# Study on Flexible Pavement Failures in Soft Soil Tropical Regions

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**Abstract.** Road network system experienced rapid upgrowth since ages ago and it started developing in Malaysia during the colonization of British due to its significant impacts in transportation field. Flexible pavement, the major road network in Malaysia, has been deteriorating by various types of distresses which cause descending serviceability of the pavement structure. This paper discusses the pavement condition assessment carried out in Sarawak and Sabah, Malaysia to have design solutions for flexible pavement failures. Field tests were conducted to examine the subgrade strength of existing roads in Sarawak at various failure locations, to assess the impact of subgrade strength on pavement failures. Research outcomes from field condition assessment and subgrade testing showed that the critical causes of pavement failures are inadequate design and maintenance of drainage system and shoulder cross fall, along with inadequate pavement thickness provided by may be assuming the conservative value of soil strength at optimum moisture content, whereas the exiting and expected subgrade strengths at equilibrium moisture content are far below. Our further research shows that stabilized existing recycled asphalt and base materials to use as a sub-base along with bitumen stabilized open graded base in the pavement composition may be a viable solution for pavement failures.

## 1. Introduction

Surface transport system plays an important role on rapid development in agriculture and industrialization of any countries. A high quality of road network system maximises its benefits to the society and facilitates to achieve the economic growth of the country. Flexible pavement, an asphaltic-pavement that flexes or deflects under vehicular loading, is the major road network in Malaysia. The bituminous road network, which has an approximate total length of 14,757 Km, is excellently bringing conveniences for road users to travel from places to places [1].

In general, the service life period of flexible pavement in bearing traffic loads without suffering any failures is designed as ten to fifteen years [2]. However, incremental of vehicles from time to time has

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been undoubtedly deteriorating the serviceability of pavement structure, particularly if the pavement is left unconcerned on upkeep and maintenance. Nowadays, critical signals are emerging for the road authorities and road users as it could be seen that pavement failures have been widespread occurring in many places. Common types of flexible pavement failures that could be observed in Malaysia consist of corrugations, depression, ravelling, cracking, potholes, patching etc. [2]. Rather than the vertical stress within all the pavement layers, horizontal stress is only effective on wearing and base course, which is the main cause of fatigue related pavement failures [3]. The crack spacing is strongly dependent on the surface layer thickness, tensile strength of the surface layer and elastic modulus of the surface layer [4]. Excess fines and very high liquid limit values combined with a very low CBR value are instigating the failure of the pavement [5]. Fuzzy regression method is better accounting the uncertainties of traditional method to assess the pavement performances [6]. The combined Overall Pavement Condition Index (OPCI) also is a good indicative of pavement condition and performance [7]. An efficient approach for reliability-based mechanistic-empirical pavement design considering fatigue and rutting failures requires much less computational effort to determine probability of failure and easy to be adopted in the engineering practice [8].
Recycled concrete aggregate and reclaimed asphalt pavement can be used as replacement for natural aggregates in road constructions [9]. Warm–mix asphalt (WMA) and high percentages of reclaimed asphalt pavement (RAP) mixtures expressed better fatigue resistance than HMA-high RAP [10]. As a solution to pavement failure, cement stabilized fly ash class F may be utilized with or without aggregate as a pavement layer [11]. Understanding on the types of pavement failures and investigating the relevant causes are the primary approaches for obtaining the effective solutions to reduce the deterioration and to provide a longer pavement lifespan.

## 2. Pavement condition assessment

Field condition assessment was conducted in Sarawak and Sabah states of Malaysia at ten predominant routes having heavy commercial vehicle traffic and various subgrade soil strata. In this phase, the total length of each road was taken as 4km where 40 segments had been taken into investigation. The results of the assessment were summarized for every 100 meter stretch in each lane. The study mainly focused in observing and recording the types of flexible pavement failures along each road, in which four major types of pavement distresses were classified, known as surface deformation, surface defects, cracking, potholes and patching. In order to further describe the condition of visible distresses recorded, scoring method as detailed in Table-1 was put into practice by rating the pavement distresses using different level of scores based on the severity and extent of occurrence observed during the assessment.

