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PEAT AND ORGANIC SOILS CHALLENGES IN ROAD CONSTRUCTION IN SARAWAK: JKR SARAWAK EXPERIENCE

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SUMMARY

Road construction on peat/organic soils has always posed challenges to Engineers, Contractors and policy-makers, be it a technical, contractual obligation, or cost implication. The success of road construction on soft soils relies on various important factors such as proper planning, analysis, design, construction, control and supervision. For Engineers, the primary boundary conditions are the stability and allowable settlement in terms of serviceability limits both as a function of time. Our current observation reveals that many of the road embankments and culvert foundation failures are associated with geotechnical factors. Majority of these failures are still repeating and quite identical / similar in nature that they are caused by failure to comply with one or a combination of the above factors. This paper presents some of the case histories of the road embankment construction closely related to the geotechnical factors investigated by the Author. Lastly, some simple guidelines on Method of Treatment, Cost and Design Principle to prevent future embankment failures related to geotechnical factors on soft ground are presented.

INTRODUCTION

Sarawak has approximately 1.7 million ha of tropical peat that covers 13% of the total land area (12.4 million ha.). It is the largest area of peatland in Malaysia. It constitutes nearly 63% of the total peatland of the country. More than 80% of the peats are more than 2.5 m depth.

Peat is identified as soils with more than 35% organic matter content. Peatlands present a challenge for road construction in tropical terrain like the lowlands of Sarawak. The lowlands in Sarawak constitute the largest peat areas in Malaysia with 1,657,600 sq. km which make up 13% of the State (Singh *et al*., 1997). The aerial extent of peat swamp forests in Sarawak is shown in Figure 1.

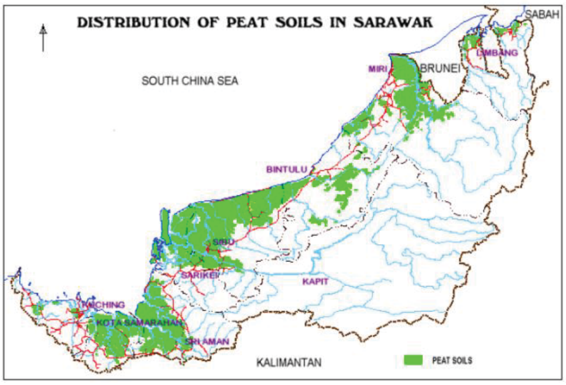

Fig. 1: Distribution of Peat in Sarawak. (Source: Jabatan Pertanian Sarawak 2001)

It is seen that peat is aerially distributed over many parts of the State and the area in different administrative divisions (Singh *et al*., 1997) is shown in Table 1.

Sibu Town is located at the confluence of the Batang Rajang and Batang Igan. Sibu Town and its surroundings are overlain with substantial formations of peat soils, almost unrivalled when compared to other parts of Malaysia. The peat formations in some parts of Sibu Town are well over 10 metres in depth. Land subsidence is a serious problem in Sibu Town with frequent refilling and repairing being carried out to reinstate structures, platforms and infrastructure.

The problems in designing and construction of embankment over very soft compressible peat and organic soils in Sibu Division arise due to the high compressibility (Cc=1.045-1.64), low shear strength (Cu=<10kPa), high natural Moisture Content and high ground water level (near to ground surface).

The engineering term "soft soils" tends to be used very loosely to refer "peat/organic soils" and "soft clay" which cannot support fill of reasonable height above the existing ground level. The reasonable height could mean 1 metre for some people but 3 or 4 metres for the others. Thus, such a way of defining "soft soils" is subjective and could result in confusion and disputes in some instances. From soil mechanics approach, we shall define "soft soils" with an undrained shear strength less than 40 kN/m^2 based on scale of strength given in B.S.5930:1981.

