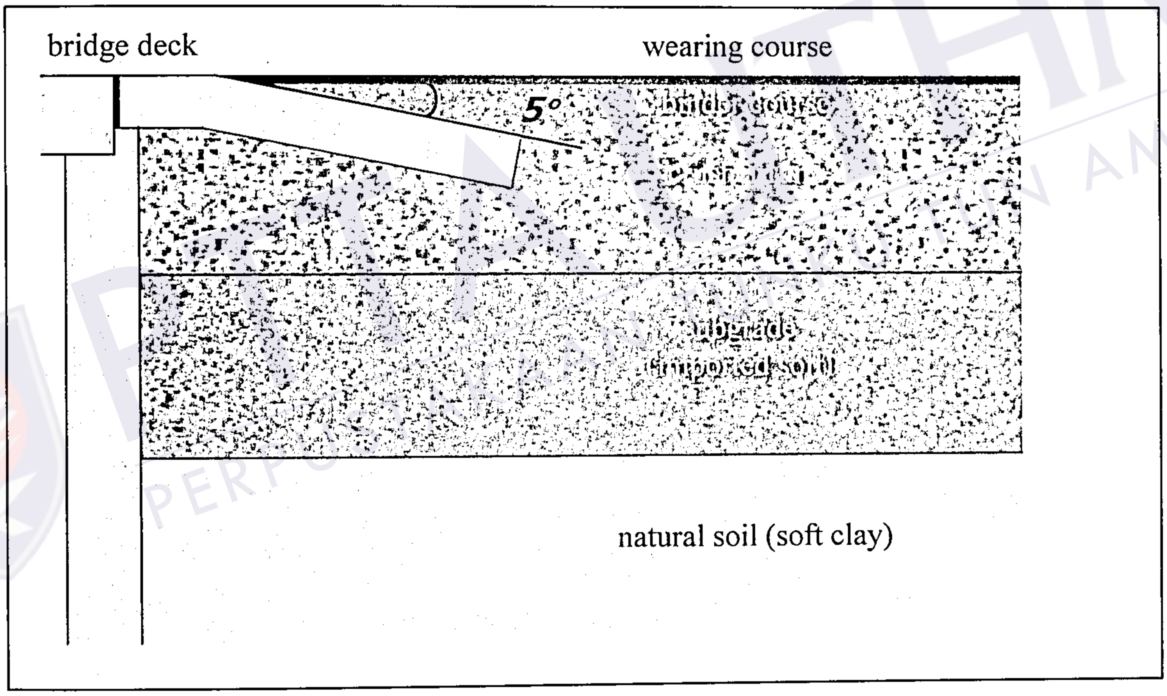

Figure 5.3: Configuration Type of Inclined Slab to the Horizontal Surface

5.4.4.4 Phreatic Level

Phreatic level represents the water pressure that may have effect to approach slab performance. It increases linearly with depth according to the specified water weight. In contrast to steady ground water flow, phreatic level parameter in soft clay has more significant effect. Moreover, Batu Pahat district receives considerably a high capacity of rainfall through out a year especially during monsoon season twice a year. Though, in dry season the condition is conversely different as ground water table becomes much lower.

According to GPR output data as shown in Figure A5.8 and Figure A5.9 in Appendix A, reflected layer below 0.69 m from the surface was most probably due to the present of moisture that intruded into the subgrade and sub-base layer. It was noted that typical cross-section of road pavement layer was about 1.825 m in reference to the original drawing of pavement section supplied by State Public Work Department. Thickness of subgrade was about 1 m while sub-base and base layer were about 375 mm and 300 mm respectively. Reasonably, phreatic level would be considered as high as it could be and it was about as near as 0.7 meter to the road surface. High level on water table could also be noticed from information in Figure A5.2 attached in Appendix A.

5.4.5 Material Parameters

Material parameters were assigned after geometrical inputs of design models were accomplished. There were about 4 material parameter included in this study; pavement layer, soil layer, concrete slab and geotextile properties. It was well accepted that the function of material parameters are on par with geometry parameters in designing purpose. Pavement properties were modelled according to the linear elastic model while Mohr's Coloumb model was used for soil layer.

However, geometrical input such as concrete slab can not be assigned as a single structural model in PLAXIS software. Because of the nature of the program itself that is pronounced more on geotechnical soil modelling rather than structural modelling, an approach of using PLAXIS in this study will be discussed later in this section. Similarly, the use of geotextile material in PLAXIS was also limited to only one material property.

5.4.6 Pavement Properties

Pavement properties used in this simulation models were taken from doctorate thesis writing by Masirin (2005). Table B5.1 in Appendix B shows typical rural road pavement properties obtained form laboratory testing. It has to be noted that pavement is a kind of elastic material and must be modelled using linear elastic model. However, it was only a simplification approach since it was not possible to model each layer of road pavement separately using different model. Therefore, the modelling of road pavement layer was an approximation due to the limitation of the software.

5.4.7 Soil Properties

Soil properties are the most important parameter in PLAXIS simulation since this software was developed specifically for the purpose in geotechnical engineering line. Similar to pavement, properties of soft clay were also obtained directly from Masirin (2005). In this simulation analysis, provable soil information and properties were very important for the validation of the data output. All valuable data of soil properties in this thesis were obtained form various soil testing procedures. Table B5.2 in Appendix B shows typical soft clay properties of Batu Pahat used in Mohr-Coulomb soil modelling.

5.4.8 Concrete Slab Properties

As PLAXIS software requires input for flexural rigidity and normal stiffness of the approach concrete, Table B5.3 attached in Appendix B will provide necessary parameters of the concrete slab used in this study based on geometrical input data with standard concrete density of 24 kN/m^3 and elastic modulus, E equal to 35 GPa. This data were used to replicate approach slab in form of plate geometry as idealised in PLAXIS software environment.

5.4.9 Geosynthetic Properties

In PLAXIS Version 8 software, only strength property of geosynthetic material is available to be evaluated. This strength parameter is based on normal axial stiffness donated as EA (normal axial stiffness). Table B5.4 in Appendix B shows two types of geosynthetics materials that were used in this study. Apparently, geosynthetic clay liner is more superior in strength parameter compared to typical geotextile material.

5.4.10 Determination of Boundary Conditions

In finite element modelling, it is fundamentally important to determine boundary condition for proposed design work. Without proper determination of boundary condition, the analysis may lead to error particularly at the outer boundary. Therefore it was necessary to conduct appropriate sensitivity analysis regarding on this matter. It was to determine how much soil geometry vertically and longitudinally, should be included in the finite element model. In Plaxis two-dimensional program, two parameters, *H* and *L* shown in following Figure A5.11 (Appendix A) were investigated in this study as follows:

1. *H* was varied from 5, 10, 15 to 20 m. These depths were simultaneously changed for the fixed *L* = 35 and 40 m with *B* were fixed to 10 m (about half of bridge span that was 20 m long). It was much easier to determine boundary for vertical direction since literally the maximum depth of soft soil in Batu Pahat is about 20 to 30 m.

2. For longitudinal boundary of design geometry, *L* was varied from 15, 20, 25, 30, 35,40 to 45 m and this time vertical boundary was fixed for the values of *H* = 15 and 20 m.

Deformation points at outer part of geometry area of point A and I were examined for each case of study. For this purpose, a 20 kN point load was imposed for each point. According to conducted study, it was found that *L* with greater than 40 m has insignificant effect on deformation profile. Though, deformation profiles were still significant for *H* is greater than 15 m but was limited to only 20 m when the nature of maximum depth of the soft soil was noticed. Thus, it was acceptable to provide *H* = 20 m and *L* = 40 m as shown in Figure A5.11.

CHAPTER VI

DATA OBSERVATION AND ANALYSIS

6.1 Introduction

During the research work, the author was able to run many simulations using the field data collected and other data produced by fellow researchers from Public works Department Malaysia (2000), Perunding Sejati (2000) and Masirin et al (2005). In this chapter, it discusses the outcomes data from simulation modelling using PLAXIS software. Prior to this chapter, research methodology and testing have been discussed elaborately in Chapter V. For appropriate data representation and understanding of data findings, required data have been transformed to more representative graphs according to the actual output data generated by the software. Reference of raw output data were made available in Appendix 'C' for detailing and further verification. Analyses of output data were in accordance with the objectives of this research as mentioned in Chapter I and appropriate research methodology has been developed as described earlier in Chapter V. Prior to the simulation modelling process, considerations regarding to limitations and scopes of study has been conducted as described in Chapter I and later at the end of this chapter in order to provide appropriate representations of the analyses conducted.

6.2 Consolidation Analysis on Transition Section

Since structural modelling of approach slab and road pavement was developed for the use in soft clay environment, it is important to look into the development of deformation profile against consolidation times. In this analysis, horizontal and 5° inclined slab with 50 cm and 100 cm subgrade were evaluated. Both of approach slab models also have been evaluated using additional reinforcement materials to reinforce the subgrade layer that were geotextile (woven type) and geosynthetic clay liner (GCL). It was to investigate the maximum consolidation time achieved by the representative models equally for short and long-term analysis. Prior to development of these representative graphs of deformation, raw calculation data of deformation can be referred in Table B6.1 through Table B6.12 in Appendix B.

6.2.1 Horizontal Slab

For unreinforced model with 50 cm subgrade, it is approximately that full consolidation has taken up to 20 years, in which maximum subgrade deformations were achieved at 11.41 mm and 10.38 mm for 100 cm subgrade according to the Figure 6.1. In addition, it is noticed that at the first 5 years after construction, consolidation of subgrade was significant with comparatively large deformation development range between these periods particularly on the approaching road pavement section. Deformations on road pavement interface at points 6.0 m and 4.3 m away from bridge abutment have reached the maximum settlements at 10.31 mm and 7.03 mm for 50 cm subgrade, while 8.96 mm and 6.11 mm for 100 cm subgrade.

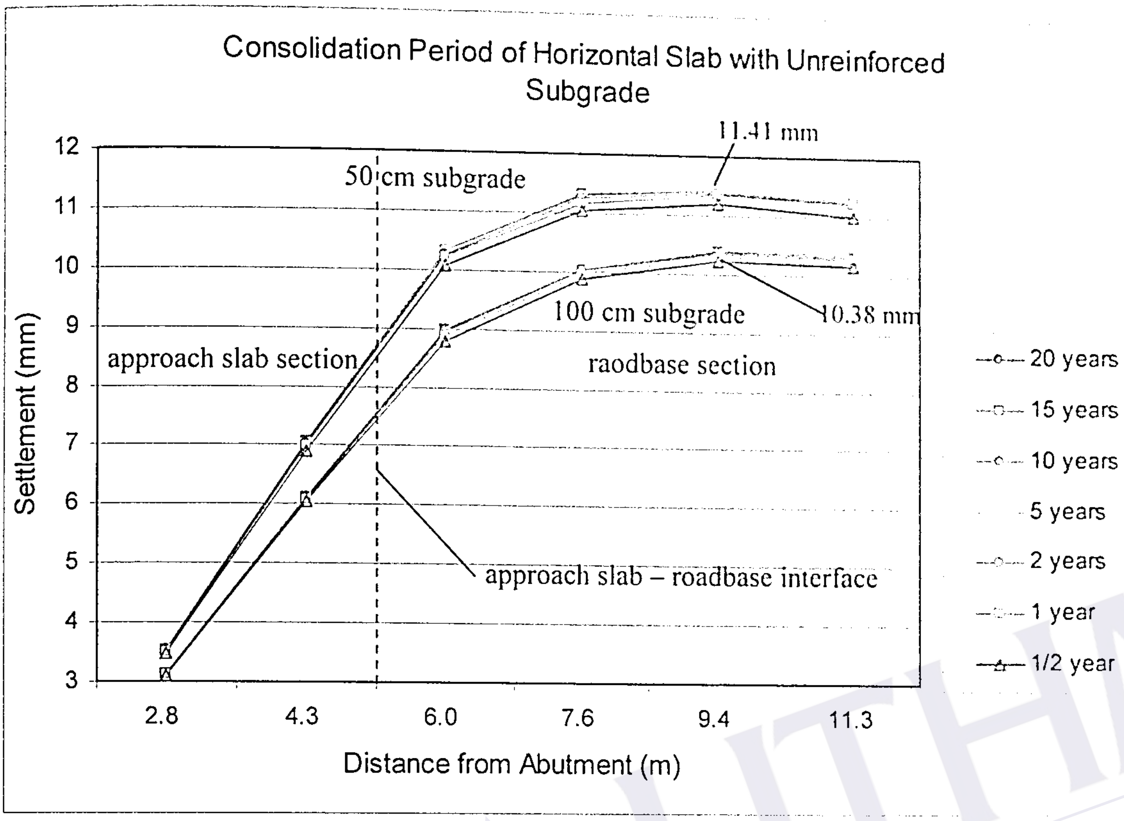

Figure 6.1: Horizontal Slab Deformation Profiles on Unreinforced Subgrade by Means of Consolidation

Meanwhile, subgrade reinforced with geotextile shows identical deformation profiles but with slightly decreased on projected maximum deformation. It was approximately that maximum deformation occurred in approaching road pavement section at target point of 9.4 m to the bridge abutment as can be seen in Figure 6.2. The deformations were approximately 11.36 mm and 11.23 mm for 50 cm and 100 cm subgrade, which has proved much better than unreinforced subgrade deformation. On the other side, deformation profiles of GCL-reinforced subgrade as shown in Figure 6.3 also illustrates comparable patterns of improvement and again, maximum deformation has achieved at improved manner that was about 11.23 mm. Though, maximum deformation of 100 cm subgrade only happened at target point 11.30 m from abutment with comparable improvement of 10.05 mm. Importantly, from the development of those deformation profiles along the transition section, it seemed that the maximum consolidations have occurred between year 10 to 20 with significant occurrence of primary consolidation within first 5 years periods.