**Table 1.** Degree of pavement distress

| Degree | **Severity** | **Description** |
|---|---|---|
| 0 | - | No distress Visible |
| 1 | Slight | Slight-( No attention required immediately) |
| 2 | Between slight and warning | Between slight and warning |
| 3 | warning | Warning-distress is distinct. Start of secondary defect |
| 4 | Between warning and severe | Between warning and severe |
| 5 | Severe | Severe – Distress is extreme. Secondary defects are well developed. Urgent attention required |

Other significant aspects that had been taken into inspection during the assessment are road shoulder conditions for its maintained cross fall and adequacy of drainage system for its effectiveness because both of the elements play an integral role in maintaining the behaviour of pavement in terms of serviceability and structural strength. These were observed and judged based on the capability of the pavement structure to drain water away from the asphaltic-wearing surface to prevent any water accumulation on the surface as well as on the shoulder edges. The existing drainage was taken into inspection to identify whether it is normal expected water flow level is adequately lowered from the pavement level to avoid the return moisture to pavement structure.

## 3. Existing pavement strength

Field tests and laboratory tests on collected soil samples were conducted to assess the existing strength of pavement structure at outer wheel path zones. The conducted field tests were proving ring penetrometer test and vane shear test, whereas California Bearing Ratio (CBR) test was carried out at laboratory.

Proving Ring Penetrometer test and Vane Shear Test were used to determine the penetration resistance and shear strength of the subgrade soil respectively. Both of these tests were carried out at outer wheel path zone nearer to the shoulder of pavement. For the former test, a penetrometer was used to test subgrade soil in three different locations and an average result was taken from the three readings as the penetration resistance of that particular soil. A similar procedure was applied in vane shear test where a vane inspection tester was used to test subgrade soil in three different locations at outer wheel path zones. Apart from the top surface, additional two readings were taken in each location at depth of 0.5m and 1.0m from the top surface.

The most important subgrade strength parameter is CBR result, which was obtained from laboratory CBR test. It gives an indication of bearing capacity of the subgrade soil. Bulk sample of subgrade soil for each road were collected at depth of 500mm from the top of road base. The test was carried out in accordance with specifications in Australian Standard AS 1289.6.1.1-1998. For unsoaked-CBR test, load penetration was conducted on a particular soil sample after the sample was oven-dried for 24 hours and compacted according to the specifications. For soaked-CBR test, the sample was soaked in water for 4 days before taken into load penetration test. The focus in this test is the effect of moisture content on the variation of CBR strength of the soil sample.

## 4. Results and discussion

### *4.1. Pavement Condition Assessment*

The distress types and its distribution for five roads in Miri are summarized and presented in Figure 1 and Table 2. Common types of distress recorded along study area in Miri were cracking, potholes, patching, corrugation, depression, raveling and delamination. Among all the distresses, corrugation and cracking contribute the highest distribution percentage of occurrences, which are 35% and 30.5% respectively. The chart in Figure 1 indicates that Road 2 is suffering of the highest occurrences distresses whereas Road 1 is of satisfactory condition having the lowest percentages of failures. It is seen that the pavement surface of Road 4 is currently in undulating condition, which is known as corrugation, a type of pavement deformation.

