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A Comprehensive Review of Flexible Pavement Failures, Improvement Methods and its Disadvantages

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Abstract. Flexible pavement failure has been a major problem encountered in various countries. Some common distress which had been listed are cracking and rutting. The causes of this distress are due to moisture, weak sub-grades and poor construction quality. High amount of distress in the pavement however is likely to cause dis-comfort for the passengers, higher accident rate and heavy traffic. Study suggested that, flexible pavement failure can be reduce, through maintenance of the wearing course of the pavement, improving the base, sub-base layer or the sub-grade soil underneath of the pavement. However, high production or material cost, high construction cost, excessive settlement, or weak inter-molecular bonds in the flexible pavement are some of the common problem encountered with the current improvement techniques. This significance difference of this review paper compare to other is that, in this review paper it focuses on the flexible pavement failure, the different types of improvement method currently applied. Consequently, it further recommend flexible pavement improvement method through by reducing the sub-base layer thickness and inclusion of light weight material in the sub-base layer so that, the settlement of the pavement is reduced.

Introduction

Land transport infrastructure is the backbone of the social-economic growth of any country [1]. Generally, road is made with flexible or rigid pavement. Flexible pavement is normally used for road construction in many countries such as Malaysia, India, Sudan, Nigeria and Pakistan [2, 3, 4, 5, 6]. Difference between flexible and rigid pavements is based on the manner in which the loads are distributed to the sub-grades. For flexible pavement, the stress will decrease with depth as the wheel load acting on the pavement will be distributed to a wider area. Meanwhile for rigid pavement, the stress distribution is almost uniform underneath due to the wheel load [7]. Flexible pavement generally consists of three layers which are the surface course, base course and the sub-base course. Generally the bonds between the flexible pavement layers are very weak in comparison with the rigid pavements [8, 9, 10]. Figure 1 demonstrates the load distribution pattern in flexible and rigid pavement.

A pavement primary function is to i) protect the sub-grade soil underneath, ii) provide sufficient surface friction, iii) provide smooth riding surface and iv) acts as a waterproofing surface [10]. Factors which influence the performance of pavement are traffic, moisture, sub-grade, construction quality and maintenance [11, 12]. This paper is a comprehensive review which summarizes facts from various independent studies regarding flexible pavement failure, case history, reduction of pavement failure through different techniques, the disadvantages of the current improvement techniques in the past 20 years. Consequently, a suggestion of potential alternatives for future research has also been listed.

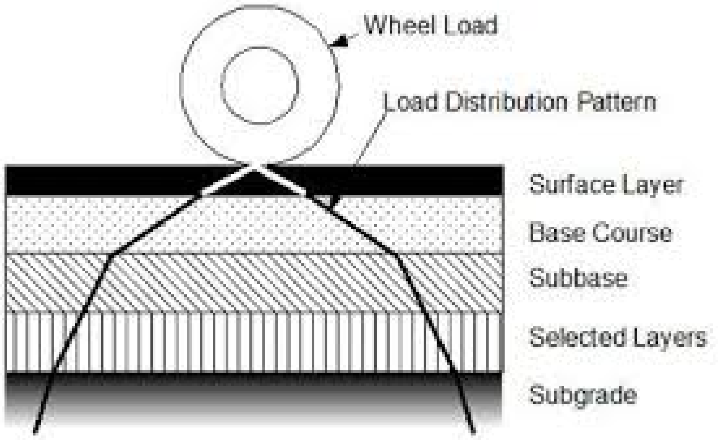

Fig.1 Load Distribution Pattern in Flexible Pavement [10]

Flexible Pavement Failures

Flexible pavement failure occurs when the applied load exceeds the maximum allowable limit [7]. Flexible pavement fails due to the three failures i) sub-grade failure ii) sub-base or base course failure and iii) wearing course failure [6, 13]. The cases of flexible pavement failure have been reported in many countries particular in developing countries [13]. The four major categories of common surface distresses of asphalt pavement are i) Cracking, ii) Surface Deformation, iii) Disintegration and iv) Surface Defects [7, 10, 11, 13, 14]. Generally, pavement deterioration process starts directly after opening of the road to traffics and over time accelerates at faster times. Some common types of cracking listed are a) fatigue cracking, b) longitudinal cracking, c) block cracking, d) transverse cracking, e) slippage cracking, f) edge cracking and g) reflective cracking [5, 7, 10, 11, 12, 13, 14, 15]. The basic type of surface deformation listed are i) Rutting, ii) Corrugations, iii) Shoving, iv) Depressions and v) Swell [10]. Meanwhile, Potholes and Patches are most common types of flexible pavement disintegration recorded. Apart from that, the most popular surface distress encountered are i) Ravelling, ii) Bleeding, iii) Polishing and iv) Delamination [10]. The most common failure in flexible pavements are rutting and cracking [16].

