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TECHNICAL PAPER

“Impact of Climate Change on the Operational Readiness of
Singapore-Malaysia High Speed Rail”

(Title contains 13 words)

by

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Impact of Climate Change on the Operational Readiness of Singapore-Malaysia High Speed Rail

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Abstract: The Paris Agreement of December 2015 signifies global unity to limit global warming to well below 2°C (above pre-industrial levels) and to pursue efforts to limit the increase to 1.5°C. The global community now agrees that anthropogenic climate change is unequivocal. According to the Intergovernmental Panel on Climate Change (IPCC), the global average combined land and surface temperature has increased by 0.78°C since the industrial revolution. Although the magnitude of change in mean temperatures is relatively small, attendant extreme weather events have been shown to have increased in frequency, and are projected to increase in the future. The potential impacts of climate change on railway infrastructure and operations have not been fully assessed in the literature. The projected urban growth in Kuala Lumpur and Singapore has led to the necessity to establish improved transport links between the two cities, including road, aviation, ports and rail. Recently, a High Speed Rail system has been jointly proposed by both Malaysian and Singaporean Governments. However, the existing railway network in the region has been affected significantly by severe weather conditions such as rainfall, lightning, wind and very high temperatures. Our research addresses a knowledge gap on the potential impacts of climate change on future rail projects in the region, and points out the vulnerabilities that may lead to impaired operations and system failures. These insights are intended to inform the holistic consideration of climate change impacts in the design stage of rail speed rail systems in Malaysia and beyond.

Keywords: railway infrastructure, high-speed rail, tracks, risk, management and monitoring, climate change, global warming, adaptation, operational readiness, resilience.

ICE Keywords: railway systems, rail track design, railway tracks, rail & bus stations, safety & hazards, infrastructure planning, maintenance & inspection, weather.

1. Introduction

High speed rail is increasingly being viewed as an important measure for improving national productivity and mobility, and has resulted in significant infrastructure development around

the world. Malaysia is a developing country which is seeking to develop new transport infrastructure to realise both short-term (via internal investment) and long-term economic benefits (via employment, improved productivity and increased business capability). As a result, the Malaysian Government has proposed building a new high speed rail line between Singapore and Malaysia, a route which currently ranks in the top ten in terms of passenger air traffic. With the projected increase in meteorological hazards associated with climate change, any new infrastructure will need to cope with potentially significantly different conditions to those of today. These projected changes introduce a new source of uncertainty for railroad operators (Remennikov and Kaewunruen, 2008; Remennikov et al., 2012).

Extreme weather has many well-established impacts on railway operations and safety, and can cause property damage, injuries and fatalities. Despite climate change posing serious challenges to infrastructure projects, little research has been conducted in Malaysia into how vulnerable the proposed system will be, especially in terms of the physical infrastructure and the planned operations on the network. It has been widely recognized that there is a need to integrate considerations of climate change and its impacts into the development policies and projects (Kramer et al., 2010; Victorian Government, 2005; News Straits Times, 2013).

The Kuala Lumpur-Singapore High Speed Rail (HSR) line is currently in the planning stages, and aims to be fully operational by 2020. The conceptual design of the HSR was produced by the Malaysia Land Public Transport Commission (SPAD) and will include 7 stations. These consist of 2 terminus stations in Kuala Lumpur and Singapore and 5 transit stations; one each in Negeri Sembilan and Malacca and three in Johor. The HSR will have 2 modes of operation; non-stop from Kuala Lumpur to Singapore with an estimated journey time of 90 minutes, and transit operation including 7 stops with an estimated total journey time of 120. The trains are expected to have a maximum operational speed of 300km/hour or faster, although the average speed will be lower due to slower speeds when approaching stations. The conceptual alignment has been developed by SPAD as shown in Figure 1. However, the detailed alignments remain confidential at the time of writing. The HSR will have a dedicated line, which is proposed to be double track on a standard gauge. The HSR project is expected to impact the way of life for Malaysians and Singaporeans in terms of society, politics and the economy. According to SPAD, the main objectives of the HSR project is to reduce travel time between Kuala Lumpur and Singapore to 90 minutes, which will in turn strengthen the link between two of Southeast Asia's most vibrant and fast-growing economic engines. The proposed journey time compares to the current journey time of 5 to 6 hours by road or 8 hours by conventional train. Although the travel time between the

two cities by plane is approximately 90 minutes, total journey time (including security and boarding) is closer to 2.5 hours. Figure 2 gives a summary of current and expected travel times for different modes of transport (International Union of Railways, 2011; 2014).