Table 1: Areas under peat in the various administrative divisions in Sarawak (Singh *et al.,* 1997)

Division	**Area (sq. km)**
Kuching Administration Division	23,059
Samarahan Administration Division	192,775
Sri Aman Administration Division	283,076
Sibu Administration Division	540,800
Sarikei Administration Division	169,900
Bintulu Administration Division	146,121
Miri Administration Division	276,579
Limbang Administration Division	25,300
Total	1,657,600

METHODOLOGIES OF INFRASTRUCTURE CONSTRUCTION OVER PEAT & ORGANIC SOILS

A wide variety of techniques for engineering construction over soft clays have been adopted by engineers. These range from pure structural options (e.g. Viaducts, bridges, pile embankments) to soil mechanics alternatives (e.g. surcharge, preloading, etc). In the soil mechanics approach, sophisticated variants, such as the use of vertical drains and vacuum preloading are commonly applied solutions. The following are some of the conventional displacement construction methods and current soil mechanics construction methodologies of infrastructure development on peat /organic soils adopted by the relevant government agencies and developers in Sibu Division.

CONVENTIONAL DISPLACEMENT APPROACH OF INFRASTRUCTURE DEVELOPMENTS

The New Sibu Airport Road and Salim/New Airport By Pass which was constructed in the 1990s provided a faster linkage of the town center with the New Sibu Hospital and the New Sibu Airport. Most sections of the proposed dual carriageway passed through a very soft peaty terrain. Due to fund and time constraints, the roads were constructed by JKR in-house design team adopting the conventional methods of 'cut and fill' or displacement method by dumping of fill materials using Bulldozer, progressively onto the soft ground. No proper soil investigation works were carried out to determine the thickness of the soft soil and ground water conditions. No geotechnical parameter inputs were incorporated in the design for ground treatment. The road embankment went into severe instability problem coupled with differential settlement during the construction stage. It has been observed that the compensating fills for some of the deep peat areas (approximately 10 meters) are very large or "not sustainable"; meaning that stabilization of the filled ground at the desired platform level cannot be achieved (as shown on photographs in Fig. 2.1a to 2.1c taken during the construction stage)

Fig. 2.1a & 2.1b : "Displacement Method" of Road Construction on Peat & Organic Soils along New Sibu Airport Road.

Fig. 2.1c : "Displacement Method" of Road Construction on Peat & Organic Soils along Salim/New Airport By Pass

Fig. 2.1d : Highlight on the defects of Conventional Method of Road Construction on Peat & Organic Soils

This "displacement method" of road embankment construction was time consuming as the fill materials take time to sink down to the firm bearing stratum due to buoyancy force (high water table level). The rate of filling was not controlled with the help of geotechnical instrumentation and many sections of road embankment experienced rotational base failure during construction. The worst experiences are the long term settlement of road embankment and pavement deformations which contribute to unsafe, poor riding quality and high road maintenance costs (as shown in Fig. 2.1d) JKR were spending about RM 1.5 to 2 million annually for the topping up (approximately 300mm) and resurfacing works for these sections of road to improve the vertical alignment and the pavement deformation. Differential settlement of road embankment problems still persists today. Moreover, the service life of the roads constructed under Conventional Method "Displacement Method" is short and road maintenance costs are exorbitantly high and financially unsustainable.

SUSTAINABLE APPROACHES OF INFRASTRUCTURE DEVELOPMENT

The recent case history of the following infrastructure projects highlights the concepts of sustainable construction on the peat and organic soils in Sibu Town.