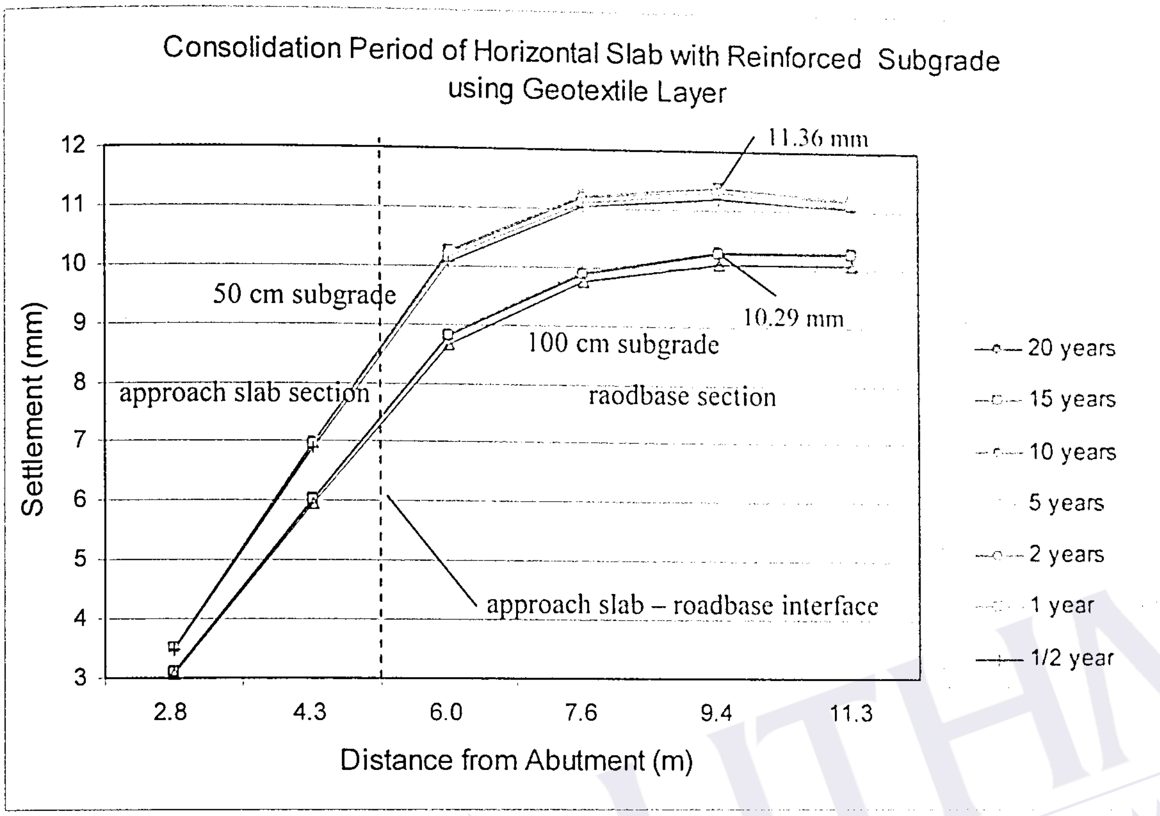

Figure 6.2: Horizontal Slab Deformation Profiles on Geotextile-Reinforced Subgrade by Means of Consolidation

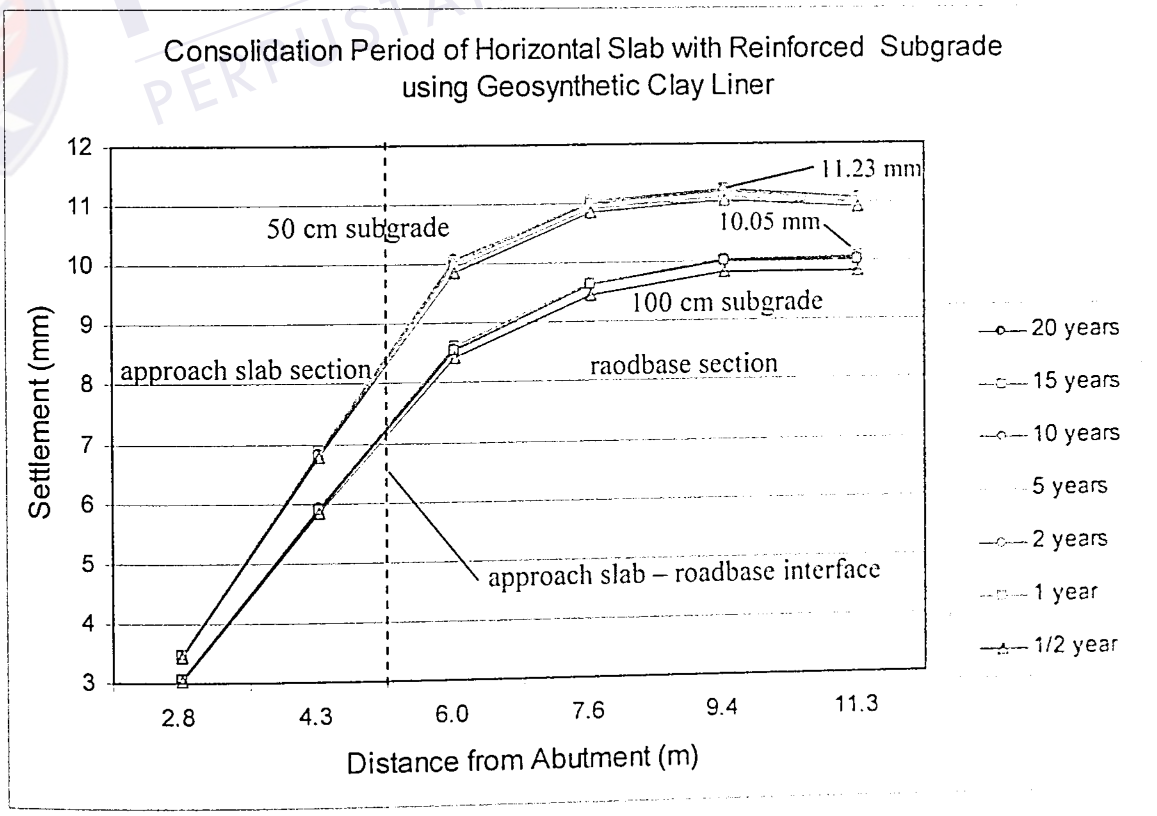

Figure 6.3: Horizontal Slab Deformation Profiles on GCL-Reinforced Subgrade by Means of Consolidation.

6.2.2 5° Inclined Slab

Similarly, slab models with 5° inclined plane have performed identically to horizontal slab model. On approach slab with 50 cm subgrade measured 4.3 m from abutment, Figure 6.4 has shown deformation that was about 7.07 mm. Though, maximum deformation has counted for 11.33 mm at target point 9.4 m to abutment. Deformation that occurred on approaching road pavement near to interface was 10.23 mm at target point 6.0m, which certainly has proved considerable improvement over horizontal slab. However, maximum deformations of both 50 cm and 100 cm subgrade were shown in the figure as 11.33 mm and 10.32 mm respectively at target point 9.4 m from abutment.

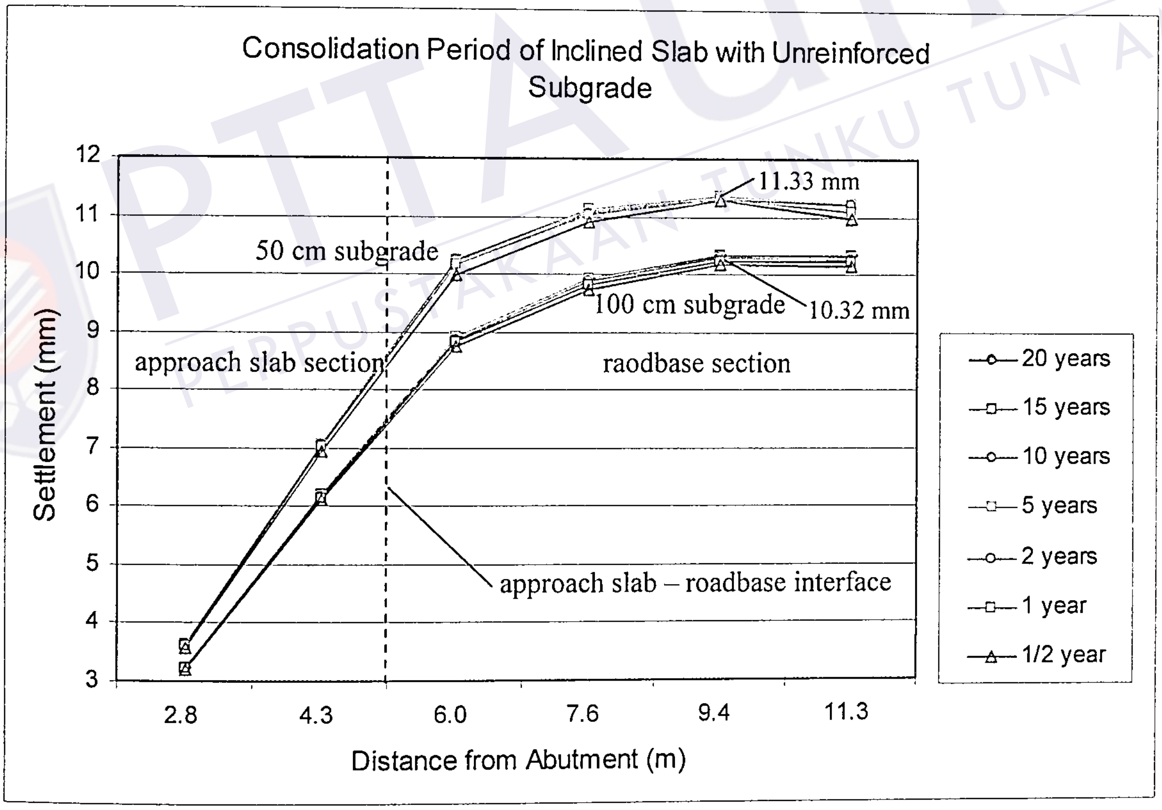

Figure 6.4: 5° Inclined Slab Deformation Profiles on Unreinforced Subgrade by Means of Consolidation

In general, deformation profiles on geotextile-reinforced and GCL-reinforced subgrades have visualized much improvement over unreinforced subgrade model and this is demonstrated in following Figure 6.5 and Figure 6.6. However, all three subgrades condition have consolidated rapidly in first 5 years after construction and as time passed with continuously loading imposed on road pavement, secondary consolidation has began to take place between year 10 and 15 accordingly. Maximum deformation for both reinforced subgrades with geotextile and GCL for 50 cm subgrades were approximately 11.30 mm and 11.16 mm, occurred at target point 9.4 m away from abutment after 20 years of consolidation. For 100 cm subgrades, they happened at approximately 10.24 mm and 10.03 mm for geotextile and GCL reinforcement as shown in Figure 6.5 and Figure 6.6 respectively.

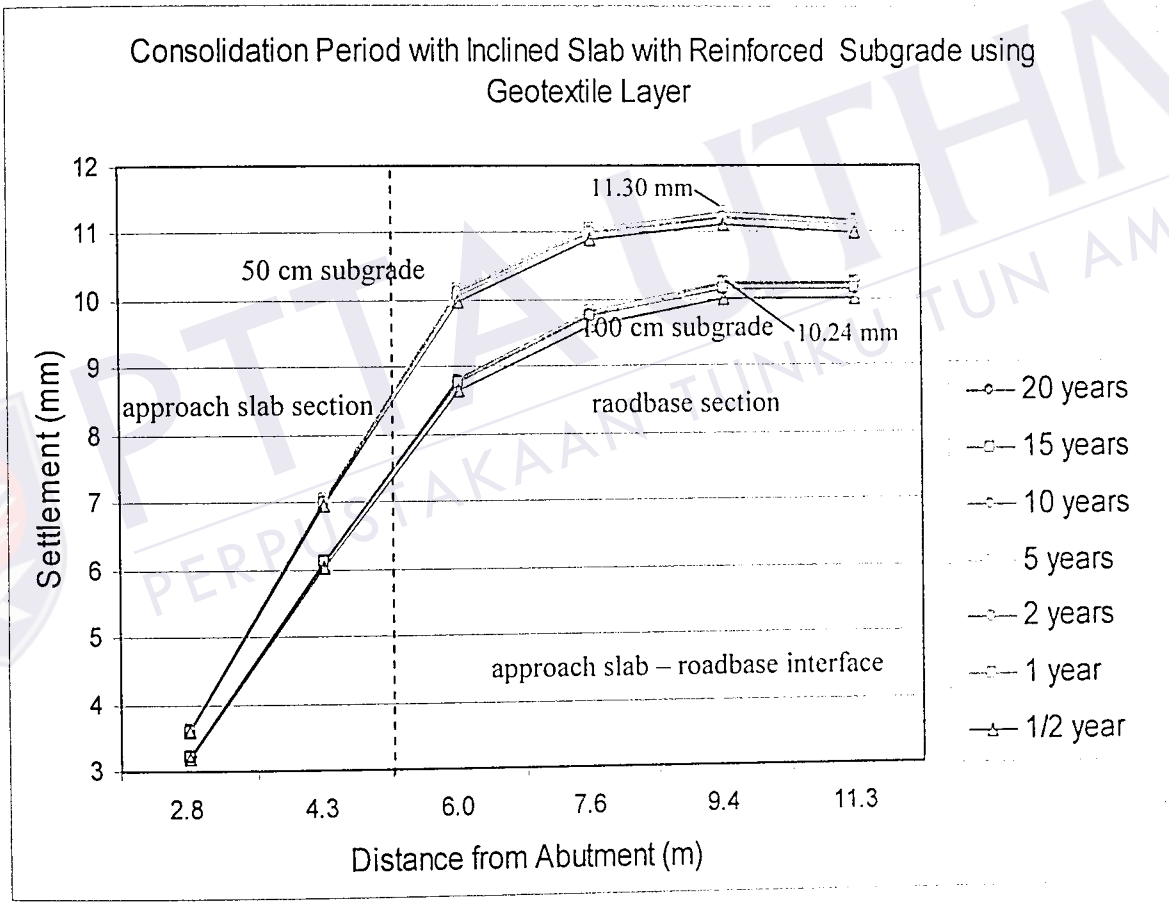

Figure 6.5: 5° Inclined Slab Deformation Profiles on Geotextile-Reinforced Subgrade by Means of Consolidation