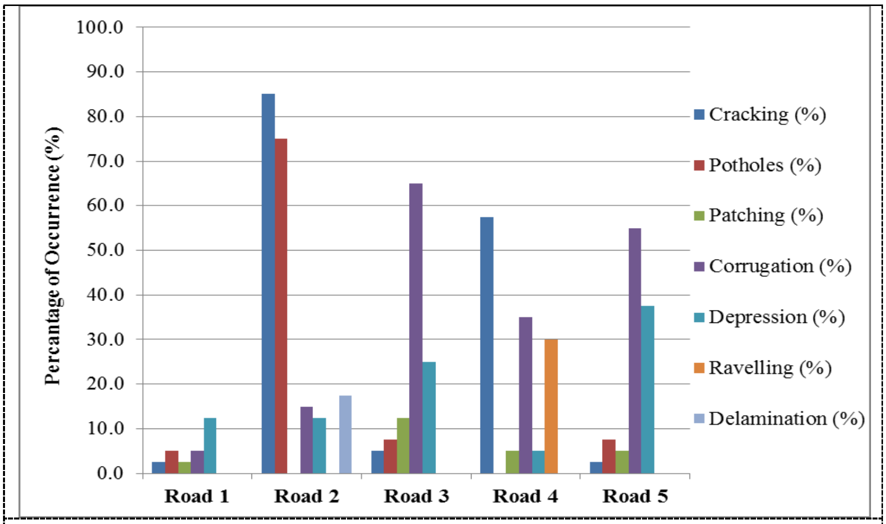


**Figure 1.** Summary of Distresses and its Distribution (Miri)

**Table 2.** Summary of distress type and its distribution (Miri)

| **Distress Type** | Road 1 | Road 2 | Road 3 | Road 4 | Road 5 | Total |
|---|---|---|---|---|---|---|
| Length (km) | 4 | 4 | 4 | 4 | 4 | 20 |
| Cracking | 1 | 34 | 2 | 23 | 1 | 61 |
| (%) | 2.5 | 85.0 | 5.0 | 57.5 | 2.5 | 30.5 |
| Potholes | 2 | 30 | 3 | 0 | 3 | 38 |
| (%) | 5 | 75 | 7.5 | 0 | 7.5 | 19 |
| Patching | 1 | 0 | 5 | 2 | 2 | 10 |
| (%) | 2.5 | 0 | 12.5 | 5 | 5 | 5 |
| Corrugation | 2 | 6 | 26 | 14 | 22 | 70 |
| (%) | 5 | 15 | 65 | 35 | 55 | 35 |
| Depression | 5 | 5 | 10 | 2 | 15 | 37 |
| (%) | 12.5 | 12.5 | 25 | 5 | 37.5 | 18.5 |
| Ravelling | 0 | 0 | 0 | 12 | 0 | 12 |
| (%) | 0 | 0 | 0 | 30 | 0 | 6 |
| Delamination | 0 | 7 | 0 | 0 | 0 | 7 |
| (%) | 0 | 17.5 | 0 | 0 | 0 | 3.5 |
| Total No. of Segments (100m stretch in each lane) | 40 | 40 | 40 | 40 | 40 | 200 |

The distress types and its distribution for five roads in KK, No. 6-10 are summarized and presented in Figure 2 and Table 3. Among all the distresses, cracking and patching contribute the highest distribution percentage of occurrences, which are 54% and 40% respectively. Figure 2 shows that Road 8 is of poor quality of pavement condition due to high occurrences of failures. Conversely, the lowest occurrence of distresses was observed on Road 10.