Figure 2 demonstrates a case study of different distress percentage in three different roads in three different countries. The most common form of distress among these three roads was cracking, rutting and potholes.

Cracking occurs due to a variety of reasons. Flexible pavement cracking comes in wide range of patterns and are resulted from a large number of causes, but generally occurs due to ageing of the surface, environmental condition or fatigue failure of the pavement [5]. The main problem with crack is that, it allows moisture which accumulates on the pavement to enter into the pavement sub-bases, resulting deterioration of the pavement at a faster rate [5]. Figure 3 and 4, shows image of cracking in flexible pavement. Potholes in general are the final result of alligator cracking. Figure 5, shows image of water ponding on potholes. As the alligator crack becomes severe, small block of pavement are displaced causing hole to remain in the pavement which is known as potholes [5]. Rutting is a major problem encountered in many flexible pavement systems. One particular reason for rutting is due to the thickness of the pavement which is not designed to carry big number of traffic and heavy axel loads [11]. One main reason for flexible pavement failure is excessive moisture [5]. Apart from that, sudden increase in traffic loading is another reason for pavement deterioration [10]. Temperature variation ranging from 50 °C to below zero conditions leads to bleeding and cracking. Besides that, poor drainage system and poor sub-grade soils are also responsible for pavement deterioration.

From review of literature in this section, it is understood that, there are different kind of flexible pavement distress encountered. However, the most common type is cracking, rutting, potholes, patches and polishing based on the three road compared. The distress level is higher in flexible pavement in comparison with rigid pavement is due to the weak inter-molecular bonding in the flexible pavement system [8, 9, 11]. When load is applied on flexible pavement, the molecules in the sub-base or base layer shift as they are not firmly hold together causing high level of settlement and distress [8].

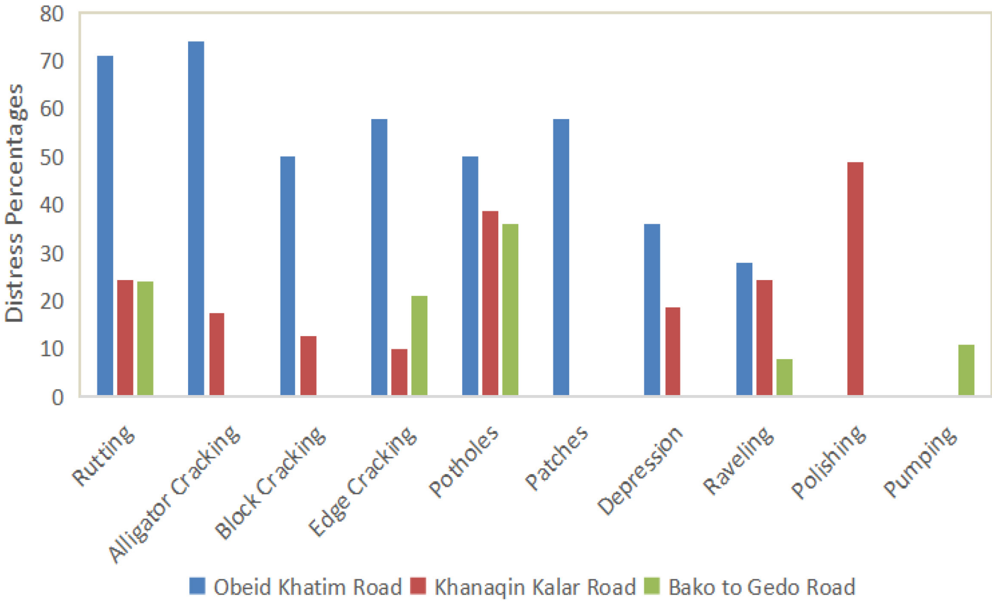

Fig. 2 Distress Percentages in Different Roads [5, 11, 17]

Fig. 3 Alligator cracking of high severe level [5]

Fig. 4 Cracking in flexible pavement [18]

Fig. 5 Water Ponding on Potholes [5]