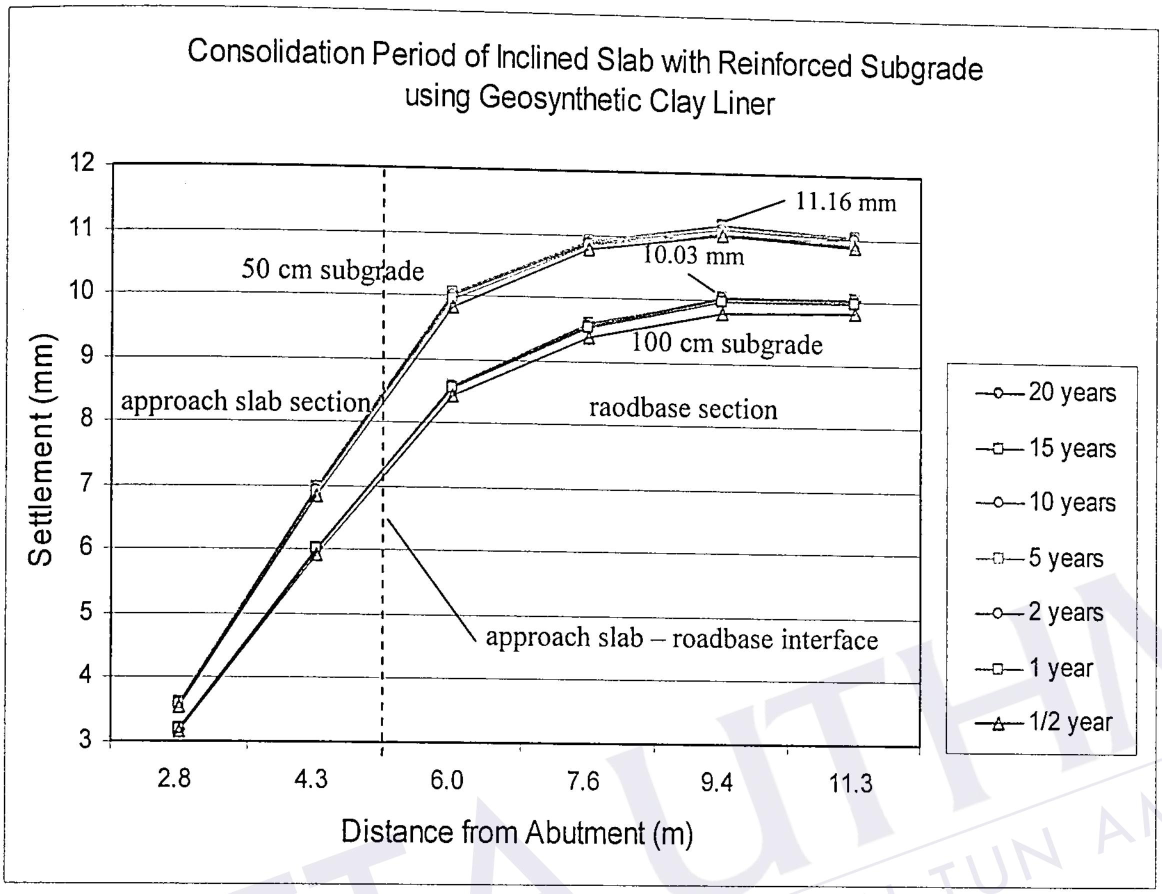

Figure 6.6: 5° Inclined Slab Deformation Profiles on GCL-Reinforced Subgrade by Means of Consolidation

6.3 Effect of Subgrade Thickness and Reinforcement on Deformation Profiles

In road pavement design, subgrade thickness of road pavement is one of the important parameter since limiting deformation on subgrade layer had been employed in design by means of rutting models approach. Further details on this distress model used in this study should be made to Chapter II. Since it is important to provide sufficient subgrade thickness in design, both horizontal and inclined slab models have been simulated with the use of different thickness subgrade to verify development of deformation against variation of thickness. Though, for the purpose of this parametric study only models with no geotextile layer have been taken into account.

It is apparent that in many geotechnical engineering structures, geosynthetic materials are always being a form factor in order to improve strength of subsoil against structural stability. Protection of the subgrade from loading imposed by traffic is one of the primary functions of pavement (Wright, 1996). In these study two types of woven geotextiles has been chosen with different property of elastic normal stiffness, EA that is the main corresponding material input in PLAXIS finite element analysis. Two types of geosynthetics material that were woven geotextile and geosynthetic clay liner (GCL) have equivalent elastic normal stiffness about 1200 kN/m and much stiffer 7000kN/m respectively. This material strength parameter was provided by geotextile manufacturer.

6.3.1 Horizontal Slab without Geosynthetic Reinforcement

In following Figure 6.7, deformation profile on horizontal slab model shows an abrupt drop for 50 cm subgrade thickness particularly near to the interface section in range 2.8 m to 6.0 m distant from bridge abutment. Maximum deformation of 11.41 mm occurred in road pavement section at point 9.4 m to abutment. Though there was significant improvement on 100 cm thick of subgrade whereas maximum deformation was counted at 11.38 mm compared to the former model with 50 cm subgrade. We also noticed at the end observed point of 50 cm subgrade model about 15.3 m distant from abutment, there was some sudden change in deformation profile. This problem was due to the proximity issue of fixity caused by the limitation of boundary condition in finite element simulation study.

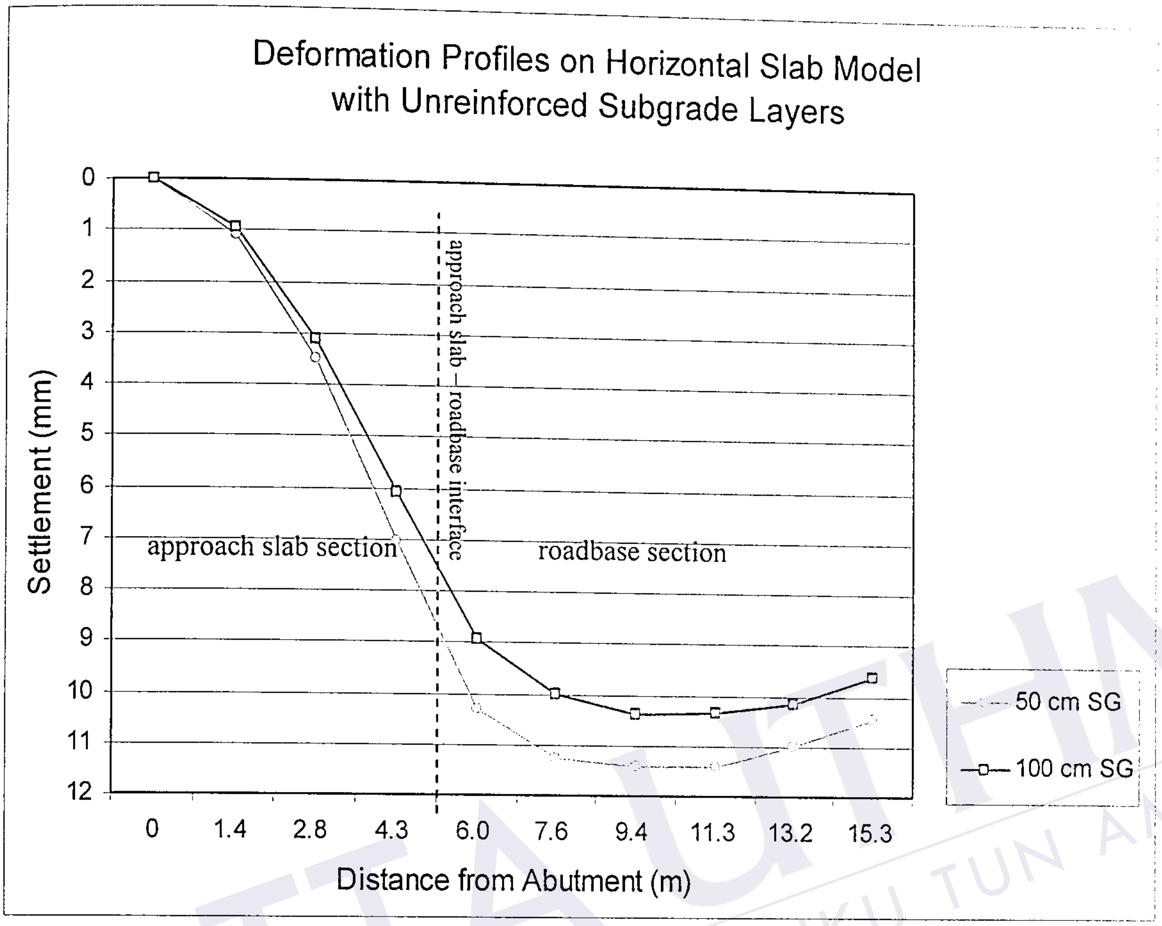

Figure 6.7: Development of Subgrade Deformation on Horizontal Slab Model with Different Thickness of Unreinforced Subgrade Layer

6.3.2 Horizontal Slab with Geosynthetic Reinforcement

Geosynthetic-reinforced horizontal slab with 100 cm subgrade layers obviously have exhibited certain improvement compared to 50 cm subgrades. This is best shown in Figure 6.8 which is exhibited both geotextile and GCL subgarade reinforcement. For geotextile-reinforced models, the improvement can be noticeable on 100 cm subgrade with deformation of 8.84 mm at road pavement section which interfaces approach slab at 1.0 m distant. At the same target point observation, slab with 50 cm subgrade deformed about 10.24 mm respectively.

On GCL-reinforced models, they have performed much better then former models in which the development of deformation profiles were reduced significantly especially on interface and road pavement section. Again, the use of thicker subgrade could improve the deformation performance entirely. This was well demonstrated at interface section of point 4.3 m and 6.0 m distant from abutment. At target point 4.3 m, the deformations were about 6.87 mm and 5.91 mm for both 50 cm and 100 cm subgrades. At the mean time, the second point exhibited 10.06 mm and 8.60 mm deformation for each respective 50 cm and 100 cm subgrades.

In comparison to the effect of the use of different elastic normal stiffness to the geosynthetic material, both reinforcement materials apparently have shown a little distinctive result. However, the use of thicker slab is more apparent to have the advantage of reducing the impact of deformation. The effect of the use of thicker subgrade in this analysis study has made a sense over the use of much stiffer geosynthetic material.

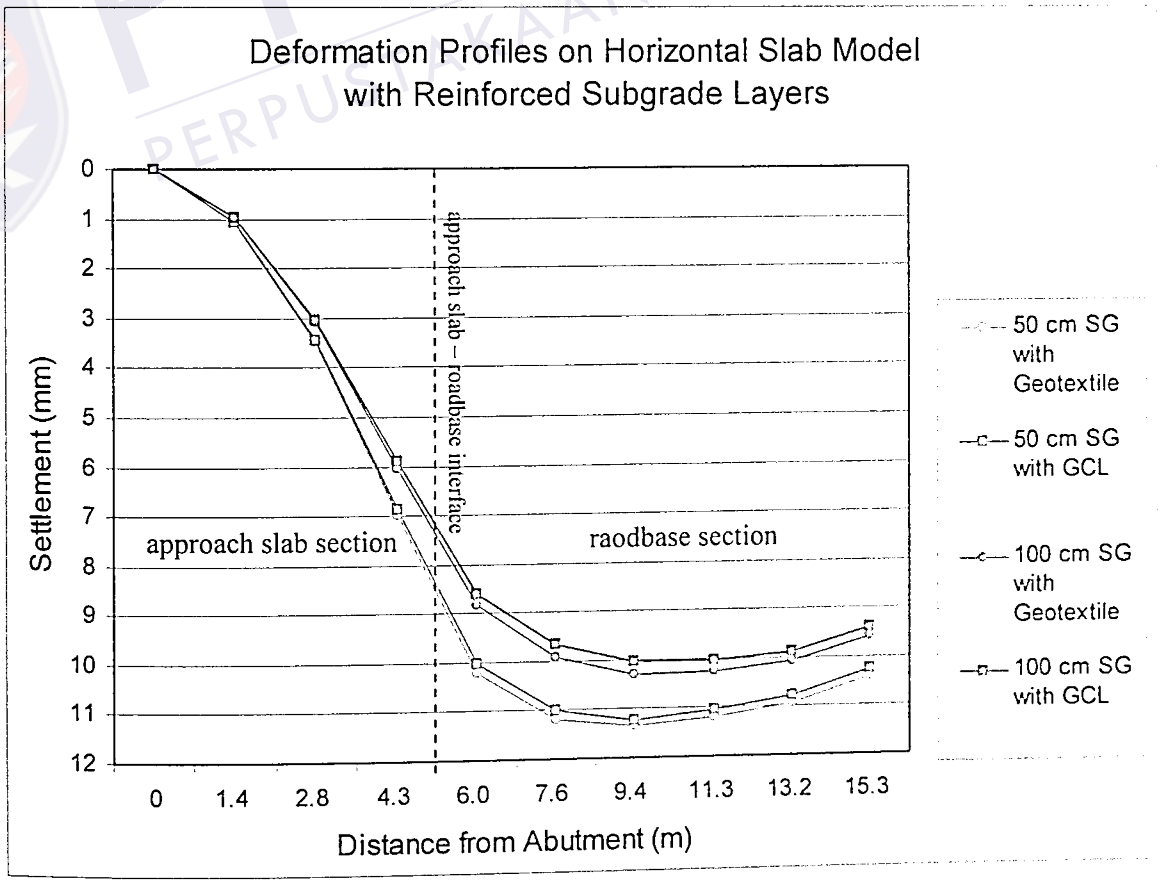

Figure 6.8: Development of Subgrade Deformation on Horizontal Slab Model with Different Thickness and Reinforced Subgrade Layer

6.3.3 Inclined Slab at 5° to Horizontal without Geosynthetic Reinforcement

According to the Figure 6.9, development profiles pattern of subgrade deformation in this model was somewhat comparable to conventional horizontal slab model. Though, maximum deformation that occurred at point 9.4 m from abutment was less than previous horizontal slab. This deformation development was about 11.33 mm and 10.32 mm for both 50 cm and 100 cm subgrade. In this regard, it has made into the conclusion that subgrade thickness could affect the performance of road pavement deformation significantly. On the view of interface section performance, increasing in subgrade layer certainly has reduced the development of deformation on this critical area.

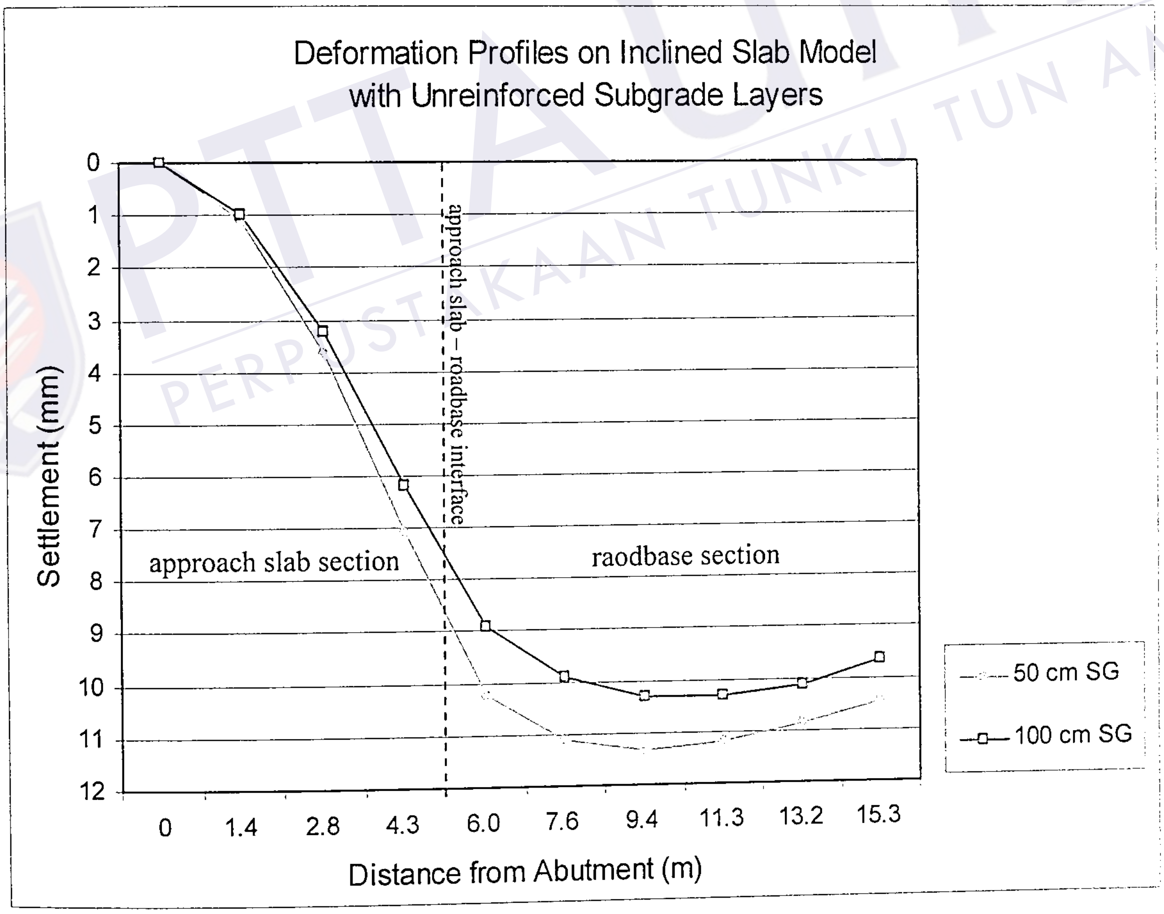

Figure 6.9: Development of Subgrade Deformation on 5° Inclined Slab Model with Different Thickness of Unreinforced Subgrade Layer

6.3.4 Inclined Slab at 5° to Horizontal with Geosynthetic Reinforcement

Figure 6.10 below shows the effect of two different geosynthetic materials of different subgrade thickness on subgrade deformation profiles. Development of deformation profiles for both geotextile- and GCL-reinforced models were obviously identical to the previous model of horizontal slab. According to the figure, it is noticed that subgrade thickness was more predominant then reinforcement parameter of gesynthetic materials in affecting subgrade deformation. This demonstration was shown by development of less severe deformation profiles on 100 cm subgrade compared to 50 cm subgrade when same reinforcement materials were used.

