REAAA Newsletter

REAAA Newsletter 2024-2
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For Members Only

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DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
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Editorial

The impact of climate change on road infrastructure is increasingly evident, with more frequent extreme weather events causing disruptions and driving up costs. The REAAA remains committed to advancing resilient infrastructure through its Climate Change, Resilience, and Disaster Management (CCRDM) Working Committee. Collaboration with international organizations like the World Road Association (PIARC) has been instrumental in sharing best practices and implementing climate adaptation strategies to address these growing challenges.

This edition of the REAAA Newsletter presents a range of articles, organized into two sections: Articles from the Technical Committee Report and Other Articles/Technical Papers. The first section includes case studies and insights from the CCRDM Working Committee. These articles focus on practical actions and innovations from countries like Australia, Japan, and New Zealand, providing real-world examples of how infrastructure resilience is being built. The second section features additional contributions focusing on topics such as sustainable practices in Malaysia, bioengineering solutions in Thailand, and carbon reduction strategies in Taiwan. These articles collectively demonstrate the diverse global efforts to mitigate the impacts of climate change on road infrastructure.

As climate change accelerates, the need for resilient infrastructure has never been more urgent. The articles featured in this newsletter underscore the importance of adaptive solutions, technology-driven risk management, and effective recovery strategies in ensuring the long-term sustainability of our road networks.

Looking ahead, the upcoming 17^{th} REAAA Conference in the Republic of Korea (October 2025) will serve as a critical platform for advancing discussions on climate resilience. The conference, themed "Future Roads: Hyper-connection," will explore how connected infrastructure can enhance road resilience in the context of climate change.

We hope the articles presented in this newsletter will inspire continued collaboration and innovation in addressing the challenges posed by climate change. Together, we can ensure that road networks worldwide are prepared to withstand the evolving impacts of a changing climate.

Acknowledgements

The contribution of the Co-Chairs of the REAAA CCRDM Working Committee, Ms Caroline Evans and Mr David Rolland; individual members of the CCRDM Working Committee; the contributors to the Newsletter articles; Mr Kieran Sharp, Ex-Officio Chair of REAAA Technical Committee and REAAA Technical Editor; and Ms Fione Gani, Corporate Development Center, Moh and Associates Inc., is gratefully acknowledged.

Publisher

The Road Engineering Association of Asia & Australia
46 B, Jalan Bola Tampar 13/14, Section 13, Shah Alam,
Selangor, Malaysia

Message from the President

Dr. Sung-Hwan Kim
President of REAAA

As we approach the final page of the calendar, there may be things we regret. However, I hope each of you can confidently say that you have lived this year to the fullest, with no regrets, and without wasting time. Time is equally given to everyone, but it becomes meaningful only for those who use it wisely. Like the trembling final leaf in The Last Leaf, we now prepare to welcome the new year with the spirit of Janus.

Over the past year, we have witnessed remarkable efforts from our members across various areas, including hosting two Governing Council meetings, participating in Technical Committee activities, engaging in YEP initiatives, organizing business forums, expanding membership, managing our website, and preparing for the 16th General Conference. I am deeply grateful for your dedication.

These efforts represent the continuous growth of our association, year after year.

Although it is unfortunate that the number of member countries has been declining, we have garnered significant interest this past year through our interactions with Ministers and Vice Ministers from Cambodia, Kazakhstan, Saudi Arabia, Bahrain, Mongolia, and Nepal.

Most importantly, the 17th General Conference will take place in the upcoming year. I would like to introduce this pivotal event, which I hope will serve as a stepping stone for the association's continued growth.

The 17th REAAA Conference will be held in my home country, the Republic of Korea, in Goyang City, near Seoul, from 26th – 31st October 2025. The theme of the conference is Future Roads: Hyper-connection. This conference marks a meaningful milestone as I conclude my term as the President of REAAA. The event is expected to attract over 5,000 participants from 130 countries, including global leaders, and experts and policymakers in the road and transport sectors. Through the REAAA Conference, Council Meetings, and the Heads of Road Authorities (HORA) meeting, participants will have invaluable opportunities to address shared challenges and collaborate on finding solutions to pressing global issues, such as climate change.

The program will feature a wide range of activities, including technical presentations, exhibitions, technical tours, and cultural events. The technical sessions will include over 250 papers across 12 fields, with special sessions focusing on emerging trends and technologies. Additionally, the 2025 International Road Traffic Expo (ROTREX) will serve as a premier platform for showcasing world-class advancements in road infrastructure. Participants will also have the opportunity to explore South Korea's cutting-edge road systems and technologies during the technical tours, as well as enjoy cultural tours celebrating the nation's rich heritage and diversity.

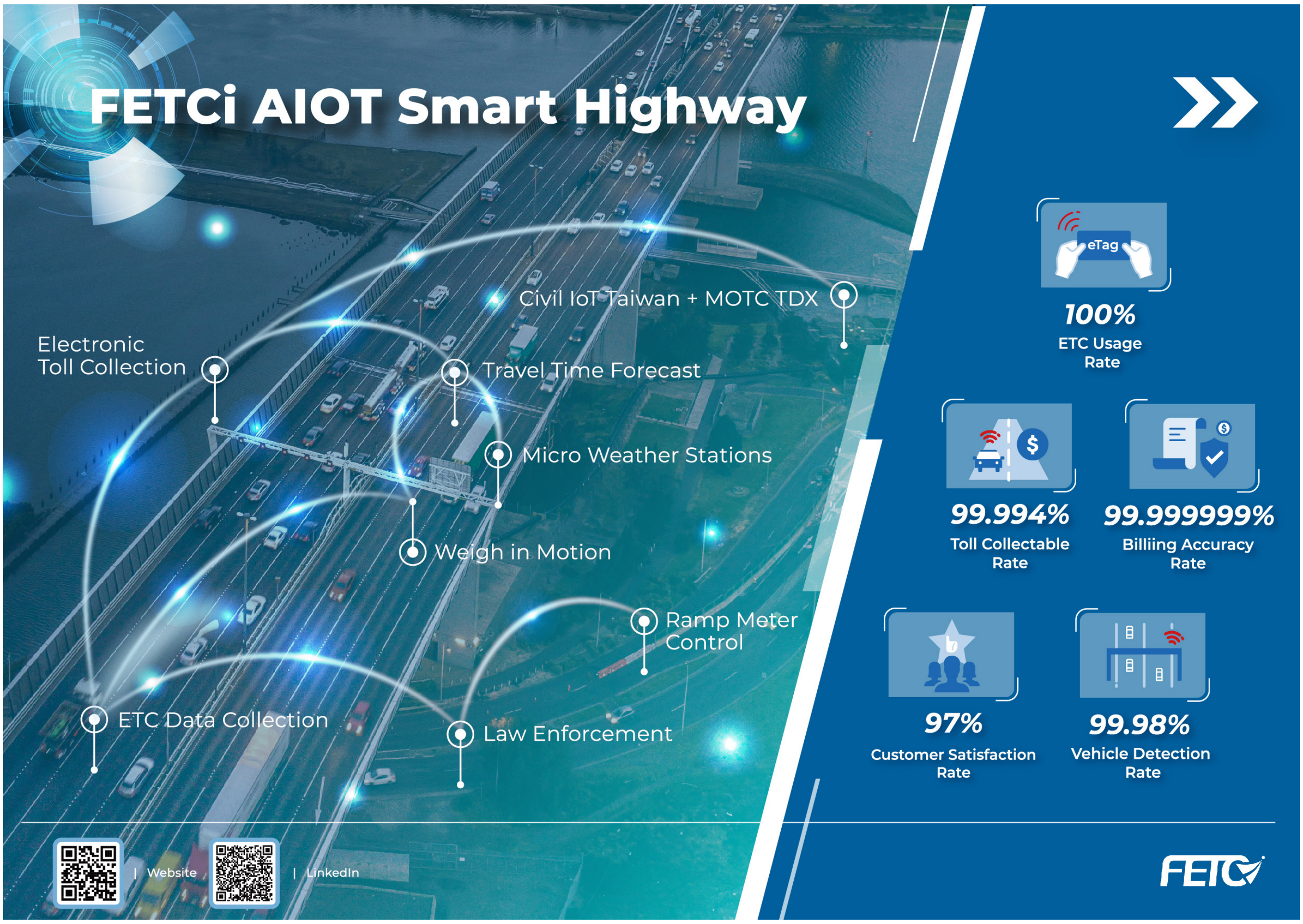
Notably, this conference will coincide with the 2025 PIARC (World Road Association) Annual Meeting and the 6th IRF (International Road Federation) Asia-Pacific Regional Congress in South Korea, making it even more significant. Representatives from over 130 countries will come together to strengthen global collaboration and shape the future of road policies and technologies.

We are working diligently to prepare for this momentous event. Your active participation and interest will be instrumental in ensuring its success. We look forward to welcoming you to Goyang City in October 2025.

Finally, I would like to express my gratitude to the CRF for their dedicated efforts in publishing this newsletter. I wish all our members a healthy and fulfilling conclusion to the year and encourage you to prepare for a prosperous new year.

Best regards,

Dr. Sung-Hwan Kim
REAAA President



122nd Council Meeting, Technical Session, and Technical Visit & The 5th International Conference on Highway Engineering 2024

The 5th International Conference on Highway Engineering 2024

"Future-Proofing Roads for Asia and Beyond"

&

PIARC International Seminar on the Transport Agency of the Future

4- 6 September 2024
Bangkok International Trade & Exhibition Centre (BITEC)

The 5th International Conference on Highway Engineering (iCHE2024) and the PIARC International Seminar on the Transport Agency of the Future was held on 4th – 6th September 2024 at BITEC, Bangkok. The event was organised by the Department of Highways and the Roads Association of Thailand. The conference program included an executive meeting, a plenary session, technical presentations, workshops, a panel discussion, a technical visit, and an exhibition. The program included Technical Sessions reporting the activities of PIARC Committee TC1.1 (Performance of Road and Transport Administrations) and a workshop organised by PIARC Committee TC3.1 (Road Safety).

Some highlights of the events follow.

122nd REAAA Governing Council Meeting

The management of REAAA is vested in a council which holds regular meetings to make policy decisions and set directions for the Association. The meeting agenda included: welcoming remarks by the President of REAAA, the Chairman of RATH, and the Secretary General of PIARC; reports by the Finance Committee, Honorary Secretary General, and working committees; and a presentation on Thailand's infrastructure status and future projects.

11th REAAA Business Forum

The topic of the 11th REAAA Business Forum was 'AI Application in Road Engineering & Management – Potential, Challenges, and Future Directions'. The program included technical issues related to the application of AI in road engineering and management, how to explore its immense potential value, and the challenges to policies, engineering, and management as well as to individual engineers. The objective of the Business Forum was to provide a platform for road authorities, academia, industry, and young professions to share and exchange their knowledge, insight, and expertise in AI technology applications.

A report on the Business Forum is included in this newsletter. The forum was an excellent learning platform to allow delegates to explore the potential and challenges of AI in road engineering and management together and collectively pave the way for a brighter future.

Technical Sessions

The theme of the technical sessions was 'Future-proofing Roads for Asia and Beyond'. There were four main topics:

A. Efficient, Inclusive and safe road management.

B. Smart mobility, digital technology and innovation for roads.

C. Sustainability and resilience of road networks.

D. PIARC International Seminar on the Transport Agency of the Future

Over 100 papers were presented in the Technical Sessions.

Technical Visit

The Ministry of Transport in Thailand has successfully deployed an innovative electronic tolling system known as M-FLOW (Multi-Lane Free Flow). M-Flow seamlessly integrates cutting-edge technologies, incorporating transponders and automatic license plate recognition (ALPR), to identify vehicles and streamline transaction processing. With an impressive throughput capacity, the M-Flow system effortlessly accommodates 2,000 – 2,500 vehicles per hour per lane at speeds up to five times faster than traditional barrier-based tolling methods.

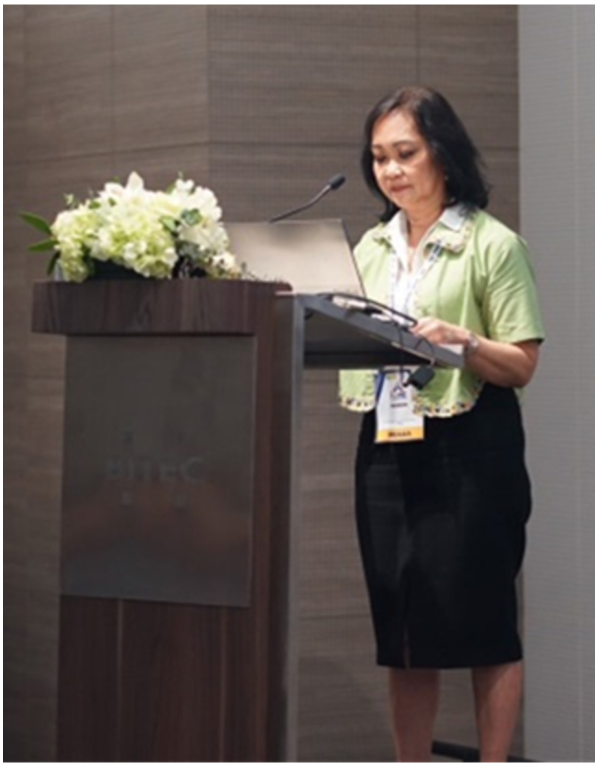
Full details are available at https://www.iche2024.com

11th REAAA Business Forum
AI Application in Road Engineering & Management – Potential, Challenges, and Future Directions

The 11th REAAA Business Forum was held on 4th September 2024 at the Bangkok International Trade and Exhibition Centre (BITEC). It brought together leaders and innovators from around Asia and Australasia to explore the theme: 'AI Application in Road Engineering & Management – Potential, Challenges, and Future Directions'. The forum served as a dynamic platform for knowledge sharing, collaboration, and discussions on how artificial intelligence (AI) is transforming the road engineering and management sector.

The event commenced with opening remarks by Mr. Aram Kornsombut, President of the Roads Association of Thailand and Honorary Member of REAAA. This was followed by congratulatory remarks from Ms. Lydwina Wardhani, REAAA Business Forum Coordinator, who emphasized AI's potential to enhance efficiency, safety, and accessibility while recognizing the challenges associated with its integration.

Mr. Aram Kornsombut, President of RATh and Honorary Member of REAAA



Ms. Lydwina M Wardhani REAAA Business Forum Coordinator

The forum featured a panel of eight distinguished international speakers from six REAAA member countries. They shared their insights, experiences, and perspectives on the application of AI in road engineering and management. Their presentations were followed by an extensive discussion session moderated by Mr Richard Moh, REAAA Council Member, Executive Director of the China Road Federation (CRF), and Chairman of MAA Group of Consulting Engineers, Taiwan.

The forum commenced with a keynote speech by Dr. Thanasak Wongtanakitcharoen, Director of the Inter-city Motorway, who discussed *M-Flow: An AI application in Thailand's barrier-free toll system*. This system leverages digital technologies such as automatic license plate recognition (ALPR), automatic vehicle identification (AVI), and automatic vehicle classification (AVC) to optimize toll collection efficiency.

Professor Jia-Ruey Chang, Graduate Institute of Architecture and Sustainable Planning, National Ilan University, Taiwan, presented on *Current developments of AI Technology in road maintenance in Taiwan.* His talk highlighted the use of AI for road damage detection, and how it can significantly improve the speed and accuracy of road maintenance management.

Dr. Inbae Kim, Principal Researcher at the Korea Expressway Corporation, delivered a presentation on *The application of machine vision-based road surface maintenance technology for coping with climate change in Korea*. He explained how classification and segmentation methods enhance the accuracy and efficiency of road maintenance efforts, particularly in addressing climate change impacts.

The next presentation was delivered by Dr Ponlathep Lertworawanich, Director of the Road Research and Development Bureau at Thailand's Department of Highways. His topic was *International Friction Index (IFI) prediction with machine learning for pavement management systems.* His study demonstrated how machine learning-based solutions improve road friction prediction, enhancing forecasting capabilities and road safety.

Dr. Ekarin Lueangvilai, General Manager of Asiam Infra Company Limited, followed with a presentation on *AI for pavement inspection: a rapid response after a flood.* His presentation focused on integrating AI technology with Ground Penetrating Radar (GPR) to inspect roads, enabling underground detection up to 2 meters deep with 90% accuracy, a significant improvement in inspection efficiency.

Dr. Kunihiro Takahashi, Senior Manager of the International Projects Division at the Metropolitan Expressway Company Limited, *discussed Cutting-edge AI technology in metropolitan expressways*. His presentation addressed the use of drones combined with AI for inspections, data collection, and reporting, particularly after earthquakes. These technologies allow rapid post-disaster assessments, ensuring minimal disruption to emergency routes and societal functions.

Mr. Tong Kum Kong from Singapore's Land Transport Authority presented on *Exploiting AI in the Singapore Land Transport Authority*. He highlighted the use of AI and video analysis to enhance construction site safety and efficient monitoring by detecting high-risk behaviours and reducing manpower requirements.

The final presentation, titled *AI in Transport*, was delivered by Dr. Richard Yeo, REAAA Council Member and Chief Operating Officer of the National Transport Research Organisation. He outlined how AI can improve traffic efficiency, reduce costs, enhance the accuracy of cost and schedule forecasting, and monitor project progress effectively.

The forum concluded with a panel discussion moderated by Mr. Richard Moh, where speakers explored the intersection of AI, technology, and infrastructure. Responding to the first question on AI's transformative role across industries, the panel underscored the importance of addressing challenges such as bias, security, intellectual property concerns, and the establishment of clear guidelines for AI-driven decision-making. They also highlighted AI's limitations, including issues with data quality and the phenomenon of AI ‘hallucinations’ (the generation of inaccurate or false information) while emphasizing the necessity of ethical frameworks.

In terms of the second question, the discussion focused on the critical role of interdisciplinary collaboration in achieving seamless connectivity within smart transportation systems. The panel suggested strategies such as synchronizing projects and fostering teamwork across diverse agencies to ensure successful implementation.

Finally, when asked to advise young engineers entering an AI-driven world, the speakers emphasized the need to cultivate broader, interdisciplinary skill sets. Proficiency in data analytics, AI technologies, and sustainability has become essential. Additionally, adaptability and critical thinking were highlighted as indispensable traits, enabling engineers to collaborate effectively with AI specialists and leverage the full potential of emerging technologies. The panel also urged young professionals to apply creativity and problem-solving skills, emphasizing that engineers should not solely rely on AI outputs but actively engage in innovative and thoughtful decision-making.

Mr. Richard Moh concluded the event by emphasizing the importance of continued interdisciplinary collaboration as AI becomes increasingly integrated into road management and other sectors. While AI holds immense potential, its successful application depends on ongoing dialogue, regulatory updates, and a shared commitment to safety and ethical practices. This transformative technology is breaking down boundaries between industries and nations, highlighting the need for unified guidelines and standards. Furthermore, AI's growing influence calls for professionals to adopt a more generalist approach which prioritizes adaptability and interdisciplinary skills to navigate an ever-evolving landscape.

Dr. Auckpath Sawangsuriya from the Department of Highways, Thailand’s, and one of the organizers of the 11th Business Forum, delivered the concluding remarks, emphasizing the importance of collaboration and the ongoing exploration of AI's role in advancing road engineering and management practices.

Panel Discussion

For more details and to access program material, please visit:

https://reaaabusinessforums.org/business-forum/11th-bangkok-thailand/

REAAA President Dr. Sung Hwan Kim (bottom left 1), REAAA Business Forum Coordinator Ms. Lydwina M Wardhani (bottom left 2), President of RATh Mr. Aram Kornsombut (bottom left 3), 11th REAAA Business Forum Moderator Mr Richard Moh (top left 1), and the speakers

RATh Executive Committee and Honorary Secretariat Mr Visit Achayanontkit (right) presenting souvenir to 11th REAAA Business Forum Moderator Mr. Richard Moh (left)

26th REAAA Young Engineers & Professional's Meeting 5th September 2024, BITEC, Bangkok Thailand

Ir. Hamzah bin Hashim
Chairman, REAAA YEP

The 26th REAAA Young Engineers and Professionals (YEP) Meeting was held successfully during the 122nd REAAA Council meeting at the Bangkok International Trade & Exhibition Center on 4th September 2024. The event was held in conjunction with the International Conference of Highway Engineering (ICHE) 2024, which was organized by the Roads Association of Thailand (RaTH). The focus of the event was on AI applications in road engineering and management, its potential, challenges and future directions. An REAAA Business Forum was held in conjunction with that meeting. A list of Seven panelists from member countries managed the forum, which was moderated by Richard Moh, a REAAA Council member from the China Road Federation.

The YEP meeting capitalized on the information gathered at the Business Forum as a basis for discussion. For the benefit of the audience, a question regarding AI applications in road engineering using ChatGPT was posed. A brainstorming session to list potential AI applications in daily operation was the next item on the agenda. Each country was invited to discuss the topic based on the 5W1H concept (What? Why? Where? When? Who and How?). By the end of the brainstorming session, the following seven potentials AI applications had been identified.

1. Early earthwork and soil treatment cost estimation – Malaysia
2. Concrete crack detection for bridges – Indonesia
3. Road damage prediction using automated road data collection techniques – Taiwan
4. Public feedback and social media analytic engine – Singapore
5. Road predictive maintenance and decision-making – Thailand
6. Automated drone inspection post disaster – Japan
7. Tunnel defect inspection – Korea.

These potential AI applications were discussed, and several conclusions were made. For example, AI can automate repetitive tasks, leading to increased efficiency and productivity in road design and operation. That could also include high-risk operations such as inspections after a disaster. AI could also perform mundane tasks consistently without fatigue or errors. To the extent, AI can analyze large amounts of data and decisions can be made quickly, often better than humans in certain contexts. However, there were several negative aspects to AI. For example, AI systems can inherit biases from their training data, leading to unfair or unethical decisions or incorrect decisions. Over-reliance on AI could also reduce human skills and critical thinking abilities to perform road engineering work from planning, design, construction and operation.

The YEPs would like to express their gratitude to the Council Members and observers who participated in the meeting. Their comments and opinions during the AI application brainstorming sessions were very valuable. The YEPs benefitted from the session; hopefully these potential AI applications will be materialized someday by member countries. The YEPs would also like to thank the Roads Association of Thailand (RaTH) for choosing this theme, for making the arrangements and for their hospitality.

123rd REAAA Governing Council Meeting, Melbourne, May 2025

The REAAA Australian Chapter will be the host for the 123rd Governing Council meeting, to be held at the headquarters of the National Transport Research Organisation (NTRO) (80A Turner Street, Port Melbourne, Victoria, Australia) from 5th – 6th May 2025. The Council Meeting will include the 27th Young Engineers and Professionals (YEP) meeting, the REAAA Business Forum, working committee meetings, and technical visits.

The meeting will be held in conjunction with the NTRO International Technical Conference, which will be held at the same venue from 7th – 9th May. The Conference will feature speakers and presentations on a range of topics of interest to REAAA members, including structures, pavements and materials innovation, decarbonisation, and sustainable asset performance. For further details of the conference, visit https://www.ntroconference.com.au/

The International Road Federation (IRF) will also be involved in these events, with the IRF Director General, Susanna Zammataro, already confirmed as a keynote speaker for the Conference.

REAAA Governing Council meeting attendees are encouraged to make the most of their visit to Melbourne, and stay on for the NTRO International Technical Conference, which will focus on innovative solutions to the challenges faced both now and into the future for transport. The venue is only 3 km from Melbourne's CBD, and is close to the city's major attractions, including Crown Casino and the Melbourne Cricket Ground.

Agenda details for the REAAA Event confirmed so far are:

Monday, 5th May:

0900-1300: 27th YEP Meeting

1400-1700: 12th REAAA Business Forum

1700-1900: Networking reception

Tuesday, 6th May:

0900-1100: Working Committee Meetings – Technical Working Committees, Hwang Award Committee, Smart Highway Committee (optional)

1400-1700: 123rd REAAA Governing Council Meeting

1900-2200: Farewell Dinner

Wednesday, May 7:

0900-1600: NTRO International Technical Conference Attendance

1600 – 1900: Industry Event with REAAA, NTRO, IRF and CHTS.

Thursday, May 8:

0900-1700: NTRO International Technical Conference Attendance

1830-2230: Gala Dinner

Friday, 9th May

0900-1700: NTRO International Technical Conference Attendance

1430 – 1700: Technical Visit: ALF (Accelerated Loading Facility) and SEA Electronic Site Visit

For further details on the REAAA Governing Council Meeting contact: reaaa@arrb.com.au

For further details on the NTRO International Technical Conference contact: events@ntro.org.au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NATIONAL TRANSPORT RESEARCH AWARDS


Please welcome
Sal Petroccitto OAM

REAAA Low-volume Roads Symposium

Inspired by the success of the REAAA New Zealand Chapter's bi-annual *Low Volume Roads Workshop*, the REAAA Australian Chapter is organising a symposium that aspires to garner the same level of enthusiasm and relevance to practitioners and decision-makers responsible for the planning, construction, and maintenance of low-volume roads.

Often treated as a lower priority when compared to high-volume roads which dominate in discussions, research, and investment due to their proportional representation of road users and freight operations, the low-volume road network nevertheless represents the vast majority, by length, of the Australian road network, reaching from cities and towns into the most remote regions and communities. They also represent a significant proportion of roads in other REAAA member countries.

The REAAA Australian Chapter is organising a Low-volume Roads Symposium, to be held in Alice Springs, Northern Territory, from 1st – 3rd October 2025. An invitation is extended to all members of REAAA to attend.

The symposium will include presentations on themes including: road safety, pavement design, sustainability, resilience, managing community expectations, treatment selection and design, maintaining a skilled workforce, road asset management, and freight logistics.

For further information, and to register your interest in the event, please contact Dr. Richard Yeo, Chair of the REAAA Australian Chapter (richard.yeo@ntro.org.au).

REAAA Conference Goyang 2025

What is the REAAA Conference?

The Road Engineering Association of Asia & Australasia (REAAA) conferences have evolved into a premier regional platform for presenting research findings, discussing, and exchanging ideas on innovative and cutting-edge technologies related to the development, construction, management, and maintenance of roads, highways, and related infrastructure. Held every two to four years by the host country of the REAAA President, these conferences are highly anticipated by professionals involved in financing, designing, constructing, and maintaining road and transportation engineering projects.

The 2025 conference will be the 17th in the series and will take place in Goyang in the Republic of Korea. This follows successful past conferences in cities such as Bangkok (1976), Manila (1978 & 2006), Taipei (1981 & 1995), Jakarta (1983), Adelaide (1986), Kuala Lumpur (1990&2013), Singapore (1992), Wellington (1998), Tokyo (2000), Cairns (2003), Incheon (2009), Bali (2017), and On-line (2021). This will be the second time the Republic of Korea hosts the REAAA Conference, with the first being in Incheon in 2009.

REAAA in Brief

The REAAA was established by road and traffic experts from the Asia and Australasia region in 1973. Its permanent Secretariat is currently located in Shah Alam in the suburbs of Kuala Lumpur.

The objectives of REAAA are to promote the science and practice of road engineering and related professions in the Asia Pacific region through developing professional and commercial links within and between countries in the region. The association's long-term vision is to be the most effective regional organization, providing members with an avenue for sharing and transferring of technology towards promoting a better future in road-related engineering, with regional and technical cooperation as its underlying principles.

Currently REAAA, which has local chapters in Malaysia, Brunei, Korea, the Philippines, Australia and New Zealand, has a total of 182 institutional members and 1,720 individual members from 36 countries in its register.

Conference Hosts

In October 2025, the "REAAA Conference Goyang 2025" will be held in Goyang, Republic of Korea. The host country, Korea, has been one of the fastest-developing nations over the past 50 years. It successfully hosted the REAAA Conference in Incheon in 2009 and the Seoul World Road Congress in 2015.