Fig. 6 Rutting in Flexible pavement [14]

Organization of the Case History of Flexible Pavement Failure

Table 1 summarizes the reasons for flexible pavement failure in different countries in the world. A road failure case study in Enugu and River states in Nigeria, concluded that, major cause of the pavement failure in that area are moisture, weak sub-grades, poor construction and maintenance quality [6]. The poor performance of the pavement however has increased the traffic and journey time. Similarly an observation based on a field study for Kabati to Mareira Road, in Kenya, observed that high intensity of crack was developed along the road which had reduced the road safety and increased the accident rate [23]. One particular reason for the failure is due the the elastic modulus for both the base and sub-base exceeded the specific tolerance [23]. The modulus was 2606 MPa and 975 MPa as compared to 1000 MPa and 300 MPa as based on literature. Case study from Izki road in Oman observed that potholes were the common form of distress developed along this road. The thickness of the Izki road were 55mm, meanwhile the depth of the potholes had reached up to 60mm. The severity for distress level in this road was classified as high, as hole depth was higher than the tolerance which was 50mm [19]. From literature review in this section, it is understood that, common causes of this failure are due to weak sub-grade soil, moisture, poor maintenance or construction and poor drainage system. Besides that, it had been noticed, that the pavement failure is particular high in least developing nation. Reasons for this could be due to the slow economic growth of the country and less support from the government in term of proper road construction and maintenance. However, the pavement failure in countries like, Nigeria, Oman, India, Kenya and Ethiopia, had causes dis-comfort for rider, heavy traffic and longer journey

Table 1 Flexible Pavement Failure in Different Countries

Location	Reasons for the Pavement Failure	References
Nigeria (Enugu and River States)	Moisture, Weak- Sub-grade Soil, Poor Construction and Maintenance Quality	**[6]**
Kenya (Kabati Road to Mareira Road)	Moisture, Weak Subgrade Soil, Poor Construction Quality	**[23]**
Ethiopia (Asendabo to Deneba Road Sections)	Low CBR Values, High Moisture, Weak Sub-grade Soil	**[22]**
India (Samarkha and Lingda in Anand district)	Weak Sub-grade Soil, Low CBR Values	**[21]**
India (Doda Bhaderwah Road)	Poor Construction and Maintenance Quality, Moisture	**[20]**
Oman (Izki Road)	Poor Construction Quality, Poor Drainage System	**[19]**

Flexible Pavement Failure Improvement

The failure of flexible pavement commonly occurs due to sub-grade failure, sub-base or base course failure or wearing course failure [7, 24]**.** Figure 8 to 10 demonstrates the sub-grade failure, wearing course and base course failure of flexible pavement. In order to reduce the rate of this failure, different techniques are currently applied. One common technique used in order to reduce the wearing course failure of flexible pavement is through maintenance [19]**.** The maintenance would consist of routine and periodic activities. Routine maintenance would include sanding, local sealing, crack sealing, filling depression, surface patching and base patching. Periodic activities would consist of surface dressing, fog spray, pavement overlaying and slurry seal.

Sub-base or base course deterioration improvement techniques

A study on the load carrying capacity of the flexible pavement when the gravel sub-base was reinforced with waste tyre rubber stated that total deflection of the pavement reduced when it was reinforced with waste tyre rubber in the sub-base layer [25]. At pressure of 600kPa (Figure 7), the deflection was 13.25mm for rubber reinforced sub-base compare to 18.75mm for normal sub-base. An independent study on the effect of dissolving crumb rubber as binder in base layer of flexible pavement system concluded that, tyre rubber used in pavement reduces cracking, improves durability and mitigate noise [27]. Another study, on the effect of using crumb rubber in the base layer suggested that both rutting and cracking properties improved as the percentage of the crumb rubber increased [26]. Similarly, an investigation regarding the use of gravel/fly ash as the sub-base material with waste tyre rubber as a reinforcing material suggested that, gravel rubber sub-base had better performance than fly ash rubber sub-base. The CBR of the gravel rubber sub-base was 13.32% at waste tyre rubber reinforcement between 5 to 6%. Meanwhile, the CBR of fly ash rubber sub-base was 8.73% at similar rubber reinforcement percentage [28]. Consequently, a study where waste tyre rubber was used as an aggregate in the base layer of the flexible pavement suggested that waste tyre rubber can be used between the ranges of 5 to 20%. Problem like rutting and cracking can be reduced particularly in hot temperature region [29].