At this initial stage of planning, the opportunity exists for HSR in Malaysia to include climate change impacts and adaptation strategies into the detailed design stage of the proposed HSR system. The ultimate goal is to better manage the weather and climate-related risks to the planned operations of the HSR system. These risks are determined by the high speed rail system design in conjunction with local conditions such as topography, geology and climate. This study aims to assess the vulnerability of the planned infrastructure and the potential ramifications of this for climate adaptation strategies (Pachauri and Meyer, 2014). In carrying out this study, a critical review of the relevant literature has been carried out. Data for the Malaysian HSR are derived from SPAD, with weather data being supplied by the Malaysian Meteorological Department. These are used to examine how projected climate change, alongside the stated operational requirements, may affect the design of the infrastructure. Potential actions to mitigate climate-related mitigate risks are then evaluated.

2. Local Climate and Geography

As illustrated in Figure 3, Malaysia is divided into 2 main regions; Peninsular Malaysia and East Malaysia, which are separated by the South China Sea. The climate in Malaysia is dominated by 2 monsoon regimes, namely the northeast and southwest monsoons. The northeast monsoon circulates during the months of December, January and February, which is Malaysia's wettest season and the period when most flooding occurs. The southwest monsoon occurs between the months of May and September, the driest period for the country as a whole, often resulting in droughts. Being in the equatorial, the average temperature throughout the year is constantly high (26°C) and has a very high humidity. Malaysia also has very high rainfall, totalling more than 2500mm per year (Malaysian Meteorological Department, 2009). The Malaysian Meteorological Department (2009) reported that the climate of the earth is warming, with the rise being due to the increasing concentration of greenhouse gases (GHGs) in the atmosphere. It is projected that in the next 50 years, Malaysia will experience higher temperatures, changing rainfall patterns, rising sea levels and more frequent extreme weather events including droughts and floods (theSundaily, 2015).

An important case study which demonstrates the impact of weather on rail operations occurred on the famous Malaysian Jungle Railway (east coast line, Figure 4), which is operated by National Malaysia Railway (KTM). The line was disrupted for almost 6 months due to a major flood in December 2014. The damage included the railway quarters, signalling, tracks, locomotives, machinery and rolling stock. The disruption affected thousands of workers, traders and children going to school. One stretch of line remains closed due to the collapse of the railway bridge in Kemubu, Kelantan (Bakshipouri et al., 2010). Construction of a new 250m long bridge across the Nenggiri River is expected to cost RM30 million (GBP4 million). This incident should give a lesson to the railway industry and policy makers that extreme weather can have severe impacts on transportation infrastructure and operations. Rebuilding railway infrastructure is often difficult and very costly, thus to provide a reliable railway system for the future, studies of the potential impact of climate change are needed. Such studies would better inform the adaptation of railway infrastructure and rolling stock to a changing climate (Krezo et al., 2016).

3. Topographical and Geological Challenges in Malaysia

The route of the planned Malaysian HSR, designed by SPAD, will run along the coastal area. It is important to note that Malaysia comprises of a wide range of rock types, from the sands and silts of the coastal plains to the granite of the Main Range. In Peninsular Malaysia, the geology ranges from Cambrian to Quaternary, that is from 570 million years before present, to around 10,000 years ago. Sedimentation was unremitting throughout the Palaeozoic and Mesozoic eras and due to the basin instability, there were major faults within and between the Palaeozoic, Mesozoic and Cenozoic groups of rocks. These are grouped according to four types of belt, namely the Western Belt, Bentong-Raub Suture, Central Belt and the Easter Belt zone. Overall, Granitoids occupy nearly half of Peninsular Malaysia.