The Republic of Korea is a dynamic country where tradition meets innovation. Known for its rich history, vibrant culture, and cutting-edge technology, it offers a unique blend of the past and future. Visitors can explore historic palaces in Seoul, stunning natural landscapes like Jeju Island, and indulge in world-famous Korean cuisine. As a global leader in industries like electronics and entertainment, Korea is the birthplace of K-pop and Korean dramas that captivate audiences worldwide. Its warm hospitality and efficient infrastructure make it an unforgettable destination for travelers.

Goyang, located just northwest of Seoul, is a vibrant and modern city known for its excellent accessibility and quality of life. It boasts key attractions like Ilsan Lake Park, one of the largest artificial lakes in Korea, and KINTEX, a premier exhibition and convention center. Goyang is also a hub for innovation, with thriving industries in technology and media. The city offers a perfect blend of urban convenience and natural beauty, making it an ideal place to live and visit. Additionally, its proximity to Seoul and well-developed infrastructure make it a gateway to Korea's culture and economy. We invite you to join the REAAA Conference Goyang 2025 and engage with road technology experts from around the globe. Your active participation will serve as a valuable contribution to this significant event.

About REAAA Conference Goyang 2025

Title	REAAA Conference Goyang 2025	**Hosted by**	ex Korea Expressway Corporation, Goyang
Dates	October 26 - 31, 2025	**Organized by**	Korea Road Association
Venue	KINTEX 2 Exhibition Hall, Goyang	**Supported by**	Ministry of Land, Infrastructure and Transport
Theme	Future Roads: Hyper-connection	**Language**	English

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Schedule

TIME	October 26 (SUN)	October 27 (MON)	October 28 (TUE)	October 29 (WED)	October 30 (THU)	October 31 (FRI)
09:00-10:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	PIARC Council Meeting PIARC Technical Committees On-site Registration Exhibition(ROTREX 2025)	Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	REAAA General Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Technical Visit / Cultural Visit
10:00-11:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	PIARC Council Meeting PIARC Technical Committees Special Session1 Technical Session Exhibition(ROTREX 2025)	YEP Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Plenary Session REAAA General Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Business Forum Korea-Indonesia Road Conference Technical Visit / Cultural Visit
11:00-12:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	PIARC Council Meeting PIARC Technical Committees Special Session1 Technical Session Exhibition(ROTREX 2025)	YEP Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Plenary Session 125th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Business Forum Korea-Indonesia Road Conference Technical Visit / Cultural Visit
12:00-13:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	PIARC Council Meeting PIARC Technical Committees Special Session1 Technical Session Exhibition(ROTREX 2025)	YEP Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Plenary Session 125th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Persons	Business Forum Korea-Indonesia Road Conference Technical Visit / Cultural Visit
13:00-14:00	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
14:00-15:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	Opening Ceremony Exhibition(ROTREX 2025)	Special Session2 124th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	HORA Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	Closing Ceremony
15:00-16:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	Technical Session Exhibition(ROTREX 2025)	Special Session2 124th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	HORA Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	
16:00-17:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	Ministerial Session Technical Session Exhibition(ROTREX 2025)	Special Session2 124th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	HORA Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	
17:00-18:00	PIARC Meeting of the National Committees	PIARC Council Meeting PIARC Technical Committees	Ministerial Session Technical Session Exhibition(ROTREX 2025)	Special Session2 124th REAAA Council Meeting Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	Technical Session Exhibition(ROTREX 2025) Technical Visit/Cultural Visit/Tour Program for Accompanying Person	
18:00-			Welcome Reception		Gala Dinner	

※ IRF & Bilateral Road Conference Schedule are subject to change depending on circumstances.

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Calendar of Events

Date	Event	Place	Type	Remarks
8th-11th April 2025	· International Seminar 'Transport Asset Management'	Arusha, Tanzania	PIARC Seminars	Road Assets Management: TC 3.3
14th-16th April 2025	· International Seminar 'Sustainable and Resilient Unpaved Earthworks and roads in the face of Climate Change' · Second Announcement of the Seminar · First Announcement of the Seminar	Abidjan, Ivory Coast	PIARC Seminars	Environment Road Earthworks TC 4.3
28th-30th April 2025	· International Seminar 'Climate Resilient Pavements'	Tunis, Tunisia	PIARC Seminars	Road Pavements TC 4.1
5th-6th May 2025	· 123rd REAAA Governing Council meeting · 27th YEP meeting · 12th REAAA Business Forum	Port Melbourne, Australia	Meetings	NTRO REAAA
7th-9th May 2025	· NTRO International Conference 2025	Port Melbourne, Australia	International Conference	NTRO
16th-18th July 2025	· 14th International Conference on Road and Airfield Pavement Technology	Chiang Mai, Thailand	Intnational Conference	Organized by Chingmai University
27th-31st October 2025	· 124th & 125th REAAA Governing Council meetings · 17th REAAA Conference · 17th REAAA General Meeting · 28th YEP Meeting · 14th HORA Meeting · 13th Business Forum	KINTEX, Goyang City, Korea	International Conference Meetings	REAAA Korea Chapter, Korea Expressway Corpration(KEC), MOLT,Korea REAAA

REAAA WELCOMES NEW MEMBERS

Existing members as at 31 December 2023	1188
Add: Newly elected/ Status changeded/ Reinstate	43
Less: Resigned/ Lost Contact/ Deceased/ Suspended/ Status changed Member	33
Total existing members as at 19 July 2024	**1198**

List of members approved by the 122nd REAAA Council Meeting on 5th September 2024 in Bangkok, Thailand.

Institutional Members

1.	Inter- City Motorway Division, Department of Highway	I.0396 Thailand
2.	Hua San Construction Co., Ltd	I.0397 Taiwan
3.	Projek Lintasan Kota Holdings Sdn Bhd (PROLINTAS)	I.0398 Malaysia
4.	Auckland Transport	I.0399 New Zealand
5.	Whitestone Contracting	I.0400 New Zealand
6.	Pinnacles Civil	I.0401 New Zealand

Ordinary Members

1.	Nor Elina binti Nassli	O.3968 Malaysia
2.	Noor Aziah binti Tarmizi	O.3969 Malaysia
3.	Ng Seng Huat	O.3970 Malaysia
4.	Irudya Mohan Rao	O.3971 Malaysia
5.	Nor Azilawati binti Abu Talaha	O.3972 Malaysia
6.	Adrian Lim Zi Liang	O.3973 Malaysia
7.	Ir. Ts. Mohd Nor bin Besar	O.3974 Malaysia
8.	Syahrul Azam bin Ahmad Shabir	O.3975 Malaysia

Ordinary Members

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10.	Ir. Rostam Shahrif bin Tami	O.3977 Malaysia
11.	Ir. Mohd Faizal bin Atan	O.3978 Malaysia
12.	Ir. Tan Khar Meng	O.3979 Malaysia
13.	Ir. Dr. Elizabeth Chong Eu Mee	O.3980 Malaysia
14.	Tracy Ducas	O.3981 Australia
15.	Andrew Holroyd	O.3982 New Zealand
16.	Rajesh Sharma	O.3983 Nepal
17.	Natalie Anne Lockwood	O.3984 Australia
18.	Ang Pui Boon	O.3985 Singapore
19.	Lukman Lim	O.3986 Singapore
20.	William Ang Zan Chung	O.3987 Singapore
21.	Swaminathan Ramanathan	O.3988 Singapore
22.	Adam Cheong Chee Meng	O.3989 Singapore
23.	Chiong Peng Wai	O.3990 Singapore
24.	Mohammad Redha Bin Mohd Said	O.3991 Singapore
25.	Toh Yan Ting	O.3992 Singapore
26.	Liu Zhenkun	O.3993 Singapore
27.	Albert Leng Teck Seng	O.3994 Singapore
28.	Tong Kum Kong	O.3995 Singapore
29.	Myat Mon Cho	O.3996 Singapore
30.	Lin Rongrong	O.3997 Singapore
31.	Ir. Ts. Dr. Anizan bin Ali	O.3998 Malaysia

Ordinary Members

32.	Ts. Mohamad Haffiz bin Abdul Mutalib	O.3998 Malaysia
33.	Dr. Norhidayah binti Abdul Hassan	O.4000 Malaysia
34.	Dr. Azman Mohamed	O.4001 Malaysia
35.	Dr. Mohd Zul Hanif bin Mahmud	O.4002 Malaysia
36.	Dr. Jaw Chang Laiw	O.4003 Taiwan

Life Members

1.	Thaddeus A. Montano	L.0440 Philippines

Status Changed from Ordinary to Life

1.	Datuk Ir. Ruslan Bin Abd Aziz	L. 0439 Malaysia

REAAA Climate Change, Resilience and Disaster Management Working Committee: Summary of Recent Activities

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Infrastructure Victoria, Australia.
Co-Chair, REAAA Climate Change, Resilience and Emergency Management Working Committee

David Rolland
Civil Engineering Consultant, Australia.
Co-Chair, REAAA Climate Change, Resilience and Emergency Management Working Committee

Introduction

The world's climate is changing, resulting in hotter and drier weather and increased frequency and intensity of extreme weather events, including natural disasters. Climate change and extreme weather events have immediate and long-lasting impacts globally: they pose a strategic risk to road organisations. These events have large impacts on the design, construction, operation, maintenance and use of road transport infrastructure. This leaves both people and assets vulnerable, resulting in significant economic and social costs.

In September 2024, the International Conference on Highway Engineering (iCHE) was held in Bangkok, Thailand. This was organised by the Department of Highways, Ministry of Transport in collaboration with the Roads Association of Thailand, and hosted PIARC and REAAA events. As part of this Conference an REAAA special session was organised on Climate Change, Resilience and Disaster Management. This session provided an overview of the latest actions being undertaken by the REAAA Climate Change, Resilience and Disaster Management Working Committee, and included a summary of collaboration activities with other road associations such as PIARC. The session also highlighted activities in REAAA member countries being used to improve the resilience of roads through adaptation solutions, best-practice learnings to recover from earthquakes and effective ways to manage disasters. A detailed report on this REAAA special session will be published in the coming months.

A series of articles has been prepared by the REAAA Climate Change, Resilience and Disaster Management Working Committee which address the following three major issues: planning for resilience, designing for resilience, and the technology and tools available to address these issues. The articles are supported by several case studies addressing examples of how to reduce the impacts of climate change on road infrastructure assets. Some of these case studies were showcased at the iCHE2024 REAAA special session.

Planning for Resilience

Planning for resilience is essential to road organisations and operators. Successful forward planning to address the impacts of climate change is not only about responding to disruptive or emergency situations but is about helping organisations make appropriate investment decisions at the right time and right place. It also involves ensuring that they can continue to provide the levels of service that its stakeholders and network users expect, both now and in the future.

Adapting to climate change plays a key role in reducing the exposure and vulnerability of road infrastructure assets to these events and helps to increase its resilience. This includes better preparing infrastructure now to: identify the climate risks to infrastructure, prioritise measures to address these risks, and plan for the most cost-effective responses.

Adaptive solutions do not have to be expensive or involve large rebuilding infrastructure projects. There are many different options for managing existing assets, so they are fit-for-purpose for changing climatic conditions. This includes structural solutions such as changing the type and frequency of maintenance activities, strengthening infrastructure to reduce the risk of damages, and building infrastructure using materials or designs that minimise the impacts of climate risks. There are also non-structural solutions which can be used to improve resilience such as managing the operation of networks using risk management systems and, in the event of a disaster, implementing business continuity plans to help cope with emergencies and recovery, including redirecting traffic. These can keep critical services and communities functioning and reduce disruptions and losses to society.

The following four case studies have been prepared by members of the committee from Australia, New Zealand and Japan:

1. Weathering the storm: Adapting Victoria's infrastructure to climate change.
2. WSP's Canary Infrastructure Asset Risk Management System (Canary).
3. Business Continuity Plan (BCP) for Hanshin Expressway.
4. Disaster response of the Kyushu Expressway to torrential rain, including saving isolated local communities.

Designing for Resilience

The escalating frequency and intensity of extreme weather events, exacerbated by climate change, pose significant threats to the resilience of road infrastructure. Rising global temperatures, characterised by more frequent heatwaves and altered precipitation patterns, are leading to increased risks of road surface damage, landslides, and flooding. Coastal regions are particularly vulnerable to rises in sea levels, which can erode coastal roads and bridges, disrupting transportation networks and hindering emergency response efforts.

Moreover, the changing climate can indirectly impact road infrastructure through increased wildfire risk and altered soil moisture conditions. Wildfires can damage roads and bridges, while changes in soil moisture can affect the stability of slopes and foundations. These climate-induced challenges highlight the urgent need for proactive measures to enhance the resilience of road networks.

Under normal operating conditions, government-controlled transport networks are expected to remain open to the public. However, road closures can occur due to unplanned events such as floods, cyclones, bushfires, and major accidents, which can vary in duration and severity. To mitigate these risks, transportation agencies must adopt a comprehensive approach that incorporates climate change considerations into all stages of infrastructure planning, design, construction, and maintenance.

The second article, which addresses the issue of designing for resilience, presents the following two case studies:

1. Victorian flood recovery survey and restoration needs.
2. Building resilient highways in Thailand – bioengineering and biochar solutions.

Technology and Tools

The ability of transport networks to provide lifeline infrastructure is crucial to the distribution and continuous flow of goods and services essential for human livelihoods, the functioning of society, and economic prosperity.

Four case studies from Indonesia, New Zealand and Australia present different tools and techniques that are being applied to help reduce the impacts of climate change on road infrastructure assets and to help organisations better plan for resilience. The case studies provide examples of technologies and tools that play an important role in supporting the ongoing resilience of road networks, ranging from a risk-based approach in the planning, investment, design and asset management phases through to post-disaster management.

The following four case studies that address this theme are presented in this Newsletter:

1. Slope failure cases related to roads in Java, Indonesia
2. National Resilience Assessment Tool (NRAT), New Zealand
3. Responding to the Marlborough 2022 flooding in New Zealand
4. Austroads' Lifeline Risk Indicator.

Climate Change, Resilience and Disaster Management: Planning for Resilience – Case Studies

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Introduction

This article presents four case studies from Australia, New Zealand and Japan which highlight different tools and techniques that are being applied to help reduce the impacts of climate change on road infrastructure assets. These can be considered to help organisations better plan for resilience.

Case Study 1: Weathering the Storm: Adapting Victoria's Infrastructure to Climate Change

In April 2024, Infrastructure Victoria released Weathering the storm: adapting Victoria's infrastructure to climate change. Work was undertaken to assess the benefits of adapting infrastructure to the changing climate.

Under-investing in infrastructure resilience leads to higher economic, social and environmental costs over time. Victorians are already paying the costs of a changing climate. Extreme weather damage costs Victoria about $AUD 2.7 billion (about $USD 1.25 billion) a year. Without action to better protect infrastructure, it will fail more often, harming and costing people and businesses. This project demonstrates that early investment in infrastructure adaptation measures can minimise the costs of recovering from extreme events and reduce the harm to people and the environment.

The research builds the economic case for adaptation action in four stages.

A high-level assessment of climate risks to Victorian infrastructure for transport, utilities infrastructure, and the built environment was undertaken, and the inter-dependencies between extreme weather events and across sectors identified. Over 40 climate-related risks to Victoria's government-owned and regulated infrastructure were identified. The project team chose the years 2030 and 2070 as dates to analyze climate risks and selected climate scenarios based on the Intergovernmental Panel on Climate Change's Representative Concentration Pathways (RCPs).

Infrastructure Victoria employed geospatial analysis and hazard mapping technologies for the research. The location of infrastructure geospatially was mapped and overlaid data representing hazards. It used these findings to compare the economic case for different adaptation measures. The analysis found that the benefits of investing in infrastructure adaptation can outweigh the costs of repairing and rebuilding after extreme weather events. It observes that some adaptation measures cost very little and can deliver a positive return on investment.

To demonstrate this research, Infrastructure Victoria conducted an economic analysis of two infrastructure sectors: electricity distribution, and road networks. In each sector, it tested the potential return on investment for different adaptation measures. Three scenarios were selected for assessment: damage to roads from floods, accessibility to roads from bushfires and landslides, and extreme winds for electricity distribution.

The economic analysis method modifies the cost-benefit analysis approach. It uses both direct and indirect costs and benefits, maladaptation, embodied emissions associated with the different adaptation measures, and the potential of different adaptation pathways. This method can be repeated across different sectors, infrastructure types and locations.

The research examined 20 adaptation measures relevant to these sectors and risks. It assessed their costs and benefits. The cost-benefit analysis demonstrated that adaptation measures can have a positive return on investment and governments can benefit from coordinating and sequencing different adaptation measures.

Seven recommendations were outlined to help the Victorian Government better assess and prepare infrastructure for more frequent and extreme weather:

1. Boost priority and oversight for infrastructure adaptation.
2. Coordinate and standardise climate projections.
3. Use asset management systems to improve resilience.
4. Integrate climate risk into government risk management.
5. Align climate and financial risks to infrastructure.

6. Update business case and investment guidance.
7. Build confidence that good adaptation measures will receive funding.

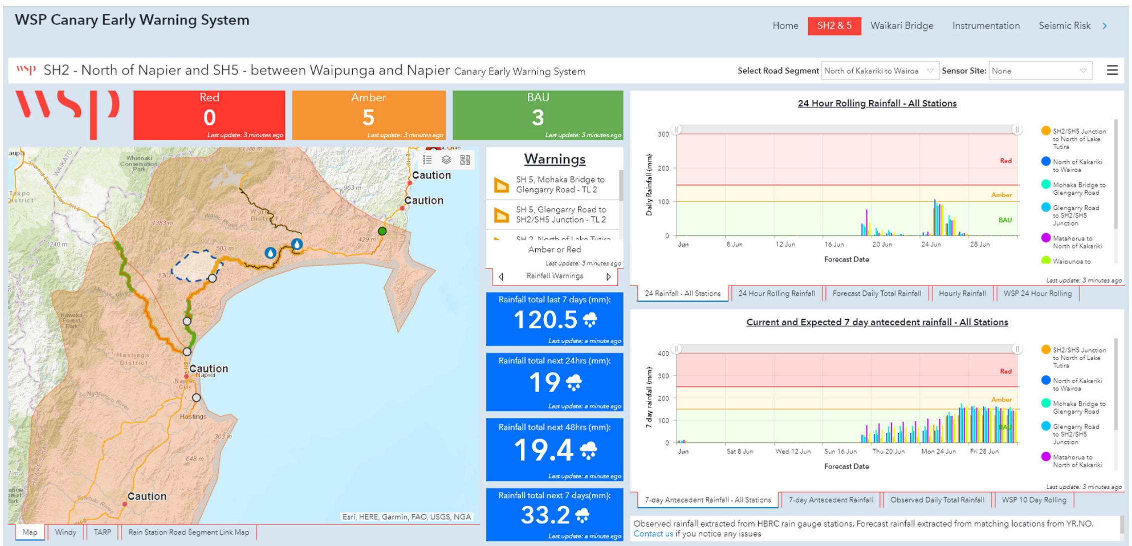
If adopted, these recommendations can support infrastructure asset managers to better consider adaptation in their normal activities and throughout the lifecycle of infrastructure. Moreover, the research shows how to assess the risks from extreme weather and compare different solutions to better protect infrastructure assets. This can help governments decide how and where to invest in infrastructure adaptation efforts.

Case Study 2: WSP's Canary Infrastructure Asset Risk Management System (Canary)

The presence of natural hazards, including landslides, rockfall, flooding and earthquakes, is well known and nothing new to New Zealand. Due to its geology, topography and geography, key transportation links have to navigate challenging mountainous or tight coastal terrain, resulting in significant exposure risk to these hazards for the infrastructure and its users.

These hazards are likely to increase due to changing climate, causing an escalation in weather extremes bringing more frequent, severe storms and causing an increased likelihood of flooding and landslides. Compounding this is the increasing financial pressures on asset owners who need to manage their infrastructure, protect life safety, and ensure operability and business continuity, particularly in times of emergency. While the most critical risks are likely to receive investment for permanent mitigation, there are often gaps where risks are either not mitigated or only temporarily managed. During these periods, it is essential to implement immediately-applicable and more affordable measures to manage the increasing risk to the infrastructure and its users.

A proactive way to manage this risk in lieu of significant investment is the use of trigger action response plans (TARPs) to manage the operability of the network based on weather forecasting and observed conditions from remote instrumentation.



Screenshot of Canary System leading up to a significant weather event

With the advancements in technology, the increases in data accessibility and the improving accuracy of forecasting meteorological conditions, the TARP process can be automated to produce real-time decision support to asset owners, network managers and emergency responders.

WSP have developed Canary over the past three years to fill this void to help bring risk management into the 21st century, helping asset owners and asset managers be better prepared for events. Canary is an alerting platform, agnostic of natural hazards or the infrastructure they impact. It is designed to translate data into digestible information into decision support. Through its robust, automated data transformation process, Canary streamlines the deployment and operation of a TARP, allowing stakeholders to make informed decisions using real-time, robust data. With the dynamic ability for subject matter experts to set trigger thresholds for each exposure element, Canary utilises forecast meteorological conditions and real-time data from remote instrumentation networks to automate alerts where pre-defined thresholds have been met. Information regarding these real-time events is curated in a series of online geospatial tools and communicated through email alerts, providing decision-makers with the facts they need to implement the action and response specific to the exposure element.

Applications of Canary to date have focused on slips on roads and flooding at bridges. The slips module has been deployed on various vulnerable state highways to help better prepare the asset owners and operators for upcoming weather events. The first process was to establish thresholds of when historical rainfall had caused damage to the network and correlate these to a time period and intensity, and then use this to set thresholds for future events. This resulted in 24 hour accumulation and antecedent rainfall thresholds with associated actions for the different thresholds, e.g. Green, Amber and Red. Using the forecast rainfall plus observed rainfall enabled risk levels at different parts of the network to be predicted to help better optimise the response by being better prepared.

The second application was similar but for optimising bridge inspections of vulnerable brings post event. Instead of using generic regional weather warnings, catchment-specific triggers based on certain design events and catchment size were used to predict what bridges were likely impacted worst. This would enable targeted inspections from bridge engineers to specific structures rather than region-wide deployments for inspection, saving time and money.

Case Study 3: Resilience Building Regarding Business Continuity Plan (BCP) of Hanshin Expressway Co. Ltd

The urban expressway network plays a vital role in supporting a region's economy and daily life. Ensuring its accessibility for emergency vehicles during major earthquakes is critical. To achieve this, the Hanshin Expressway Co., Ltd., which manages the urban expressway in the Osaka metropolitan area, has implemented a Business Continuity Plan (BCP), a comprehensive and cross-cutting action plan, as a non-structural measure in addition to structural measures such as earthquake resistance measures. This comprehensive approach minimizes disruption during emergencies, facilitates swift recovery, and ensures clear priority actions and role divisions.

The importance of the BCP is that it avoids confusion throughout the company and helps companies to recover quickly by clarifying in advance the priority actions to be taken and the division of roles in the event of an emergency.

In addition to the response action itself, it is also important to continually review the contents of the BCP through drills, exercises, and other means to examine and improve issues that arise.

Development of the BCP

(1) The concept of BCP

A BCP specifies the activities to be performed by the organization during normal times, as well as ways and means to continue operations in an emergency to minimize damage to business assets, and to enable the continuation, or early recovery, of key operations. Its benefits include ensuring operations stay above acceptable levels during crises and enabling timely restoration within an acceptable time.

(2) BCP – Disaster response timeline

The BCP has been formulated on the premise that, even in the event of a disaster or other damage, operations will not be interrupted, and even if operations are interrupted, they will be restored as quickly as possible. Based on this policy, the BCP specifies how organizations should respond and operate in the event of a disaster, including preparing resources such as people, materials, and information in advance.

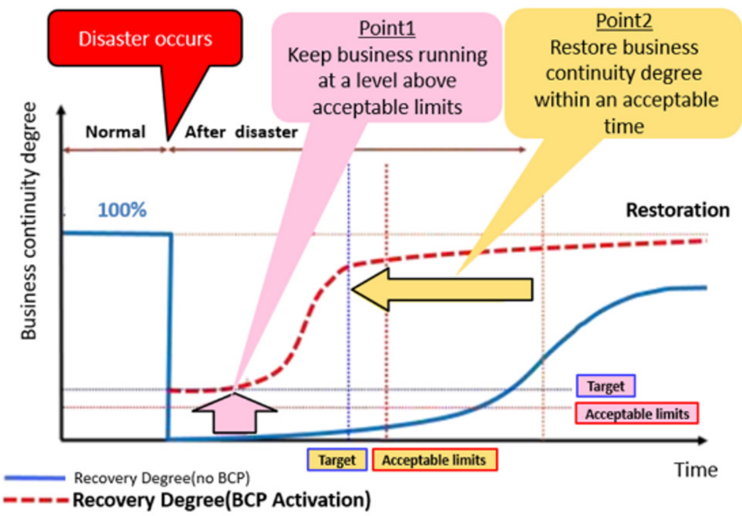
(3) BCP – Contingency organization system

The BCP introduces a dedicated contingency framework differing from regular operations. Employees are assigned to specific Task Force teams, each with defined responsibilities. The Disaster Recovery Action Plan organizes these actions, clarifying each team's role and ensuring effective coordination.

Continuous Review of the BCP

(1) Comprehensive emergency drills and exercises, and road clearing training

It is important to review the BCP on an ongoing basis while confirming its effectiveness. Hanshin Expressway Co., Ltd. conducts preliminary drills such as comprehensive disaster exercises and road clearing drills to identify issues and make improvements. After the exercises, all concerned parties gather to discuss issues and points to be improved, and make revisions to the BCP.



Recover with and without BCP

Emergency drills and exercises

Case Study 4: Disaster Response of the Kyushu Expressway to Torrential Rain Including Saving Isolated Local Community

In recent years, extreme weather conditions and severe disasters have frequently been occurring because of the effects of global warming. In a disaster, expressways are expected to serve as an emergency route as 'Roads for Life' to facilitate relief efforts and disaster recovery in cooperation with the affected local governments.

In July 2020, a maximum hourly rainfall over 70 mm/h and cumulative rainfall 800 mm for the first three days were recorded on the Kyushu Expressway in Kumamoto Prefecture. Engineers at the Kumamoto Expressway Office worked hard and quickly to repair the damaged parts of the roadway, and then delivered life support for local people by offering free gates at its parking area so they could be used in emergencies.

1. Quick repair of damage to the expressway

(a) Lifted concrete pavement slab

Core holes were drilled to promote drainage under the concrete slabs to prevent further lifting of the concrete slabs. Urethane foam was then injected at 1 m intervals into the cavity under the pavement slab. For quick operation, early-strength Portland cement, called ONE DAY PAVE enabling sufficient compressive strength in 24 hours, was used.

(b) Damaged embankment slopes

While left lane restrictions, steel sheet piles were placed to ensure the stability of the slope.

2. Life support for disaster-stricken areas

Due to the heavy rain, the National Highway Route 219 in southern Kumamoto Prefecture had to be closed, isolating local communities alongside the Kyushu Expressway. For this reason, an alternative free-charge-of-law route was applied on the toll road by opening emergency gates at three locations.

(a) Installation of emergency gate

At each location, inbound and outbound runways had to be secured to allow access to and from local roads. While the Yamane Service Area was able to do this easily only by placing security guards, the Ayugaeri Bus Stop and the Sakamoto Parking Area required the construction of an outbound runway at Ayugaeri and both inbound and outbound runways at Sakamoto. These facilities were constructed immediately by the NEXCO office.

(b) Operation of the gates

Two examples of the temporarily constructed outbound runway at Sakamoto PA are shown below. The construction included the removal of entry barriers, guardrails, and trees, the installation of flexible pipes in the drainage ditch, filling with crushed stone, and the laying rubber plates on top of the flexible pipes. For safety reasons, guards are stationed all day long at the gate and junctions to check permits. The inbound and outbound lanes at Sakamoto PA were still in operation as of January 2023.