Another study regrading the utilization of waste plastic in the base layer has stated that, it had improved the overall performance of the pavement in term of strength and durability [30]. Similarly another study carried out regarding the use of waste plastic as a reinforcement material for gravel/fly ash sub-base suggested that, there was some improvement on the CBR of the sub-base. The CBR was

16.42% for gravel sub-base reinforced with 0.3% of waste plastic. Consequently, the CBR was 18.64% for fly ash sub-base reinforced with 0.4% of waste plastic [28].

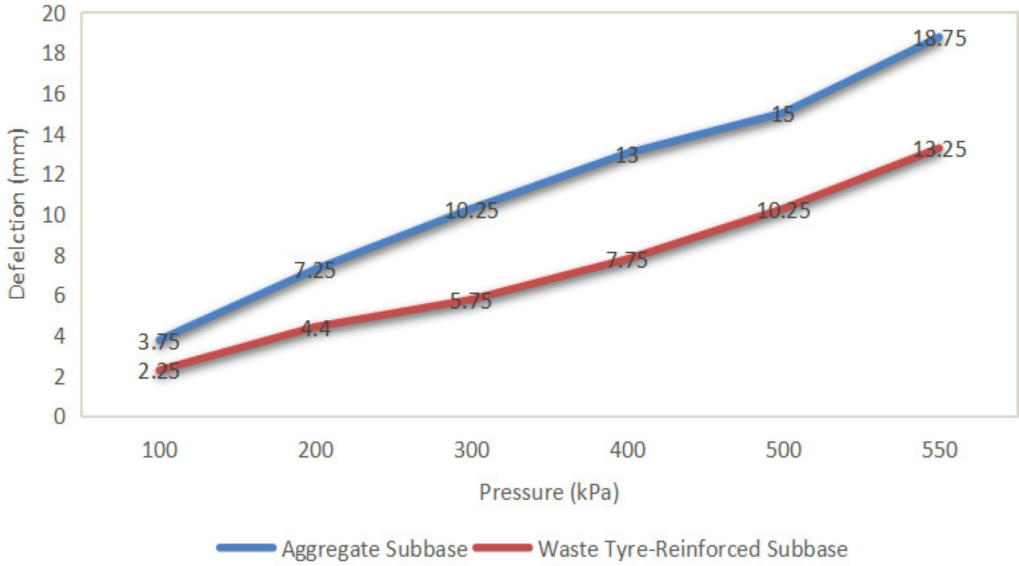

Fig. 7 Deflection of aggregate versus waste Tyre-Reinforced sub-base [25].

Flexible Pavement Sub-Grade Deterioration Improvement Technique

The sub-grade soil underneath the flexible pavement can be strengthened through common three techniques i) soil improvement without admixture, ii) soil improvement with admixture and iii) soil improvement using stabilization [33]. Soil improvement without admixtures would include methods such as soil replacement, preloading and vertical drains. Meanwhile soil improvement with admixtures would include methods such as stone column. Some of the most common ground improvement technique are soil stabilization, soil improvement through the use of geo-textiles or geo-synthesis, stone column and vertical drains [32].

Soil Improvement Using Stabilization

The addition of 25% of fly ash and 12% rice husk is able to strengthen the sub-grade expansive soil when fly ash and rice husk ash was used as soil stabilization for soil [34]. The unconfined compression strength was noted to be 1300kPa. Consequently, when the fly ash was increased to 25%, the failure strain increased from 6% to 9% meanwhile, the failure stress increased from 330kPa to 680kPa. One significant outcome of this study is that, the sub-base thickness can be reduced if the soil underneath were treated with the recommended percentage of rice husk ash and fly ash. As a result, it will be cost saving. Similarly, the use of chemical stabilization such as potassium chloride, calcium chloride and ferric chloride on expansive soil is able to improve the strength of the soil. The unconfined compression strength values were increased by 133%, 171% and 230% when 1% of KCI, $CaCl_2$ and $FeCI_3$ were added in the soil respectively [35]. Another study observed that, the maximum unconfined compression strength was recorded to be between 293 and 295kN/m2 at 6 and 8%rice husk ash contents respectively, when rice husk ash was used as soil stabilization. Consequently, there was also an improvement on the CBR of the soil. The unsoaked CBR was 18.5% when 6% rice husk was added compared to natural soil CBR of 8.5% [36]. The unconfined compression strength was noted to be 1152kN/m^2 at 8% OPC and 20% waste glass mixture when waste glass was used an admixture to stabilized black cotton soil for roads [37].