. The use of stiffer material of geosynthetic material also could provide some significant change on development of deformation profiles if compared to the less stiffer material in term of elastic normal stiffness parameter. More importantly, interface region between approach slab and road pavement end has improved a little. Again, subgrade thickness was still dominant in affecting subgrade performance even with the use of stiffer material as subgrade reinforcement. In fact, it has tended to prove that the use of stiffer geosynthetic material may not significantly change the subgrade deformation profiles.

In comparison to the effect of the use of different elastic normal stiffness, both reinforcement materials clearly have shown identically to the result of horizontal models. Once again, it was proved that the use of thicker slab was more apparent to in providing less severe deformation profile development particularly on critical region of interface section.

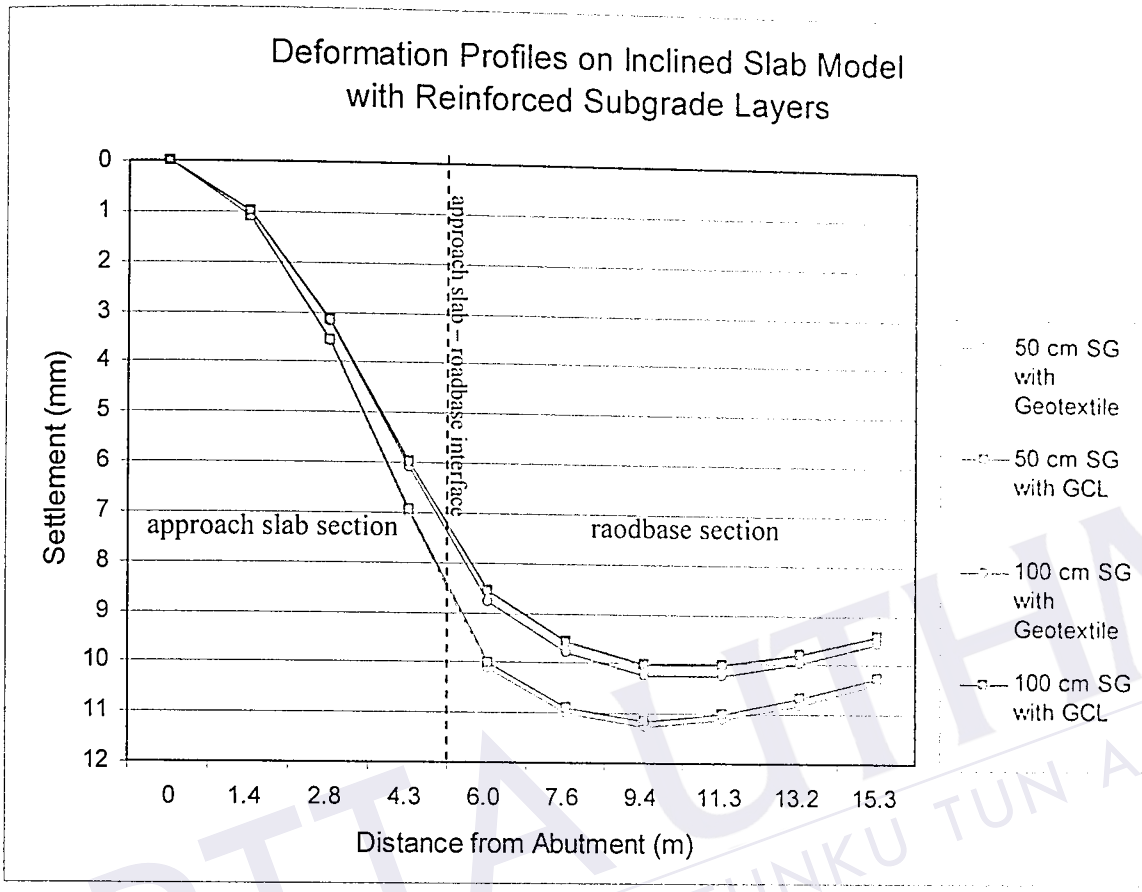

Figure 6.10: Development of Subgrade Deformation on 5° Inclined Slab Model with Different Thickness and Reinforced Subgrade Layer

6.4 Comparative Analysis on Deformation Profiles of Different Approach Slabs Models

Comparative analysis among all different approach slab models was conducted according to output data from the plotted graph in Figure 6.11. The performances of five different models with fixed subgrade thickness of 100 cm were studied with reference to the effect of different reinforcement configuration on different approach slab models. For this purpose, two models of slab were evaluated: they were conventional horizontal slab and 5° inclined slab. Each kind of this model reinforced with two different types of geosynthetic materials differentiated by means of elastic normal stiffness. In addition, a model of bridge approach section with no approach slab was also evaluated as a benchmark in this comparative analysis.

Preliminary, it has to be noted that distance point from 4.3 m toward bridge abutment were top points on subgrade layer under 5.0 m slab whereas points located at 6.0 m to 9.4 m were under road pavement section. For roadway section with no slab approach provided, distance point 9.4 m toward bridge abutment were entirely under road pavement section.

According to the Figure 6.11, it is noticed that roadway section near to bridge abutment severed the most with an abrupt drop on deformation gradient for bridge approach model without any provision of transition medium or approach slab. This steep sloping profile occurred immediately near to bridge abutment and began to flatten at target point 6.0 m away from abutment. Afterward, it has flattened and reached the maximum deformation of 10.19 mm at point 9.4 m from abutment.

However, deformation profiles on horizontal approach slab have improved significantly over bridge approach section with no transition slabs provision either with or without subgrade reinforcement. As shown in similar figure, deformation profiles on approach slab section have been flattened moderately. For all types of slab models, steeper sloping profiles have only begun at target point 2.8 m from abutment and furthered at point 4.3 m from abutment which is approximately where the approach slab intersects the road pavement section. At target point 6.0 m from abutment which is approximately only 1.0 m to approach slab end, deformation profile has begun to flatten moderately.

From the figure, it is also noticed that GCL reinforcement subgrades have performed a little distinctive with major improvement against deformation particularly on road pavement interface section. Deformations on interface point at location 6.0 m on road pavement have shown significant decrease, which were 8.60

mm and 8.59 mm respectively for both horizontal and 5° slab orientation model. Though, comparison between both models conceivably has no significant different with only small improvement on interface section for the slab with 5° inclined plane over conventional horizontal slab.

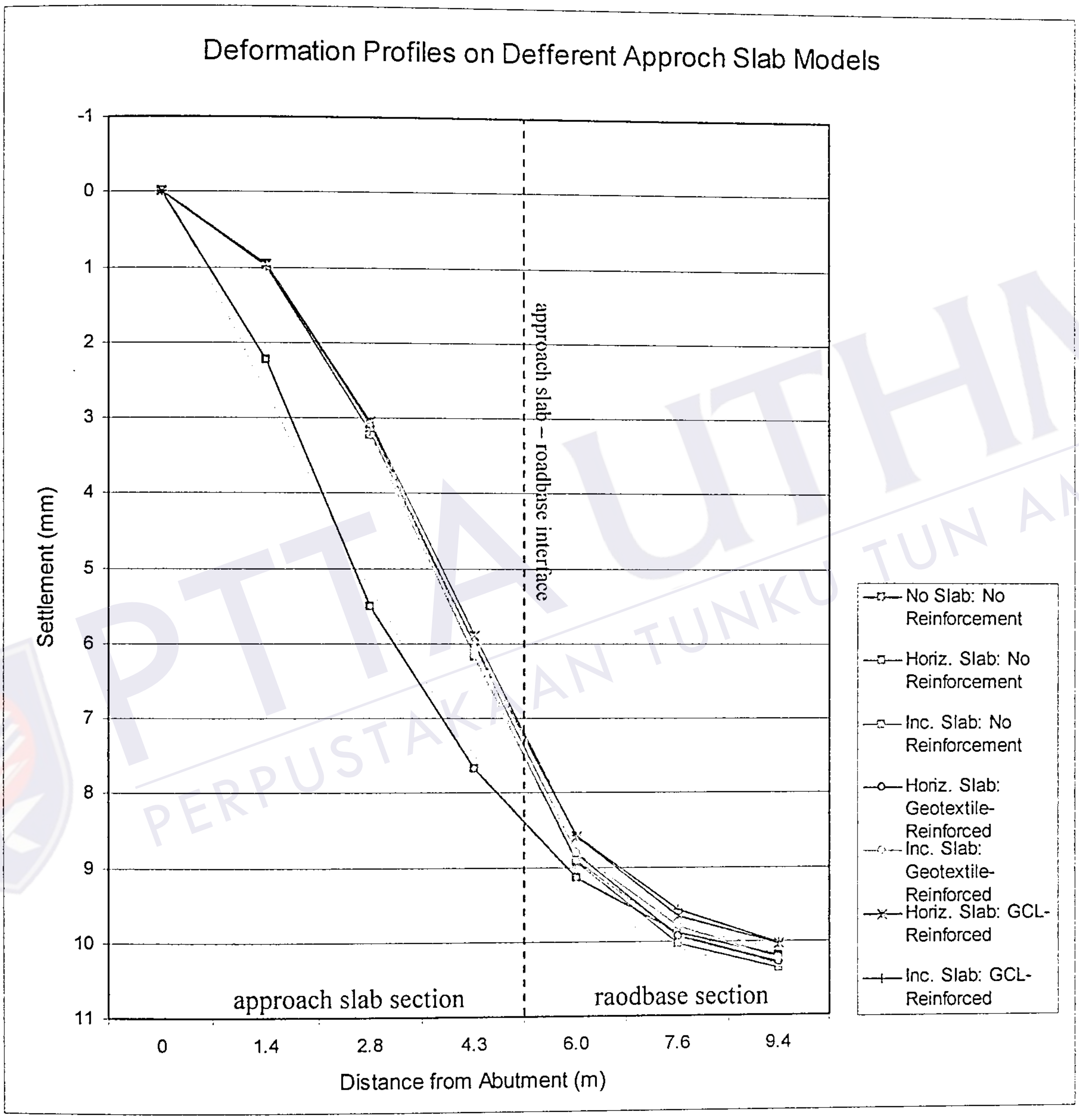

Figure 6.11: Development of Subgrade Deformations on Different Approach Slab Models

In comparison of those models, generally horizontal slab and 5° inclined slab have proved some comparable performance in order to provide smoother transition between approach slab and road pavement section. The use of higher elastic normal stiffness in design also had significant effect on performance of approach slab model. All in all, inclined slab at 5° to horizontal had demonstrated better on performance against development of deformation profiles particularly at target points near to the interface section between end of approach slab and approaching road pavement structure. For details on this analysis, further reference should be made to Section 6.5 in this chapter.

6.5 Deformation Analysis on Interface Region

It was primary important to study on development of deformation profile at interface region since the actual problem was inspected notably within this area with the apparent occurrence of depression. Moreover, development of deformations in Figure 6.11 did not give details on interaction between approach slab end and approaching road pavement. According to Figure 6.12, it was noted that both approach slab models have performed correctly in order to minimise the effect of bump with the development of comparably smooth transition between approach slab and road pavement. By the way, the performances of inclined approach slabs were improved in conceive manner with much smoother profiles in the interface region. Further details for raw data out put should be made to Table B6.14 in Appendix B.

Deformation points have also decreased steadily beyond the road pavement section. Additionally with provision of slab orientation, development of deformation profiles at approach slab section was greater in inclined slab model. This situation probably has provided some conceivable manner of improvement against development of deformation profiles toward road pavement section compared to horizontal slabs which have much steeper profiles. In addition, the use of thicker reinforced subgrade with more superior elastic normal stiffness material has demonstrated additional improvement on its performance.