The Jalan Nang Sang/Teku Link was constructed with new methodology of *"Partial Replacement of Peat Soils with preloading".* The very soft compressible peat soils are excavated out and replaced with sand fill materials that provide a stronger and less compressible foundation. The experience on this road indicates that the excavation and replacement depth up to a maximum of 5 m is viable in terms of cost and practicality. The excavation was extended to the toe of the embankment to increase the stability of the embankment. Due to anticipation of high post-construction-settlement of the varying peat depth along the roadway, 1.5 meters surcharge was introduced with rest period of 9 months for the whole stretch. Upon completion of pre-consolidation of road formation, surcharge was removed based on *"ASOKA Method of 90% primary consolidation Analysis"* and subsequently the road pavement works were completed with premix sealing. The geotechnical instrumentation works were adopted to monitor excess pore water pressure and consolidation settlement during and after construction. To date, this stretch of road has minimal pavement deformation recorded at the bridge and culverts approach due to secondary consolidation settlement of the embankment. The average post construction differential settlement is not more than 150mm for duration of two (2) years. It is proven to be viable and sustainable to construct road with ground improvement techniques.

Fig. 2.2a.

Fig. 2.2b.

Fig. 2.2c. Fig. 2.2d.
Fig. 2.2e. Fig. 2.2f.

Fig. 2.2a. to 2.2f. Stages of construction

▪ Settlement Calculations based on Surface Investigation & laboratory testing datas

Borehole	Total Settlement (mm)	Total Settlement for 1 year (mm)	Total Settlement for 2 years (mm)
BH1	347.1	44.5	62.5
BH2	1425.7	132.6	185.1
BH3	837.3	206.0	291.3
BH4	797.0	146.1	206.2
BH5	675.2	122.9	173.5
BH8	241.1	106.6	149.5
BH9	44.1	43.3	-
BH10	49.6	46.3	-
BH11	105.3	76.5	95.7
BH12	87.3	82.9	-
BH13	1020.3	419.1	589.7

Remarks: GROUND TREATMENT REQUIRED DUE TO EXCESSIVE SETTLEMENT

Table 2 : Settlement Criteria and Calculations

In conclusion, this method sums up the essential requirements for a successful embankment construction over very soft compressible soils as follow:

1. Appreciation of the project requirements in terms of serviceability criteria (deformation tolerances, bearing capacity, etc), cost implications (construction and maintenance costs), and time (construction time, service life).
2. Thorough knowledge of the site geology through proper desk study, collection of geological information; effective planning and supervision of subsurface investigation works and laboratory testing for the acquisition of necessary reliable parameters for geotechnical designs.
3. Proper geotechnical design practices to address both stability of the embankment and control of deformation.
4. Full time proper supervision of the construction works by dedicated qualified QAQC personnel/Engineers.
5. Careful and proper monitoring of the geotechnical instrumentation on the performance of the embankment during and after construction.

CASE HISTORIES OF GEOTECHNICAL DISTRESS ON PEAT/ORGANIC & SOFT SOILS

Case History No. 1

The project is the Upgrading of Kuching/Sibu federal trunk road from Julau Junction to New Sibu Airport. The road embankment along Ch. Km 8 + 450 to Km 8 +700 was constructed with Ground Treatment Type 3-BambooMattress/Geotextile design(Peat Areas) as shown in Fig. 3 below but failed to sustain with even 1m height of fill above the existing ground.

Subsequent soil investigation carried out revealed that the peat depth of the site is about 14m underlying with a 3m deep of soft clay and stiff shale formation beneath. The natural moisture content of peat is over 1000% with organic content exceeding 75%. The SPT N-value was recorded "Zero value per 300mm penetration of SPT Hammer" from 0 m to 14 m for the soft organic soils layer.

The construction of the whole embankment was based on stage construction with 15m wide counterberms and instrumentation works installed to monitor the excess pore water pressure and rate of settlement. The entire section of road sealing works was delayed for more than 12 months. To date, the road embankment still undergoes excessive settlement exceeding the serviceability limit of JKR requirement.

The lesson learned on this case study is the inappropriate design approach based on soil mechanics method. The structural design method (pile-supported embankment) should have been adopted to arrest the deep-seated soft organic soil stability problem in the long run and reduce the construction time. A simple bearing capacity equation (q_{allow}=(Su *N_c/FOS) check on the embankment stability should have been adopted as the undrained shear strength of the soft organic soils is in the range of 5 to 10kPa only. The post construction settlement over a duration of 3 years has exceeded 350mm. This is another proof of unsatisfactory design of road construction methodology on soft organic soils.