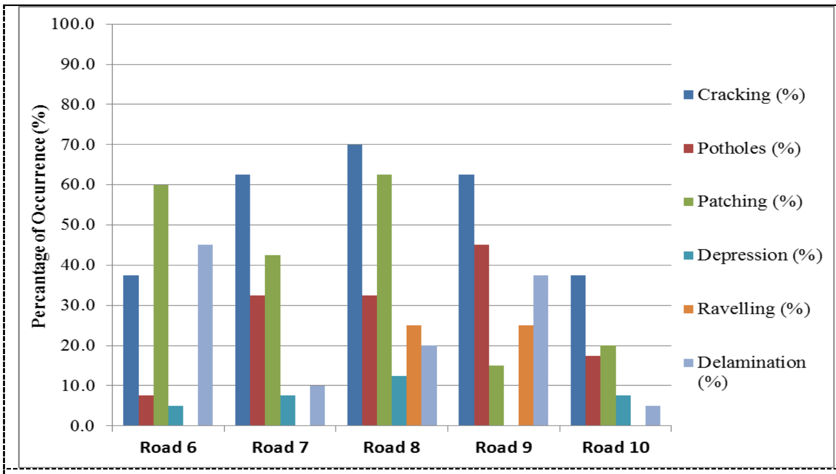


**Figure 2.** Summary of Distresses and its Distribution (KK)

**Table 3.** Summary of distress type and its distribution (kk)

| Distress Type | Road 6 | Road 7 | Road 8 | Road 9 | Road 10 | Total |
|---|---|---|---|---|---|---|
| **Length (km)** | 4 | 4 | 4 | 4 | 4 | 20 |
| **Cracking** | 15 | 25 | 28 | 25 | 15 | 108 |
| **(%)** | 2.5 | 85.0 | 5.0 | 57.5 | 2.5 | 54 |
| **Potholes** | 3 | 13 | 13 | 18 | 7 | 54 |
| **(%)** | 7.5 | 32.5 | 32.5 | 45 | 17.5 | 27 |
| **Patching** | 24 | 17 | 25 | 6 | 8 | 80 |
| **(%)** | 60 | 42.5 | 62.5 | 15 | 20 | 40 |
| **Depression** | 2 | 3 | 5 | 0 | 3 | 13 |
| **(%)** | 5 | 7.5 | 12.5 | 0 | 7.5 | 6.5 |
| **Ravelling** | 0 | 0 | 10 | 10 | 0 | 20 |
| **(%)** | 0 | 0 | 25 | 25 | 0 | 10 |
| **Delamination** | 18 | 4 | 8 | 15 | 2 | 47 |
| **(%)** | 45 | 10 | 20 | 37.5 | 5 | 23.5 |
| **Total No. of Segments (100m stretch in each lane)** | 40 | 40 | 40 | 40 | 40 | 200 |

*4.2. Proving Ring Penetrometer Test Results*

The field test results for Road No. 1-6 are tabulated in Table 4. The obtained result shows that that Road 2 has the lowest penetration resistance of 394.66kPa corresponding to 0.255kN of penetration load. Conversely, the penetration load and penetration resistance are the highest in Road 4, which were recorded as 0.412kN and 1130.05kPa respectively. This shows that the subgrade soil of Road 4 is having relatively high bearing capacity in resisting the applied load. It was justified by the extent of penetration of penetrometer into the shoulder surface during the field test, the penetrometer could hardly penetrate into the surface. Large force was required to push the penetrometer into the ground and only 3.5cm of the cone was embedded into the soil.

**Table 4.**Summary of proving ring penetrometer test results

| **Road** | Penetration Load (kN) | Penetration Resistance (kPa) |
|---|---|---|
| **1** | 0.313 | 485.22 |
| **2** | 0.255 | 394.66 |
| **3** | 0.305 | 835.79 |
| **4** | 0.412 | 1130.05 |
| **5** | 0.591 | 915.36 |

*4.3. Vane Shear Test*

Shear strength results at various depth obtained from each road subgrade are presented in Table 5. It is shown that the shear strength increases when the vane instrument penetrates into ground and turned at deeper layer. However, there was a special case for Road 1, in which the shear strength decreases from depth of 0.5m to 1m. This could be caused by the presence of water layer at certain level between the range of 0.5m and 1m that weakens the soil and decreases the soil shear strength. In comparisons of all the roads, Road 2 soil has the lowest shear strength of 22kPa whereas Road 3 soil has the highest shear strength of 184kPa. For Road 2, the vane instrument was relatively easy to be pushed and rotated uniformly into the ground. Yet, the maximum shear strength is only 70kPa at 1.0m below the ground surface. For Road 3 and 5, the soil has very high shear strength that goes up to 260kPa and 240kPa respectively at 0.5m below the surface. During the field test, the instrument was hardly to be pushed and rotated in the soil beyond 0.5m depth.