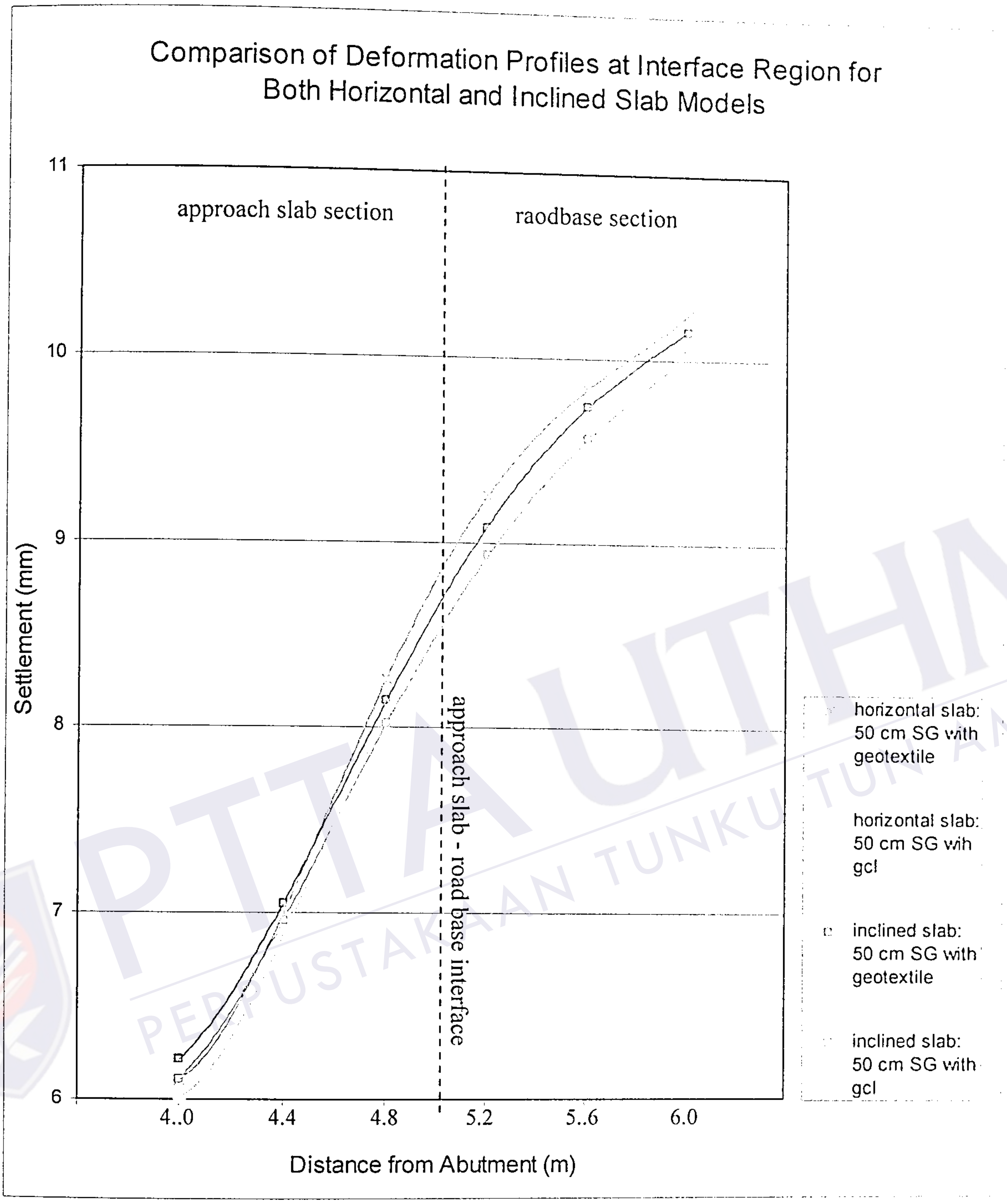

Figure 6.12: Deformation profiles of Horizontal and 5° Inclined Slab within Interface Region

Increase in thickness of reinforced subgrades obviously has improved the model performance entirely as discuss earlier in this chapter. As shown in the similar figure, the best performance model was demonstrated by inclined slab model supported by subgrade thickness of 100 cm with GCL reinforcement. The figure also clearly proved that 5° inclined slab performed better than conventional horizontal slab. On the whole, GCL material with higher normal axial stiffness was superior to geotextile material and 100 cm subgrade thickness was prominent above all other thinner subgrades and reinforcement components in this study. With exclusion of performance analysis on inclined slab model, it was apparent that the performance of all slab models were control mainly by subgrade thickness and reinforcement component of subgrade could provide minor change in development of deformation profiles.

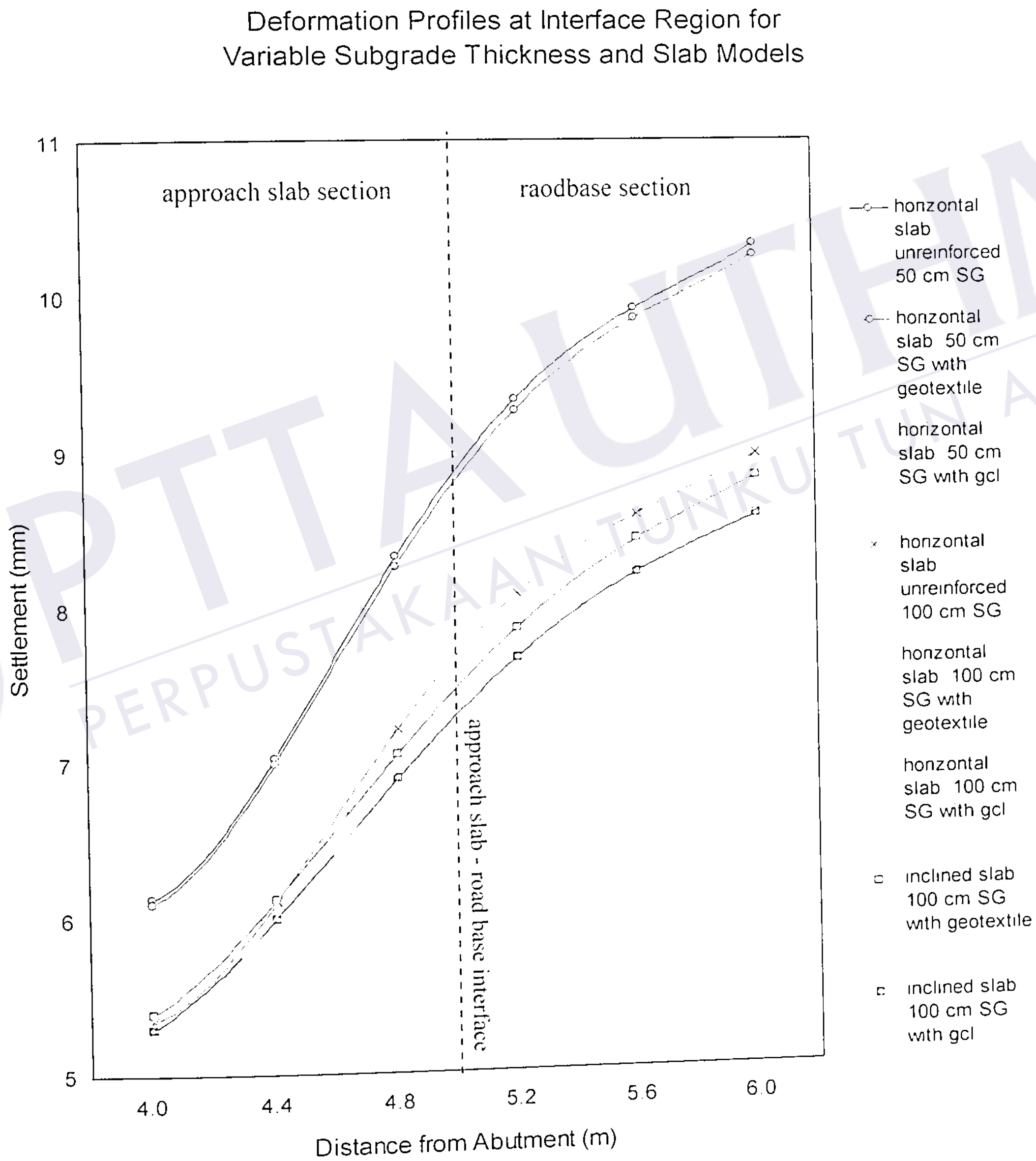

Figure 6.13: Deformation profiles of Horizontal and 5° Inclined Slab within Interface Region for Various Subgrade Thickness and Reinforcement

6.6 Limitation of Research

It is noted that this study has been conducted by means of 2-dimensional analysis, instead of more precise 3-dimensional simulation used in other researches. The model of 2-dimensional analysis used in this study was plane strain models based on geometrical input of long section area in composition of x-y direction. According to this model, displacements and strains in z-direction are assumed to be zero. The cross sectional area was not included in the study because of the limitation of 2-dimensional analysis and complexity in geometrical model configuration.

Preliminary, it is important to verify that the study has focused on the occurrence of bump at the interface section between approach slab and road pavement end instead of focusing on the problem that happened at connection joint. In this regard, non-integral abutment with provision of expansion joint has been used in modelling of bridge abutment – approach slab interface. Though, the entire structures of bridge have been simplified accordingly which have excluded some other bridge component such as wingwall, backfill materials and drainage provision.

This study was also did not count for repeated load that is supposedly demonstrate the actual imposed load from the movement of traffic. Instead, it has employed permanent loadings form traffic loads, which certainly did not visualize the real form of traffic movement. Though, it is permissible to simplify the determination of traffic loads under limitation of PLAXIS software since the analysis was prone to focus on consolidation study of permanent traffic loads in order to demonstrate the most severe distress. In addition, the use of equivalent standard axle load could not be complied due to the simplification of traffic load determination. Consequently, standard 18 kips or 80 kN load imposed on single axle dual tyres has been used in this study. Selection of point load along the observed section also primarily depends on the generation of meshes, thus the target points of deformation analysis were selected unevenly between to adjacent points.

Other simplification approach in modelling such in material design has also been employed appropriately in this study since PLAXIS software did not provide specific material modelling but only requires considerable material data input to be used in modelling of non-soil material. Additionally, this simplification has altered the actual geometrical arrangement of other components included in the modelling which was expectedly could lead to some minor error on calculation. Other than that, geosynthetic materials used in this study were also modelled modestly in view of the fact that only elastic normal stiffness parameter is considered in PLAXIS program.

CHAPTER VII

CONCLUSION AND RECOMMENDATION

7.1 Introduction

Since the beginning of research, the author has gained many experiences relating to the process of information and data collation, site investigation and observation process, and simulation analysis using existing PLAXIS Version 8 software. From the initial site investigation data gathered through series of site observations, it was found that serious surface depression occurred not only along Parit Karjo rural road, but the author also noticed that there are occurrings elsewhere around Parit Raja vicinity where the rigid structures such as concrete bridges and culverts connected to flexible road pavement were experiencing obvious differential settlement. Concurrently using the Ground Penetrating Radar equipment (GPR) to observe subsoil condition of affected area, it was found that the supporting subgrade layer of road pavement experienced severe deterioration caused by the intrusion of water table in which expectedly has provided some consequent cause of further road surface deterioration. In this chapter, the author made an attempt to conclude the research work based on the research analysis and related chapters written earlier in this thesis especially analysis and observation on data findings in previous Chapter VI. At the end of this chapter, the author proposed some recommendations for possible further and future research work or studies pertaining to acquiring alternatives to solve or reduce the differential settlements as discussed earlier in this research work.

7.2 Conclusion

The following conclusions are derived by means of the research work that has been conducted by the author. They are based on the reviews, observations and analyses discussed in earlier chapter in this thesis.

7.2.1 The Application of PLAXIS Software in Modelling Approach Slab Concept

According to methodology of research (Chapter V) that has been developed and data analysis form this research work as discussed in Section 6.2 through 6.5 in Chapter VI, it was clear that the application of PLAXIS software could be extended in such way in this research in order to obtained very promising results for this simulation analysis. In Chapter 6, simulation modelling on inclined slab at 5° to horizontal has been accomplished with success. As a result, this kind of approach slab models configuration has to be said outstanding in comparison to road pavement section model which was not provided with approach slab. It also happened to horizontal slab models configuration over similar control model.

On the other side, unexpectedly there were no highly significant effect on might due to the method of simulation work conducted during the study. In PLAXIS, geometrical input is one of the primary important parameter in modelling. Since ends of approach slab near to abutment were designed to provide rotational movement such in non-integral abutment design, free movement in vertical direction at the another end of approach slab near to flexible road pavement has provided some plain characteristic in deformation behaviour for both approach slab models. By the way, critical analysis on interface region has found that there are some unique characteristic on development of deformation profile at particular location as discussed in Section 6.5 when the simulation was conducted in smaller distance range for target points of deformations.

On the whole, PLAXIS software is essentially can be employed in simulation analysis of subgrade deformation despite of surrounding limitation issues. PLAXIS software is an exclusive platform in geotechnical engineering since it allows others material model and geometrical input to be combined altogether for modelling purpose which is lacking in some others modelling software. In addition, some highlight such as determination of boundary condition that is not verified in PLAXIS manual should be conducted properly in order to minimise the effect of fixity problem in finite element calculation. However, the results from this study should be in any form considered as approximation for the actual performance data in regards to the limitation issues as described in previous Chapter VI (Section 6.6), within the scopes of research mentioned in Chapter I (Section 1.4).

7.2.2 Interface of Approach Slab and Flexible Road Pavement

Analysis on critical interface region between end of approach slab and approaching roadbase on subgrade layer has been discussed in Chapter 6 elaborately. This critical area has always contributes to development of surface depression or

Undoubtedly, it was the main reason of why this analysis has been conducted in this research in attempt to verify and understand the deformation behaviour at interface region correctly.

According to the findings from the analysis, it was apparent that inclined slab at 5° to horizontal has performed a significant improvement on development of deformation profiles within this transition region if compared to conventional model of horizontal slab. Orientation of approach slab at some angle to horizontal surface has proved an apparent effect on interface region with comparable improvement of defomation profiles development. Though, additional reinforcement to subgrade layer did not prove change in gradient and the use of thicker subgrade only reduced the development of deformation significantly compared to reinforcement but still did not change the shape of gradient profiles.

Flattened gradient on interface section demonstrated by inclined slab over horizontal approach slab was an evident to answer that it was right to provide bridge with orientated slab used as an attempt to reduce the development of deformation profiles on particular region. The use of subgrade deformation in this research was also reasonable since the intrusion of ground water was highly expected as reviewed in Section 5.2.3 using GPR observation equipment.

7.2.3 Performance of 5° Inclined and Horizontal Approach Slab Concept

It was found that 5° inclined slab with subgrade reinforcement could provide more significant improvement at interface region on subgrade layer if compared to the conventional horizontal slab model. The developments of steep gradient profiles have been reduced significantly at this particular critical area and theoretically, it surface is design in correct manner, controlling on deformation patterns in subgrade layer could minimise the effect on surface deformation according to the rutting model criteria. Regional subgrade deformations particularly at transition and interface regions have to be well controlled to prevent distraction to upper layer of road pavement that will result in occurrence of bump.

In this study, the use of horizontal slab with subgrade reinforcement could provide better performance against subgrade deformation but the profile patterns within interface region remain unchanged but only decreasing the deformation profiles moderately. On the other view, it was apparent that the introduction of inclined slab could provide some improvement for interface characteristic against development of deformation. The advantage of the use of inclined slab would be more significant with the application of thicker subgrade reinforcement. However, the use of geosynthetic for reinforcement component did not prove their reliability as expected. This might due to the limitation in PLAXIS which only considering one parameter of strength that was normal axial stiffness in lieu of other probable important parameters particularly for geosynthetic clay liner (GCL) material.

In view of consolidation analyses that have been carried out previously in Section 6.2, those models typically have shown abrupt change in deformation within first five years period. Though, the maximum of deformation devoted by secondary consolidation has occurred variously between 10 years to 20 years in average. Secondary consolidation problem or also known as creep in soft clay environment is quite critical as in long term run, it can affect on design life of the road pavement.