Soil Improvement with and without Admixtures

Road constructed with tyre bales and geo-textile, to date have been in services to six years without any distress. Tyres bales are aligned on soft ground, before filling it up with soil for the construction of the pavement [39]. Test results indicated that, performance of bamboo-geotextile reinforcement showed better performance than un-reinforced soil [38]. Un-reinforced embankment settled about 744mm, while bamboo-geotextile reinforced embankment settled about 588mm [38]. Apart from that, the bamboo-geotextile embankment experienced a 9.4mm lateral movement while un-reinforced embankment experienced a movement of 13.6mm. An independent study on pavement observed that, pavement section which had geo-synthetic reinforced have less rutting depth compare to un-reinforced sections [40]. This improved performance is due to the ability of the geosynthetics to control lateral spreading of the base layer in the flexible pavement [40]. Figure 8 shows pavement with geo-synthetics and without geo-synthetics reinforcement. Another investigation regarding the use of geo-textile as reinforcement in flexible pavement for black cotton soil, observed that, there was a definite improvement in stability of the sub-grade below the pavement where the geo-textile was laid. The settlement of the soil was less compared to section without geo-textile and also fewer cracks were developed on the pavement [41]. The use of bamboo grid reinforced soil had better performance than un-reinforced soil bed. The bearing capacity increased and the settlement reduced. Bamboo grid has the capacity to bear a load of 10kN and settle only about 30mm. Meanwhile, un-reinforced soil can bear a load of only 4kN and settle about 32mm [42].

The use of pre-loading with prefabricated vertical drains and vacuum on soft clay, observed a reduction of the water content, an increase of un-drained shear strength and a reduced settlement [43]. Vibro-stone columns can support embankments as high as 15m to be constructed on soft soil besides improving the shear strength and compressibility parameters of the ground [47]. Application of stone column and PVD are the most technology used for ground improvement of soft soils [45]. Stone column installed in soft soil improves the bearing capacity of the soil considerably. Application of prefabricated vertical drains can significantly shorten the period of primary settlement. The main purpose of vertical drain system is to shorten the drainage path of the pore water. Geo-grid encased granular pile is able to increase the load carrying capacity of the soil [44]. Performance of the granular piles improves as the granular piles are encased with geo-grid and the piles diameter is increased. At a footing diameter of 50mm, 65mm and 80mm, the ultimate loading carrying capacity of plain clay bed, granular piles and en-cased granular piles were 0.150kN, 0.480kN and 0.720kN for 50mm footing, 0.255kN, 0.835kN and 1.200kN for 65mm footing and 0.385kN, 1.400kN and 1.730kN for 80mm footing, respectively. Another independent study observed that, there was an improvement of the bearing capacity due to encasement of the stone column. The limiting axial stress of normal soil, stone column without geo-grid reinforcement case and geo-grid encased stone column case was 57.9kPa, 198.9kPa and 291.7kPa respectively [46].

From literature review, in this section it is understood that, there are various techniques currently applied in order to reduce the pavement deterioration. One most popular technique used in order to reduce the wearing course failure of flexible pavement is through maintenance. Currently the sub-base layer in the flexible pavement is strengthening through rubber and waste plastic reinforcement. There had been an improvement on properties such as rutting, cracking and settlement. Sub-grade soil plays a vital role for the failure of flexible pavement. Soft soil is particularly very unstable for construction. Ground improvement technique such as, soil stabilization, use of geo-textile or goe-synthesis, stone column are some of the most popular technique used in order to strengthen the soft and unstable soil. It had been observed, that the bearing capacity of the soil improves if the soil is strengthen through the mentioned techniques. Current pavement improvement technique is able to reduce the level of pavement failure, without which pavement may have collapsed as a faster rate.