**Table 5.**Summary of vane shear test results

| | Shear Strength kPa | | |
|---|---|---|---|
| **Road** | Surface | 0.5m | 1.0m |
| **1** | 138 | 222 | 146 |
| **2** | 22 | 49 | 70 |
| **3** | 184 | 260 | - |
| **4** | 61 | 104 | 229 |
| **5** | 44 | 240 | - |

*4.4. Sand Cone Replacement field density Test(FDT)*

The FDT results are shown in Table 6. It shows that Road 2 clay subgrade has the highest bulk density of 14.15kN/m3 at moisture content of 20.47%, with dry density of 11.75kN/m3 and Road 5, silt subgrade, has the lowest moisture content 9.78%. The soil sample for Road 2 was collected during rainy day whereas for Road 5 soil sample was collected under sunny weather. The significant degradation in dry density may be due to infiltration of rain water into pavement.

**Table 6.**Summary of sand cone replacement test results

| **Road** | Bulk Density (kN/m3) | Dry Density (kN/m3) | Moisture Content |
|---|---|---|---|
| **1** | 12.82 | 11.28 | 13.65 |
| **2** | 14.15 | 11.75 | 20.47 |
| **3** | 13.75 | 12.42 | 10.76 |
| **4** | 11.89 | 10.44 | 13.91 |
| **5** | 13.08 | 11.92 | 9.78 |

### *4.5. Standard Proctor Compaction Test*

The standard proctor compaction test results are summarized and shown in Table 7. Road 2 has the lowest optimum moisture content (OMC) of 9% and maximum dry density (MDD) of 16.35kN/m3 and Road 3 has the highest OMC of 12.4% and MDD of 16.87kN/m3. The degree of compaction was computed for each sample using the field dry density and maximum dry density from compaction curve. The degree of compaction for all the soils lies within the range of 70% which vary significantly from the general range of relative compaction of 90% -100%. This variation in the degree of compaction of all the road subgrades could be caused by intrusion of water into the soil that decreases the field dry density.

**Table 7.**Summary of standard proctor compaction test results

| **Road** | Optimum Moisture Content, OMC (%) | Maximum Dry Density, MDD (kN/m3) | Degree of Compaction (%) |
|---|---|---|---|
| **1** | 11.0 | 16.06 | 70.26 |
| **2** | 9.0 | 16.35 | 71.86 |
| **3** | 12.4 | 16.87 | 73.60 |
| **4** | 10.2 | 15.55 | 67.14 |
| **5** | 12.0 | 16.50 | 72.23 |

### *4.6. California Bearing Ratio (CBR)Test*

The laboratory CBR test results are shown in Table 8 to 10. The unsoaked CBR test results shows that Road 2 clay subgrade has the highest CBR of 60.65% and dry density of 14.76kN/m3 at the lowest moisture content of 10.16%. As a result of soaking for 4 days, Road 2 soil shows considerable amount of reduction in CBR of 52.20% with only 2.82% increase in moisture content. In soaked-CBR test, it has the lowest CBR of 8.45% and highest dry density of 14.75kN/m3 at the moisture content of 12.98%. The result indicates that Road 2, clay subgrade is problematic in bearing capacity as a minor increase in water content leads to substantial amount of reduction in CBR.

On the contrary, Road 4, silt subgrade shows less water sensitiveness, the large increase in water content (9.95%) causes only a minor reduction in CBR (2%). The unsoaked and soaked CBR values for Road 4 are 32.88% and 30.88%. Figure 3, a comparison chart shows the variation between unsoaked CBR and soaked CBR for each road subgrade soil.