Before and after installation of the gate at Sakamoto PA (outbound)

Operation of the gate at Sakamoto PA (outbound)

Conclusions

Planning for resilience is essential to help governments decide how and where to invest in adapting infrastructure to more frequent and extreme weather. It can be used to show how to assess the risks from extreme weather and compare different solutions to better protect infrastructure assets. Resilience planning also shows ways to better manage response before, during and after disaster events.

This article has outlined a range of methods that are being used in Australia, New Zealand and Japan to help assess climate risks and actions to improve resilience, adaptation and recovery throughout the lifecycle of infrastructure. These actions can be considered to better prepare and equip infrastructure, keep communities safer, minimise disruptions, and reduce disaster recovery costs.

Climate Change, Resilience and Disaster Management: Designing for Resilience – Case Studies

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Introduction

Under normal operating conditions, government-controlled transport networks are expected to remain open to the public. However, road closures can occur due to unplanned events such as floods, cyclones, bushfires, and major accidents, which can vary in duration and severity. To mitigate these risks, transportation agencies must adopt a comprehensive approach that incorporates climate change considerations into all stages of infrastructure planning, design, construction, and maintenance.

The REAAA Climate Change, Resilience and Disaster Resilience Committee has been conducting research to develop solutions that transport agencies can implement to keep transport networks open and connected through designing transport networks for resilience.

Two case studies are presented in this article, as follows:

1. Victorian flood recovery survey and restoration needs:

   An overview of how data from the National Transport Research Organisation (NTRO)'s iPAVE can be used to identify sections of road which have been impacted by floods, in order to provide recommendations for proactively constructing more resilient pavements.

2. Building resilient highways in Thailand – bioengineering and biochar solutions:

   A summary of how integrating soil bioengineering and biochar techniques into Thailand's highway infrastructure offers a sustainable approach to mitigating landslides, reducing carbon footprints, and promoting ecological restoration.

Case Study 1: Victorian Flood Recovery Survey and Restoration Needs

The National Transport Research Organisation (NTRO) was engaged by Victoria's Department of Transport and Planning (DTP) to assess the condition and treatment needs of almost 8,500 kilometres of arterial roads, or one-third of the road network, which was impacted by rain and flood events in October 2022.

These major rain events produced a total measured rainfall of 200 mm in a one-week period (Figure 1), leading to extensive flooding and saturation of open country across the north and west of the state. The entire Murray River Basin, where the flat terrain holds water over extended periods, was impacted. Other parts of the state in low-lying areas were also affected because of concentrated flows along streamlines and across sloping ground. The result was an extended period of saturation, with high surface water levels severely impairing access. This meant that many roads were at risk of further road pavement damage as vehicle movement was restored.

There was a need to undertake a rapid assessment using NTRO's state-of-the-art iPAVE technology (Figure 2) to capture the condition of the network at 100 m intervals and utilise this information to identify sections of road which showed significant damage. A program of works was prepared to restore the affected sections to a suitable condition. As the survey and analysis needed to be completed within a period of two months, a concentrated effort was required by the NTRO teams drawing also on historical data collected on the same network in 2021 and in early 2022 prior to the events.

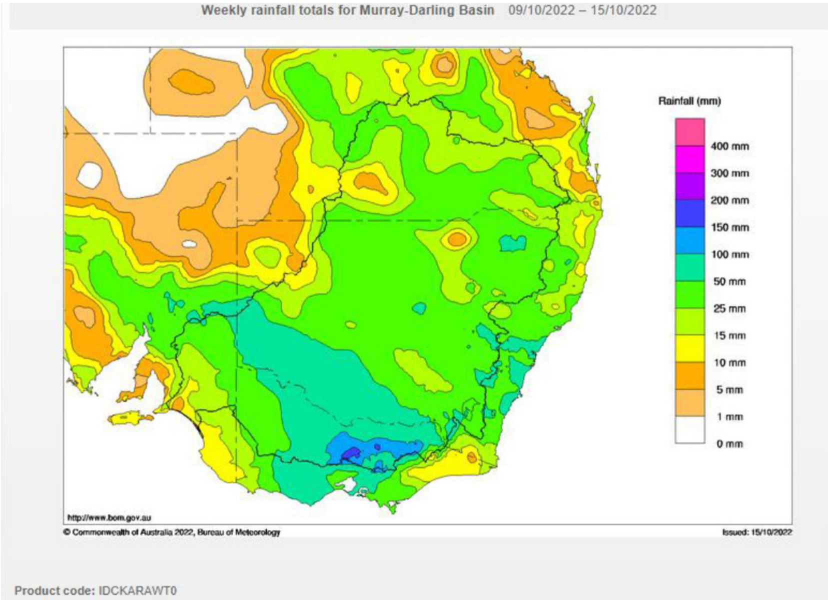

Figure 1: Rainfall recorded in the flood event period of October 2022
(Source: https://www.extremestorms.com.au/major-rain-event-and-significant-floods-victoria-12-to-15-october-2022/)

Figure 2: NTRO's Intelligent Pavement Assessment Vehicle (iPAVe) (Source: NTRO)

After the flooding, it was found that about 880 km of the road network was severely affected and needed remedial action such as resurfacing, shape restoration, and rehabilitation. The road conditions had deteriorated drastically, with over 90% of the roads being in poor or very poor condition, as shown in Figure 3.

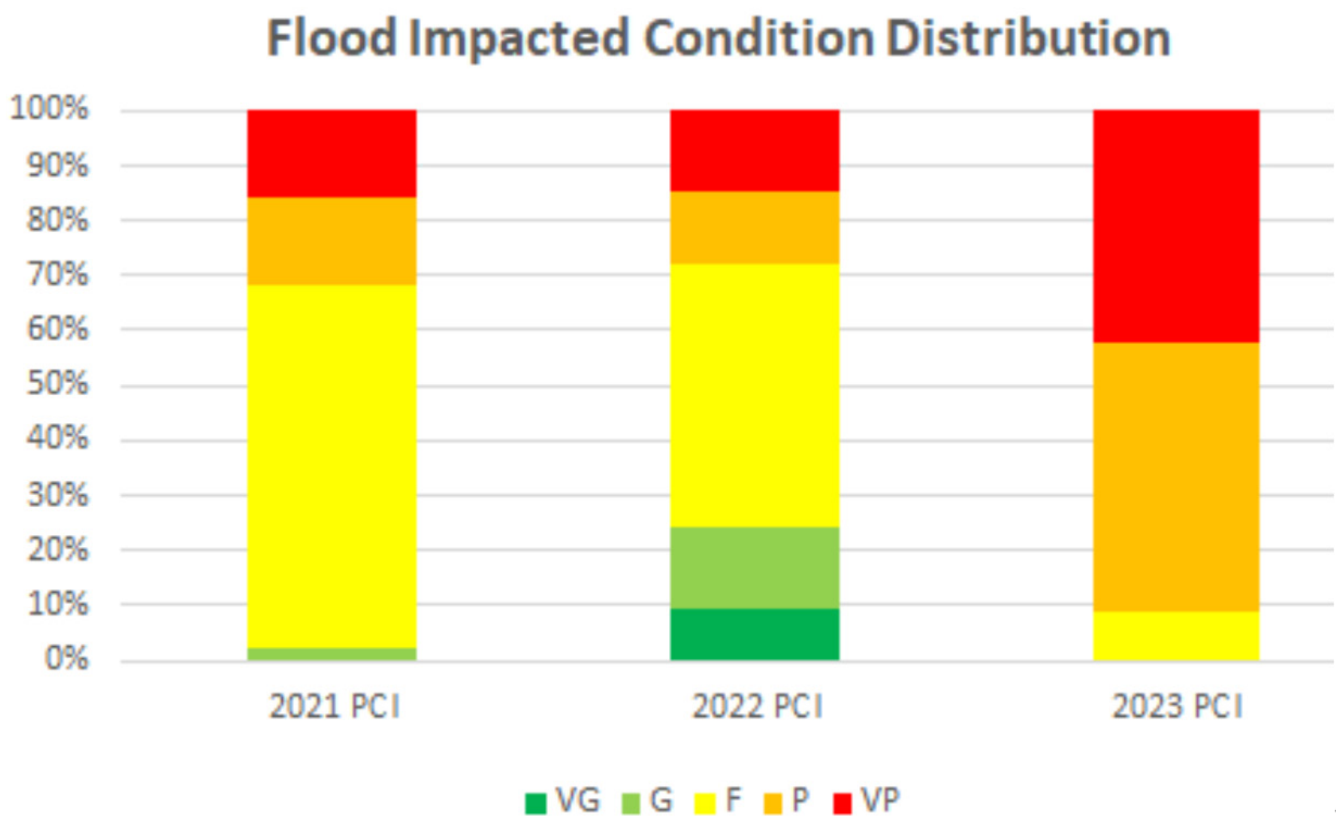

Figure 3: Distribution of condition pre- and post-flood (Source: NTRO)

The results of this assessment provided the following community, performance and cost benefits.

Community Benefits: The DTP has utilised the collected data and treatment recommendations in an accelerated recovery program. Whilst this has targeted the affected sections, it also allows entire routes to be returned to a more secure operation, allowing communities and the transport network to remain connected and serviced. At a much broader level, the team also offered improvement strategies that take a wider network view to help ensure essential routes are available in such circumstances.

Performance Benefits: The performance of the road network improved by identifying the rehabilitation needs of affected sections. This was achieved by establishing an efficient and repeatable process for surveying, collating, and analysing needs quickly. Notably, almost 150 km of road was completed per calendar day using a 4-step process as shown in Figure .4. The process is now ready to be repeated with valuable lessons learned.

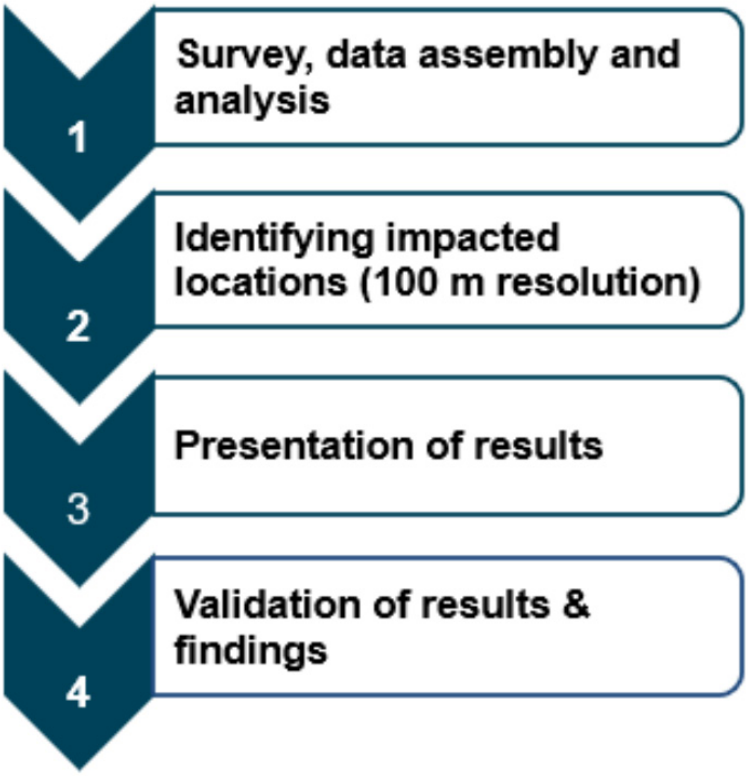

Figure 4: Flood recovery methodology (Source: NTRO)

Cost benefits: Implementation of the treatment program will generate immediate benefits by allowing continuous access at normal travel speeds. The full suite of treatments also aim to leave a legacy network that is more fit-for-purpose in support of the community and transport task, with less likelihood of severance in the future, particularly where surfacing and road pavement improvements are applied with complementary drainage measures.

Lessons learned from the October 2022 experience also provide more sustainable solutions where traditional materials are improved and substantially reused through stabilisation techniques and waterproofing road surfaces.

This project considered the experiences of Queensland, Western Australia, and other locations where road closures are a recurring issue. By implementing a more comprehensive forward-planning approach, such occurrences can be prevented. As the climate continues to change, transport agencies must prepare for repeated events and develop a more resilient transport network.

Around 8,500 km of roads affected by floods In Regional Victoria were evaluated using iPAVe3. The assessment involved comparing past iPAVE surveys of the identified sections, examining their structural and surface conditions, and determining the affected roads' Remaining Useful Life (RUL) and rehabilitation requirements. Recommendations were provided to emphasise the importance of constructing more resilient pavements. Taking a proactive approach and adopting a 'build back better' strategy is crucial in ensuring that more sustainable and resilient treatments are implemented to provide long-lasting, cost-effective solutions.

Case Study 2: Building Resilient Highways in Thailand – Bioengineering and Biochar Solutions

Thailand's highways face increasing challenges from climate change, including more frequent landslides and erosion driven by short, localised intense rainstorms or 'rain bombs'. These events de-stabilise slopes, disrupt transportation, and incur high maintenance costs. Shallow landslides, caused by surface runoff and soil saturation, are particularly prevalent in hilly and coastal areas such as Chiang Mai and Phuket (Figure 5). However, innovative nature-based solutions, such as soil bioengineering and biochar integration, are proving effective in mitigating these risks while delivering long-term ecological benefits.

Figure 5: Recent landslides in Phuket

Soil bioengineering uses vegetation and natural materials along with engineering techniques to stabilise slopes. Native species such as vetiver grass, with its deep and fibrous root systems, reduce erosion and anchor the soil. Flexible bioengineering structures such as vegetated flapped soil bags and micro-screw piles (Figure 6) ensure long-term slope stability while supporting vegetation and promoting biodiversity. These cost-effective solutions restore ecological value, improve slope drainage, and require minimal maintenance once established.

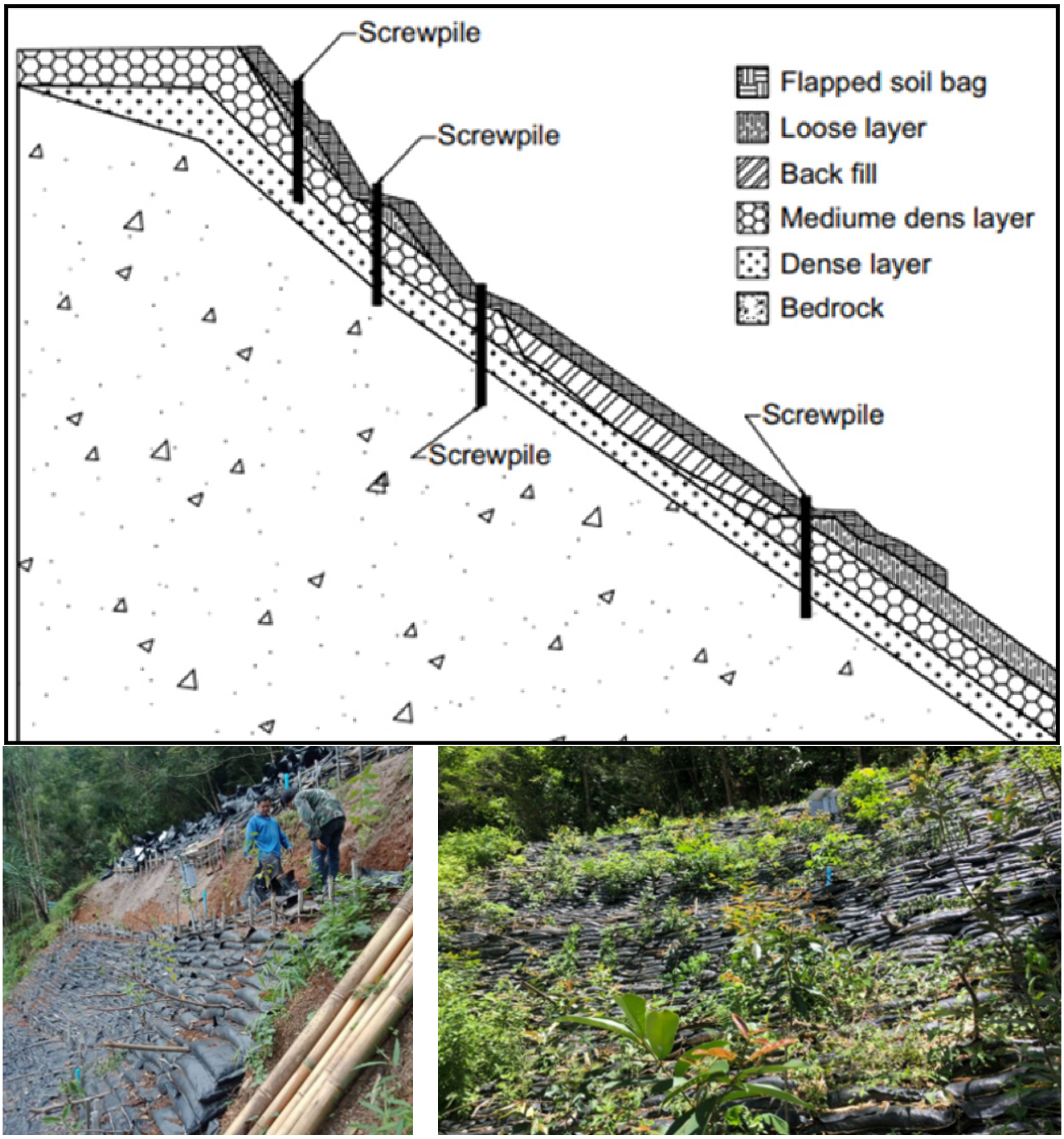

Figure 6: Bioengineered slope using screw-piles and vegetated flapped soil bags at rural road 4088, Kanchanaburi Province, Thailand

Biochar, a carbon-rich material derived from organic waste, has emerged as a promising soil amendment for slopes in highway projects. Its porous structure (see Figure 7) enhances soil moisture retention while preventing infiltration, fosters vegetation growth, and reduces erosion over time. By sequestering carbon, biochar aligns with Thailand's bio-circular-green economy (BCG) goals. Demonstration sites in northern Thailand have showcased the potential of biochar made from plant residues generated during roadside tree trimming, integrating waste management into highway sustainability practices. Training sessions for Department of Highways staff have emphasised biochar production from tree trimmings collected during landscape maintenance. This initiative has not only increased awareness of sustainable practices but also showcased how organic waste can be transformed into a valuable resource for highway stabilisation projects.

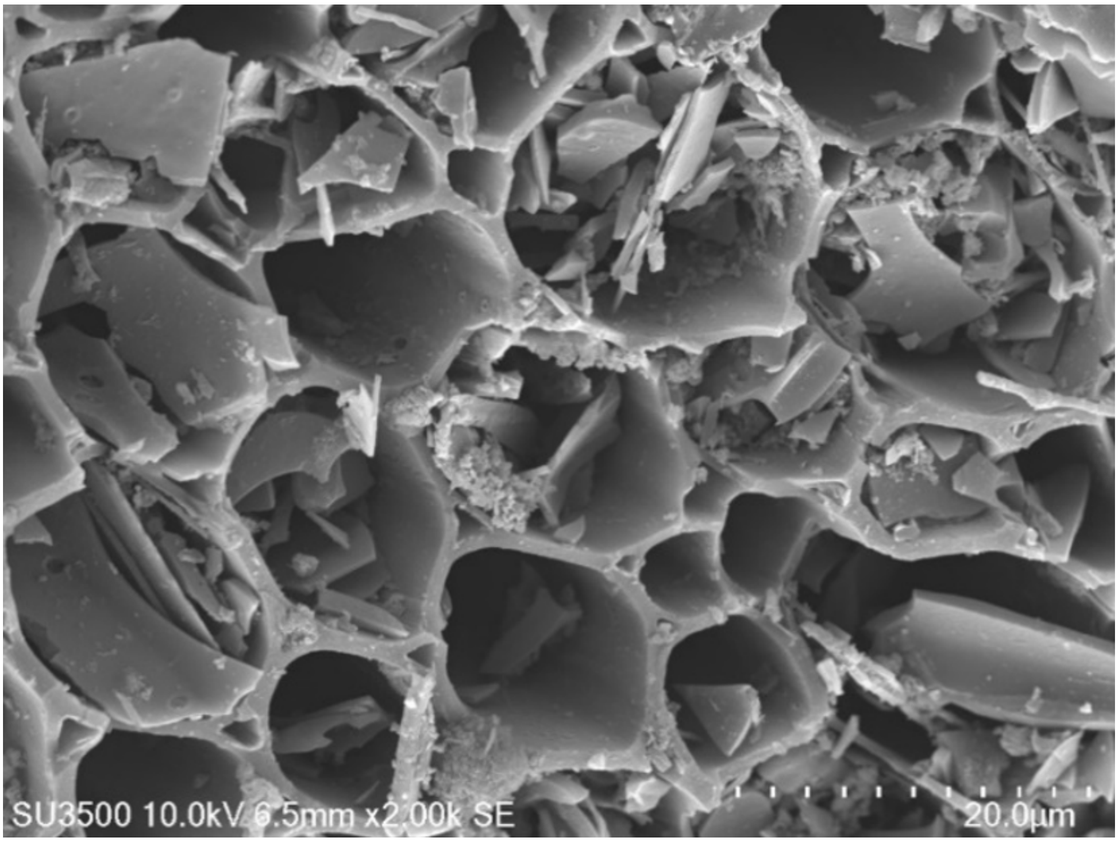

Figure 7: SEM image of bamboo biochar

Case studies highlight the success of these approaches. In Chiang Mai, a capillary barrier system (CBS) combined with biochar, prevented water infiltration and stabilised slopes prone to landslides (Figure 8). Life cycle assessment (LCA) of the CBS revealed reduced carbon emissions due to local material sourcing and biochar integration. The bioengineering technique was used in Phuket to stabilise the failed slope by using flapped soil bags, biochar-amended soil and erosion control blankets to facilitate robust vetiver grass growth (Figure 9). While nearby untreated slopes failed during heavy rains, the bioengineered sections remained stable, underscoring the effectiveness of combining vegetation with biochar and engineering solutions.

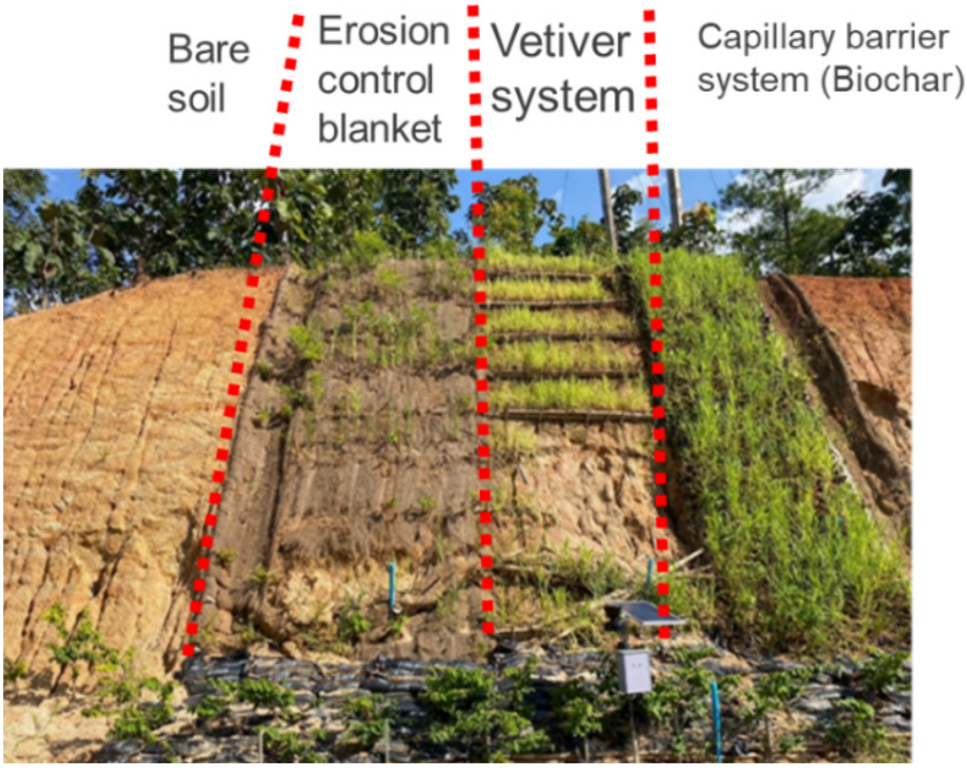

Figure 8: Bioengineering test sections in Chaing Mai province, highway No. 1192 (KM 11+500)

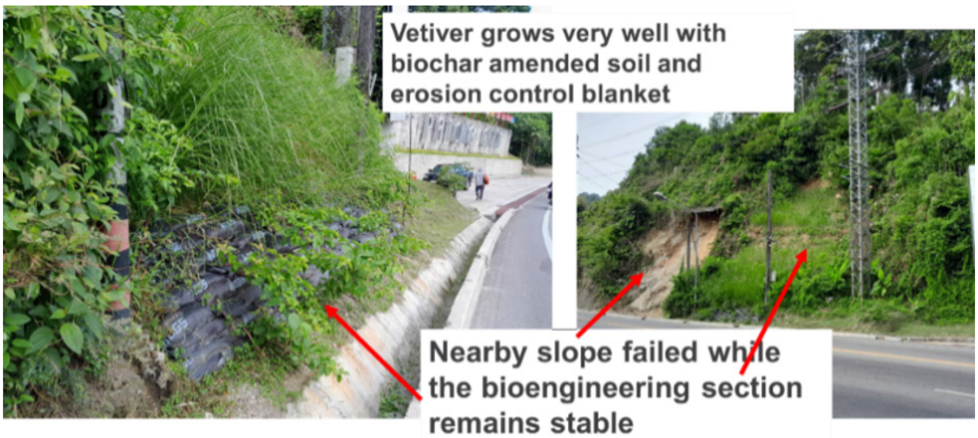

Figure 9: Bioengineered slope with vetiver and biochar in Phuket province

In conclusion, soil bioengineering and biochar offer sustainable, practical solutions to Thailand's highway challenges. Vegetation such as vetiver, coupled with innovative structures, stabilises slopes while restoring ecosystems. Biochar enhances soil properties and contributes to long-term erosion control and carbon sequestration. Successful case studies have demonstrated the feasibility and benefits of these approaches, from mitigating landslides to reducing carbon footprints. As climate change intensifies, integrating nature-based solutions into highway infrastructure will not only reduce disaster risks but also foster environmental conservation and resilience for future generations.

Climate Change, Resilience and Disaster Management: Technology and Tools

Slope Failure Cases Related to Roads in Java, Indonesia

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Introduction

The climate in Indonesia is predominantly hot and humid, with rainfall primarily concentrated in low-lying areas. Mountainous regions, on the other hand, tend to have lower temperatures. The wet season spans from November to April, while the period from May to October is generally characterized by dry weather. Indonesia undergoes arid conditions during El Nino and humid conditions during La Nina. The rapid development of roadways in Java Island has, in some cases, changed the natural slope into a steeper cut slope. The slopes may be more likely to be unstable during an intense rainfall or earthquake. Java is characterized by a central hilly to mountainous volcanic belt comprised of deeply-weathered Tertiary ashes and tuffs resting on a relatively weak and unstable sedimentary sequence dominated by mudstones. The region is one of the most tectonically active in the world. This case study overviews roadside slope failure cases on national roads and toll roads in Central Java.