In eastern peninsular Malaysia, the geology consists of sedimentary basins from Gunung Gagau in the north to Gunung Pantii in the south. The sediments, comprising of sandstone, conglomerate and shales with minor coal seams and volcanos, show fluvial, lacustrine and deltaic conditions of deposition. It is noted that Malaysia's coastal area consists of mostly quaternary deposits. Only in the straits of Malacca is the coastal geology in the form of ordovician phylites, schists and limestone. Kinta and Klang Valley contain valuable tin ore (a historic factor in location of Kuala Lumpur, Malaysia's capital).

As shown in Figure 5, the proposed HSR route, starting from Kuala Lumpur, will pass through a carboniferous area, which prominently consists of limestone. The route then will

cross granite geology in the Seremban area. Towards the south, the alignment will pass through limestone and sandstone regions. In the southern part of the route, the HSR line from Melaka to Nusajaya lies on a coastal area with a geological profile of marine and continental deposits. The soil conditions are mostly in the form of clay, silt and peat. According to Bakshipouri et al. (2013), approximately 40% (236.827km²) of the Kuala Lumpur area is underlain by limestone and karst, which are extensively developed and classified as extreme Karst class Kv. The process of karst formation commences as rainfall (H₂O) falls from the atmosphere onto the surface, where it then infiltrates the ground. Mixed with CO₂ from the air and soil, this water produces a weak carbonic acid (H₂CO₃), which seeps further into the ground and makes contact with the limestone (CaCO₃) and/or dolomite (CaMg(CO₃)₂) (Waltham and Fookes, 2003; Milne et al., 2014; Tan, 2001).

4. Climate Change Projections

4.1 Climate and Weather

The American Meteorological Society defines climate as “The slowly varying aspects of the atmosphere-hydrosphere-land surface system. It is typically characterised in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities”. According to Dessler (2012), weather refers to the actual state of the atmosphere at a particular time. Climate, in contrast, is used for statistical descriptions of the weather over a period of time, usually several decades.

4.3 Climate Change in Malaysia

Malaysia is located near to the equator, and is characterised as a tropical country with a monsoon climate. It experiences heavy precipitation all year round. The weather is strongly influenced by topographical features, particularly the mountain and sea-land configuration. Two monsoons dominate the Malaysia climate; the summer Southwest Monsoon from May to September, and the winter Northeast Monsoon from November to February. Tropical storms and depressions form in the South China Sea and the Indian Ocean.

Southeast Asia is currently experiencing increasing surface air temperatures. The El Nino-Southern Oscillation (ENSO), a time scale based oscillation of the Indian Ocean Dipole (IOD) and the intraseasonal Madden Julian Oscillation (MJO), influence the observed interannual and intraseasonal rainfall distribution in Southeast Asia. There are several studies that demonstrate the increase in tropical cyclones originating in the Pacific. These events

cause major impacts to the Philippines and Vietnam, including the floods in Peninsular Malaysia in 2006 and 2007 (Malaysia Meteorological Department, 2009; IPCC, 2014). The increasing temperature and decreasing rainfall have both significantly increased the intensity and spread of the forest fires in Southeast Asia. Fires in peat regions in Indonesia during the El Nino dry season are now common every year and have caused haze in most ASEAN countries. The countries that are badly affected due to this haze are Indonesia, Malaysia and Singapore. In 2005, the Prime Minister of Malaysia declared a state of emergency in Port Klang, Selangor, 40km from Kuala Lumpur, after the Air Pollutant Index (API) reached 500 (The index's pollutant components combines carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide and is reported in ppmv. PM₁₀ particulate matter is reported in µg/m³) (Joshi, 2005; Mukhlisin et al., 2015). According to the Malaysian Metereological Department (2009), an average temperature increase of 0.5°C to 1.5°C has been recorded in Peninsular Malaysia, with the SON period recording the highest increase in temperature, followed by DJF.

Malaysian rainfall distribution patterns are determined by seasonal wind flow patterns and local topographic features. The east coast of Peninsular Malaysia experiences more heavy rain as the area is exposed to the South China Sea. Conversely, the west coast area of Peninsular Malaysia is likely to be sheltered from heavy rains due to its topographical location. Thus, the east coast experiences more flooding during the monsoon season compared to the west coast. It was also found that the south coast will experience more rainfall during April, and that the east coast is also likely to see increased rainfall during this period.