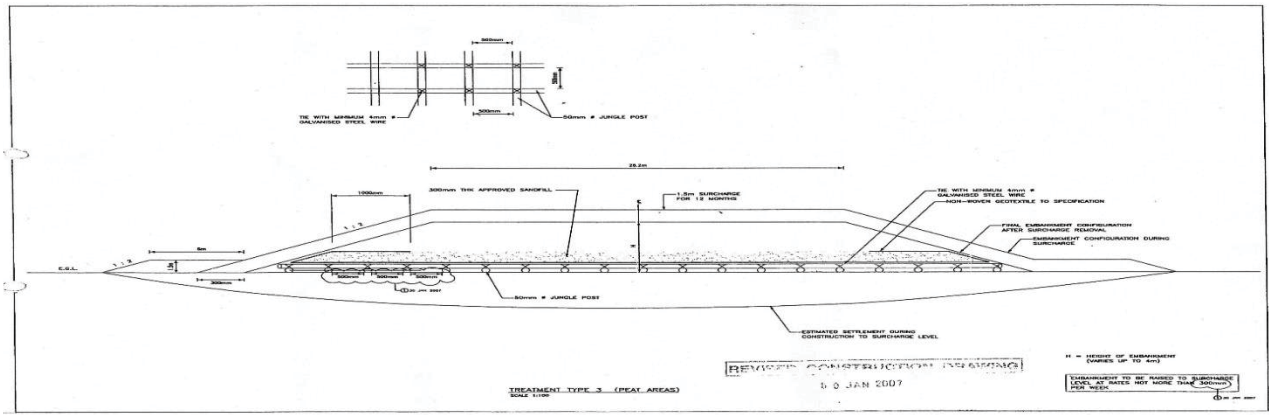

Fig. 3 Schematic detail of ground treatment Type 3 (Peat Areas)

Case History No. 2

The project is the Sg. Bidut access road constructed by hydraulic sandfill based on Total Replacement and Surcharging approach. The overall serviceability limit of the road based on function and performance criteria on settlement seem to be satisfactory based on our 36 months post construction observational studies. However, one section of the road embankment along Km 12 + 100 to Km 12 + 400 recently undergoes severe lateral movement and collapse of road embankment at the R. C. Culvert due to the over draining of ground water from the surrounding oil palm plantation development. (as shown on photographs in Fig. 3.2a to 3.2b)

The lesson learned is the avoidance of using peat soils as the retention bund material for retaining the hydraulic sandfill (fine-grained sands) embankment due to the high permeability of the fibrous peat soils and could not serve as "clay liner" to prevent seepage problem in the event of "Critical Hydraulic Gradient" resultant from blockage or inadequate discharge capacity of balancing culvert. The lowering of future ground water regime and differential level should be incorporated in the design of long term embankment stability of sandfill embankment.

However, another lesson learned is the serviceability limit of the road which is well design within the design criteria. The 36-month maximum post construction settlement data along the whole longitudinal profile of the road is less than 289mm.The maximum change of grade over 25m chainage is less than 1.5%.These data indicate good riding quality of the road based on sustainable road construction methodology on peat/organic & soft ground.

Fig. 3.2a.

Fig. 3.2b.

PROJECT: JALAN SG. BIDUT, SIBU DIVISION, SARAWAK.