Roadside Slope Failure: Residual Soil Cases

The national roads studied were in a section of the Tawangmangu-Cemorosewu road in Karanganyar, Central Java. The topography is relatively high due to steep hills and valleys with the problematic geological condition of weathered rock and silty sand (Figure 1). The main problem with these roadside slopes is the construction of cut slopes. Geotechnical exploration was conducted after the slope failure. The use of a geoelectric-resistivity test for the investigation, combined with hand boring for soil sampling, was a reasonable choice in terms of interpreting the potential failure surface of the slope and determining the soil properties. The investigation suggested that a geometrical method, such as terracing and a gravity wall, may be beneficial to prevent further slope failures. Installing low-cost technology for slope monitoring was needed to increase road safety. The IoT-based technology comprises of a rain gauge and soil moisture sensors.

Figure 1: Debris deposit of the roadside slope failure: Tawangmangu-Cemorosewu road in Central Java

Roadside Slope Failure: Clay-shale Cases

In 2012, a landslide occurred on toll road Semarang-Bawen in Central Java due to the exposure of the clay shale slopes following cuts during the construction of the toll road (Figure 2). The exposed layer of clay shale reacted with the atmosphere, leading to a sudden collapse to the weathered clay shale slope. Due to weathering, the initial properties of the clay shale changed following the degradation of the structure. The degradation of the clay shale reduced its shear strength, leading to slope instability. Shotcrete and bolts were applied as a remedial measure to prevent further slope failures (Figure 3). In some areas, the shotcrete used to prevent weathering did not work well and, as a result, slope failure is progressing.

Figure 2: Slope failure at Toll Road Semarang-Bawen, Central Java, Indonesia

Figure 3: Slope remedial measures using shotcrete and bolt at Toll Road Semarang-Bawen: (left) successful work, (right) unsuccessful work

Toll roads represent high-cost infrastructure and investment for the country. The slope health monitoring system should be implemented regularly, efficiently, and effectively. Muntohar & Bahti (2024) applied InSAR technology to evaluate the potential slope movement over time. A detailed InSAR result for the Semarang-Bawen toll road, overlaid with data points representing ground displacement rates – measured in millimetres per year (mm/year) – is shown in Figure 4. The colour scale on the left side of the image ranges from –10 mm/year to +25 mm/year, indicating varying rates of ground movement. This visual representation allows for an in-depth analysis of the ground displacement patterns across the region. The findings highlighted the effectiveness of InSAR in detecting ground displacement with high precision, enabling timely intervention to prevent infrastructure damage and ensure safety.

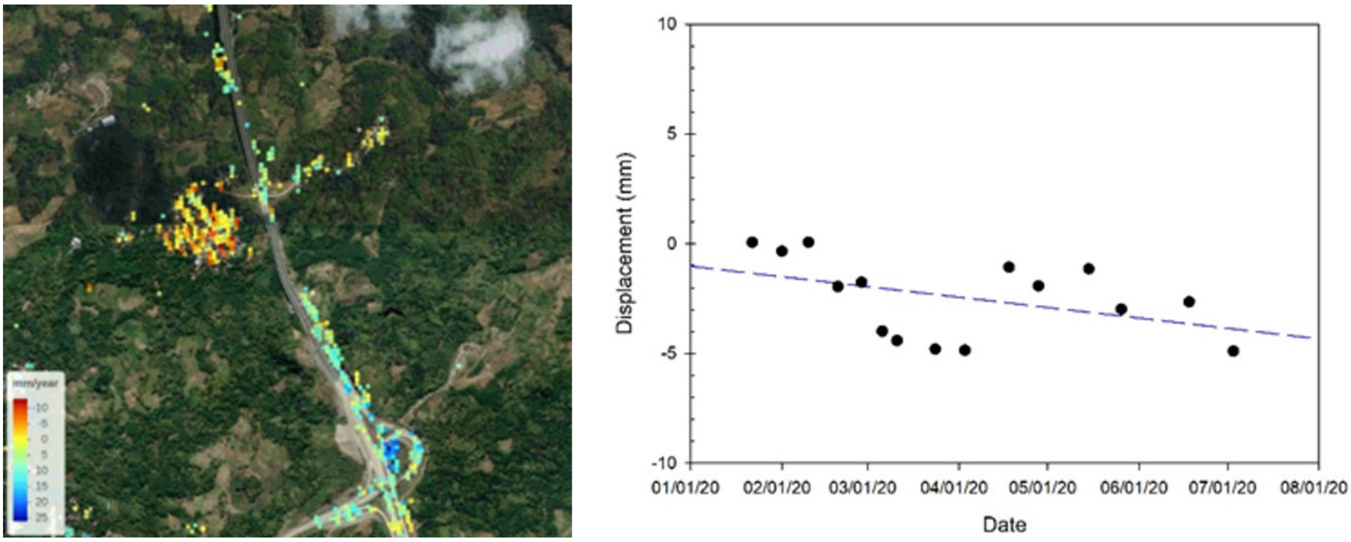

Figure 4: Visualization of InSAR results for Semarang-Bawen Toll Road (left);
Time-series result for Semarang-Bawen toll road (right)

Need for Low-cost Technology for Slope Monitoring

In many low-middle income countries, a low-cost technology for slope monitoring is a solution that can be effectively implemented. Traditional monitoring systems are often expensive and difficult to maintain, particularly in resource-limited settings (Figure 5). The integration of Internet of Things (IoT) technology into slope monitoring offers an innovative low-cost technology. The primary technology in IoT-based monitoring systems includes low-cost environmental sensors. These sensors measure a variety of parameters, including: soil moisture, inclinometers and accelerometers, vibration sensors, and temperature and rainfall sensors. Once the data is collected, it is transmitted via wireless communication technologies (e.g. Wi-Fi). However, many developing countries face challenges related to inadequate infrastructure and poor network connectivity, especially in rural or mountainous areas. Ensuring reliable data transmission is critical for the success of IoT-based systems.

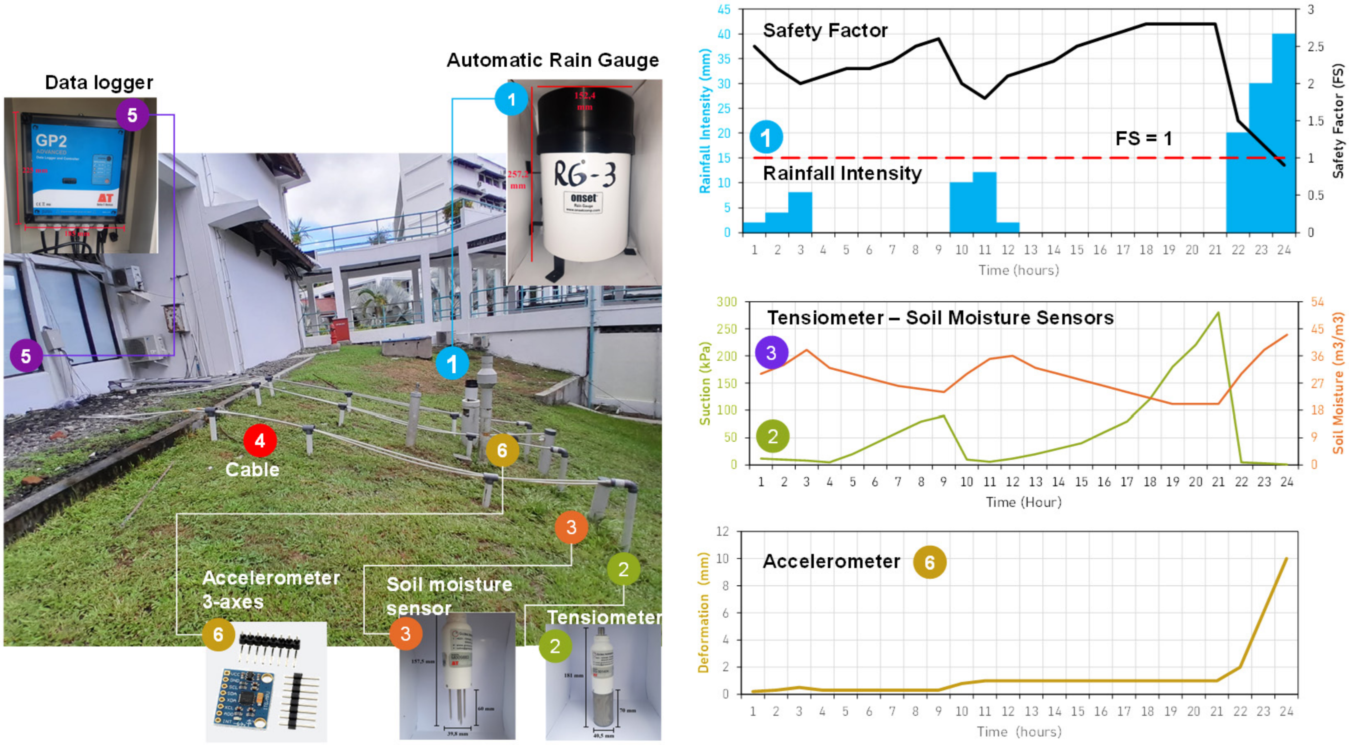

Figure 5: Traditional slope monitoring systems (Muntohar et al. 2024)

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Climate Change, Resilience and Disaster Management: Technology and Tools

National Resilience Assessment Tool (NRAT), New Zealand

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Introduction

Improving resilience on New Zealand's State Highways (SH) is critically important in achieving the New Zealand Government's overall objective of supporting economic growth and productivity, as well as ensuring connections are available and communities are better protected.

The NZ Transport Agency Waka Kotahi (NZTA) has established a National Resilience Assessment Tool (NRAT) to help better manage the resilience of the land transport network. The NRAT is a new, easily-accessible geospatial tool that provides a nationally-consistent overview of key resilience risks (such as rockfalls, landslides, flooding, and erosion) on New Zealand's state highways.

The NRAT digital platform contains regularly-updated geospatial data that is used to assess, monitor, and report on the disruption risks on the NZTA network, allowing resilience of the network to be proactively managed in a more efficient and effective way than before.

Increased maintenance and resilience of NZ's roads are key strategic priorities in the Government Policy Statement on Land Transport 2024. With the development of NRAT, and government focus, a more proactive approach to preventing, managing, and resolving outages on the SH network can now be taken. This will contribute to boosting overall network resilience.

By providing the tool on a geospatial platform along with its methodology, user guides and training for the tool, NRAT makes resilience risk information more readily available, transparent, and consistent.

The ability to download and analyse the 4500+ risks in the current tool will enable better investment decisions from a national and regional perspective. Five key benefits are summarised in Figure 1.

Figure 1: Summary of benefits of NRAT

Problem

Prior to NRAT, a national program business case prepared in 2019 had assessed the natural hazard risks across the SH network, identifying and rating some 480 risks which were loaded onto a geospatial hub. This was, however, a snapshot in time of the key SH risks. Around the same time, the SH maintenance contractors were also required to develop and manage a risk register for the SHs which they oversaw, using their own methodologies. Examples of the disruption to the land transport network caused by natural hazards is shown in Figure 2 and Figure 3.

Figure 2: Example of disruption to the land transport network caused by natural hazards

Figure 3: Disruption caused by storm surge to the SH network on the Coromandel Peninsula

These two sources of risk databases did not match, and they were managed in different ways. This resulted in limitations to national level prioritisation because there were inconsistencies in data gathering and reporting, which in turn led to an incomplete understanding of the overall risks to the SH network.

Increasing the frequency and severity of weather events meant that more resources were required to manage risk and to keep the network open and in good condition. Expenditure on emergency works has been growing over the last decade and a proactive approach to building resilience into the network is required to meet the expectations of stakeholders.

Solution

The NRAT will enable better operational and investment decisions and management reporting from a national and regional perspective. By bringing natural hazard data into one spatial platform, NRAT provides a nationally consistent overview of current and future disruption risks, which provides a level of data visibility that has not been available previously.

Broader future scenario-based insights can be added over time as projections and models are updated and improved, including climate change projections. This helps anticipate areas likely to experience future impacts, including those which may not have been subject to damage in the past. Future disruption risk is also identified for volcanic, seismic, tsunami and cyclonic hazards.

Having a centrally-coordinated and available tool with clearly-defined methodology and requirements makes it easier for suppliers to identify and assess risks for ongoing updates of the risk database. This then makes it easier for network management teams to prioritise and monitor damage and to more effectively control the risks.

An overall assessment using NRAT informs asset management planning needs, particularly if the asset is deemed vulnerable. This supports building the resilience of the network into everyday maintenance and renewals programs, and enhanced capital improvement programs where additional resilience is necessary.

Data Gathering and Analysis

The NRAT is available to approved NZTA staff and maintenance suppliers. Assessment occurs in the office or field using the Survey 123 ARCGIS application. The system is a multi-criteria analysis tool to evaluate relative disruption risk. Various consequence criteria are multiplied by the likelihood to provide an overall risk score. This is banded into a coloured risk category, as can be seen in Figure 4.

Fibonacci Weighting	Consequence criteria						Likelihood
	Scale of Outage	Duration of Outage	ONRC[15]	Lifeline Criticality	Detour Length if Closed[16]	AADT	
1				Low	Short (<30mins extra time)	<1000	
2	Partial closure	<12 hours	Primary/ secondary collector			1001-5000	Rare (>1 in 50yr)
3		12-48 hours		Medium	Moderate (30-90 mins extra time)	5001-10,000	Unlikely (1 in 30 yr)
5		48 hrs to 7 days					
8	Full closure	7 days to 1 month	Regional/ arterial			10,001-20,000	Possible (1 in 10yr)
13		1-3 months		High	Long (>90mins extra time)	20,001-40,000	Likely (1 in 5yr)
21		3-6 months	National (including High Volume)		None	>40,000	Almost certain (<1 in 2yr)
34		>6 months					

National Network Disruption Risk Score (range)	<100	101-180	181-400	>401
National Network Disruption Risk Category	Low	Medium	High	Critical

Figure 4: Methodology for calculation of NRAT disruption score on the NZ state highway network

Site photographs and other information are added directly into the tool, as shown in Figure 5. The date of the assessment and the assessors' name are included in the attribute table alongside links to supporting documentation.

Active operational control measures (such as Trigger Action Response Plans), ongoing monitoring responses, improvement suggestions and funding estimates are included. Also recorded are landslide and rockfall risks which have had industry-standard geological life safety assessments applied.

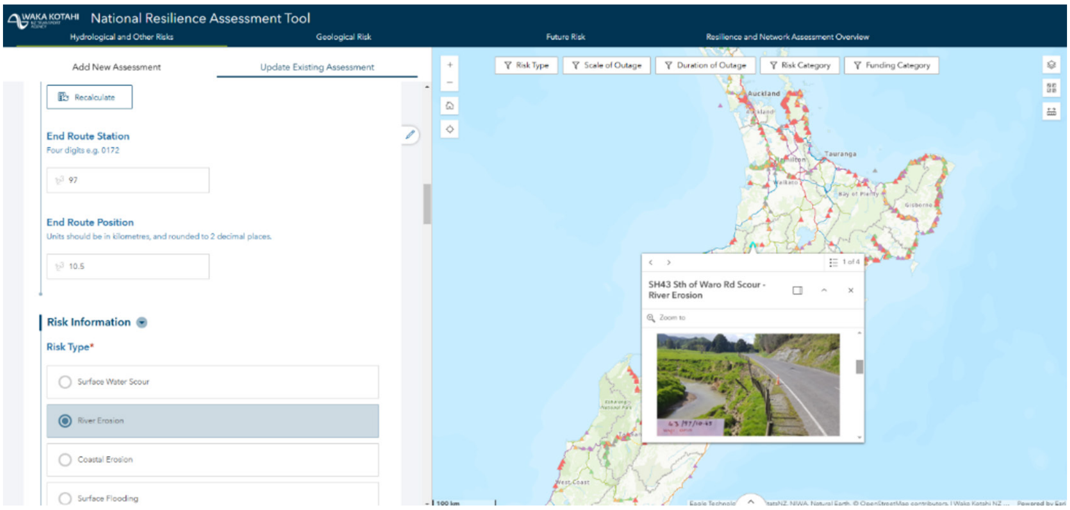

Figure 5: Updating an existing risk assessment within the NRAT

Risk assessments are peer reviewed and moderated by subject matter experts to ensure information is consistent and reliable. Comparable disruption scores can be grouped across regions or hazard types for evaluation. Data can be exported for further analysis as shown in Figure 6.

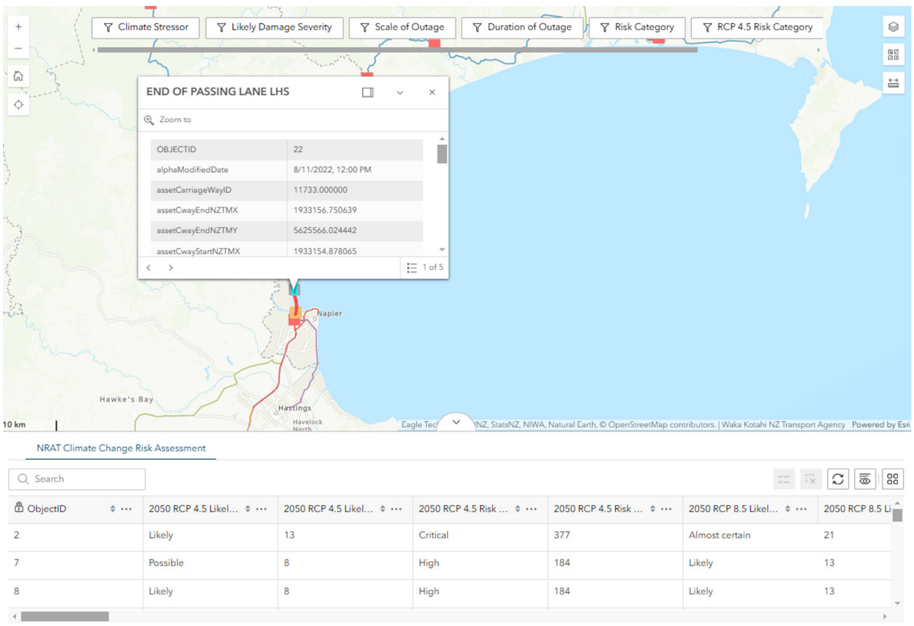

Figure 6: Future SH disruption risks (under projected scenarios) are prepared for export

Use and Outputs

If a site is deemed vulnerable, response management actions are proposed. If appropriate, an improvement project will be developed. NRAT makes it easier for suppliers to communicate the resilience disruption risks they see or anticipate on the network as well as making it easier for investment decision-makers to see and compare SH network disruption risks more effectively. NRAT helps refine the application pipeline given the only entry point for resilience funding requests sits as an integrated component within the tool. Residual risk can be reported to the NZTA executive management structure.

Balancing Outcomes

The NRAT can inform a wide range of queries and assessments, providing useful information for completing the evidence base for business cases and other evaluations where resilience issues need to be taken into consideration. While developing corridor plans, NRAT data can be used alongside other data to assess the available level of services.

NRAT is proving useful in developing the improvements program by providing funding in the right places to proactively address network risks caused by natural hazards.

The editable tool is currently in use with restricted internal and external access.

Summary of Benefits

The benefits of NRAT include:

- an extensive database of natural hazard disruption risks on the SH network recorded geospatially, based on information collected from the field or via desktop assessments
- helping take a more proactive, objective, and transparent approach to managing resilience issues on the SH network (see Figure 7)
- standardisation of information to inform business case development, helping identify and prioritise funding needs for resilience improvement programs
- making it easier to monitor progress and report on SH network risk, enabling robust evidence for decision making
- planning where level of service may need to be adjusted to meet the needs of the network and its users.

Figure 7: NRAT is helping take a more proactive approach to managing resilience issues on the SH network

Climate Change, Resilience and Disaster Management: Technology and Tools

Responding to the Marlborough 2022 Flooding in New Zealand

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Background

In 2022, a slow-moving weather system brought heavy rain to the Marlborough district in New Zealand from 16-20 August (Figure 1) with Tunakino recording 1,126 mm (5.2 times the average monthly rainfall). The Rai River experienced its largest flood on record, while the Wairau River saw the third-largest flood, The Pelorus River reached a peak flow of 1,700 m3/s, and widespread landslips caused road closures and property damage.

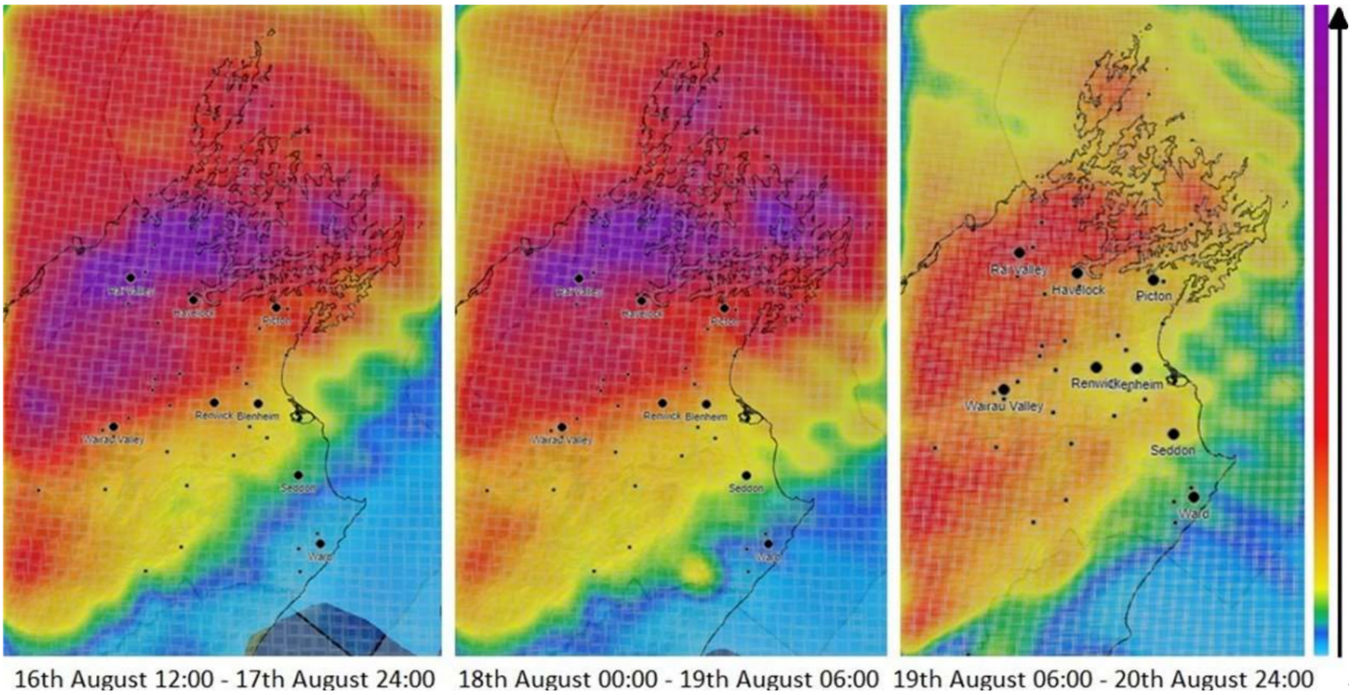

Figure 1: MetService gauge-corrected rainfall radar imagery, showing rainfall distribution over Marlborough for the three bands of rain, 16-20 August 2022

The Marlborough Sounds is geographically a very challenging district with many areas only having access from one road (Figure 2). The community which relies on these roads was left cut off, so it was crucial to gauge the scale of the issues on the road network quickly so the community could be supported and the network prioritised.

Figure 2: Map Snip showing Marlborough Sounds area with roads coloured according to pavement type
Note the three direct areas that only have one road in and out

Technology Solution

To ensure efficient response to this event, the maintenance contractor decided to develop an in-house system to capture, store and report the faults on the roading network. This was developed on ESRI, a system that allows for custom field application setups that can be aligned with underlying data standards. The benefits of utilising ESRI are that it is based around GIS, which uses the location as the key attribute and can be developed quickly. It allows for other organisations to collaborate with each other by setting up groups if they are existing ESRI users. This decision was made as public communication was deemed a high priority and utilising a system that deals in location and mapping made it far easier to clarify the scale of the issues and garner buy-in from the public regarding delays and the engineering challenges involved.

The initial step was to capture the data; this was done using the field application called 'Quick Capture', an ESRI product App which integrates with the platform. This is crucial in the development of further applications on top of dashboards and work management solutions. Quick Capture, shown in Figure 3, is a one button fault pickup solution that allows for up to five photos and notes to be captured quickly in the field on a mobile device.

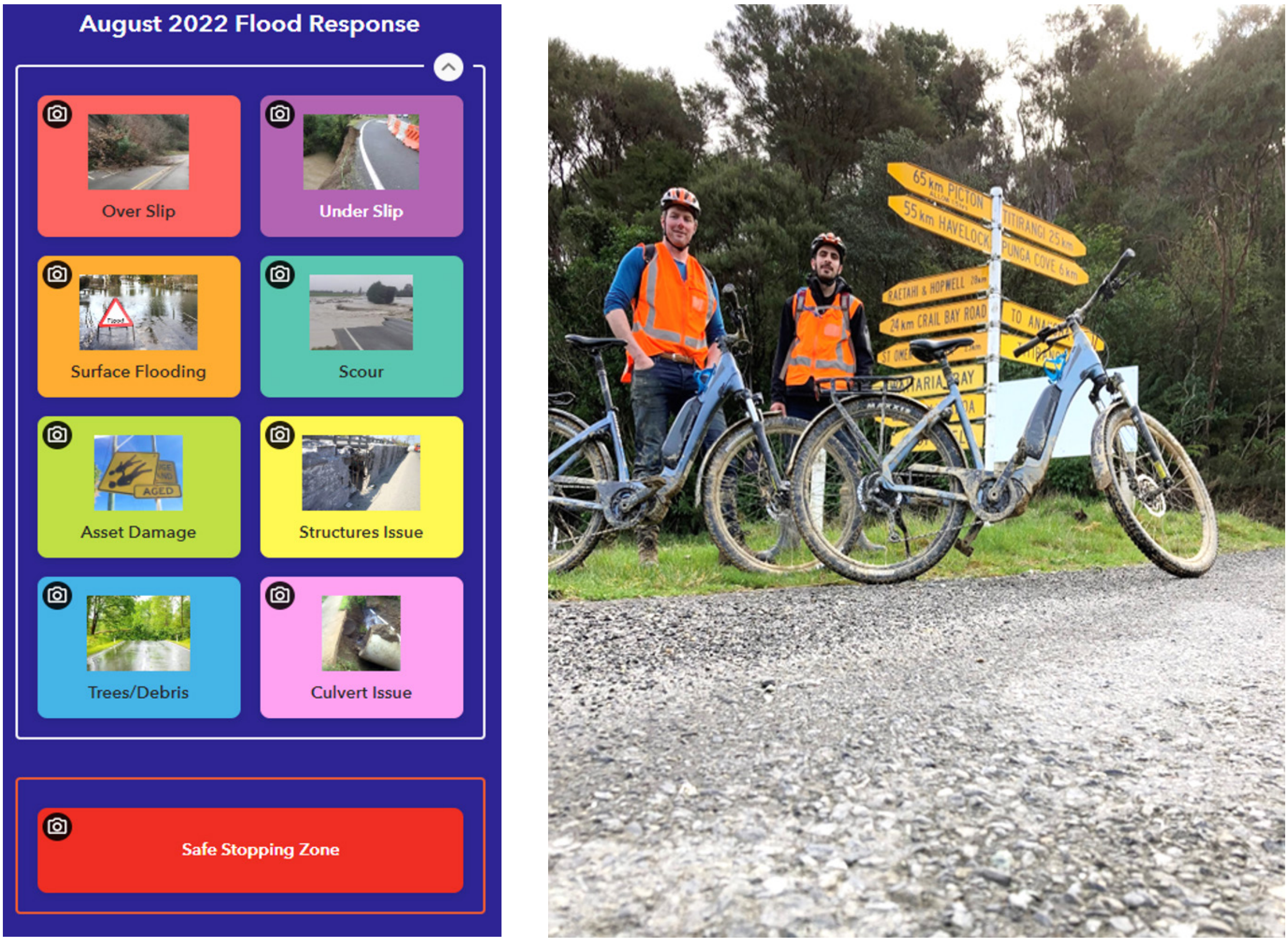

Figure 3: Quick Capture solution setup for the event response on a cell phone and two ebikes geared up for three days of cycling and data collection

A key advantage of this solution is the ability to run off a low power device as well as work in areas without cell phone reception in an offline mode. This allowed creativity in assessing the network as many of the roads were blocked. The team deployed two ebikes on Kenepuru Road to navigate around the blockages and assess the cut off area in three days (Figure 3).