**Table 8.**Summary of unsoaked-CBR test results

| **Road** | Moisture Content (%) | Dry Density (kN/m3) | CBR (%) |
|---|---|---|---|
| **1** | 11.02 | 13.596 | 17.77 |
| **2** | 10.16 | 14.76 | 60.65 |
| **3** | 12.11 | 14.36 | 16.30 |
| **4** | 12.06 | 11.93 | 32.88 |
| **5** | 12.19 | 12.653 | 19.26 |

**Table 9.**Summary of soaked-CBR test results

| **Road** | Moisture Content (%) | Dry Density (kN/m3) | CBR (%) |
|---|---|---|---|
| **1** | 11.29 | 13.595 | 16.49 |
| **2** | 12.98 | 14.75 | 8.45 |
| **3** | 21.50 | 13.97 | 8.51 |
| **4** | 22.01 | 12.05 | 30.88 |
| **5** | 14.63 | 12.650 | 17.15 |

**Table 10.** Relationship between moisture content and CBR

| **Road** | Increase in Moisture Content (%) | Loss of CBR (%) |
|---|---|---|
| **1** | 0.27 | 1.28 |
| **2** | 2.82 | 52.20 |
| **3** | 9.39 | 7.79 |
| **4** | 9.95 | 2.00 |
| **5** | 2.44 | 2.11 |

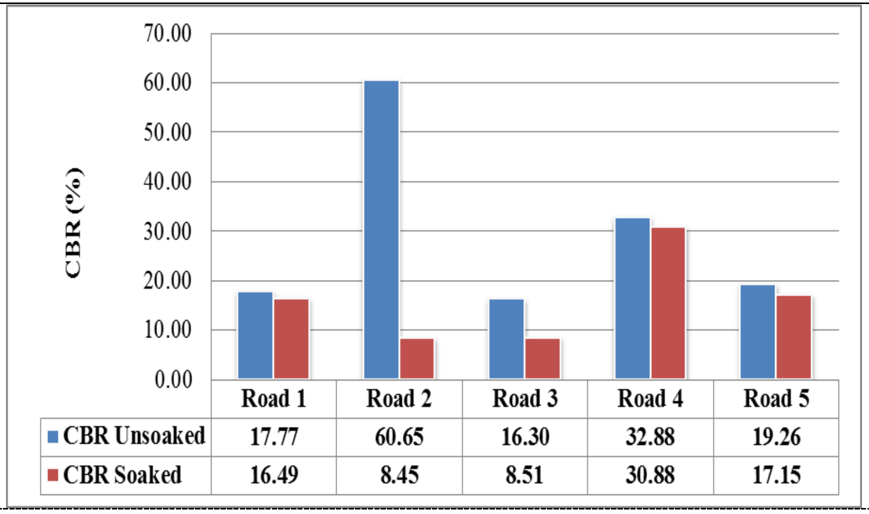


**Figure 3.** Comparison chart for Soaked and Unsoaked CBR of all of the Road subgrades

*4.7. Resilient Modulus and Resistance Value*

In addition to CBR, resilient modulus (Mr) and resistance value (R-Value) are the important parameters in evaluating the stiffness of subgrade soils and the capability of a soil structure in resisting lateral distribution of pressure from applied vertical loads. The Mr and R-Value for each of the road subgrade were computed by the equations [12] and summarized in Table 11.

$$Mr\ (psi) = 1500*CBR \quad (1)$$

$$R= (2555*CBR^{0.64}- 1555)/555 \quad (2)$$

Where *Mr* = Resilient Modulus in psi, or 0.00689MPa
*CBR* = Laboratory soaked CBR in %
*R* = Resistance Value

Road 2 clay subgrade has the lowest R-value of 15.94 whereas Road 4 silt subgrade has the highest value of 39.22. Based on the R-value for each subgrade, further classification of soil type can be identified. The R-values show that subgrade soil of Road 2 and Road 3 is sandy clay, whereas subgrade soil of Road 1, Road 4 and Road 5 is sandy silt. In overall, all of the road subgrade soils consist of sand constituents. The overall results of R-value indicate that sandy clay subgrade is having low resistance against vertical stress from traffic load. Furthermore, clay subgrade soils for Road 2 and Road 3 has the lowest Mr, 87.39MPa and 88.01MPa respectively.