GEOTECHNICAL ANALYSIS ON CONSOLIDATION SETTLEMENT OF ROAD EMBANKMENT DURING & POST CONSTRUCTION

Borehole	Chainage	Calculated 90% Settlement(mm)	Settlement Plate	Measured Settlement(mm)	Asoaka 90% Settlement(mm)	Post construction Settlement(mm)-36months	Methods of Construction
BH 1	1000(Area 'A') 1450	347.1 347.1	S2 @ Ch.0370 S3 @ Ch.0800 S4 @ Ch.1150	301 @ 359 days 188 @ 554 days 288 @ 604 days	272 175 274	163 @ Ch.1000 284 @ Ch.1450	0.5 m Top Soil excavation
BH2	2000(Area 'B')	1425.7	S5 @ Ch.1600	532 @ 623 days	556		Full depth excavation of peat layer + PVD + 0.5m surcharge
			S6 @ Ch.2150	954 @ 623 days	899	131 @ Ch.2150	
			S7 @ Ch.2360	1249 @ 665 days	1165	141 @ Ch.2300	
BH3	3000(Area 'B')	837.3	S8 @ Ch.2800 S9 @ Ch.3140	545 @ 561 days 1073 @ 576 days	532 990	51 @ Ch.2925 117 @ Ch.3075 156 @ Ch.3650	
BH4	4000(Area 'B')	797.0	S10 @ Ch.3556	1041 @ 589 days	984		Full depth excavation of peat layer + PVD + 0.5m surcharge
			S11@ Ch.4145	771 @ 268 days	N.A.		
			S12 @ Ch.4425	509 @ 512 days	540	170 @ Ch.4550	
BH5	5000(Area 'B')	675.2	S13 @ Ch.4825	405 @ 268 days	N.A		Full depth excavation of peat layer + PVD + 0.5m surcharge
			S14 @ Ch.5135	679 @ 511 days	632		
BH6	6000 (Area 'B')		S15 @ Ch.5600 S16 @ Ch.6110	77 @ 183 days 94 @ 183 days	73 100	207 @ Ch.5950 289@Ch.6110	Full depth excavation of peat layer + PVD + 0.5m surcharge
BH7	7000(Area 'C')		S17@ Ch.6600	129 @ 182 days	123	33 @ Ch.6900 117 @ Ch.7675 180 @ Ch.8000	Full depth excavation of peat layer

Table 3: Geotechnical Analysis on Construction Settlement of Road Embankment During and Post Construction.

CONCLUSION

In conclusion, this paper sums up the case histories of geotechnical distress of road construction and lessons learned on the essential requirements for a successful embankment construction over soft compressible peat or soft organic soils.

Therefore, under all the 5 phases of road construction spanning from the Concept Phase, Design Phase, Implementation Phase, Completion Phase up to Maintenance Phase, the following criteria should be taken into consideration in order to ensure that road construction over peat/organic & soft soil is feasible and sustainable throughout the designed service life.

- Appreciation of the project requirements in terms of serviceability criteria (deformation tolerances, bearing capacity, etc.), cost implications (construction and maintenance costs), and time (construction time, service life).
- Thorough knowledge of the site geology through proper desk study, collection of geological information; effective planning and supervision of subsurface investigation works and laboratory testings for the acquisition of necessary reliable parameters of geotechnical designs.
- Proper geotechnical design practices to address both stability of the embankment and control of deformation.
- Full time proper supervision of the construction works by dedicated qualified QAQC personnel/Engineers.
- Proper monitoring, evaluation and interpretation of the geotechnical instrumentation datas on the performance of the embankment during and after construction.
- Review of the current techniques of road design and construction on deep-seated soft soils (peat/organic soils).
- Database collections and observational studies on the recent new techniques of proven infrastructure design and construction.
- Formulate specific guidelines for infrastructure planning, design and construction practices on soft soils (peat/organic soils and soft clay).
- Change of stakeholder's mindset to consider sustainable methods of construction for better long term sustainability of infrastructure developments.
- The relevant government agencies should recognize the escalating cost of maintenance on unsustainable construction methodology and provide "incentive package" for the ratepayers of sustainable infrastructure development.
- Fund allocation for research studies on sustainable methodology of infrastructure design (serviceability limit) on various types of soft soils foundation.

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