To display and interact with the fault data, an interactive dashboard and data views were created to perform two functions: managing the work, and communicating with stakeholders. These data views were shared with the relevant controlling authorities so maps and communication channels could be updated and controlled by the correct authorities. The dashboard the Marlborough Roads Recovery Team (MRRT) uses to manage and update the work is shown in Figure 4, while the public-facing web map built from the data by the local council to communicate with the communities affected is shown in Figure 5.

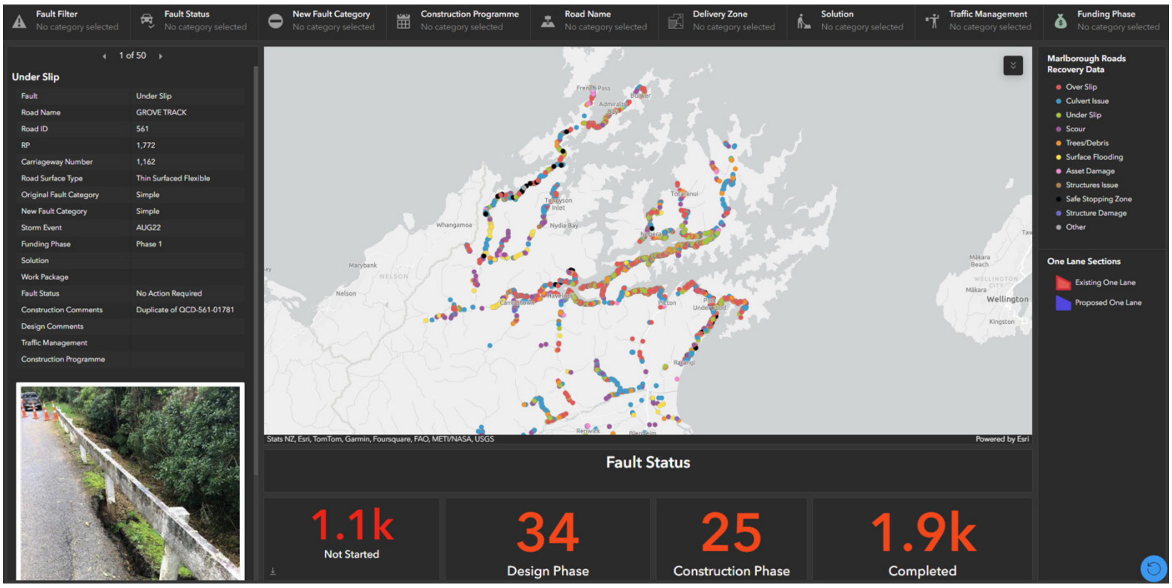

Figure 4: Dashboard that the team uses to manage and prioritise the work
(It is fully interactive, based on zoom and filters at the top which can be used)

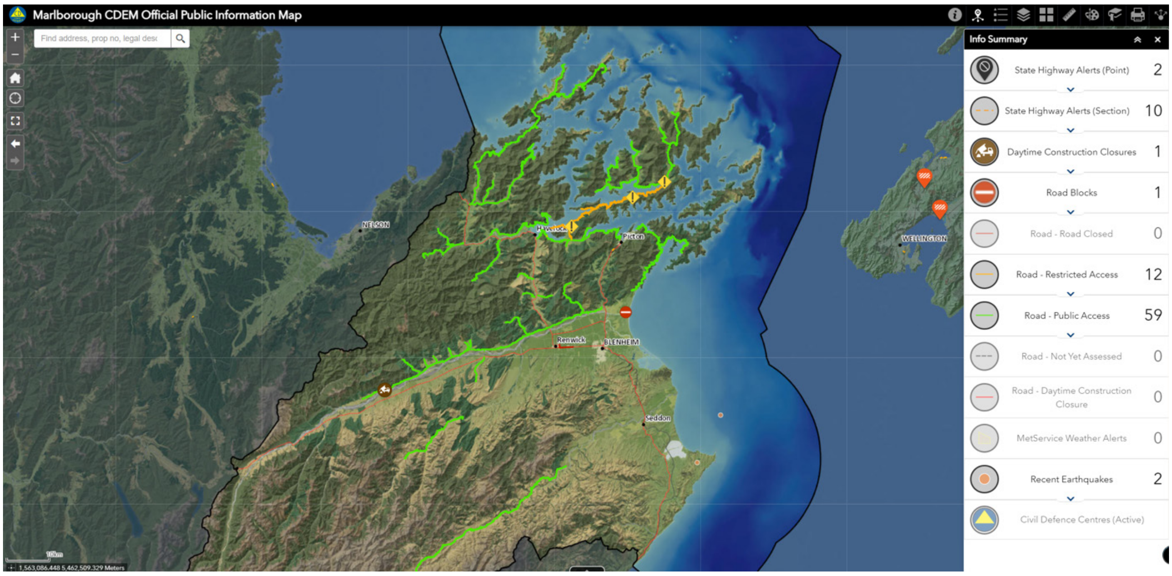

Figure 5: This map is open to the public and used to communicate road delays and closures

A key advantage of this solution is the ability to run off a low power device as well as work in areas Utilising these tools in unison has allowed the MRRT to collaborate with engineering consultants through data sharing where many layers of data have been added to help plan repairs such as slope stability and watershed variables. This has worked well as each organisation's IP and data is protected but still accessible to all parties in the group. Having a core database at the centre of this scenario has improved the ability to communicate with the public as well as with road controlling authorities. Due to the nature of this event it has been crucial to collaborate across many industries: the ESRI has enabled this workflow to happen naturally without bureaucratic 'headbutting'.

Climate Change, Resilience and Disaster Management: Technology and Tools

Austroads' Lifeline Risk Indicator

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In October 2024, Austroads released an updated Lifeline Risk Indicator Tool[1] , an online resource designed to enhance road connectivity for rural and remote communities across Australia and New Zealand. This tool has two purposes:

1. to identify lifeline freight routes and allow road managers to establish a lifeline route network
2. to rank investments in lifeline routes in terms of economic and social impacts.

This updates previous work by Austroads in 2016 in the Identification of *a Risk Indicator to* Support *'Lifeline' Freight Routes*[2]. The 2016 work investigated current practice in identification and investment in freight routes in Australia and New Zealand and also explored international best practice for Lifeline routes by the World Bank and OECD countries.

Maintaining road connections to rural or remote communities is vital as there is often a lack of alternative connections. Where there are few road options to communities, these are known as lifeline routes. Lifeline routes ensure communities remain connected when alternative routes are cut-off due to natural disasters such as floods or earthquakes. An example of flooding in the Kimberly region in Western Australia in 2018 is shown in Figure 1.

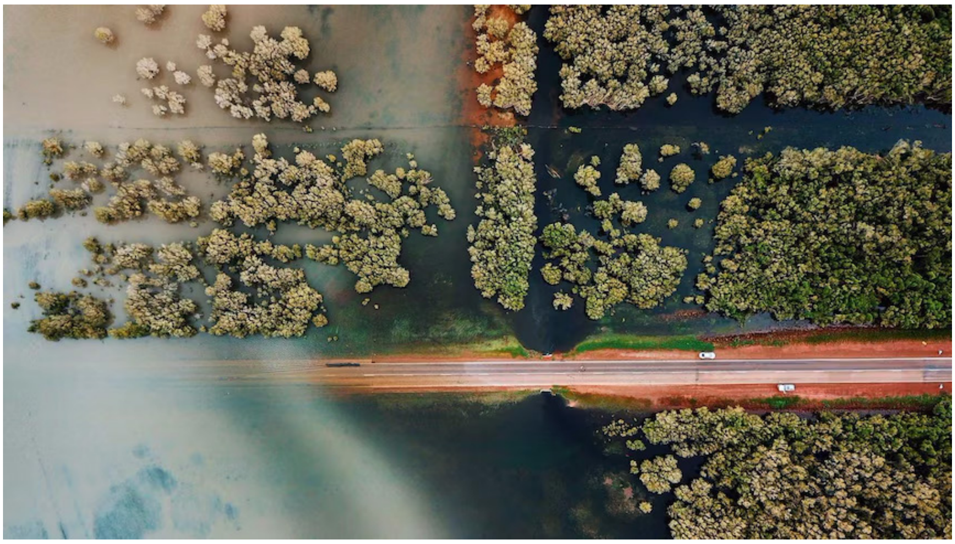

Figure 1: Flooding in the Kimberly, Western Australia in 2018
(Courtesy of the Australian Broadcasting Corporation)

Road infrastructure investments are currently planned and prioritised under what is considered a 'top-down' process. Road agencies are typically funded through budgetary processes whereby road funding needs are mostly weighed against other budget priorities. However, when a road is a lifeline route, i.e. where there are limited transportation alternatives, the external impacts and costs imposed on both users and non-users from this road becoming inaccessible can be significant.

These impacts can be difficult to both measure and value and, because of this, lifeline routes may have been historically underfunded. This is pertinent with climate change because road managers are increasingly encountering problems managing natural hazard events on lifeline routes.

For investment in lifeline routes to rural and remote communities, Austroads recommended that the benefit-cost ratio (BCR) assessment should be only part of the decision making, and not the sole deciding factor. Investing in infrastructure with a low BCR should be seen as not only acceptable but also occasionally essential if strategic objectives are to be met.

The Lifeline Risk Indicator Tool features two key assessment modules:

1. Lifeline route identification: This module ranks routes based on their significance, allowing road managers to establish a comprehensive lifeline route network tailored to their communities' needs.
2. Risk assessment and response analysis: This module evaluates routes based on risk score changes following investments, thus helping to identify which routes are most effective at mitigating key risks.

The tool outputs include:

- Lifeline route identification: Ranks routes to establish a network of vital connections.
- Risk change ranking: Assesses the effectiveness of investments in reducing risks on specific routes.
- Non-cost-benefit analysis investment ranking: Highlights routes based on their economic and social contributions, offering a broader perspective on investment justification.

The updated tool is now available for access on the Austroads website at austroads.info/lifeline. It is intended to complement existing assessment methods, such as *CSIRO's Transport Network Strategic Investment Tool* (TraNSIT) and BITRE's *Australian Transport Assessment Planning Guidelines.* In addition to freight routes, the tool could also be adapted to incorporate public transport routes.

Conclusion

Case studies from Indonesia, New Zealand and Australia provide examples of technologies and tools that play an important role in supporting the ongoing resilience of road networks, ranging from a risk-based approach in the planning, investment, design and asset management phases through to post-disaster management. The case studies highlight the importance of efficient and effective collaborative sharing of real time data in a geospatial format.

The integration of Internet of Things (IoT) technology in monitoring offers the opportunity for an innovative low-cost technology.

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[1] Austroads, *Opportunities to Increase Freight and Supply Chain Resilience*, 2024 presentation
[2] Austroads, *Identification of a risk indicator to support 'lifeline' freight routes*, 2016 https://www.onlinepublications.austroads.com.au/items/AP-R525-16

Climate Change Impacts on Road Engineering and Management

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Introduction

The pace and impact of climate change have emerged as critical global challenges in the 21st century. According to the assessment report of the United Nations Intergovernmental Panel on Climate Change(IPCC), the global average temperature has risen by approximately 1.1 °C since the Industrial Revolution and continues to increase (Figure 1). This directly intensifies the frequency and severity of extreme weather events. Phenomena such as high temperatures, extremely heavy rainfall, typhoons, and rising sea levels pose heightened risks to the structural integrity of infrastructure.

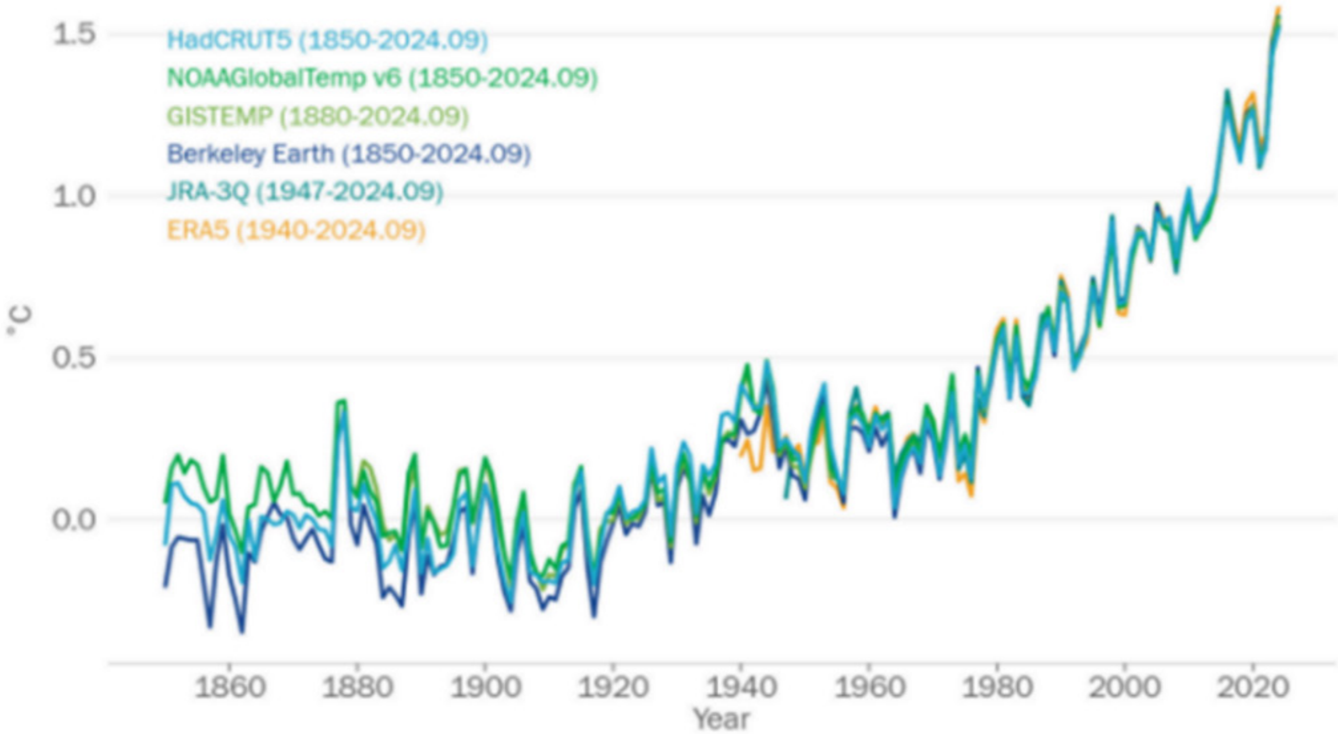

Figure 1: Global average temperature trends
(Source: World Meteorological Organization, State of the Climate 2024 Update for COP29)

Taiwan is located in the geologically fragile Circum-Pacific seismic belt; as such, it is particularly vulnerable to the effects of climate change. Prolonged or intense rainfall increases the risks of roadbed instability and landslides (Figure 2). Prolonged high temperatures accelerate the aging of pavement materials, and rises in sea-levels, coupled with coastal erosion, threatens the stability of ports and coastal highways.

	
Sudden landslide on connecting road to Sbunaw Tribe in Fuxing District, Taoyuan, following continuous rainfall (Source: PTS News, 15 September 2024)	Retaining wall displacement and over 50 metre hollowing of roadbed following rainfall in Guantian District, Tainan (Source: Era News, 23 September 23 2024)

Figure 2: Illustration of natural disasters resulting from heavy rainfall

In response to the challenges posed by climate change, traditional road engineering standards are being updated to adapt to more complex risk scenarios. The government is gradually establishing systems to mitigate climate risks. For example, the Regulations for Geological Site Investigations and Geological Safety Assessments of Geologically Sensitive Areas mandate geological surveys during the environmental impact assessment phase of public construction, including geological safety evaluations of high-risk areas such as landslide and liquefaction zones. Suitable alignments of road projects must be selected based on geological conditions and reinforcement measures must be implemented during the design phase. Additionally, the government's Water Act includes runoff sharing and outflow control regulations, with engineering measures required to alleviate downstream flood risks caused by heavy rainfall. Permeable and drainable pavement designs aim to mitigate the environmental effects of increased impervious surfaces due to urbanization.

In 2023, the government formally enacted the Climate Change Response Act, laying the legal foundation for national climate adaptation and carbon emission reduction. The goal is to reduce greenhouse gas emissions by 24±1% compared to 2005 levels by 2030 and achieve net-zero emissions by 2050. To this end, the government has proposed short-, medium- and long-term carbon reduction pathways, focusing on sectors such as construction, transportation, industry, electricity, and carbon sequestration (Figure 3). The short-term strategies (~2030) emphasize preliminary policy and technological implementation, including setting carbon reduction baselines, updating power structures, and accelerating the promotion of electric vehicles; while the medium- and long-term strategies (~2050) focus on accelerating low-carbon technology adoption and industrial transformation.

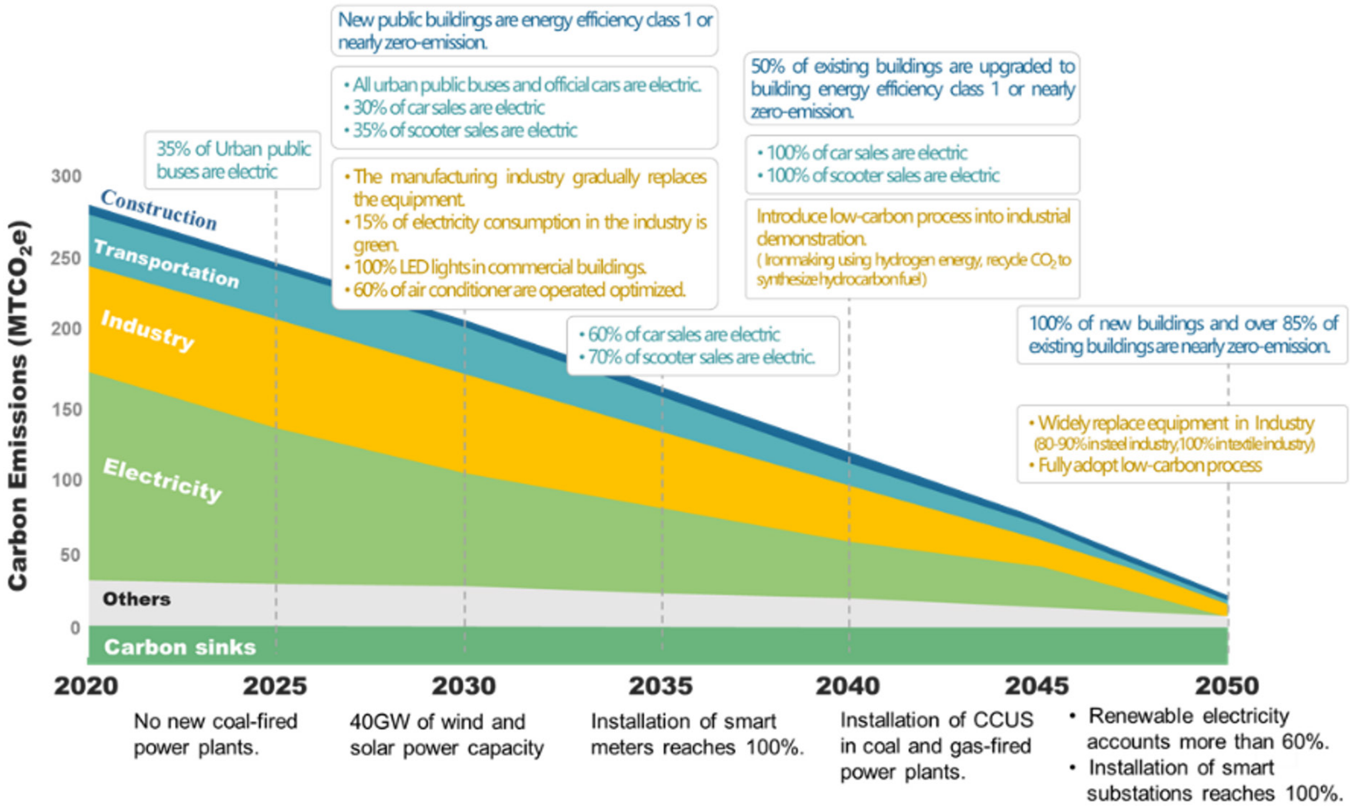

Figure 3: Taiwan's Pathway to Net-Zero Emissions in 2050
(Source: National Development Council)

To ensure sustainable development in public engineering, the government is promoting the Four Transformations of Construction, including standardized design, precast components, mechanized construction, and professionalization of personnel. Standardized design reduces construction errors, precast components enable weather-resilient construction with stable quality and safety, mechanization relies on automated equipment to enhance speed and efficiency, and professionalization focuses on cultivating technical talent. According to the Public Construction Commission, publicly-funded construction in Taiwan accounts for approximately 10% of total national greenhouse gas emissions. Road engineering, as a key component of national infrastructure, should adopt a life-cycle carbon management perspective, addressing planning, design, construction, and operational maintenance phases to systematically achieve the net-zero vision (Figure 4).

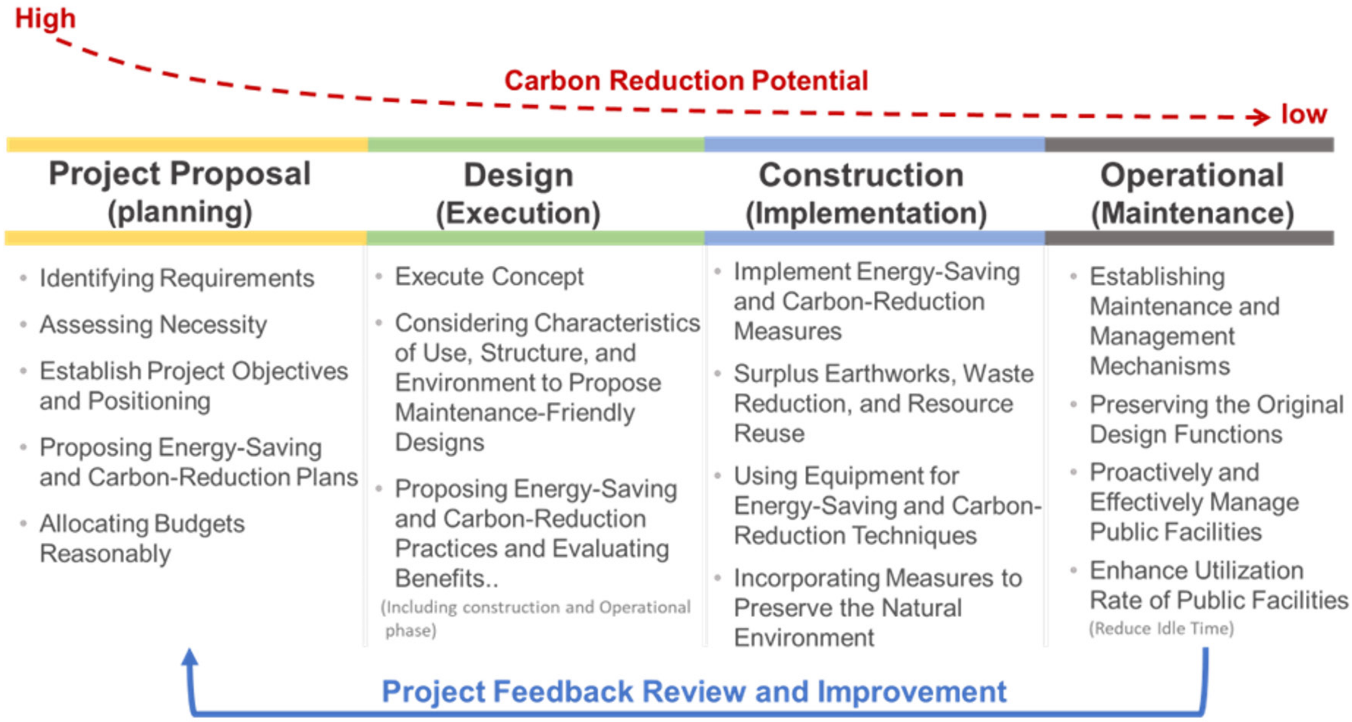

Figure 4: Life cycle carbon management of road engineering

Effective carbon emission control necessitates setting reduction targets and audit mechanisms for each phase of a project's life cycle. Authorities can establish carbon reduction baselines and goals based on historical data from representative projects, providing benchmarks for implementing carbon management. The aim is to quantify the embodied carbon during the design phase and implement total quantity control to achieve source-level reductions, thereby optimizing the overall carbon management process (Figure 5).

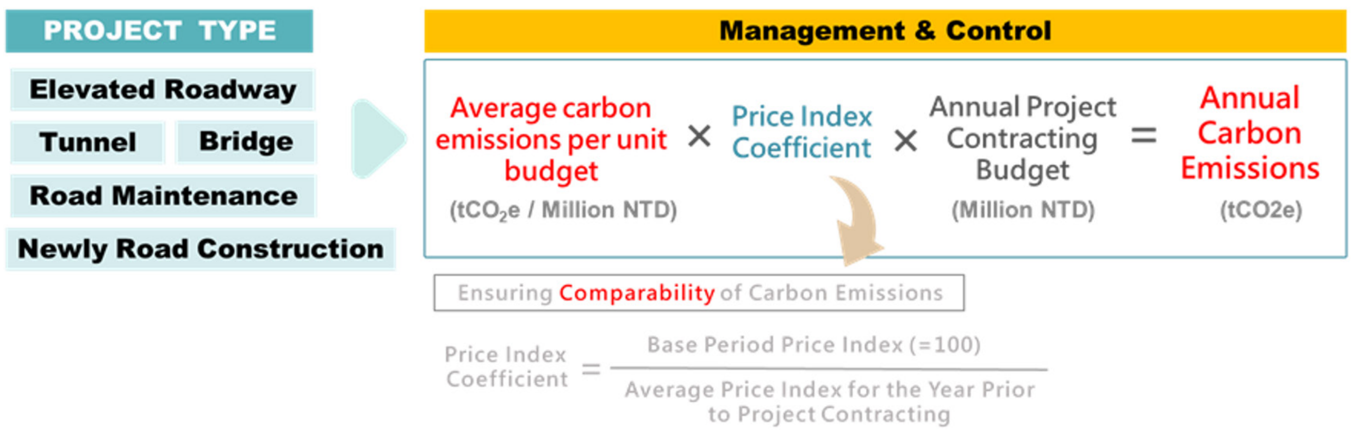

Figure 5: Total quantity control formula for engineering carbon budgets

The production of cement generates approximately 0.8-0.9 t of carbon, while 1 t of steel production emits approximately 1.9 t. Therefore, initial reduction strategies should prioritize material reduction and longevity, incorporate modular designs to decrease road reconstruction frequency, and improve maintenance efficiency. Permeable materials or green vegetation coverage can enhance road resilience. Green procurement policies further extend these efforts by embedding green material usage ratios into procurement specifications to drive reductions from the source. Innovative construction methods during the construction phase, such as adopting electric or hybrid construction equipment to replace traditional fossil-fuel-powered machinery, can significantly reduce emissions. Digital tools can optimize construction processes through precise simulation and resource allocation, thus minimizing waste. In the operational maintenance phase, regular monitoring and upkeep can reduce the need for road reconstruction.