5. Extreme Weather and its Potential Impact on Railway Infrastructure

Natural hazards due to extreme weather events have occurred frequently in Malaysia during the past decade. The most devastating natural disasters experienced in Malaysia have been due to floods and landslides. The risks and consequences to these events can affect railway infrastructure and operations, as explained in Table 1.

i) Floods

Severe and destructive floods in the southern peninsular of Malaysia occurred in two events back to back in December 2006 and January 2007, which are known as Typhoon Utor. The massive flood in Kota Tinggi Johor started when the Northeast monsoon brought heavy rain through a series of storms. The series of floods were unusual as the 2006 average rainfall return period was 50 years, while 2007 was equivalent to a 100 year return period. Extreme

localised weather events are among the natural causes that triggered the flash floods (Sani and Diya, 2014). Significant consequences from such severe floods were evident in the shutdown of transportation, logistics and railway systems. The impacts caused shortages of medicines, food, clean water and consumables.

ii) Landslide

South East Asia suffers more landslides compared to other parts of the world due to its climate and geography. According to the United Nations University (United Nations University, 2005), among natural disasters, landslides are the seventh ranked in terms of fatalities, after windstorms, floods, droughts, earthquakes, volcanos and extreme temperatures. An average of 940 people annually were killed by landslides in the decade from 1993 to 2002. Most of these victims were from Asia. It is important to note that there are many factors that can trigger landslides including changes in slope geometry, changes in water level, rainfall intensity, and changes in loading. However, in Malaysia, the major cause of landslides is due to high precipitation (Zakaria et al., 2007).

Figure 6 shows the impact of an extreme rainfall event. In the case of rock falls and landslides, road vehicles can often swerve to avoid the hazard. Trains do not have this option, and as a result even a minor landslide can cause a derailment risk (Dr.Dave, 2012; Jaroszweski et al., 2015). It is important for the infrastructure manager to design the slope and track embankment with the consideration of extreme rainfall due to climate change.

iii) Sea Level Rise

A rise in the sea level has the potential to affect the 100 year return period flood level, which is usually the standard used in Malaysian when designing the platform level for bridges (Ahmad and Ismail, 2013).

iv) Heat

There are many impacts of hot and dry weather to railway infrastructure, the most obvious being the risk of track buckling. The definition of buckling is a track deformation constituting a reportable misalignment, which would render the line unfit for the passage of trains at line speed and/or necessitates emergency remedial work to a running line under either a temporary speed restriction or closure of the line. Track buckling is an extremely dangerous as it can cause catastrophic derailment of trains and disrupting to operations.

Figure 7 shows a Singapore bound train which was derailed on 26th of January 2013 due to rail buckling (News Straits Times, 2013). The wagons landed on their sides, trapping the crew and injuring five passengers. Train services in the southern part of Malaysia were disrupted for several days due to the difficulties rescuers and maintenance crews had reaching the remote location of the incident.

6. Infrastructure Design Requirements for Operational Readiness to Climate Change

As well as examining the impact of climate change on rail operational readiness, it is also important to insure infrastructure resilience to emerging risks from climate change (Harris and Ramsey, 1994).

6.1 Horizontal and Vertical Alignment

SPAD has developed a baseline alignment for HSR Malaysia but the detailed alignment remains confidential at the time of writing. Thus, this article will discuss the conceptual alignment of the HSR line in Malaysia. According to the International Union of Railways (2011, 2015) the typical parameters for new high speed lines include:

- The maximum gradient (depending on geographic characteristic and operating conditions) for dedicated passenger traffic is 35mm/40mm per metre run subject to suitable rolling stock.
- Track centre distances for 200 km/h and 300 km/h speeds are 4m and 4.5 to 5m respectively.
- Maximum cants are between 150mm and 170mm.
- Minimum curve radius is shown in Table 2.

To reduce the use of structures in uneven terrain, the maximum design of gradient is always implemented. SNCF adopted a maximum gradient of 35mm/m for its Paris-South East line which made it possible to reduce drastically the number of bridges and tunnels on moderately uneven terrain, and reduce the cost of construction to about 65% of a two-lane motorway on the same terrain. However, powerful rolling stock and massive earthworks are needed if these concepts are to be accomplished. The climate change risk associated with this approach will be very high since high rainfall or droughts will affect the degree of soil moisture in earthworks.