**Table 11.** Correlation between CBR with resilient modulus and resistance-value

| **Road** | CBR (%) | Resilient Modulus, Mr (MPa) | Resistance-Value | CBR (%) |
|---|---|---|---|---|
| **1** | 16.49 | 170.55 | 25.56 | Sandy Silts |
| **2** | 8.45 | 87.39 | 15.94 | Sandy Clay |
| **3** | 8.51 | 88.01 | 16.02 | Sandy Clay |
| **4** | 30.88 | 319.38 | 39.22 | Sandy Silts |
| **5** | 17.15 | 177.37 | 26.27 | Sandy Silts |

## 5. Summary of Failures

While summarizing the results from all tests, nature of subgrade soil is considered as one of the factors driving to pavement failures. This is justified in Road 2, having the low soil strengths, including 49kPa of shear strength, 394.66kPa of penetration resistance and CBR of 8.45% which is less than CBR of 10%, deemed necessary to adequately support the heavy traffic load without causing severe deformation [13].

In addition to subgrade properties, inadequate and poorly maintained cross fall of shoulders and drainage systems are causing pavement failures. The pavement and shoulder condition observed at one of the junction in Road 5 during our survey is shown in Figure 4

The condition of drainage structure is also one of the decisive causes of pavement failures. The main issue concerned is blockage in drainage structure due to deposition of silts, presence of excess grasses and waste products. One of the blocked drains observed at Road 2 is shown in Figure 5.

**Figure 4.** Accumulation of water on turning junction of Road 5


**Figure 5.** Blockage in part of a longitudinal drain in Road 2

The effects of traffic loading could not be underrated along the entire life span of pavement. The heavy vehicle rolling loads are the critical causes for fatigue and rutting failures. Figure 6 shows the multi-axle heavy vehicle observed on Road 9 in an industrial area. Figure 7 shows the transportation of timber materials by heavy-loaded vehicles from Miri to Bintulu along Road 2. The pavement structures will be damaged significantly if they are not designed to carry the existing actual traffic loading capacity [14]. The soil sample collected in Road 2 showed large reduction of CBR in lab test for increasing very small amount of moisture content. The strength of the sensitive clay is highly susceptible to effect of moisture. The bearing capacity of sensitive clay would also suffer and has a constant reduction when the structure is subjected to cyclic loadings [15].

**Figure 6.** Multi-axle heavy vehicle on Road 9

**Figure 7.** Heavy loaded vehicles were transporting timbers along Road 2

## 6. Conclusion and recommendation

The study results show that subgrade strength, water penetration in pavement, defective condition of shoulder and drainage system, as well as under rated traffic loadings are the influential factors for failures. In tropical regions excessive infiltration of precipitated water into pavement layers and retaining for longer period due to inadequate drainage capacity is a critical cause for the pavement failures. Another main cause may be of providing inadequate pavement thickness by considering very conservative values of soil strengths in design stage by assuming the condition of optimum moisture content whereas actual soil strength during the life span are for behind due to prevailing equilibrium moisture content particularly at outer wheel path zones. Based on this study and our continuing research study on the performance of pavement structures and its life span, we suggested the following design and construction recommendations.

As a viable solutions for most of the deceive flexible pavement in Sarawak and Sabah, cut the existing asphalt surface along with base material for the minimum of 250 mm depth, recycle with required amount of stabilizing materials such as cement, lime or mixture of fly ash and lime and lay as a subcase. The open graded bitumen stabilized natural gravel or crushed rock by removing the fines up to 2mm size for better permeability, is recommended as a road base. Particularly in the tropical regions for having a consistent design drainage capacity of shoulders, always maintain its cross fall, avoid planting trees or bushes at the edge of the shoulder before table drains. The trees may be planted in the reserve after the table or storm water drains.

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