7.3 Recommendations

It is known that PLAXIS software is an essential simulation program for

Version used in this study only allowed for two-dimensional simulation analysis. In many cases, geotechnical modelling with three-dimensional model is more recommended since the geometrical structures are not always uniform in z-direction. In lieu of the advantages of 3D software programming, components in z-direction are unable to be analysed according to the two-dimensional model that only consider vertical and horizontal components. Traffic loadings parameter such as contact area can also be configured correctly according to 3D analysis.

The study should also be made in laboratory scale test environment because of some other modelling components cannot be represented in software simulation due to the limitation in software design environment. Additionally, analysis on deformation can be conducted based on actual loadings behaviour which count for repeated traffic load for certain loading cycles. Other approach slab arrangement such as cantilevered approach slab should also be preferred in the future research.

In general, the author has found that there are some improvement should be needed for future research. These recommendations have been purposed such as follows:

- The use of PLAXIS 3D software is possible in order to analyses the development of deformation for approach slab models. This can be more realistic with the ability of representative 3D geometrical and material modelling.

- With the advantage of 3D modelling, analysis on cross sectional area can be conducted accordingly in order to evaluate the effect of lateral movement of the road embankment and additional geometrical parameter such as provision of drain along side the section.

- Analysis using repeated loads of moving traffic should be considered for future research work. This is primary important since load from the moving traffic are introduced to the approach slab-road pavement structure by means of repetition behaviour.

- Analysis on approach slab model with integral abutment bridge should be essential in the future since many new bridges were currently developed in such way in order to avoid the consequent problem regarding on joint construction in which also creates another bump problem.

- Finally, development of laboratory scale test can be essential since many uncertainties when using software modelling could not be answered despite of various limitations that might invalidates the expected result if not well controlled in the previous research.

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APPENDIX A

FIGURES

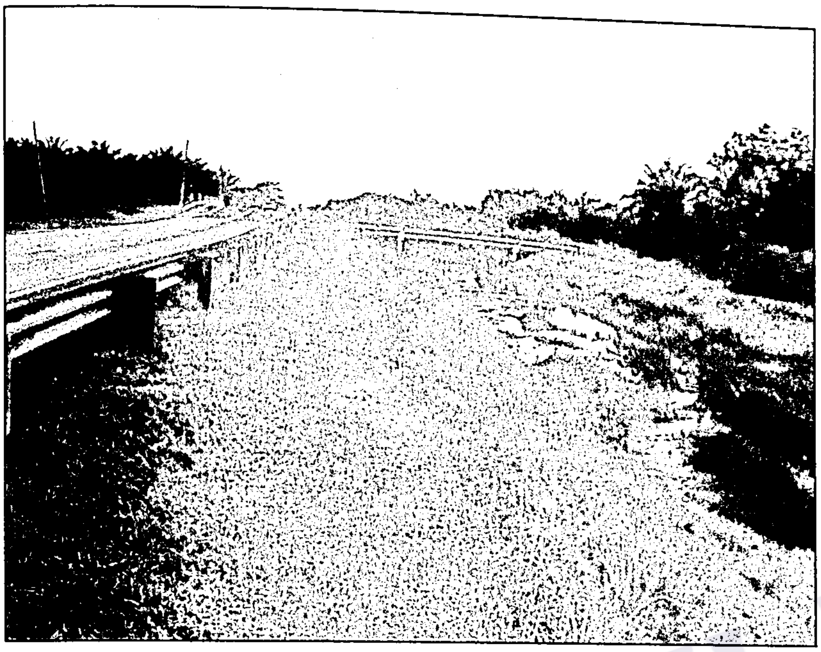


Figure A5.1: Nearby Trench Water Level in Dry Season

Figure A5.2: During Year end Monsoon Season, the Level of Water has Raised Noticeably to the Higher Level

Figure A5.3: Road Pavement Surface after over a Month Period of Overlay

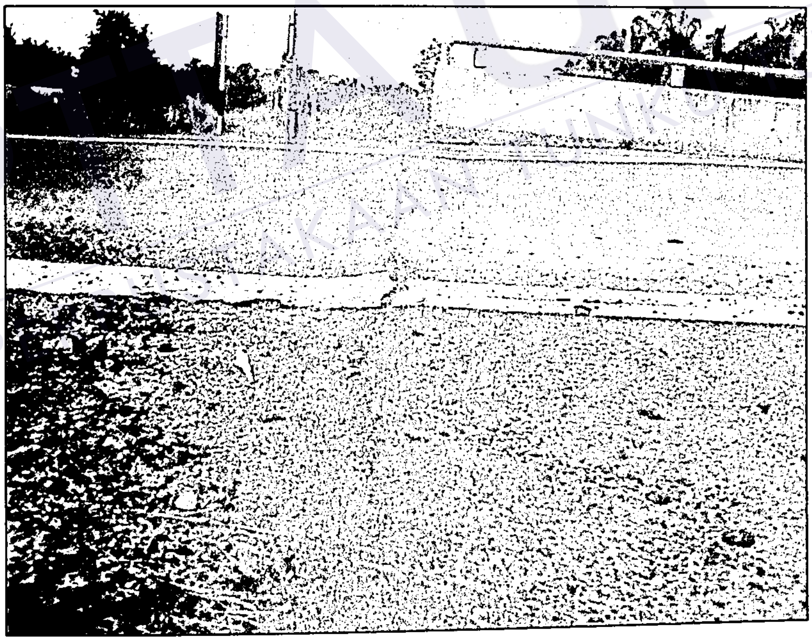


Figure A5.4: Bump on Connection between Road Pavement and Approach Slab was Reappeared after Five Month Period of Overlay

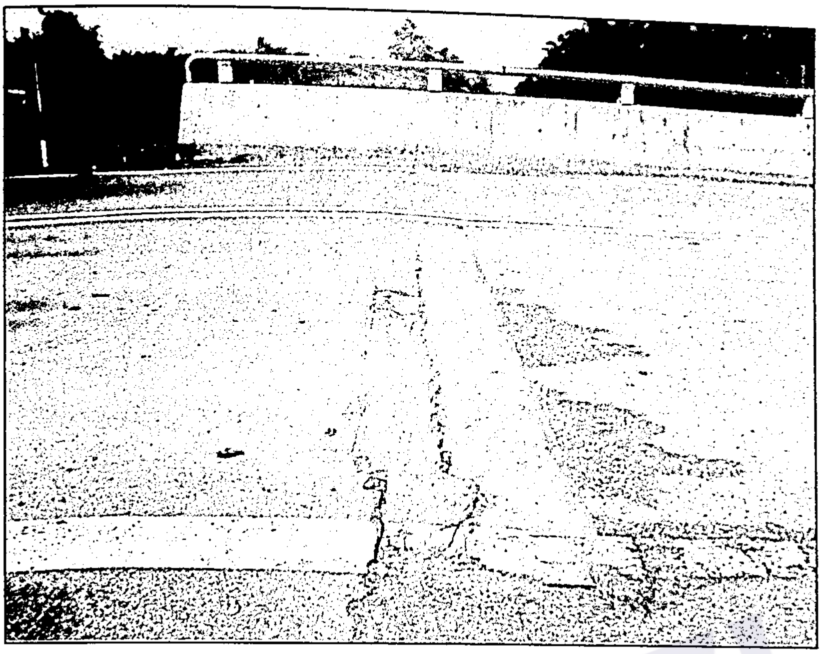


Figure A5.5: Severe Deterioration of Joint between Bridge Slab and Approach Slab was also Noticeable

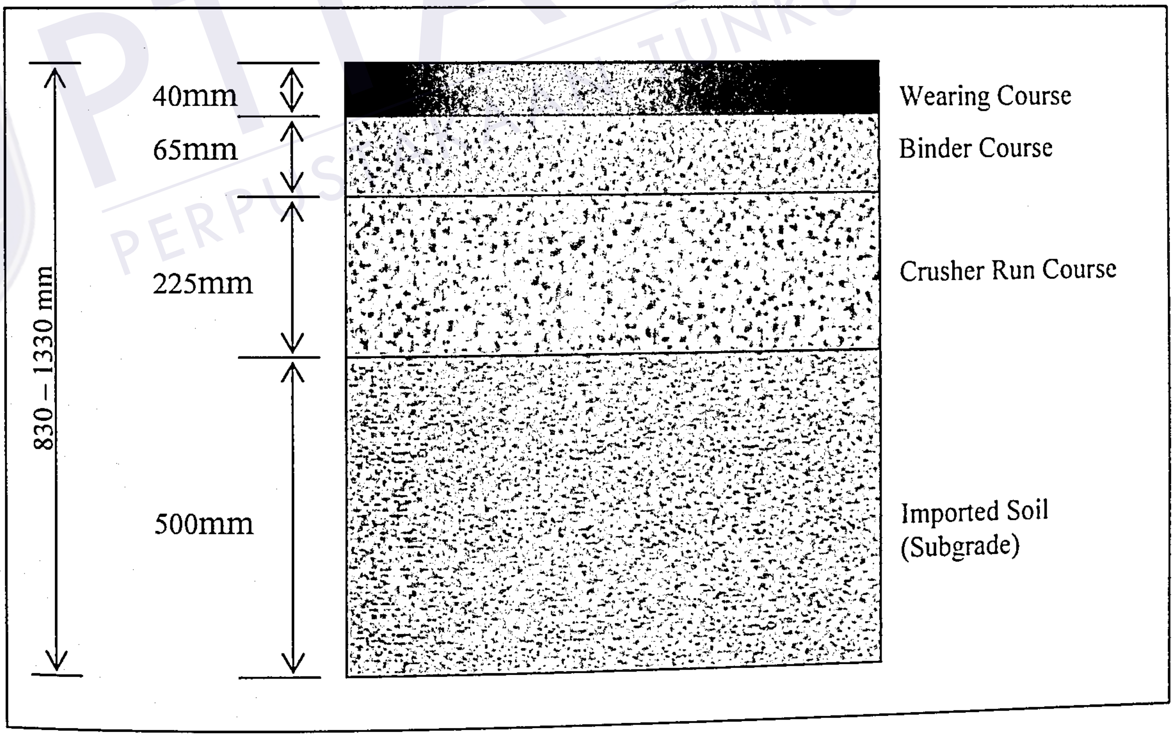


Figure A5.6: Typical Cross Section of Rural Road Pavement in Batu Pahat District (Public Work Department, 2001)