In summary, the role of road engineering is evolving from mere infrastructure provision to a core domain of climate adaptation and carbon reduction efforts. Through policy support and technological collaboration, resilient and sustainable infrastructure systems can be achieved.

Climate Change Impact on Road Engineering and Management: Sustainable Approaches to Mitigate the Impact of Climate Change on Road Infrastructure

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Introduction

The root cause of climate change is the generation of greenhouses gases such as carbon dioxide, methane, nitrous oxide, and fluorocarbons. These gases are proliferating in the atmosphere because of human activities and they are increasingly trapping more heat. In terms of the impact of climate change on road infrastructure, many of the activities performed by road owners/operators are either directly affected, or influenced, by climate. Weather and climate-related factors – which can usually be obtained from historical climate records – form an integral part of the routine design of road pavements, including drainage systems. These factors also influence the frequency of the maintenance of infrastructure assets.

Since Malaysia is situated in an equatorial region, its climate involves uniform high temperatures, high humidity, and high rainfall. There are two broad seasons: the Northeast Monsoon season from December to March and the Southwest Monsoon season from June to September. During the Northeast Monsoon season the east coast of peninsular Malaysia experiences the heaviest rain while June and July are the driest months. Flooding can erode road foundations, leading to costly repairs or the collapse of roads, while droughts and heatwaves can soften road surfaces, leading to cracking, rutting, and even buckling of asphalt.

Sea-level rises, especially in coastal regions, pose a threat to road networks. Road located in low-lying areas are prone to flooding from storm surges, even in areas that have not previously experienced regular flooding. The National Aeronautical and Space Administration (NASA) has been monitoring sea levels using satellite technology since 1993. They found that the global mean sea level has increased by 111 mm since 1993 (Figure 1). Furthermore, the shifting precipitation patterns have resulted in the worsening of flood and landslides events in Malaysia. Recent flooding and landslides have resulted in roads being closed, leading to an increase in travel distances and travel times. Examples of road flooding and road collapse are shown in Figure 2 and Figure 3.

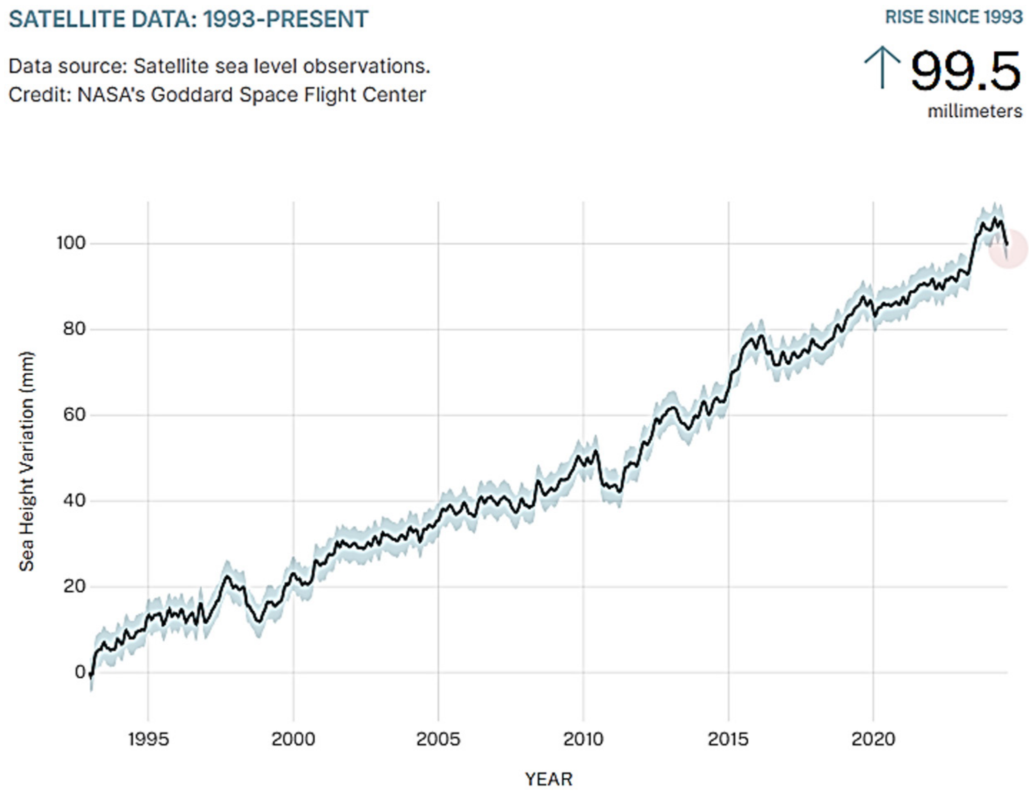

Figure 1: NASA Sea-level satellite data
(Source: https://climate.nasa.gov/vital-signs/sea-level)

Banjir: 20 jalan Persekutuan di Kelantan ditutup - JKR

Bernama
29/11/2024 18:50 MYT

Figure 2: Newspaper article – Federal road closure due to flooding
(Source: https://www.astroawani.com/berita-malaysia)

Tanah runtuh: Jalan Aring-Kenyir ditutup sepenuhnya

03 Disember 2024 11:32am

Masa membaca: 1 minit

Figure 3: Newspaper article – road collapse following heavy rain
(Source: https://www.astroawani.com/berita-malaysia)

Challenges for Road Engineering and Management

Road engineering and design must evolve to accommodate the new environment conditions brought about by climate change. This requires the development of more sustainable and resilient materials as well as structures more capable of coping with extreme weather and able to adapt with changes.

Some of the options for meeting these challenges include the following:

a) The selection of materials that can withstand temperature extremes, increased humidity, and flooding.

b) Designing drainage systems so that the road is capable to draining larger amounts of water in a relatively short time period but at the same time not causing rivers to flood; slope protection needs to be provided for roads in vulnerable locations.

c) The need to increase the frequency of routine inspections to avoid costly maintenance and rehabilitation.

d) Innovative funding solutions to meet the costs of repairing climate-induced road damage.

e) Protecting road users from the potential hazards associated with extreme climatic events.

f) Long-term planning and adaptation of national and regional transportation policies and frameworks.

Road Engineering and Management Strategies

Based on a report by a PIARC Technical Committee (PIARC Strategic Plan 2008-2011), a systematic approach should be developed for mitigation and the development of an adaptation plan. The plan should consist of five basic steps:

a) Assess current climate trends and and future projections for a region, identify climate change effects and trends that would impact on road pavements, and quantify/qualify the degree of uncertainty.

b) Undertake a climate vulnerability assessment of road pavements within the geographic region:

   i. identify current vulnerabilities based on current climate variability risks and trends

   ii. identify future potential vulnerabilities based on future projected climate scenarios and future climate risks

   iii. use a design program to evaluate the effects of varying climatic conditions on the performance of user-defined pavement structures.

c) Develop adaptation action plans, undertake a risk appraisal to categorise the nature of the risks associated with each vulnerability, and identify and assess and options available to respond to the risks associated with each of the vulnerabilities.

d) Implement adaptation action plans.

e) Monitor and evaluate the interventions on an ongoing basis and regularly review and modify the plans at predefined intervals.

Mitigation and Adaption Strategies by The Public Works Department (PWD) Malaysia

Realising on the impact of climate change, Malaysia's Public Works Department (PWD) has always emphasized the need to consider sustainability when implementing road projects. To achieve these goals, the JKR have developed a set of action plans that need to be implemented in road projects. In terms of the management of the road network, the PWD, as the main implementing agency of the government's infrastructure projects in Malaysia, is guided by PWD's Strategic Plan 2021-2025, Theme 4: Leading Sustainability.

Under Theme 4, the PWD has introduced various initiatives to promote the adoption of innovative technologies in road infrastructure development. These include the following:

a) Specification for building and road projects to use green products such as products that have Eco-Labelling or a MyHijau Mark.

b) Requirements for Construction Waste Management Plan (CWMP) for managing waste systematically through a reduce, reuse, and recycle approach.

c) A PWD Malaysia specification that requires the contractor to ensure that all waste generated on site is managed in accordance with the Solid Waste and Public Cleansing Management Act 2007 and the Environmental Quality Act 1974.

d) The use of building information modelling (BIM) and associated sets of processes to produce, communicate, analyse, and use digital information models throughout the project's life cycle.

e) Improving design standards towards sustainable development by considering life cycle perspectives.

f) The application of MS ISO 14001 (Environmental Management System, EMS) certification developed in 2002.

g) The JKR/SIRIM Standard Green Product Scoring System (GPSS), which was published in 2017, to support Government Green Procurement (GGP) and to promote green products and technologies in Malaysia.

h) The development of the Penarafan Hijau JKR (pH JKR) Manual for the road sector, an initiative which provides a sustainable development rating scheme for the use of government road projects at both the design and construction stages. The objectives of this rating scheme are to: gauge the sustainability level achieved by government projects by considering sustainable elements incorporated during the design and construction stages; facilitate improvements to be made from time to time; and encourage projects to be developed and operated sustainably.

i) The provision of an on-site detention (OSD) pond to cater for surface runoff from the roadside drainage before discharge into a river as part of a flood mitigation measure in flood-prone areas. An example of an on-site detention pond design is shown in Figure 4.

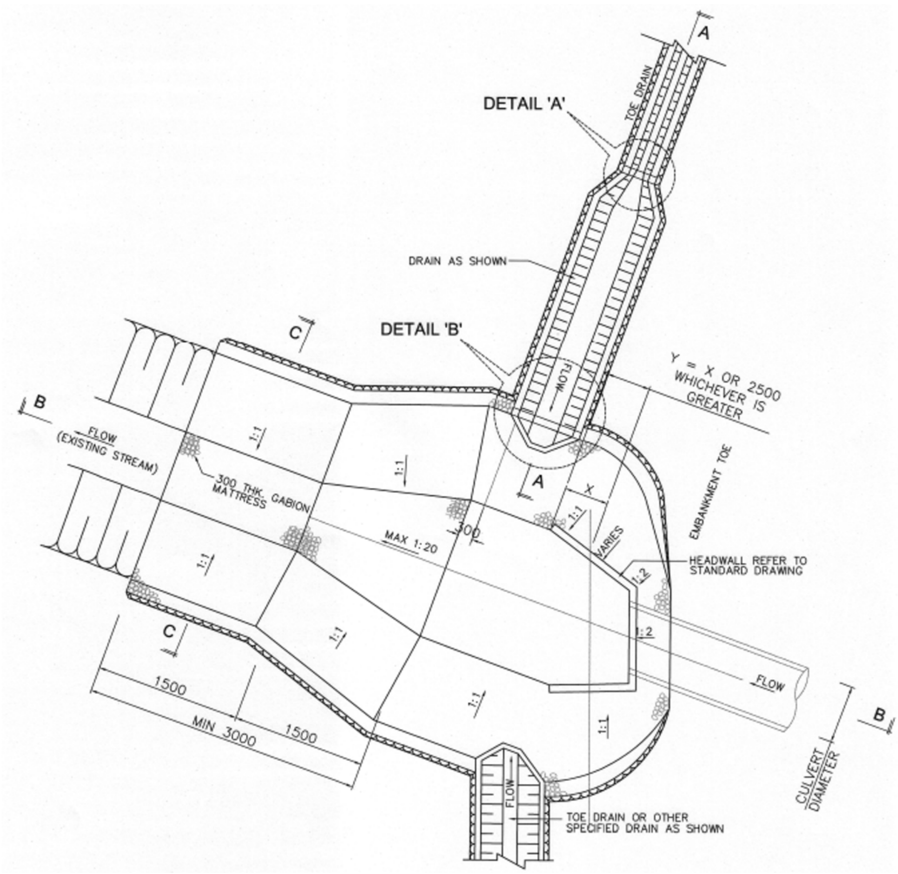

Figure 4: Example of an on-site detention pond design

j) Designing long-span bridges to reduce the number of bridge piers in the river to avoid disruption of river flow that might cause floods. An example of a long-span bridge is shown in Figure 5.

Figure 5: Example of a long-span bridge

k) Encourage the use of specialty mixes such as super fibre mixes, stone mastic asphalt, cup lump-modified asphalt, polymer-modified asphalt, latex-modified asphalt, crumb rubber-modified asphalt, fibre-modified asphalt, and MR6-plastic to increase the durability and lifespan of the pavement structure.

Conclusions

Climate change is causing a dramatic increase in temperatures and altering rainfall patterns in Malaysia. Increasing temperatures and changing precipitation patterns will change the road environment and increase the risk to road engineering and management. However, it also provides an opportunity for innovation and improvement. PWD Malaysia always encourages the adaptation of climate change mitigation practices to road engineering. By integrating climate change adaptation into planning, design, and maintenance practices, road networks can become more resilient to the impacts of extreme weather and other climate-related events.

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Biochar Capillary Barrier System: Thailand's Strategies and Approaches for Resilient and Sustainable Nature-based Solutions to address Climate Change Impacts on Road Engineering

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Introduction

Residual soil and weathered rock slopes are typically found in mountainous and hilly terrains in most tropical regions like Thailand and ASEAN countries. These earth slopes are often in the unsaturated condition with negative pore-water pressure or matric suction. The presence of matric suction is a favourable condition because it has a beneficial effect on the shear strength of unsaturated soils and thus increases the stability of slopes. However, when rainfall infiltrates into a slope, the pore-water pressure increases, the matric suction decreases, and the stability of the slope is reduced. This phenomenon causes the slope to become more prone to failure. This is commonly known as rainfall-induced slope failure and is one of the most destructive natural disasters; they are often random and sudden events that are often hard to predict.

According to Iverson (2000) and Polemio & Petrucci (2000), rainfall is the main cause of landslides and slope instability. Rainfall-induced slope failures and surface erosions have been increasingly becoming more severe in Thailand and many other ASEAN countries tropics climates due to more frequent extreme climate conditions and potential climate impacts (severe storms, floods, violent monsoons, strong typhoons, rises in sea levels, frequent tidal surges, prolonged drought, forest fires, prolonged and heavy rainfall, etc.). This climate extremity, in addition to improper urbanization and natural resource exploitation in mountainous and hilly terrains, increases the potential risks of landslides and surface erosion, resulting in catastrophic damage to residential and land transportation infrastructure, a reduction in agricultural productivity, degradation of wildlife and natural forests, time losses and loss of human life.

With the increasing severity of landslides and surface erosion, limited annual government budgets, and global concerns related to environmental issues, the nature-based solution, e.g. an application of vegetative cover placed on top of the capillary barrier system (CBS), is becoming an attractive solution because of its lower cost, higher sustainability, more environmentally friendly measures as well as improved aesthetics compared to traditional concrete-based solutions. CBS is a two-layered cover system that consists of an upper finer-grained layer overlying a coarser-grained layer; it is designed based on unsaturated soil mechanics. This technique has been continuously developed and investigated in several slope stabilizations and erosion control applications (Grimshaw 1994; Khire et al. 2000; Yang et al. 2004; Tami et al. 2004; Zornberg et al. 2010; Rahardjo et al. 2012; Rahardjo et al. 2016; Satyanaga et al. 2021). It can be effectively used to improve slope stability during rainfall by maintaining high values of matric suction in the underlying soil (e.g. Rahardjo et al. 2016), resulting in stable conditions of the slope at all times, and thus mitigate rainfall-induced slope failures during the most critical rainfall events (e.g. Grimshaw 1994; Khire et al. 2000; Yang et al. 2004). By using this technique, it is possible to use 'biochar' in the fine-grained upper layer.

Biochar is a carbon-enriched material produced from the thermochemical conversion of various biomass wastes such as wood waste, agro-waste, food waste, manure waste, and municipal/industrial sludge (Zhang et al. 2022). Although this application for slope stabilization has been traditionally used as a landfill cover to reduce water infiltration into protected waste materials, its application to slope stability as an alternative means to effectively control suction is still limited to only relatively warm climates (Scarfone et al. 2022); it has been rarely applied to slopes in the tropics, including Thailand. The main objective of this article is, therefore, to investigate the performance and effectiveness of biochar capillary barrier systems for resilient and sustainable nature-based solutions (Figure 1).

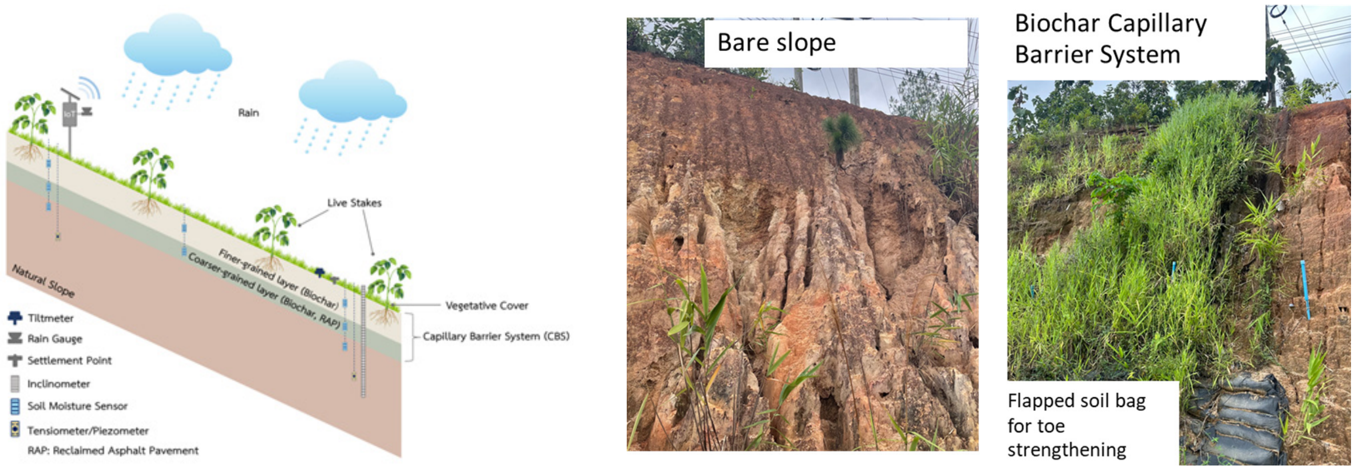

Figure 1: Biochar capillary barrier system

Background

The CBS works based on the contrast between the unsaturated hydraulic properties of the finer and coarser layers. The coarser layer typically has a very low degree of saturation and corresponding unsaturated hydraulic conductivity, which decrease many orders of magnitude with decreasing degrees of saturation. Since the unsaturated hydraulic conductivity of the coarser layer is typically very low and can be many orders of magnitude lower than that of the finer layer, the coarser layer acts as an almost impermeable barrier. This is in contrast to what would occur under fully saturated conditions when the hydraulic conductivity of the coarser layer would be much higher than that of the finer layer.

Infiltrating water starts to enter the finer layer At the top of the slope. The suction at the interface between the finer and coarser layers is relatively high since the water content is low; the coarser layer behaves as an impermeable layer and water is diverted laterally down the slope within the finer layer due to the effect of gravity. At the middle of the slope, the amount of water flowing laterally within the finer layer increases. The degree of saturation at the base of the layer is greater than that further up the slope, and the corresponding suction at the interface is lower. If the suction at the interface decreases to a point where the degree of saturation of the coarser layer increases until continuous water channels are formed within the coarser layer, the coarser layer becomes highly hydraulically conductive, and breakthrough occurs into the coarser layer and eventually into the underlying soil. No more water can be diverted laterally beyond this point on the slope, and infiltration water percolates into the coarser layer. In accordance with lateral drainage, rainwater can also be removed from the CBS by evaporation and evapotranspiration.

Performance and Effectiveness of Biochar Capillary Barrier Systems

The hydraulic characteristics of the nature-based solution for slope resiliency and sustainable mitigation to rainfall-induced slope failure and surface erosion were comprehensively investigated along cut slopes and fill slopes in National Highways in the northern part of Thailand. They included: Highway No. 1192 at km post 11+500, Highway No. 118 at km post 46+700, Highway No. 21 at km post 324+151, and Highway No. 21 at km post 329+700. The topographical conditions at these sites are mountainous and hilly. They are commonly prone to rainfall-induced slope instability under natural and engineered systems due to their slope composition of decomposed granite and colluvium deposits as well as its average annual rainfall of 1,200 – 1,300 mm.

These four experimental sites were installed with a series of field instrumentation consisting of soil moisture sensors, piezometers, tensiometers, an inclinometer, tiltmeters, a rain gauge, and settlement points. They were located near the crest, middle, and toe on each site of the slope.

In addition to the pore-water pressure, soil moisture, and soil movement data collected from the sites over two years, the physical and hydraulic properties of the biochar nature-based solution were determined in the laboratory. The specific gravity (Gs) of the biochar was approximately 1.35. The particle size distribution (PSD) and the soil-water characteristic curve (SWCC) of the biochar is illustrated in Figure 2.

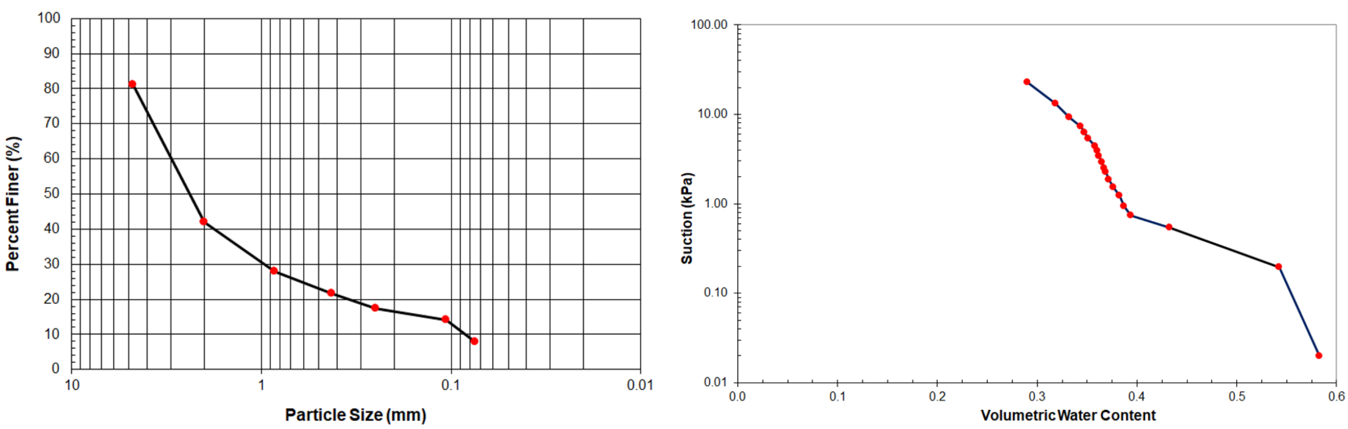

Figure 2: PSD and SWCC of biochar

The performance and effectiveness of the nature-based solution in terms of minimizing rainwater infiltration into the slope and increasing stability against rainfall-induced slope failure and surface erosion were investigated based on the results of the field monitoring as shown by the optimal preservation of negative pore-water pressure in the biochar CBS treatment (see Figure 3).

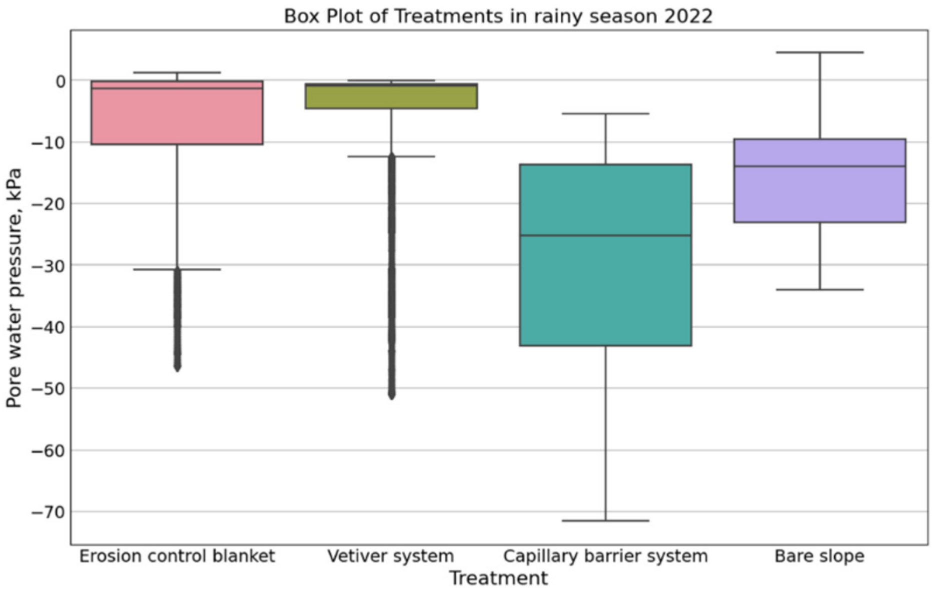

Figure 3: Box-plot of pore-water pressure of different treatments showing the better performance of the biochar capillary barrier system in preserving negative pore-water pressure

Recommendations

A biochar capillary barrier system is timely and efficient for the adoption of strategies and approaches for resilient and sustainable nature-based solutions in Thailand. This technique also supports the advancement of effective, resilient and sustainable mitigation with respect to the increase and the faster recovery of highway slopes' factors of safety under extreme events and climate change impacts. Biochar is generally produced using waste sources such as biosolids, wood, or farm manure. It can be added to topsoil on highway bioslopes to improve topsoils, decrease hydraulic conductivity, and increase the water-holding capacity of topsoil. Therefore, the application of biochar in capillary barrier systems can be potentially considered as a cost-effective state-of-the-art solution for highway slope resiliency, sustainability, environmental-friendliness, and aesthetics in Thailand and other ASEAN countries.

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Super Fibre Mix: A Sustainable Solution for Climate-Resilient Road Construction

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Introduction

According to the US National Aeronautical and Space Administration (NASA), the global average surface temperature has risen by about 1 C since the late 19th century, a change driven largely by increased carbon emissions into the atmosphere related to human activities (see Figure 1). While this change might be small, it represents a rapid accumulation of heat in the Earth's system. Rising temperatures, intensified heavy rainfalls, and more frequent extreme weather occurrences present significant challenges to the transportation sector because of the impacts on road infrastructure through accelerated pavement deterioration, leading to increased maintenance costs, reduced service life, and potential safety hazards.