Tunnelling in the Kuala Lumpur area will be the best method of construction since it would be extremely difficult to construct the infrastructure without significant and long-

lasting disruption to surface transport. Previous LRT and MRT projects in Kuala Lumpur have demonstrated that tunnelling can be successful. However, Kuala Lumpur is a limestone area. Sink holes will most likely be the greatest risk during the construction phase. Studies need to be carried out to mitigate this problem.

6.2 Earthwork

The nature of earthworks will very much depend on the **topography** of the route. They will be governed by the rules set out by the Government, which will include environmental protection. The Government of Malaysia, via the Malaysia Public Work Department, has set the guidelines to ensure that each project should comply with these rules. Sections which are constructed in cuttings and tunnels will make the alignment lower than the surrounding area, causing these sections to be prone to flooding. Therefore, the point of discharge and flood level of these sections needs to be measured during the early stages.

Other climate risks that must be assessed include the extreme rainfall events that Malaysia experiences during the monsoon season. Drainage is a common problem during the construction phase. Most developers in Malaysia ignore the runoff from the construction area, thus floods frequently occur in the immediate vicinity of build sites. This also applies to building construction when runoff affects rail operations, as happened to the two railway lines in Serdang (which is 15km from Kuala Lumpur). The floods put a halt to the two important rail services, the Commuter and Express Rail Lines (ERL), in 2005. Not only do the tracks become slippery, but the water poses a danger to trains and passengers **due to the fact that high voltage electricity (e.g. 1500V-DC/AC, 25kV-AC) is commonly used for train operations and signalling**. The solution to this problem implemented by the Drainage and Irrigation Department (DID) was to upgrade a 1km stretch of a drain located just few metres away from the station. This work cost the Malaysian Government £450,000, which could have been avoided if such measures had been taken beforehand (Zakaria and Shaaban, 2007).

The flash flood that hit Klang Valley on the 12th of May 2015 affected KTM Batu Tiga Station, as seen in Figure 8. Passengers were refunded 30 pence and were informed by the KTMB to alight and find their own transportation from the station. This passenger measure cannot be implemented when it comes to HSR, as the fares and operations are more costly compared to other rail services. Therefore, it is important for the developers and policy makers involved in the HSR project to integrate climate change considerations into their track vertical profile.

6.3 Soil Stabilisation

The proposed route of the Malaysian HSR line transverses undulating ground including several limestone areas, swampy areas and low lying areas where floods occur annually. There were several design concepts for HSR Malaysia. These concepts, however, are merely guidelines and can only be confirmed once soil investigations are carried out. However, based on the risk analysis, geotechnical design and ground improvement methodologies have been proposed, including:

i. Cut Slope

Maximum height of cut slope is expected to be up to 4 benches with the height of each typical bench at 5m and gradient of 1(V):1.5(H). Each bench is separated with a 2m-wide berm for maintenance access and berm drainage. For this typical configuration the slope is stable and does not normally need stabilisation work. Turfing by hydroseeding is necessary to minimise erosion.

ii. Fill Slope

Fill slope is proposed to be constructed at 1(V):2(H) gradient with a bench height of 5m and berm width of 2m. Based on plans provided by JKR, it is anticipated that the maximum height of fill slope will be about 15m. Fill materials shall be compacted to 90% of Maximum Dry Density (MDD) based on Modified Proctor Compaction, except within one metre of road subgrade where the fill shall be compacted to 95% of MDD.

iii. Bridge Foundations

It is very likely that piers and abutments of the bridge will need to be supported on piles. The use of Prestressed Concrete Spun Piles enables piling works to be completed in a short time and is economical compared to bored piles or micro piles. If it is found that spun piles are not suitable, it may be due to the shallow bedrock or hard/very dense ground. In that case, bored piles or micro piles shall be used.

iv. Bridge Approaches

Bridge approaches will be designed to comply with settlement criteria as specified by the Authority. If the existing ground is not capable of supporting the fill approach, the ground shall be treated or the fill shall be supported on piles i.e. piled embankment.

v. Vehicular Box Culvert (VBC) Foundation

VBC can be founded on the original ground if the ground is capable of supporting the load imposed by the VBC, traffic and fill above the VBC. Otherwise, the ground will need to

be treated or the VBC will need to be supported on piles. Type, size, length, capacity and spacing of piles shall be determined based on soil investigation data.

vi. Proposed Ground Treatments

For embankments over soft ground, the following treatments can be considered. The use of such treatment will be based on the merits and demerits of each treatment.