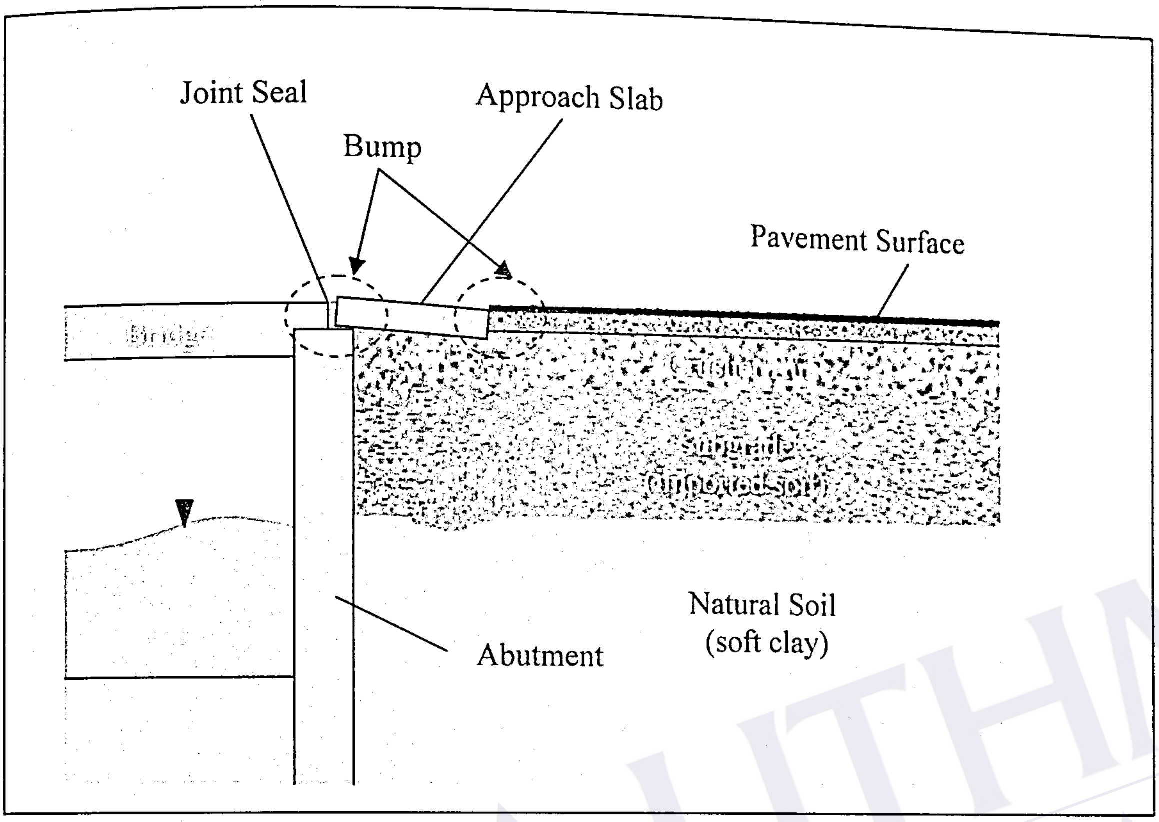


Figure A5.6: Typical Differential Settlement Problem on Approach Slab

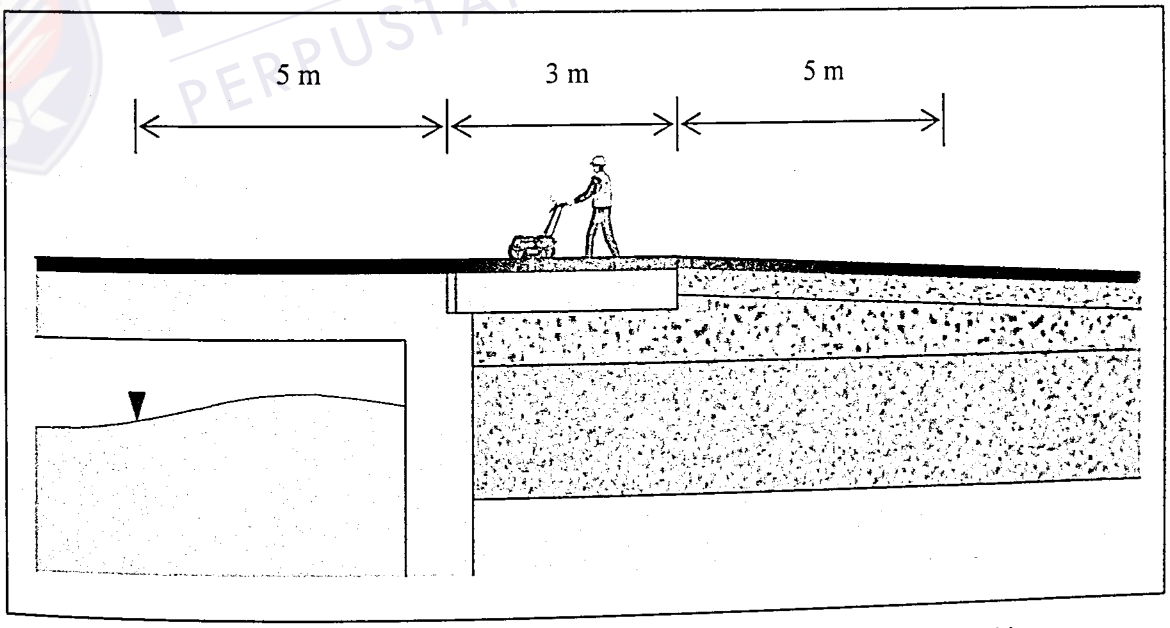


Figure A5.7: Length Characterization of GPR Observation on Site

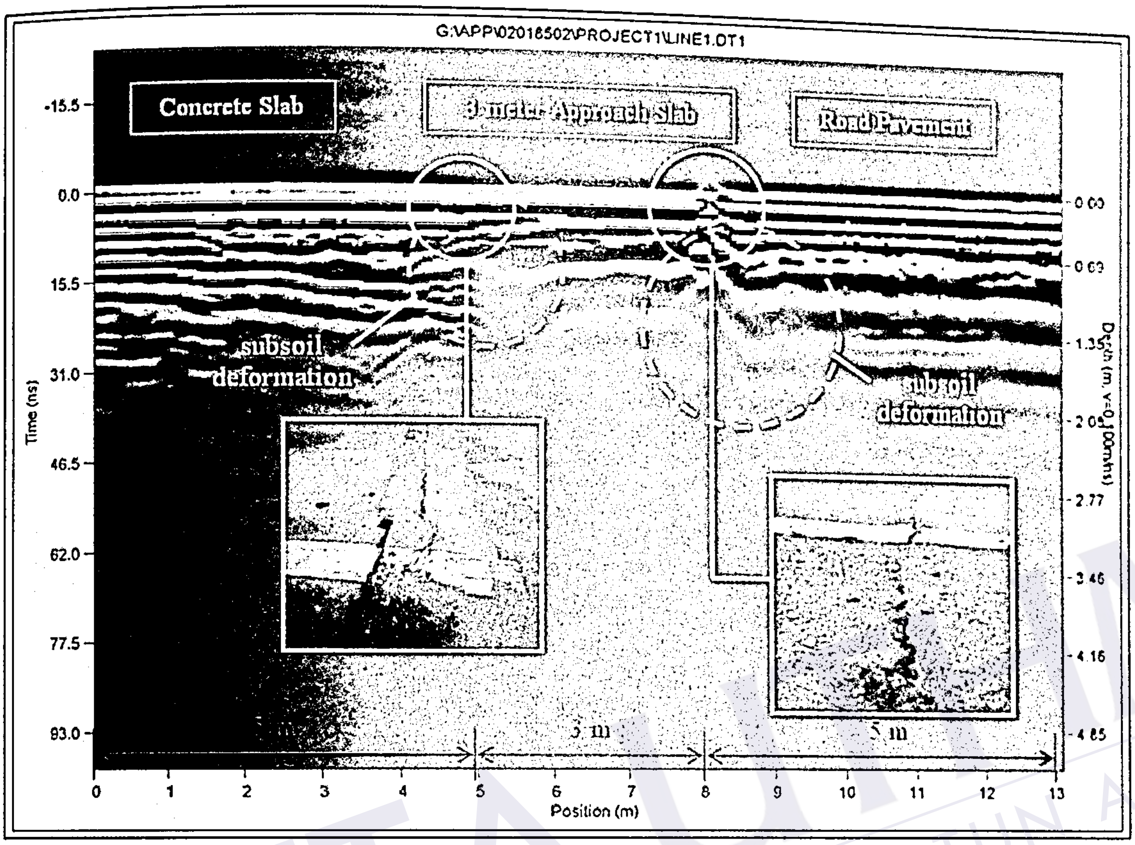


Figure A5.8: Soil and Pavement Deformation Pofile Shows Unfavourable Condition in Soil Layer and Bumpy road Pavement Surface

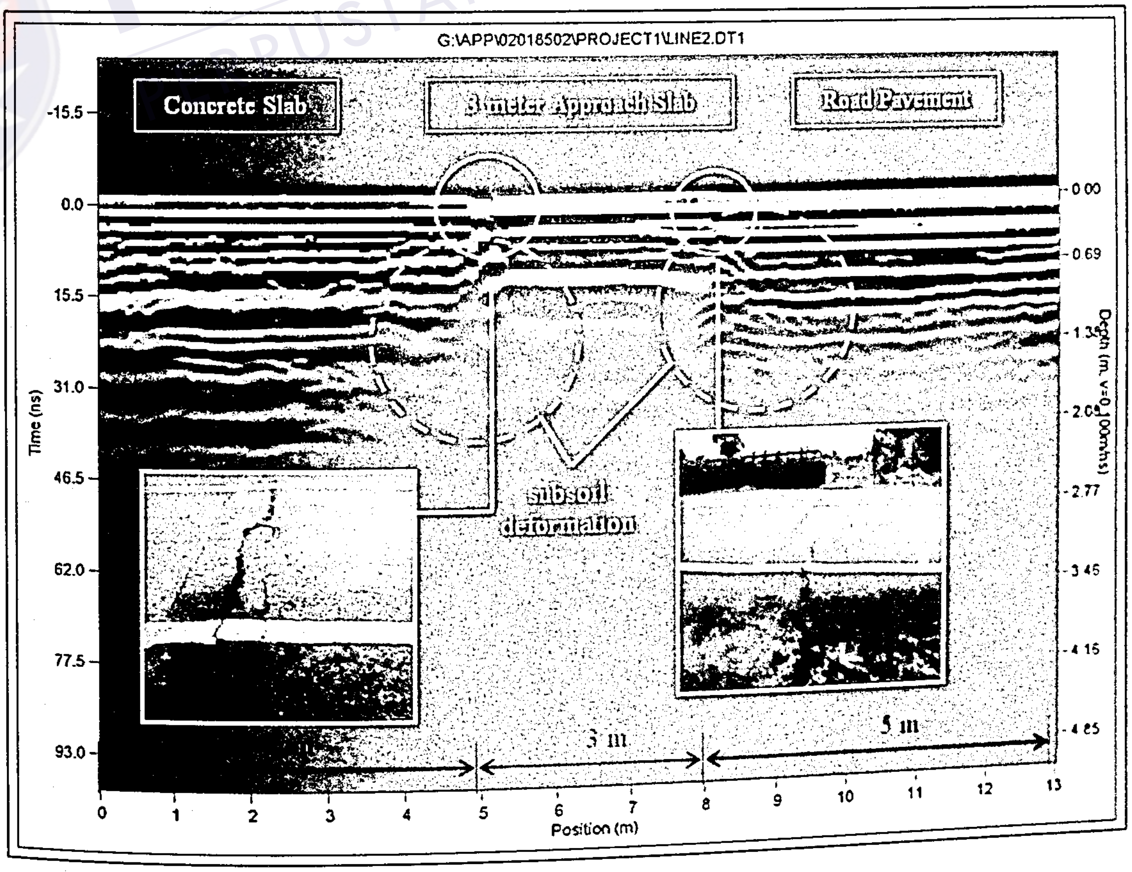


Figure A5.9: Comparable Surface and Subsurface Observation at Different Point

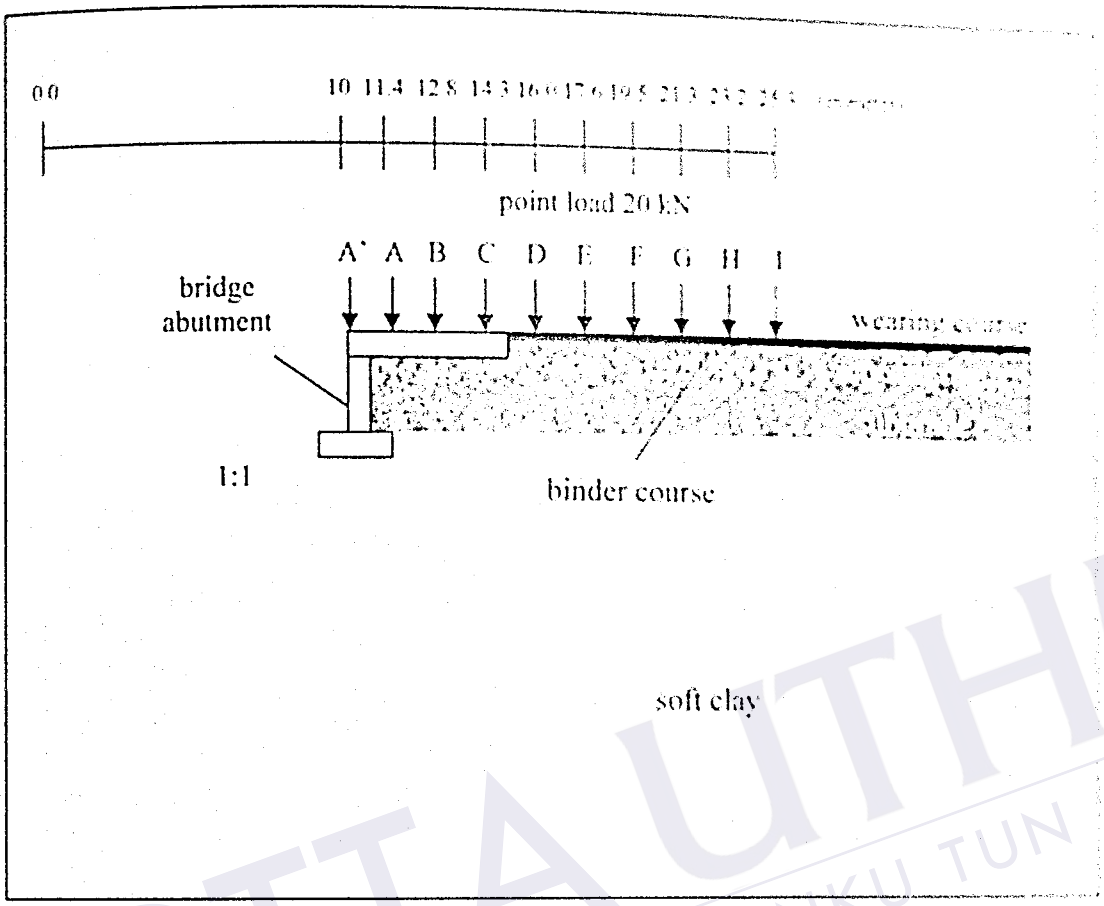
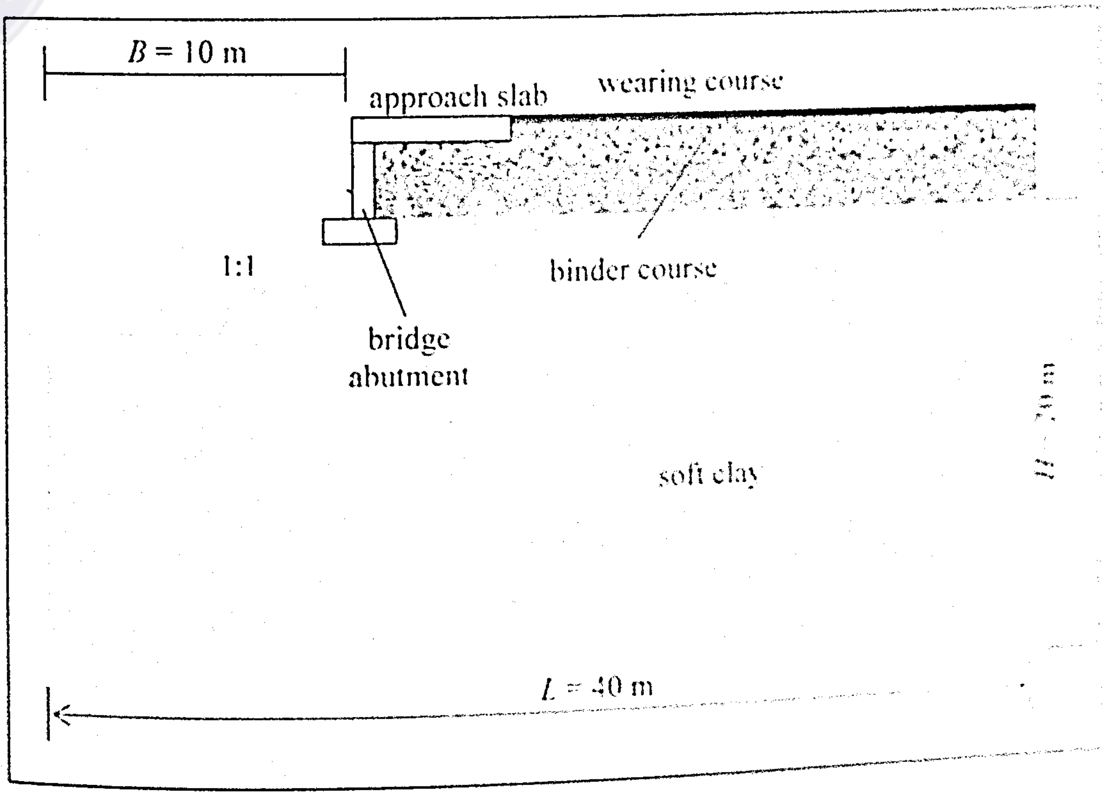


Figure A5.10: Deformation Profile Section of Design Model



APPENDIX B

TABLES

Table B5.1: Typical Rural Road Pavement Properties (Masirin, 2005)

Parameter	Value				Unit
	Layer 1	Layer 2	Layer 3	Layer 4	
Soil unit weight above phreatic level, γ_{unsat}	17.30	16.54	17.60	18.40	[kN/m ^{3}]
Soil unit weight above phreatic level, γ_{sat}	18.00	17.50	18.00	19.00	[kN/m ^{3}]
Permeability in horizontal direction, k_x	0.001	0.001	0.001	0.001	[m/day]
Permeability in vertical direction, k_y	0.001	0.001	0.001	0.001	[m/day]
Young's modulus, E_{ref}	100000	4500	4500	4500	[kN/m ^{2}]
Poisson's ratio, v	0.270	0.250	0.250	0.250	[-]
Friction angle, ϕ	24.00	27.00	27.00	27.00	[°]
Dilatancy angle, ψ	0.00	0.00	0.00	0.00	[°]
Cohesion, C_{ref}	3.00	1.00	1.00	1.00	[kN/m ^{2}]

Table B5.2: Typical Batu Pahat Soft Clay Properties (Masirin, 2005)