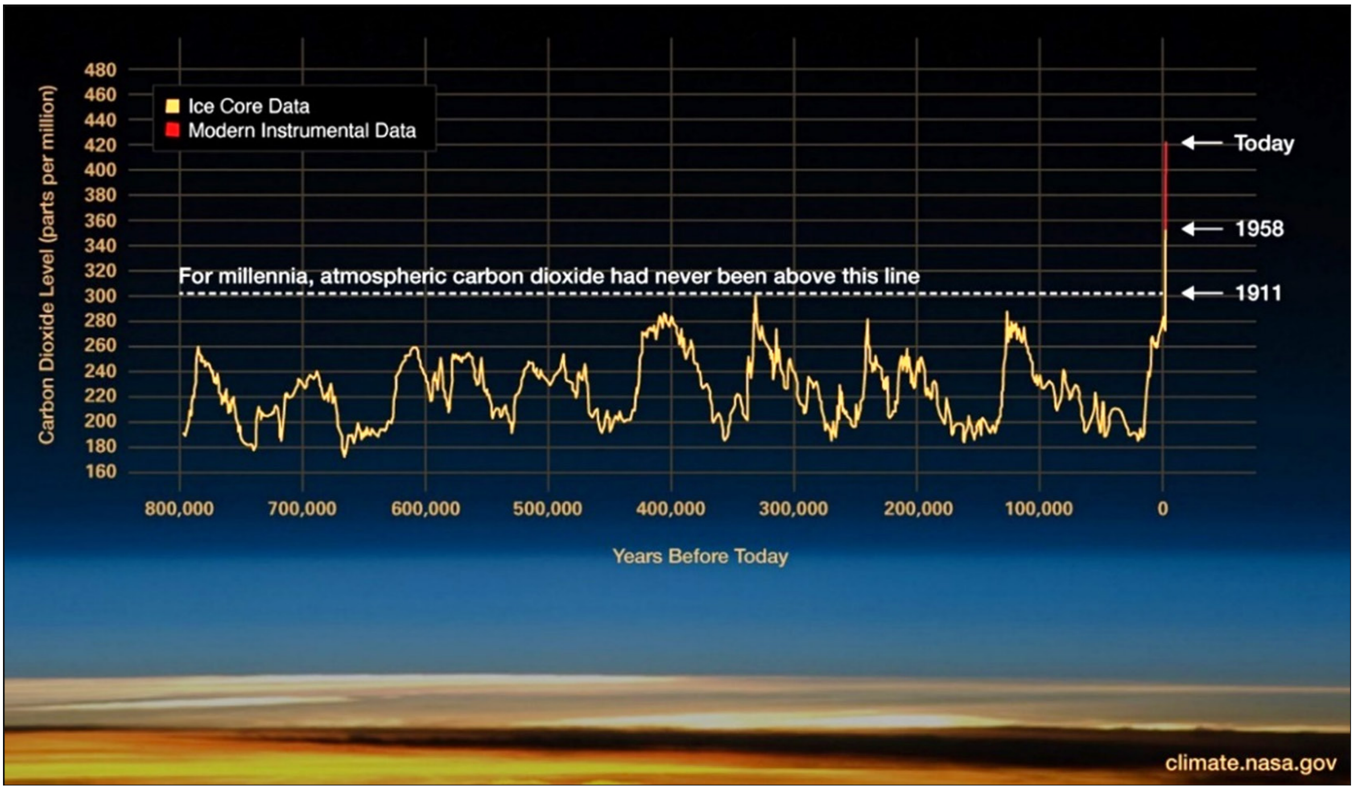

Figure 1: Atmospheric carbon dioxide levels on Earth (NASA 2024)

To address these challenges, road engineers and managers must adopt innovative and sustainable approaches to ensure the long-term resilience and performance of transportation networks. One such promising technology is Super Fiber Mix (SFM).

SFM is a hot asphalt premix reinforced with high-tensile synthetic fibre blends – aramid and polyolefin – designed to make the asphalt more resistant to rutting and cracking. The mix can be used as a wearing course (nominal aggregate sizes of 10 mm, 14 mm, 20 mm), a binder course (nominal aggregate size 28 mm) and a bituminous macadam layer (nominal aggregate size 40 mm). No modifications are required at the batching plant; the fibres only require a small dosage of 0.05% by overall weight of asphalt mix. SFM also seamlessly integrates into standard asphalt paving operations. Its installation follows the same construction methods, temperature specifications, and compaction techniques as conventional asphalt, ensuring efficient workflows with no training required.

A photo showing the SFM being mixed at the batching plant is shown in Figure 2, while a view of the distribution of the fibre in the SFM is shown in Figure 3.

Figure 2: Mixing of SFM at batching plant

Figure 3: Distribution of fibre in SFM

Laboratory and Field Studies

Both laboratory and field studies have shown that the incorporation of these synthetic fibres has enhanced the material's mechanical properties. A summary follows.

Fatigue Life

Fatigue cracking is one of the most critical distresses responsible for the failure of asphalt pavements. It is mainly caused by excessive traffic load repetitions, insufficient thickness of the pavement, or the use of unstable bituminous mixes (Barman et al. 2018). SFM incorporates aramid fibres, which are renowned for their extremely high tensile strength of 2,758 MPa, which is effectively six times greater than that of mild steel. This three-dimensional fibre reinforcement within the asphalt matrix results in a consistently substantial increase in the tensile strength of the mix, as demonstrated by laboratory testing. As a result, SFM exhibits enhanced resistance to fatigue cracking compared to conventional asphalt mixes.

Moisture Damage

Fundamentally, the structural stability of asphalt mixes results from the interlocking of aggregate particles and the adhesion of the asphalt-aggregate interface, the latter being more susceptible to moisture damage (Cui & Wang 2022). Moisture damage to the pavement is mainly caused by water immersion, leading to the accumulation of water in the air voids within the mixture. Water molecules can disrupt the bonding strength between the asphalt film and the mineral aggregate, resulting in peeling of the bitumen and ravelling of the pavement surface. Laboratory testing has demonstrated that SFM exhibits enhanced resistance to moisture damage. The presence of polyolefin and aramid fibres results in a bridging effect, physically holding the asphalt film and mineral aggregates together. This enhanced aggregate-binder adhesion ensures a higher degree of aggregate coating by the asphalt binder, even in the presence of moisture.

Rutting

Rutting, or permanent deformation of the pavement surface, is a major concern in regions experiencing hot climates, aggravated by rising temperatures associated with climate change. As temperatures rise, the binder softens, making it more susceptible to deformation under traffic loading, leading to accelerated pavement deterioration. SFM can mitigate this effect by enhancing the cohesive energy between the asphalt molecules through the incorporation of aramid and polyolefin fibres, thereby significantly improving the mix's resistance to rutting.

Photos of SFM pavements after six years service in Perak and Negeri are shown in Figure 4 and Figure 5.

These enhanced mechanical properties translate into numerous benefits that directly contribute to climate change mitigation:

- **Reduced maintenance requirements:** Based on the RUBICON Toolbox software, SFM can extend typical pavement life in Malaysia by 50%-70% (assuming similar sub-structure conditions). This is attributed to its high resilient modulus, a critical parameter in evaluating pavement performance under repeated traffic loads. The improved durability and longevity of SFM minimizes the need for frequent maintenance and rehabilitation activities, thereby reducing traffic closures and supporting economic development.

Figure 4: SFM after 6 years of service in Perak, Malaysia

Figure 5: SFM after 6 years of service in Negeri Sembilan, Malaysia

- **Reduced carbon footprint:** By extending pavement service life, SFM can contribute to a reduction in the overall environmental impact associated with road infrastructure. This includes the conservation of raw materials such as aggregates and bitumen, as well as a reduction in construction waste generated during maintenance and rehabilitation. SFM allows for the more efficient allocation of budgets, enabling the rehabilitation of a larger network of pavements by minimizing the need for deep treatments.

  Furthermore, SFM contributes to a reduced carbon footprint by decreasing greenhouse gas emissions throughout the pavement's lifecycle. This includes reduced emissions associated with the production of new materials (no pre-blending of bitumen is required), construction processes, and the transportation of materials. In 2024, aramid and polyolefin fibres used in SFM were awarded MYHIJAU certification by the Malaysian Green Technology and Climate Change Corporation (MGTC), signifying their compliance to global environmental standards.

- **Potential for sustainable materials:** SFM offers the capability of incorporating recycled asphalt pavement (RAP), a material obtained by milling and screening of existing asphalt pavements. The utilization of RAP in SFM represents a crucial step towards enhancing the sustainability of the road infrastructure industry. SFM-RAP minimizes the consumption of virgin aggregates and bitumen and diversion of road construction waste to landfills Furthermore, the incorporation of RAP in SFM can contribute to cost-effectiveness by reducing the overall cost of the pavement compared to conventional RAP while simultaneously enhancing the performance of the asphalt mixtures.

Conclusion

In conclusion, the rising temperatures and increased annual precipitation rate associated with climate change pose significant challenges to the durability and resilience of road infrastructure. This is further exacerbated by the increasingly high and heavy traffic loading in Malaysia. However, by embracing innovative technologies such as SFM, the road industry can effectively adapt and mitigate these challenges. Owing to its ease of implementation, competitive pricing, enhanced mechanical properties, improved durability and reduced environmental impact, SFM can offer a promising solution for building more sustainable and resilient road networks in Malaysia.

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QASTALANI HiMA (Highly Modified Asphalt): A Sustainable Solution for Enhanced Road Performance and Environmental Responsibility (ESG)

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Introduction

In the modern world, where environmental sustainability is among the top concerns on the global agenda, the construction and maintenance of road infrastructure has to be readdressed with a serious urge for innovation. The concept of sustainable development embraces three cornerstones: environmental integrity, social well-being, and economic viability. Among them, the most urgent is the reduction of greenhouse gas (GHG) emissions. Indeed, the construction and maintenance of road pavement represents one of the major sources of GHG emissions. As economies continue to grow, so does the demand for improved transportation and road infrastructure, thereby enhancing this challenge.

In response to these issues, QASTALANI HiMA (highly-modified asphalt) represents a revolutionary solution for road construction. It is designed for enhanced durability, enabling the construction of thinner pavements without sacrificing structural strength. This minimizes not only the need for raw materials but also reduces maintenance requirements while increasing resilience against harsh weather conditions and heavy traffic. Most importantly, it can drastically reduce the emissions linked to the road pavement industry. By promoting longer-lasting road surfaces, QASTALANI HiMA fits perfectly into Environmental, Social and Governance (ESG) assessments and goals for a sustainable future.

This article discusses the benefits of QASTALANI HiMA and underlines how it is positioned to transform road infrastructure in a sustainable manner. By assessing its performance characteristics, implementation strategies, and broader implications for ESG compliance, QASTALANI HiMA's plays a crucial role in promoting sustainable road construction practices that foster environmental stewardship and enhance community welfare. The adoption of QASTALANI HiMA is not merely about advancing material technology; it embodies a commitment to creating safer, more durable roads that respect the environment and serve the communities that depend on them.

Environmental, Social and Governance (ESG) Scoping Standards

The United Nations Sustainable Development Summit 2015, which took place in New York from 25–27 September 2015, introduced 17 Sustainable Development Goals (SDGs) aimed at addressing global challenges. Among these goals, two are particularly relevant to infrastructure development:

- SDGs 9: Build resilient infrastructure, promote inclusive and sustainable industrialization, and encourage innovation.
- SDGs 13: Take urgent action to combat climate change and its impacts.

SDGs 9 focuses on the creation of sustainable and resilient infrastructure, emphasizing the importance of enhanced scientific research and the advancement of technological capabilities. SDGs 13, on the other hand, highlights the importance of developing, transferring, disseminating, and promoting environmentally sound technologies such as QASTALANI HiMA as comprehensive measures to address the impacts of climate change, which is posing a severe threat to ecosystems. Infrastructure must not only maintain its structural integrity amid extreme environmental conditions and effectively manage the resulting economic and social impacts, it must also minimize its negative contributions to the environment throughout its entire lifecycle: during construction, operation, and eventual decommissioning.

Challenges and Issues

Sustainable development necessitates the assessment of the environmental impacts throughout the life cycle of a project to effectively tackle significant sustainability challenges, including the critical issue of global warming. GWP (Global Warming Potential) serves as a relative indicator of the amount of heat that a GHG retains in the atmosphere.

Greenhouse gases – including carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), water vapour, and various fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons, and sulfur hexafluoride – have different GWP values based on factors such as their concentration in the atmosphere, their potency, and their atmospheric lifespan (Ehhalt et al. 2001). GWP is typically expressed as a multiple of CO2 and is calculated over specific timeframes, commonly 20, 100, or 500 years. For example, the GWP of carbon dioxide is assigned a value of 1, while the GWP of other greenhouse gases is converted into equivalent CO2 values based on their respective lifetimes and GWP figures, as illustrated in Table 1. Global carbon dioxide emissions from fossil fuels and industry totalled 37.15 billion metric tons ($GtCO_2$) in 2022 (Figure 1). Emissions were projected to have risen by 1.1% in 2023 to reach a record high of 37.55 $GtCO_2$. Since 1990, global CO_2 emissions have increased by more than 60% (Annual Global emissions of carbon dioxide 1940-2023 by Ian Tiseo, Jun 12 2024).

Table 1: Emission metric values of four greenhouse gases (IPCC 2014)

GHG	Life time (yr.)	Global Warming Potential (GWP)	
		Cumulative forcing (CO_2-eq) over 20 years	Cumulative forcing (CO_2-eq) over 100 years
CO_2	Not defined	1	1
CH_4	12.4	84	28
N_2O	121	264	265
HFC	1.5	506	138

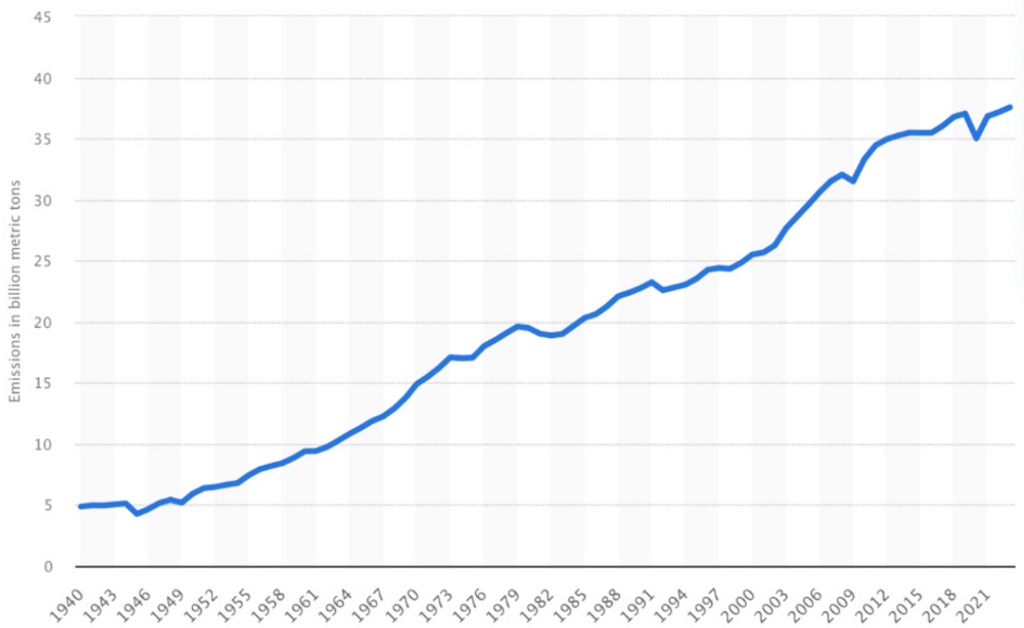

Figure 1: Total annual carbon dioxide (CO2) emission worldwide from 1940 to 2023 (in billion metric tons)

From the perspective of road construction, it is essential to reduce the contribution to Global Warming Potential. Two key areas must be taken into account:

- Focus Area 1: Reduce environmental impacts by minimizing greenhouse gas emissions associated with the construction and maintenance phases of road projects.
- Focus Area 2: Optimize the management of the road network to lessen the environmental impacts, including the greenhouse gas emissions produced by the vehicles utilizing these roads.

The GHG emissions associated with the production of raw materials and the construction of a pavement are illustrated in Figure 2. This includes emissions generated from all elements of the pavement, including the extraction of raw materials, their transportation, and the installation of the asphalt on-site. The initial phase involves the production of aggregates, asphalt, and Portland cement. The subsequent phase includes various activities such as mixing, transportation, paving, compaction, and the curing of the premixed aggregate course.

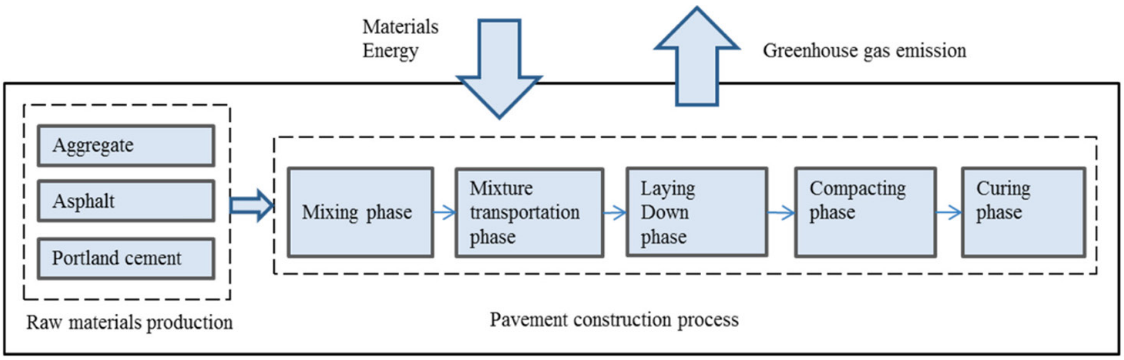

Figure 2: Evaluation system boundary of GHG emissions for asphalt pavement construction

The frequent repairs and reconstruction of roads constructed with less durable materials generates substantial GHG emissions. The key sources of these emissions, in the context of road construction and maintenance, include the production of conventional asphalt, construction activities using equipment such as excavators, pavers, and rollers, which are major sources of CO2 emissions. The delivery of raw materials, including aggregates and bitumen, and the need for regular maintenance and reconstruction exacerbates these emissions.

Conventional asphalt pavements generally require maintenance every 5 to 7 years and major reconstruction every 15 to 20 years. Each maintenance cycle generates similar emissions from production, transportation, and machinery usage, and this compounds the total GHG emissions over the lifespan of the road.

Each road maintenance treatment generates CO2 emissions through various life cycle phases, including: (i) the production of materials, (ii) the transportation of these materials, and (iii) the preparation of mixes at the asphalt plant, along with laying new layers, compaction, and the removal of old layers. Transportation distances include transport from quarries to the asphalt plant, then to the construction site, and finally from the site to a landfill. GHG Emission estimates were calculated using the PaLATE software.

The input parameters for calculating CO2 emissions in PaLATE, as well as the emissions associated with each maintenance activity, are shown in Table 2. These inputs include the volumetric composition of the asphalt mix (the ratio of bitumen to aggregate), transportation distance, and the equipment utilized for transporting and laying the asphalt mix.

Table 2. Input data and results of calculation of emission related to road maintenance work
(Source: Impact of CO2 Emissions on Low-volume Road Maintenance Policy Cast Study of Serbia)

Input data		Type of maintenance: Overlay 40 mm	Overlay 100 mm	Reconstruction
Quantities	Overlay (cm)	4	10	10
	Depth of milling (cm)	4	10	10
Road section	Width (m)	7	7	7
	Length (km)	1	1	1
Volume and transport distances of materials				
Asphalt mix	Volume (m^3)	280	700	700
	Distance (km)	48.28	48.28	48.28
Virgin aggregate	Volume (m^3)	280	700	878
	Distance (km)	48.28	48.28	48.28
Bitumen	Volume (m^3)	14.5	36.7	36.7
	Distance (km)	48.28	48.28	48.28
RAP to landfill	Volume (m^3)	295	737	737
	Distance (km)	80.47	80.47	80.47
Calculated emissions of maintenance treatments				
Emissions	t/km	267	668	986

Note: RAP = reclaimed asphalt pavement.

QASTALANI HiMA as a Sustainable Solution for ESG Initiatives: Road Facilities Maintenance Branch, Public Work Department, Malaysia (Jabatan Kerja Raya-CSFJ)

Field Trial

In April 2023, the Road Facilities Maintenance Branch, Public Work Department, Malaysia (Jabatan Kerja Raya- CSFJ), embarked on an innovative project to study the performance of QASTALANI HiMA binder under severe traffic conditions. Testing was conducted along route FT209 from KM0.00 to KM0.50, near the Pasir Hor, Padang Enggang Exit in Kota Bharu, Kelantan. It is an essential corridor that has to carry extremely high volumes of traffic, including frequent heavy vehicles.

This has resulted in deterioration of the road surface, mainly in the form of potholes and cracking. This necessitated frequent interventions from local PWD teams that undertook minor repairs almost monthly and major overhauls every four to five months. These ongoing maintenance efforts, besides being very costly, also introduced significant risks to road users.

Despite these surface issues, the road's underlying foundation remained sound and structurally intact. This stability negated the need for more extensive treatments, such as cold in-place recycling or complete reconstruction, which is usually reserved for foundational failures. The application of QASTALANI HiMA binder, therefore, became Jabatan Kerja Raya-CSFJ's focus in terms of effectively attending to the surface defects while capitalizing on the strength of the existing foundation. This approach not only improved the longevity and performance of the road but also ensured a cost-effective solution to managing heavy traffic on this crucial route. This section of road was seen as an ideal control site in terms of testing the effectiveness of the QASTALANI HiMA binder as a solution to improve surface durability without having to resort to more invasive reconstruction procedures.

The control section was divided into three different pavement designs: perpetual pavement, thickness reduction pavement, and thin wearing resurfacing pavement. The original design consisted of a 75 mm thick binder course (ACB28) and a 50 mm thick wearing course (ACW14) with 60/70 bitumen binder. An aerial view of the test site is shown in Figure 3.

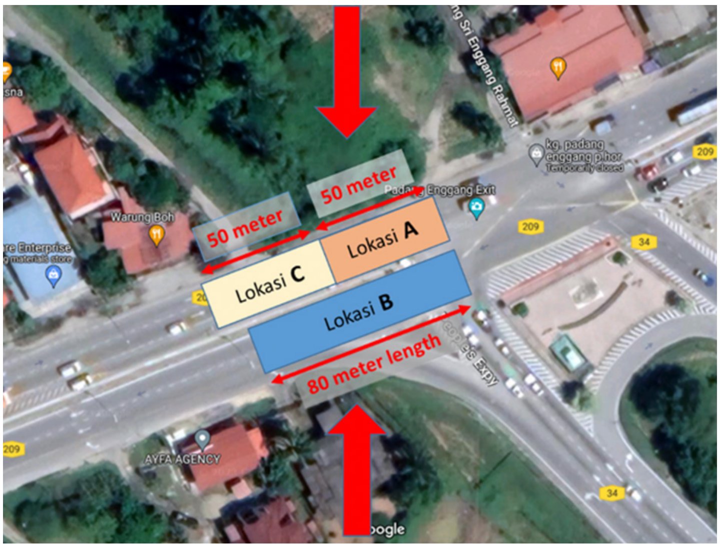

Figure 3: Sections of QASTALANI HiMA binder test pavement

To study the performance of the QASTALANI HiMA binder and to evaluate these three innovative concepts, the pavement design was modified as shown in Figure 4.

- **Control Section A:** Thickness reduction pavement using ACW14 with a 40 mm thick wearing course and ACB20 with a 60 mm binder course.
- **Control Section B:** Perpetual pavement with ACW14 set at a thickness of 50 mm for the wearing course and ACB20 at 70 mm for the binder course.
- **Control Section C:** Thin wearing resurfacing by replacing the existing wearing course with a 40 mm thick ACW14 course.

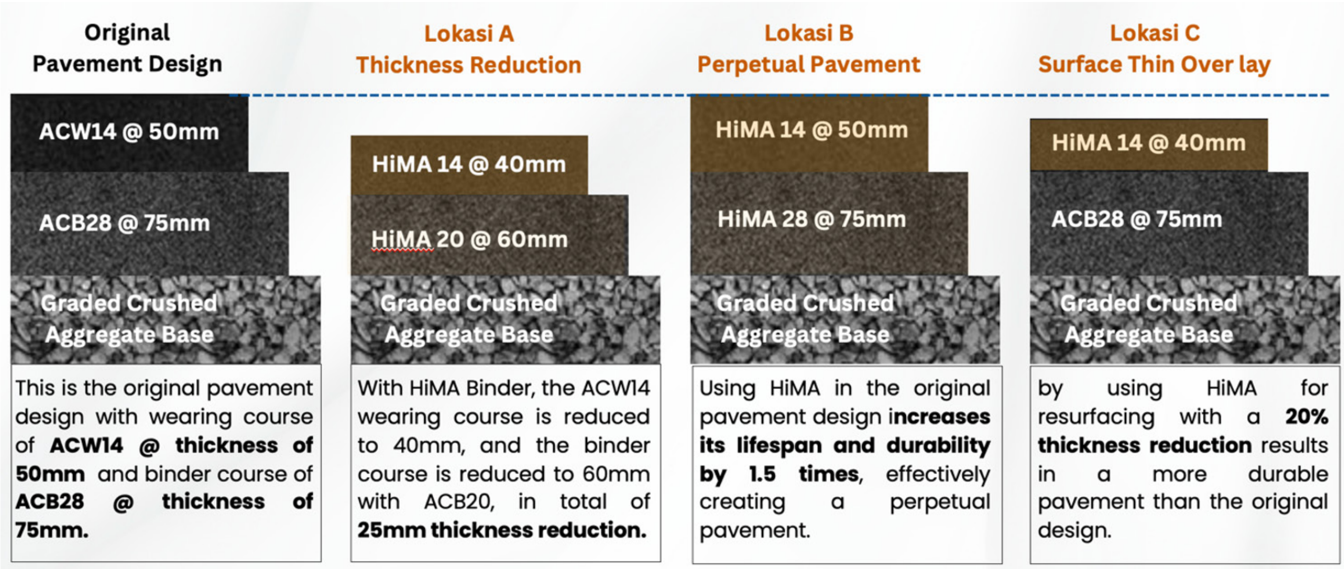

Figure 4: Cross-section of test sites

Construction of the sections was completed in April 2023. Since then, no repairs have been needed after more than 18 months of trafficking, when previously the pavement had required repairs monthly.

The success of the control section demonstrated that the use pf the QASTALANI HiMA binder created not only a more durable pavement but also represented a very practical approach to a reduction of the original pavement thickness by 20%. This will directly contribute to the reduction of GHG emissions through minimizing aggregate and bitumen use, the transportation of premixed material, and the operating costs of the machinery on site. This innovative solution improved the performance of the pavement and increased its durability compared to conventional materials.

Environmental Benefits of QASTALANI HiMA

Research indicates that QASTALANI HiMA can lower GHG emissions by approximately of 20% over the pavement's lifecycle in comparison to traditional asphalt alternatives (Asphalt Pro Magazine).

The GHG emission reduction is achieved primarily through two methods:

Reduction in Material Demand

The extended life of QASTALANI HiMA pavements which comply to SDGs 9, often referred to as 'perpetual pavement,' significantly reduces the need for raw materials over time. This reduction in material demand lessens the environmental impacts associated with the extraction, processing, and transportation of construction materials. Consequently, as fewer resources are required for repairs and replacements, the overall GHG emissions are substantially lowered.

Data obtained from the Malaysian pavement industry, depicted in Figure 5, highlights the difference in pavement service life between traditional and innovative pavement materials. Conventional bitumen binder types typically have a service life of about 5 years. By incorporating specialized mix types, this lifespan can be enhanced to approximately 7.5 years. In contrast, QASTALANI HiMA pavements can achieve a service life of up to 10.5 years when constructed and maintained under optimal conditions (refer to case study conducted by the US Federal Highway Administration (FHWA, USA). This extended durability not only underscores the value of QASTALANI HiMA in terms of long-term performance but also reinforces the importance of the use of innovative materials in advancing sustainable road engineering practice.