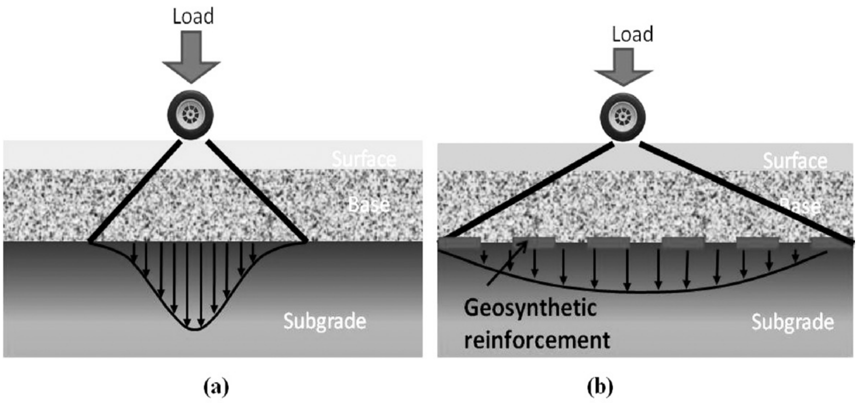

Fig. 8 (a) Pavement without geo-synthetics reinforcement (b) pavement with geo-synthetics reinforcement [40]

Fig. 9 The use of geo-textile for separation between foundation soils and the backfill material [48]

Disadvantage of Current Flexible Pavement Improvement Techniques

The disadvantages with the currently flexible pavement improvement methods have been listed in Table 2. The major problem with the surface maintenance of the flexible pavement is the cost. The maintenance cost of flexible pavement is usually 10 times more than that of rigid pavement. In many countries, about 60% from the road budget is spent on maintenance and rehabilitation [55]. Consequently the, main disadvantages with the base or sub-base reinforcement method is generally the fact that there still exist very weak inter-molecule bonds.

There is a number of disadvantages of soil stabilization using lime of which are sulphate attack, carbonation and environment impacts [49]. Soil stabilization using lime involves the calcination of calcium carbonate [49]. As the calcination occurs at a high temperature, therefore, it is responsible for the emission of large amount of carbon dioxide into the environment. Hence, the use of lime as a stabilization have negative impact on the environment [49]. Some common problems with geotextiles, geo-nets, geo-composites and geo-pipes are clogging, its long -term performance, handling, storing and installation [15]. Ground improvement using stone column is not suitable for sensitive clay. Stone columns installed at a distance of less than 3.66m can cause problem such as high lateral pressure and displacement of adjacent structures [51]. Geo-technical problems such as excessive settlement, liquefaction and low bearing capacity are usually observed with stone column [53]. In general, there is still lots of improvement needed for the current ground improvement techniques, the current ground improvement technique is very expensive and requires lots of skilled labor. Besides that, a lot of waste is also generated [50].

From literature review in this section, it is understood, that there is a number of drawbacks from the current flexible pavement improvement techniques. High maintenance cost, weak bonds, release of large amount of carbon dioxide in the environment excessive settlement, liquefaction potential is some common disadvantages observed.

Table 2 Flexible Pavement Improvement Method and its Disadvantages

Locations	Improvement Methods	Disadvantages	Reference
Surface or Wearing Course Layer of the Flexible Pavement	Sanding, Local Sealing, Crack Sealing, Filling Depression, Fog Spraying, Slurry Seal	Very High Maintenance Cost	**[13, 55]**
Base or Sub-base Layer of The Pavement	Rubber, Waste Plastic or Industrial Waste Material Reinforcement	Weak Inter-Molecules Bonds,	**[54, 56, 57]**
Sub-grade Soil Underneath the Pavement	Soil Stabilization, Geo-Textiles, Stone Column, Prefabricated vertical drains, Jet Grouting	Sulfate Attack, Carbonation, Excessive Settlement, Low Bearing Capacity, Liquefaction, High Lateral Pressure	**[49, 53, 58]**

Conclusion and Recommendations

Based on the comprehensive review of various journals, the distress level in flexible pavement is high and usually comes in different form. Consequently, the most common types of pavement failure are cracking and rutting. Flexible pavement failure is particular high in least developing nation in the world. Currently, there are several techniques such as, maintenance of the surface of the pavement, improving the sub-base layer of the pavement or improving the bearing capacity of the sub-grade soil underneath. However, it has been observed, that, there are a number of drawbacks from the current techniques. It is recommended in the future to carry out an in depth study regarding performance of flexible pavement on soft soil if the sub-base is constructed using high strength lightweight material and a reduce thickness. It is also recommended, in the future to compare in term of cost and structural performance of the high strength lightweight flexible pavement system with the current traditional flexible pavement system. It is also suggested that in the future in depth study is carried out regarding the micro-structure behaviour of the sub-base layer of the flexible pavement so that, the behaviour of the inter-molecular bonding can be understood better.

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