Parameter	Value	Unit
Soil unit weight above phreatic level, γ_{unsat}	21.00	[kN/m ^{3}]
Soil unit weight above phreatic level, γ_{sat}	24.00	[kN/m ^{3}]
Permeability in horizontal direction, k_x	0.50	[m/day]
Permeability in vertical direction, k_y	0.50	[m/day]
Young's modulus, E_{ref}	250000	[kN/m ^{2}]
Poisson's ratio, v	0.00	[-]

Table B5.3: Material Parameters of the Approach Slab

Parameter	Value	Unit
Normal Stifness, EA	8.75×10^6	kN/m
Flexural Rigidity, EI	4.577×10^4	kNm^2/m
Poisson Ratio, v	0.0	-
Weight	6.0	kN/m/m

Table B5.4: Material Parameters of the Geosynthetic Liners

Geosynthetics Type	Normal Axial Stiffness, EA
Woven Geotextile	1200 kN/m
Geosynthetic Clay Liner	7000 kN/m

APPENDIX C

PLAXIS OUTPUT DATA

Table B6.1: Deformation of Horizontal Slab with 50 cm Unreinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,082	3,468	6,889	10,061	11,015	11,182	10,994	10,230	10,186
1	1,097	3,517	6,996	10,225	11,159	11,334	11,222	10,891	10,343
2	1,098	3,519	7,012	10,252	11,262	11,383	11,225	10,952	10,423
5	1,096	3,521	7,025	10,298	11,286	11,405	11,241	10,972	10,449
10	1,096	3,522	7,031	10,314	11,292	11,412	11,241	10,994	10,454
15	1,096	3,523	7,033	10,312	11,295	11,410	11,226	10,991	10,456
20	1,096	3,523	7,034	10,312	11,295	11,410	11,219	10,971	10,482
Max. Deformation	1,098	3,523	7,034	10,314	11,295	11,412	11,241	10,994	10,482

Table B6.2: Deformation of Horizontal Slab with 100 cm Unreinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,967	3,103	6,038	8,784	9,857	10,203	10,151	9,949	9,426
1	0,966	3,114	6,076	8,874	9,959	10,273	10,264	10,052	9,527
2	0,968	3,117	6,095	8,912	10,013	10,324	10,306	10,103	9,607
5	0,966	3,118	6,107	8,940	10,032	10,345	10,344	10,132	9,634
10	0,966	3,121	6,111	8,952	10,035	10,377	10,338	10,154	9,650
15	0,966	3,121	6,113	8,955	10,036	10,380	10,351	10,153	9,655
20	0,966	3,121	6,113	8,957	10,036	10,381	10,352	10,154	9,655
max. deformation	0,968	3,121	6,113	8,957	10,036	10,381	10,352	10,154	9,655

Table B6.3: Deformation of Horizontal Slab with 50 cm Geotextile-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,089	3,478	6,885	10,046	11,023	11,174	11,018	10,753	10,201
1	1,091	3,492	6,939	10,153	11,106	11,273	11,053	10,821	10,303
2	1,094	3,502	6,969	10,201	11,19	11,318	11,152	10,923	10,354
5	1,095	3,509	6,985	10,208	11,214	11,356	11,193	10,939	10,402
10	1,096	3,51	6,994	10,236	11,215	11,354	11,194	10,94	10,405
15	1,096	3,51	6,995	10,239	11,216	11,358	11,195	10,94	10,407
20	1,096	3,51	6,996	10,243	11,216	11,358	11,194	10,941	10,407
max. deformation	1,096	3,51	6,996	10,243	11,216	11,358	11,195	10,941	10,407

Table B6.4: Deformation of Horizontal Slab with 100 cm Geotextile-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,956	3,072	5,962	8,658	9,739	10,051	10,052	9,854	9,331
1	0,966	3,100	6,024	8,790	9,883	10,243	10,231	10,003	9,518
2	0,963	3,091	6,021	8,808	9,899	10,263	10,239	10,047	9,585
5	0,959	3,095	6,037	8,826	9,923	10,261	10,251	10,053	9,588
10	0,958	3,092	6,042	8,838	9,937	10,290	10,264	10,069	9,599
15	0,958	3,094	6,043	8,841	9,940	10,281	10,263	10,067	9,602
20	0,958	3,094	6,044	8,843	9,942	10,280	10,259	10,063	9,602
max. deformation	0,966	3,100	6,044	8,843	9,942	10,290	10,264	10,069	9,602

Table B6.5: Deformation of Horizontal Slab with 50 cm GCL-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,082	3,440	6,767	9,864	10,854	11,047	10,896	10,605	10,073
1	1,083	3,454	6,814	9,956	10,917	11,102	10,963	10,693	10,191
2	1,086	3,464	6,843	10,013	11,001	11,193	11,004	10,748	10,245
5	1,088	3,470	6,861	10,045	11,022	11,201	11,042	10,775	10,267
10	1,088	3,471	6,866	10,056	11,013	11,211	11,053	10,798	10,269
15	1,088	3,473	6,868	10,047	11,004	11,232	11,047	10,796	10,278
20	1,088	3,473	6,868	10,045	11,021	11,228	11,039	10,791	10,281
max. deformation	1,088	3,473	6,868	10,056	11,022	11,232	11,053	10,798	10,281

Table B6.6: Deformation of Horizontal Slab with 100 cm GCL-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,951	3,034	5,835	8,421	9,461	9,816	9,835	9,639	9,138
1	0,961	3,061	5,910	8,555	9,618	10,002	10,003	9,810	9,320
2	0,957	3,055	5,906	8,569	9,641	10,037	10,044	9,871	9,411
5	0,952	3,050	5,905	8,580	9,652	10,039	10,040	9,859	9,392
10	0,951	3,051	5,910	8,592	9,664	10,052	10,052	9,875	9,413
15	0,951	3,052	5,911	8,594	9,667	10,053	10,054	9,878	9,417
20	0,951	3,052	5,912	8,597	9,674	10,048	10,048	9,880	9,420
max. deformation	0,961	3,061	5,912	8,597	9,674	10,053	10,054	9,880	9,420

Table B6.7: Deformation of 5° Inclined Slab with 50 cm Unreinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,100	3,564	6,928	9,982	10,883	11,259	10,948	10,102	10,148
1	1,118	3,617	7,040	10,152	11,024	11,318	11,096	10,272	10,300
2	1,118	3,619	7,054	10,168	11,065	11,314	11,197	10,347	10,419
5	1,118	3,623	7,064	10,201	11,103	11,329	11,198	10,369	10,415
10	1,118	3,625	7,069	10,236	11,102	11,324	11,198	10,873	10,447
15	1,118	3,626	7,072	10,221	11,081	11,312	11,196	10,853	10,428
20	1,118	3,626	7,072	10,213	11,080	11,313	11,196	10,851	10,432
Max. Deformation	1,118	3,626	7,072	10,236	11,103	11,329	11,198	10,873	10,447

Table B6.8: Deformation of 5° Inclined Slab with 100 cm Unreinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,988	3,201	6,100	8,747	9,726	10,153	10,139	9,838	9,412
1	0,989	3,217	6,146	8,832	9,825	10,237	10,218	9,932	9,517
2	0,993	3,222	6,163	8,867	9,868	10,282	10,271	9,995	9,594
5	0,991	3,225	6,178	8,893	9,893	10,301	10,294	10,046	9,621
10	0,991	3,227	6,183	8,903	9,905	10,302	10,301	10,027	9,637
15	0,991	3,227	6,185	8,907	9,908	10,317	10,306	10,119	9,642
20	0,991	3,228	6,186	8,908	9,910	10,319	10,305	10,118	9,644
Max. Deformation	0,993	3,228	6,186	8,908	9,910	10,319	10,306	10,119	9,644

Table B6.9: Deformation of 5° Inclined Slab with 50 cm Geotextile-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,107	3,575	6,937	9,980	10,893	11,113	10,988	10,647	10,203
1	1,111	3,594	6,991	10,049	10,971	11,198	11,035	10,704	10,296
2	1,115	3,607	7,021	10,113	11,012	11,241	11,117	10,783	10,351
5	1,117	3,615	7,039	10,152	11,048	11,285	11,145	10,831	10,405
10	1,118	3,618	7,044	10,151	11,027	11,301	11,153	10,819	10,401
15	1,118	3,618	7,045	10,151	11,026	11,298	11,148	10,737	10,399
20	1,118	3,619	7,046	10,148	11,024	11,297	11,148	10,821	10,386
Max. Deformation	1,118	3,619	7,046	10,152	11,048	11,301	11,153	10,831	10,405

Table B6.10: Deformation of 5° Inclined Slab with 100 cm Geotextile-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,979	3,173	6,033	8,633	9,604	10,006	10,008	9,739	9,319
1	0,992	3,209	6,098	8,763	9,764	10,162	10,163	9,909	9,496
2	0,998	3,203	6,087	8,780	9,790	10,208	10,200	9,968	9,564
5	0,985	3,200	6,115	8,795	9,799	10,217	10,218	9,957	9,564
10	0,983	3,202	6,122	8,805	9,811	10,223	10,224	9,975	9,581
15	0,983	3,203	6,123	8,808	9,815	10,236	10,236	9,977	9,586
20	0,983	3,204	6,124	8,810	9,816	10,234	10,235	9,979	9,589
Max. Deformation	0,998	3,209	6,124	8,810	9,816	10,236	10,236	9,979	9,589

Table B6.11: Deformation of 5° Inclined Slab with 50 cm GCL-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	1,103	3,548	6,845	9,817	10,758	11,004	10,863	10,524	10,053
1	1,107	3,567	6,894	9,927	10,823	11,062	10,901	10,551	10,142
2	1,110	3,579	6,925	9,993	10,859	11,107	10,972	10,629	10,215
5	1,112	3,587	6,943	10,026	10,901	11,158	11,016	10,687	10,253
10	1,112	3,588	6,948	10,028	10,903	11,159	11,014	10,693	10,261
15	1,113	3,590	6,950	10,032	10,905	11,161	11,016	10,701	10,290
20	1,113	3,590	6,951	10,034	10,906	11,162	11,016	10,698	10,292
Max. Deformation	1,113	3,590	6,951	10,034	10,906	11,162	11,016	10,701	10,292

Table B6.12: Deformation of 5° Inclined Slab with 100 cm GCL-Reinforced Subgrade against Consolidation.

No. of Years	Target Points from Abutment								
	1.4 m	2.8 m	4.3 m	6.0 m	7.6 m	9.4 m	11.3 m	13.2 m	15.3 m
	A	B	C	D	E	F	G	H	I
0,5	0,975	3,145	5,925	8,423	9,364	9,793	9,804	9,546	9,133
1	0,988	3,183	5,995	8,551	9,532	9,974	9,982	9,724	9,314
2	0,984	3,176	5,984	8,566	9,563	10,025	10,026	9,790	9,402
5	0,980	3,171	5,996	8,572	9,564	10,027	10,028	9,770	9,387
10	0,978	3,176	6,002	8,582	9,573	10,019	10,022	9,789	9,407
15	0,978	3,173	6,003	8,584	9,579	10,015	10,016	9,793	9,411
20	0,978	3,172	6,004	8,585	9,580	10,016	10,016	9,795	9,413
Max. Deformation	0,988	3,183	6,004	8,585	9,580	10,027	10,028	9,795	9,413

Table B6.13: Development of Deformation at Target Points of Subgrade Layer for Different Approach Slab Models.

Approach Slab Models													
	Distance from Left Boundary			10 m			15 m						26 m
	Distance Point from Abutment				1.4	2.8	4.3	6.0	7.6	9.4	11.3	13.2	15.3
	Reference Points	Bridge End/ Slab/ Pavement		bridge	approach slab			pavement					
		Target Points		A'	A	B	C	D	E	F	G	H	
	Subgrade Reinforcement		Subgrade Thickness										
1) NO SLAB	Unreinforced		SG: 50cm	0,000	2,678	6,620	9,128	10,500	11,071	11,218	11,094	10,831	10,453
			SG: 100cm	0,000	2,237	5,521	7,689	9,140	9,890	10,192	10,155	9,947	9,627
2) HORIZONTAL SLAB	Unreinforced		SG: 50cm	0,000	1,098	3,523	7,034	10,314	11,295	11,412	11,420	10,994	10,482
			SG: 100cm	0,000	0,968	3,121	6,113	8,957	10,036	10,381	10,352	10,154	9,655
	Geosynthetic	Geotex 1200	SG: 50cm	0,000	1,096	3,51	6,996	10,243	11,216	11,358	11,195	10,941	10,407
		GCL 7000		0,000	1,088	3,473	6,868	10,056	11,022	11,232	11,053	10,798	10,281
		Geotex 1200	SG: 100cm	0,000	0,966	3,100	6,044	8,843	9,942	10,290	10,264	10,069	9,602
		GCL 7000		0,000	0,961	3,061	5,912	8,597	9,674	10,053	10,054	9,880	9,420
3) INCLINED SLAB at 5°	Unreinforced		SG: 50cm	0,000	1,118	3,626	7,072	10,236	11,103	11,329	11,198	10,873	10,447
			SG: 100cm	0,000	0,993	3,228	6,186	8,908	9,910	10,319	10,306	10,119	9,644
	Geosynthetic	Geotex 1200	SG: 50cm	0,000	1,118	3,619	7,046	10,152	11,048	11,301	11,153	10,831	10,405
		GCL 7000		0,000	1,113	3,590	6,951	10,034	10,906	11,162	11,016	10,701	10,292
		Geotex 1200	SG: 100cm	0,000	0,998	3,209	6,124	8,810	9,816	10,236	10,236	9,979	9,589
		GCL 7000		0,000	0,988	3,183	6,004	8,585	9,580	10,027	10,028	9,795	9,413

Table B6.14: Development of Subgrade Deformations at Approach Slab – Roadbase Interface.

Distance from Abutment (m)			4.0	4.4	4.8	5.2	5.6	6.0
Types of Model:	Subgrade Reinforcement	Subgrade Thickness	Target Points					
			C'	C	D'	E'	F'	D
1) Horizontal Slab	Unreinforced	50 cm	6,133	7,034	8,318	9,323	9,902	10,314
		100 cm	5,354	7,034	7,213	8,072	8,576	10,314
	Geosynthetic-Reinforced	50 cm	6,102	7,034	8,259	9,251	9,834	10,314
		100 cm	5,296	7,034	7,125	7,974	8,471	10,314
	GCL-Reinforced	50 cm	6,002	7,034	8,087	9,050	9,637	10,314
		100 cm	5,188	5,912	6,955	7,766	8,245	8,597
2) Inclined Slab at 5°	Unreinforced	50 cm	6,201	7,072	8,187	9,131	9,783	10,236
		100 cm	5,445	6,186	7,134	7,940	8,510	8,908
	Geosynthetic-Reinforced	50 cm	6,212	7,046	8,149	9,080	9,740	10,152
		100 cm	5,395	6,124	7,056	7,851	8,416	8,810
	GCL-Reinforced	50 cm	6,105	6,951	8,021	8,923	9,561	10,034
		100 cm	5,303	6,004	6,900	7,661	8,202	8,584