Option 1: Total Removal and Replacement

In this treatment, the whole layer of soft soil is removed and replaced either with suitable earth or sand if the ground water table is present within the excavation. The sand is placed up to 300mm higher than the ground water table. Earth/sand can be placed above the sand fill. No surcharge treatment is required for this treatment as the compressible layer is removed. This treatment is suitable for soft ground less than 3m thick.

Option 2: Partial Removal and Replacement with Surcharge

In contrast to Option 1, only partial removal of soft material is carried out and replaced with sand and/or suitable earth fill. If the water table is present, sand is used as replacement material and placed 300mm above the water table. Geotextile separator is placed along the base of the excavation to avoid mixing of replacement fill with the original soft ground. The maximum depth of removal is about 3m.

Surcharge, between 1m to 1.5m thick above finished road level is required to accelerate the consolidation of the remaining soft soils. This treatment is suitable for relatively low embankments and soft soils less than 5m thick.

Option 3: Replacement with Surcharge and High Strength Geotextile Reinforcement

This option is similar to Option 2 but with the addition of high strength geotextile reinforcement along the base of excavation to increase the factor of safety against slope stability failure. In addition, surcharge as per option 1 is required to accelerate the consolidation of soft soil. This treatment is suitable for a high embankment with relatively thicker soft soil. A typical section of the treatment is shown in the appendices.

Option 4: Surcharge and Vertical Wick Drains

In this particular treatment, there is no removal and replacement. A geotextile separator is placed on the original ground (after clearing the ground), and followed by about 1m thick of sand blanket. **Vertical wick drains are installed** at triangular spacing of 1.0m to 1.5m c/c to accelerate the consolidation of soft soil. This treatment is suitable for embankments on very

thick soft soil for which the consolidation period will be long i.e. more than 12 months if only the treatment with surcharge is adopted.

If necessary, geotextile reinforcements shall be placed along the base of the fill to increase the safety factor against slope failure (Milne et al., 2014).

Option 5: Stone Column

This is a method where columns of soft ground are replaced by compacted stone columns, forming stone/soil composite. The stone columns act as vertical drains, accelerating the consolidation of soft ground which is compressed by fill load, strengthening the soft soils against shear failure and reducing the magnitude of settlement of the soft soils.

Similar to the Vertical Wick Drain, geotextile separators and a 1m layer of sand blankets are required. Normal sizes of stone columns range from 600mm – 1000mm in diameter and are installed at a spacing of 1.5 – 2 times diameter of the columns. Since the size of the columns is much greater than the Vertical Drain, the consolidation period is normally less than 3 months.

Since the consolidation period is shorter and settlement magnitude is reduced, this method is suitable at bridge approaches.

Option 6: Piled Slab Embankment

In this treatment, geotechnical problems such as settlement, bearing capacity and slope stability can be solved/ minimised. The only disadvantage using this treatment is the cost. This treatment is proposed for embankments at bridge approaches to overcome the differential settlement between a pile founded structure and a normal embankment. A typical section of the treatment is shown in the appendices.

Merits and Demerits of Each Ground Treatment Option

Table 3 shows merits and demerits of each ground treatment option for comparison.

In civil engineering, the engineers can only be sure of the exact ground condition (especially deep below the ground) once the tunnelling or excavation has started. Even though soil investigations (such as taking a soil sample) and testing are performed, these only act as a guide, and will never be fully accurate because underground conditions vary greatly with the amount of water present. Malaysia's major problem during construction is

groundwater. A high proportion of the claims and litigation in construction contracts arise from groundwater problems.

6.4 Structures and Tunnelling

Design structures such as viaducts and elevated structures for railway tracks will eliminate the possibility of flooding to the HSR tracks in low lying areas. However, pier scouring will be a risk to the United Kingdom based on the Environment Agency's 2008 Tidal Thames Extreme Water Levels. This estimates that all tunnel portals are at risk of fluvial flooding against a best estimate peak flood level of a 1 in 200 year return period

6.5 Drainage

One failure system that could paralyse the whole railway operation is drainage. Weakness of drainage design often leads to flooding. Usually the selection of rainfall intensity will be based on the return period or Average Recurrence Interval (ARI) selection. Rainfall intensity is not a measure of how often it rains, rather it is about heavy downpours that only occur once in a hundred years, for example. Normally rainfall intensity is measure in mm per hour over a given duration. The heaviest rainfall deluges are likely to be experienced for a short period. Most rainfall intensity measurements use 5 minute durations. ARI describes how often a particular rainfall event can be expected to occur. The ARI is normally expressed in years.

As discussed earlier, the heaviest rainfall will occur during the monsoon season. As previously discussed, there were two 2 major events back to back in Johor in December 2006 and January 2007. This area coincides with the planned route of the Malaysian HSR. The massive flood in Kota Tinggi Johor started when the Northeast monsoon brought heavy rain through a series of continuous storms. As highlighted earlier, the series of floods were unusual as the 2006 average rainfall return period was 50 years and the return period of the 2007 event was 100 years. Localised extreme weather events are one of the major natural causes that triggered flash floods (Harris and Ramsey, 1994; Lane and Dora, 2011; Kwon and Park, 2006). Thus, selection of ARI should accommodate climate change and should not just be based on historical data but future projections of rainfall intensity. However, the cost will be excessive if a return period of 100 years is used as a design standard. As such, the return period used in the design of HSR platform level well-considered. Should the HSR developer or policy-maker accept the failure of operations once a year, or should they build to withstand

a high return period event? The answer will depend on many factors including financial and economic viability as well as the climate projections for the given area.

6.5 Track Structure and Substructure

Continuous welded rail (CWR) with continuous ballast is frequently adopted by designers for most high speed railway tracks. It is important that the rail be designed to accommodate projected changes in climate such as extremely hot weather to prevent buckling occurring, as Malaysia will experience higher temperatures in the future. Continuous ballasts are favoured as they allow automated maintenance, meaning it is often specified where there is a discontinuity in the track support, such as transitions on or off fixed structured or over structural movement/ expansion joints (Remennikov et al., 2012). However, according to Kwon and Park (2006), since the beginning of the high-speed train operations in Korea in April 2001, several unfavourable impacts were observed on the operating ballast-track lines, including the flying ballast phenomenon. This in turn caused damaged wheels, broken glass at stations, and damaged acoustic screens. It has also been noted that the track design of HSR Malaysia could incorporate these findings:

- At wind velocities of of 20 m/s, ballast laid on the wind tunnel will start to move and will completely blow out at a wind velocity between 25 m/s and 45m/s. Furthermore, for ballasts stacked between ties, at wind velocities wind of only 33m/s flying ballast is observed.
- As the mass of ballast becomes smaller, the ballast starts to move at lower wind velocities.
- Flatter ballast (high flakiness ratio) has a higher critical wind velocity compared to rounded ballast.
- Higher tie or a lower ballast surface will prevent ballast flying.
- Countermeasures should be focused at the centre of the track due to the strongest airflow being observed in this region.
- The probability of ballast flying at a train speed of 350km/hr is about double that at 300km/h.

There is also a new form of railhead damage known as ballast pitting that often occurs on high speed lines because of the speed and energy of the vehicle which is thought to generate an explosive crushing of the ballast particles. This in turn damages the railhead . This mechanism is also thought to be be associated with the nose region of vehicles (Quinn and Hayward, 2008).

The track bed is the ground base onto which a railway track is laid. Normally the track bed is laid on natural ground with the removal of 100mm or 50mm thickness of topsoil. According to Bonnet (2005) the control of water in the track bed is a major factor in designing the construction layers in relation to the sub-grade material, which are shown in Table 4.

7. Concluding Remarks

Although international communities have agreed to set a common goal for global warming reduction, climate change is still a natural threat to critical infrastructure. Malaysia is still far behind in terms of assessing the risks and vulnerability of the railway operations to climate change. There is a lack of studies on the potential regional and local impacts of climate change on Malaysian railway infrastructure and operations. Now that Malaysia is planning to build a new high speed rail line between Singapore and Malaysia, the mitigation and adaption measures to the risk of climate change are crucial in assuring:

- Railway safety
- Reliability
- Capacity for the future
- Value for money
- Prevention and recovery of assets from natural disaster.

The impact of climate change to the operational readiness of HSR in Malaysia is thus highlighted in this paper. The vulnerability of rail infrastructure has been evaluated with the use of local geographical information. Mitigation and risk management measures have been proposed to help track engineers and designers better manage the risks, which should in turn improve infrastructural and operational resilience.

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Table 1: Overview risks of HSR Malaysia

Climate Impact Group	Risks	Safety Impact	Performance Impact	Likely Negative Impact from Climate Change	Long or Short Term	Adaptation Measures
Sea Level Rise	Increased flooding generally	Medium	High	High	Long	Platform level needs to cater for sea level rise and drainage design must cater for ARI plus climate change projections.
Increased Rainfall	Landslide	High	High	High	Long	Drainage design must cater for ARI plus climate change projections
Increased Rainfall	Settlement	High	High	Low	Long	Need to monitor the ground movement and the relationship with rainfall intensity, especially in the karst area in Kuala Lumpur.
Heat	Track buckling	High	High	High	Long	Need to study rail designs resilient to high temperature or provide watchmen

Table 2: Minimum curve radius for HSR⁶⁻⁷

Minimum speed	Ideal Curve Radius	Recommended Curve Radius
200km/h	2,500m	3,500m
300km/h	5,500m	7,000m

Table 3: Merits and demerits of each ground treatment option

Type of Treatment	Merits	Demerits
<u>Option 1</u> (Total Removal and Replacement)	i) No stability and settlement problem ii) construction iii) Cost effective iv) No surcharge required	i) For shallow soft soil only ii) Disposal of unsuitable materials
<u>Option 2</u> (Replacement with surcharge)	i) Suitable for low embankment and shallow soft soil ii) Easy construction iii) Cost effective iv) No surcharge required	i) Not suitable for high embankment and thick soft soil ii) Stability problem for high embankment iii) Long surcharge period as limited surcharge thickness due to stability problem iv) Disposal of unsuitable materials
<u>Option 3</u> (Replacement with surcharge and high tensile reinforcement)	i) Suitable for high embankment and thick soft soil ii) Easy construction iii) Cost effective	i) Long surcharge period for high embankment and thick soft soil ii) Disposal of unsuitable materials
<u>Option 4</u> (Surcharge and vertical wick drains)	i) Suitable for high embankment and thick soft soil ii) Faster surcharge period iii) Overcome stability problem with high tensile reinforcement	i) Slightly more costly compared to OPTION 3 ii) Specialist contractor for vertical drain required
<u>Option 5</u> (Stone Column)	i) Short surcharging period ii) Less settlement	i) More costly compared to OPTION 4 ii) Specialist contractor for stone column
<u>Option 6</u> (Piled slab embankment)	i) Can solve all geotechnical problems ii) Ease construction iii) No surcharge period	i) More costly compared to OPTION 5
<u>Option 7</u> (Elevated Structure)	i) Suitable to replace high embankment over swampy/thick soft soil ii) Narrow ROW compared to embankment option	i) Costliest Option

Table 4: Type of sub-grade material and their drainage natures

No.	Type of sub grade material	Drainage properties
1	Non cohesive materials like gravel and sand	Drains well and normally makes good sub-grades
2	Cohesive Clays and slits	Very low permeability due to the small pores between their particles. In this case rainwater falling on the track needs to be collected in the ballast and channelled to drains before it gets to the sub-grade. If not, in long-term the track settlement will begin to show itself.
3	Organic peats and silts	The most difficult sub-grade to build on and should be designed by specialists. It has a variety of textures, will usually shrink if drained or if subjected to repeated loading.
4	Sedimentary rocks like sandstone or limestone	Often permeable by water and also contains springs and lenses or layers of other materials. Provided suitable means of drainage, this sub-grade material will offer a satisfactory sub-grade even if waterlogged.
5	Igneous rocks like granite	Impermeable and are unlikely to give any problems to the sub-grade.

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