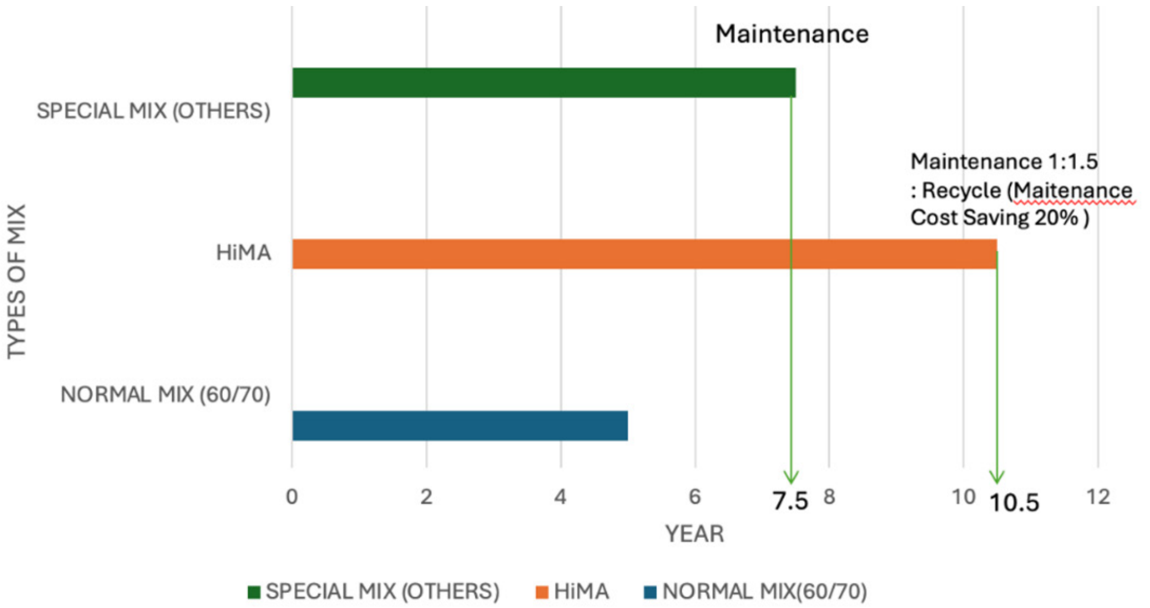

Figure 5: Comparison of pavement service life between traditional and innovative pavement materials

The GHG emission reduction is achieved primarily through two methods:

Pavement Thickness Reduction

The second method which complies with SDGs 13 by contributing to sustainability in road construction is pavement thickness reduction shown in Figure 6. The advanced performance characteristics of QASTALANI HiMA enables a reduction in the thickness of the pavement layers without sacrificing structural integrity (Figure 6) while still maintaining the durability and load-bearing capacity necessary for heavy traffic.

Aside from the advantages already discussed, thinner pavement layers reduce the overall dead load applied to the subgrade, leading to a lower risk of deformation and associated maintenance issues. This is particularly important in areas with soft or unstable soil conditions, where traditional thicker pavements might exacerbate structural failures.

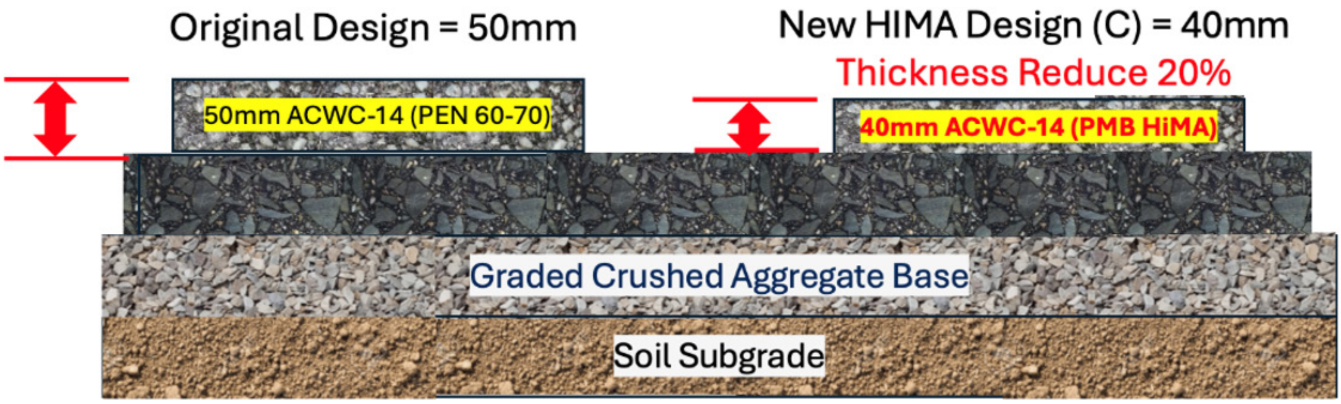

Figure 6: Reduction in pavement thickness of 20% using QASTALANI HiMA binder
(JKR Kelantan QASTALANI HiMA trial road date, April 2023)

In April 2023, JKR Malaysia implemented QASTALANI HiMA binder in a control section located in Kelantan, Malaysia. The incorporation of the binder resulted in a reduction of the original thickness from 50 mm to 40 mm, a 20% reduction from the original design (Figure 7). This not only resulted in substantial savings of virgin aggregate (70 m^3/km), asphalt mix (70 m^3/km), and bituminous binder (3.85 m^3/km), but also achieved a reduction in GHG emissions of 67 t/km, based on the formula published in the report, 'Impact of CO2 emissions on low volume road maintenance policy: Case Study, Serbia ' (see Table 3).

Table 3: Results of calculation of emission related to road maintenance work
(Impact of CO2 emission on low volume road maintenance policy cast study, Serbia)

		Original design	HiMA design	Saving /Different
Quantities	**Overlay (mm)**	50	40	**-10**
	Depth of milling (mm)	50	40	**-10**
Road Section	**Width (m)**	7	7	**n/a**
	Length (km)	1	1	**n/a**
Asphalt Mix	**Volume (m3)**	350	280	**-70**
Virgin Aggregate	**Volume (m3)**	350	280	**-70**
Bitumen	**Volume (m3)**	18.35	14.5	**-3.85**
Emissions	**t/km**	334	267	**-67**

Social Benefits Associated with the Use of QASTALANI HiMA

As already discussed, one of the major benefits of QASTALANI HiMA is its improved performance compared with conventional asphalt, including better resistance to rutting and cracking. These properties are very important in terms of maintaining safe driving conditions, particularly for roads subject to heavy traffic and extreme weather conditions. The use of QASTALANI HiMA will reduce the possibility of deterioration of the surface and the associated in potholes and cracking. This has direct implications on the safe driving environment because it minimizes the likelihood of those hazards occurring, and hence crashes. The incorporation of QASTALANI HiMA technology into pavements is a proactive approach in the interests of public safety and protection of road users .

Apart from improving safety, the use of QASTALANI HiMA has resulted in a reduction in disruptions on the road network. Traditional asphalt pavements need to be maintained frequently, and this may disturb traffic flow, causing considerable losses in travel time. Such disruptions frustrate drivers who use these roads every day, while on their way to and from work. The use of QASTALANI HiMA reduces interventions, leading to fewer closures. This reduction in disruptions contributes positively to the quality of life by minimizing travel time and reducing the stress associated with navigating through construction zones.

Governance Benefits Associated with the Use of QASTALANI HiMA

The use of QASTALANI HiMA has other benefits aside from increasing the durability and safety of the roadways: considerable social benefits related to regulatory compliance and cost management. These advantages play a crucial role in shaping public perceptions and influencing decisions related to infrastructure development.

One of the major contributions to the social relevance of QASTALANI HiMA is its capability to achieve and often outperform the most rigorous regulatory requirements for road durability and safety. With the use of increasingly stringent standards for infrastructure by governments and agencies, the superior performance characteristics of QASTALANI HiMA are an asset worthy of great value. The incorporation of QASTALANI HiMA within a construction project shows how the public and private sectors in both countries are serious about the adoption of advanced, sustainable technologies. Not only will this compliance make project approvals easier, but also this adherence to environmental regulations is crucial in order not to lose public confidence and support in infrastructure. Moreover, demonstrating a proactive approach to using innovative materials reinforces the reputation of organizations involved in road management as industry leaders in sustainability and safety.

Performance of Highly Modified Asphalt (HiMA)

Polymer modified bitumen (PMB) has been extensively use in Malaysia and worldwide. Generally, increasing the amount of styrene-butadiene-styrene (SBS) modifier in base bitumen will enhance the performance of this PMB binder, particularly in terms of resistance to thermal sensitivity, rutting, and cracking resistance. However, there is a limitation to the SBS content in base bitumen: it is usually capped at 6% due to viscosity concerns. Beyond this threshold, the PMB binder can become excessively viscous, impairing its compaction ability when mixed with aggregate.

The Kraton Corporation in the USA developed a specialized type of SBS modifier that allows the SBS content to be increased up to 7.5% while maintaining a manageable viscosity. This advanced PMB binder, known as QASTALANI HiMA (highly-modified asphalt), retains optimal compaction properties when mixed with aggregates and exhibits superior performance (Figure 7).

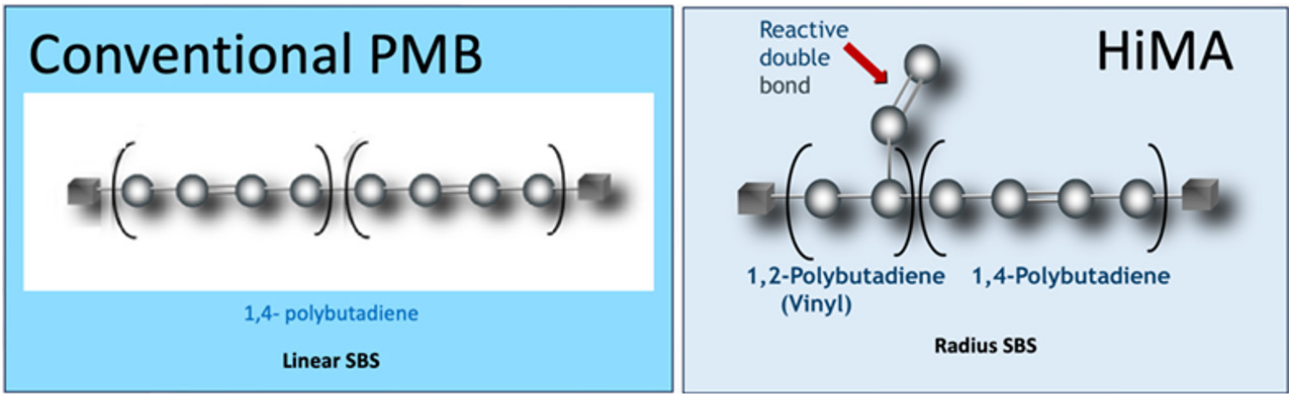

Figure 7: SBS Molecule type for linear and radius type

Styrene-Butadiene-Styrene (SBS) linear grade, shown in Figure 8, features straight molecular chains that enhance the elasticity and flexibility of the asphalt, improving resistance to cracking and rutting. In contrast, SBS radial grade has a branching, star-like structure, creating a more cohesive polymer network within the asphalt, leading to superior strength and durability. The main differences between the SBS linear and radial grades are their molecular structures and resulting performance. The linear grade has straight chains, while the radial grade's branches offer better elasticity and durability. Thus, SBS radial grade is ideal for demanding applications such as QASTALANI HiMA, which requires a higher polymer content for enhanced performance.

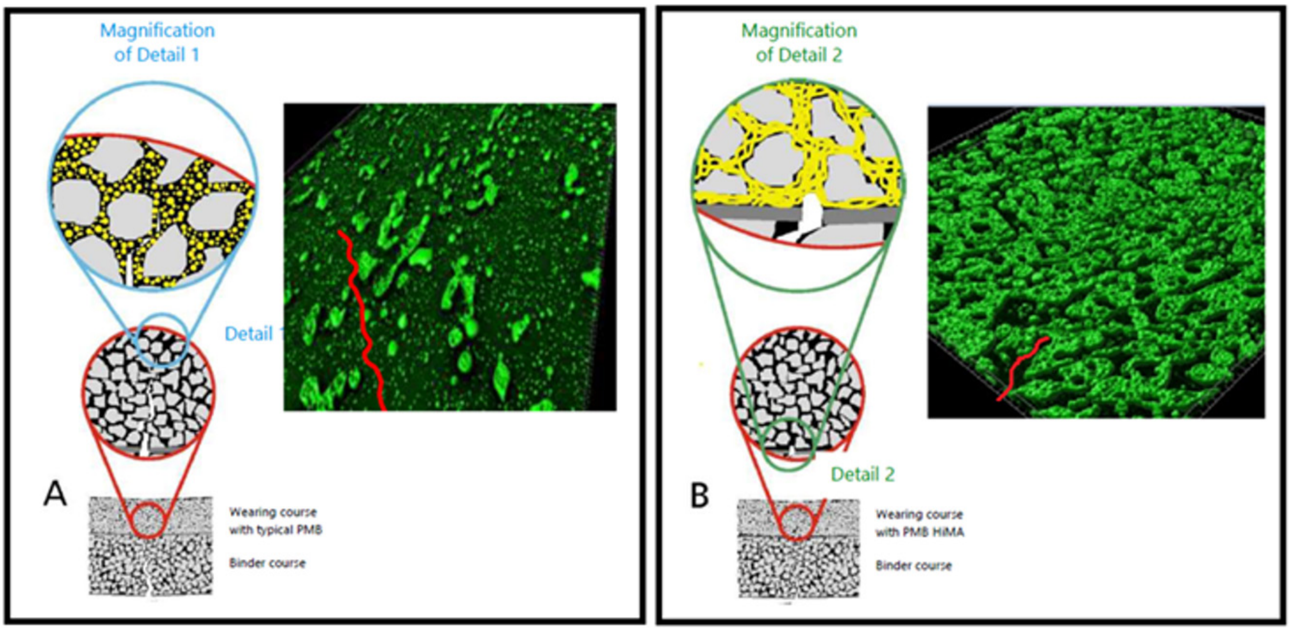

Figure 8: 3D Modelling of conventional PMB (4.5% SBS) vs QASTALANI HiMA (7.5% SBS)

The extreme high polymer network within the QASTALANI HiMA binder significantly enhances its thermal sensitivity and elastic recovery properties, thereby extending the lifespan of road pavements and potentially reducing the required pavement thickness.

Conclusions

QASTALANI HiMA is a breakthrough technology in road construction, offering sustainability to roads and, most importantly, contributing to addressing some of the major current environmental challenges. HiMA meets, and often exceeds, modern requirements for durability, safety, and the reduction of GHG emissions. Its properties allow thinner pavements that can preserve the structural integrity of the road, which translates into lower materials consumption and reduced maintenance needs in the long run.

The successful implementation of QASTALANI HiMA in road projects shows its potential for reducing the frequency of repairs, thus providing safer roads for all users and improving community well-being. Its compliance with the SDGs highlights the need to consider new technologies in the battle against climate change and in the pursuit of resilient infrastructure.

The environmental, social, and governance benefits associated with the use of QASTALANI HiMA make it a good choice for modern road construction. The use of this advanced material is not only an investment in durability and performance but also one that helps to create a more sustainable future. Embracing alternatives such as QASTALANI HiMA will be crucial to transforming the road infrastructure landscape for the betterment of the environment and the quality of life within communities.

Evaluation of Rutting Resistance and Moisture Susceptibility of Hotmix Asphalt Reinforced with Aramid and Polyolefin Fibres in Malaysia

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Introduction

In recent years, the global oil market has experienced a significant price surge, resulting in a substantial increase in the cost of bitumen. In fact, the price of bitumen per tonnage in 2023 had increased by 78% compared to 2021 (Ab Wahab 2024). Due to the subsequent escalation in the cost of asphalt, all road agencies have demanded enhanced performance from their bituminous products, including increased resistance to moisture and rutting.

Moisture can cause premature degradation of asphalt pavements manifest as stripping, ravelling, and potholes. Fundamentally, the structural stability of asphalt mixtures results from the interlocking of aggregate particles and the adhesion at the binder-aggregate interface, the latter being more susceptible to moisture damage (Cui et al. 2022). Therefore, enhancing this interfacial adhesion is crucial to improve the moisture resistance of asphalt mixes and to extend service life.

On the other hand, rutting is caused by the gradual deformation, of plastic deformation, under the repeated action of traffic loads and the shear failure of the asphalt layer, resulting in the formation of depressions in the asphalt pavement (Luan et al. 2023). Even though this only occurs on the pavement surface, this lateral flow can also endanger the middle and lower layers. The nature of the defect also presents a significant safety hazard to road users, especially motorists.

Xiao et. al. (2024) investigated the effects of lignin fibres (LFs), polyester fibres (PFs) and polypropylene fibres (PPFs) on the water stability of stone matrix asphalt (SMA), a gap-graded asphalt mix according to the Chinese standard method. The PF-enhanced asphalt mixt exhibited the highest freeze-thaw split TSR values, reaching 85%, while LFs-enhanced mixes had the lowest TSR, at 83.2%. Liao et. al. (2023) evaluated rutting resistance using Hamburg Wheel Tracking (HWT) of 50% reclaimed asphalt mix (RAP) prepared with various bio-based rejuvenators and a soft binder to compare with control mix with 20% RAP content at two conditioning temperatures of 44°C and 50°C for. Only the 50% RAP mixes utilizing corn oil and modified vegetable oil did not reach 12.5 mm maximum rut depth after 20,000 passes at 44°C. However, at the test temperature of 50°C, all mixes failed except for the 50% RAP mix without any rejuvenator.

In the study described in this paper, the moisture and rutting resistance of aramid-polyolefin fibre-modified asphalt mixes (APFMA) was investigated. A series of tests were conducted, including tensile strength ratio, Marshall immersion index, Hamburg wheel tracking and dynamic creep modulus. The field performance of APFMA after 31 months in service compared to conventional mix was also evaluated. Additionally, a five-year life-cycle cost analysis of the APFMA on a Malaysian protocol road will be conducted to assess its economic advantages.

Materials

In this study, the aramid-polyolefin fibre modified asphalt (APFMA) was blended using the same mix design as the conventional asphalt mix for the wearing course layer adhering to either Malaysia's Public Work Department (PWD) specifications for federal and state projects or PLUS Berhad's Series 900: Flexible Surfacing specification for highway projects (PLUS Berhad, Jabatan Kerja Raya 2008). The synthetic fibres were added to the hot aggregates in the pugmill at an asphalt batching plant prior to the spraying of bitumen. The fibre dosage was maintained at 500 g/ton of asphalt mix, equivalent to 0.05% of the total mix weight. All samples were taken from asphalt batching plants supplying to actual projects in Peninsular Malaysia and were subsequently tested by independent laboratories. The APFMA samples were divided into four regions in Malaysia – central, southern, northern and east coast – depending on the locations of the asphalt batching plants (Table 1).

Table 1: Location of asphalt batching plants for APFMA samples

Region	Location of asphalt batching plants (states)
Central	Selangor, Kuala Lumpur
Southern	Melaka, Negeri Sembilan, Johor
Northern	Perak, Pulau Pinang, Kedah
East Coast	Pahang, Kelantan, Terengganu

Asphalt Binder

Matrix asphalt with a penetration grade of 60/70 was selected for the study. The physical properties of the asphalt binder conformed to Specification MS124 (SIRIM 1996).

Aggregates

In Malaysia, aggregate specifications differ depending on the type of roads it will be used on. Federal and state road projects employ AC14 gradation with a nominal aggregate size of 14 mm, whereas highway road projects necessitate ACWC20 gradation with a nominal aggregate size of 20 mm (PLUS Berhad, Jabatan Kerja Raya 2008). For the tensile strength ratio and dynamic creep modulus tests, the AC14 gradation is used whilst, for the Marshall Immersion Index and Hamburg Wheel Tracking tests, ACWC20 gradation is used. Mineral fillers of either hydrated lime or ordinary Portland cement at 2% are incorporated for both types. Figure 1 shows the gradation limits for all the mixes.

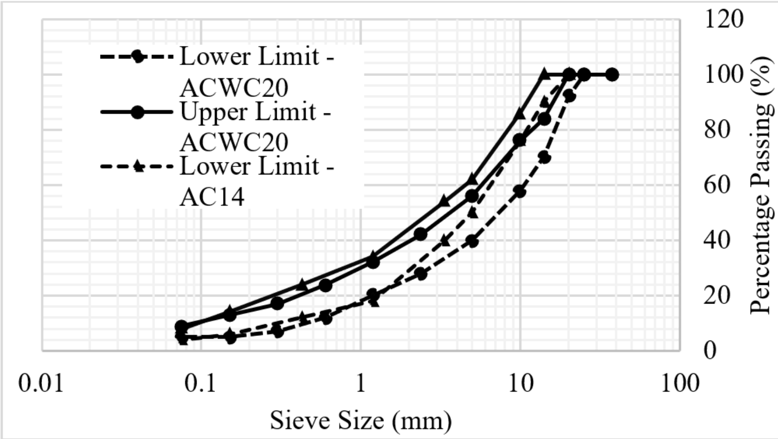

Figure 1: Gradation limits for all mixes

Fibres

A combination of two synthetic fibres was used in this study: aramid and polyolefin (Figure 2). The physical properties are presented in Table 2. Due to their long length, both fibres exhibit a relatively high surface area, facilitating easy dispersion during mixing. This characteristic also enhances their interfacial bonding between the fibres, aggregate and bitumen, thereby improving the overall mechanical properties of the asphalt mix. During incorporation of these fibres into the pugmill, the polyolefin component will melt and coat the hot aggregates, acting as a distribution agent for the high-tensile aramid fibres. This will ultimately create a continuous reinforcing network within the asphalt mix.

Figure 2: Synthetic fibres – aramid (left) and polyolefin (right)

Table 2: Physical properties of aramid and polyolefin fibres

Parameter	Aramid	Polyolefin
Specific Gravity	1.44	0.91
Density	1,440 kg/cm³	910 kg/cm³
Tensile Strength	2,758 MPa	–
Operating Temperature	–73 to 427 °C	–
Length	19 mm	19 mm
Form	Monofilament	Serrated
Color	Yellow	Yellow
Acid/Alkali Resistance	Inert	Insert

Methodology

Tensile Strength Ratio

Tensile Strength Ratio (TSR) testing was conducted according to AASHTO T283. Eight Marshall specimens with a diameter of 101.6 mm and a height of 63.5 mm were prepared and divided into two groups: dry and wet. All specimens in the wet (conditioned) group were subjected to vacuum saturation operation, with the samples left submerged in water until the degree of saturation was between 70 and 80%. After 24±1 hours in the 60°C water bath, the conditioned samples were removed and placed in a water bath at 25±0.5°C for 2 hours. No conditioning was required for the dry samples. All eight specimens were then placed on their side between the bearing plates of the testing machine. The load was applied at a constant rate of 50.8±5 mm per minute until the specimen cracked.

Tensile Strength and Tensile Strength Ratio are calculated using the following equations:

$$Tensile\ Strength = \frac{2P}{\pi t D} \quad (1)$$

where P = maximum load (lbs), t = specimen thickness (inch) and D = specimen diameter (inch).

$$Tensile\ Strength\ Ratio\ (TSR) = \frac{S_2}{S_1} \quad (2)$$

where S_1 = average tensile strength of the dry subset (kPa), and S_2 = average tensile strength of the conditioned subset (kPa).

Marshall Immersion Index

Similar to the TSR test, eight Marshall specimens were also randomly divided into two groups. Specimens for the dry group were soaked in a water bath at 60°C for 30 minutes, while specimens for the wet group were soaked in the same water bath for 24 hours. Afterwards, Marshall Stability and Flow testing was conducted on all eight specimens, according to ASTM D1559: 1989). The load was applied at a rate of 50.8±5 mm per minute until the maximum load was reached. The maximum load and indicated flow value were then recorded. The immersion index of the asphalt mixture was calculated to the nearest whole number as follows:

$$Marshall\ Immersion\ Index = \frac{S_2}{S_1} \quad (3)$$

Hamburg Wheel Tracking

Hamburg Wheel Tracking testing was performed in line with the PWD specification for rubber-modified asphalt (Jabatan Kerja Raya 2019). Loose samples were first compacted into four cylindrical specimens using a Superpave Gyratory Compactor. The test was performed at a temperature of 50°C, without submersion in water. Preconditioning was first conducted for 30 minutes. The loading rate for the oscillatory steel rolling wheels was set at 52±2 passes across the specimen per minute. The testing machine disengaged either when 20,000 passes had occurred, or a maximum vertical deformation of 12.5 mm had been reached. The maximum rut depth and its corresponding number of passes were then reported (AASHTO 2011).

Dynamic Creep Modulus

Dynamic unconfined, compressive creep testing was performed on the asphalt mixes according to EN 12697-25 to calculate for dynamic creep modulus (BS EN 2016). Test conditions followed the PWD specification for polymer modified asphalt (Table 3) (Jabatan Kerja Raya 2008). The permanent deformation was recorded immediately with the beginning of the first periodic loading pulse until 3600 pulses have occurred. Cumulative permanent deformation was then calculated using the following equation:

$$\varepsilon_n = 100\left(\frac{u_n}{t_i}\right) \quad (4)$$

where ε_n = the cumulative axial strain of the test specimen after n loading cycles (%), μ_n = the cumulative permanent deformation of the test specimen after n loading cycles (mm), and t_i = the initial thickness of the test specimen (mm). The creep modulus was calculated between the 2000th and 3600th load cycles (Jabatan Kerja Raya 2008).

Table 3: Dynamic, unconfined and compressive creep test conditions

Pre-conditioning		Testing	
Test temperature	25°C	Test temperature	40°C
Applied axial stress	150 kPa	Applied axial stress	300 kPa
Loading frequency	0.5 Hz	Loading frequency	0.5 Hz
Loading time	0.2 s	Loading time	0.2 s
Rest period	1.8 s	Rest period	1.8 s
No. of load cycles	30	No. of load cycles	3600

Methodology

Moisture Resistance – Tensile Strength Ratio

The tensile strength ratio (TSR) value is an indicator of the moisture resistance of an asphalt mixture. The average tensile strength and TSR value for all samples are presented in Figure 3 and Figure 4 respectively. For the unconditioned set, the APFMA from the Northern region had the highest tensile strength, at 44% higher than the conventional mix. After 24 hours immersion in 60 C in a water bath, the APFMA still maintained better performance than the control mix for all regions. The APFMA from the Northern region reported upwards of 71% higher tensile strength values compared to control mix in wet condition. Meanwhile, the calculated TSR values revealed that the average of all regions for APFMA was 18% higher TSR than the control mix.

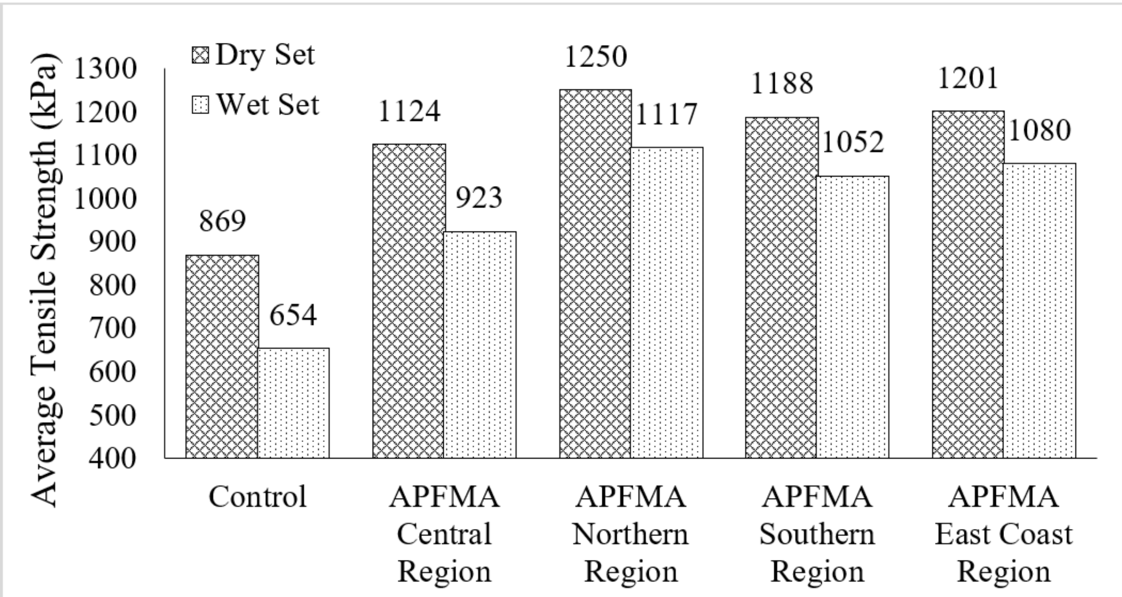

Figure 3: Average wet and dry tensile strength for control and APFMA

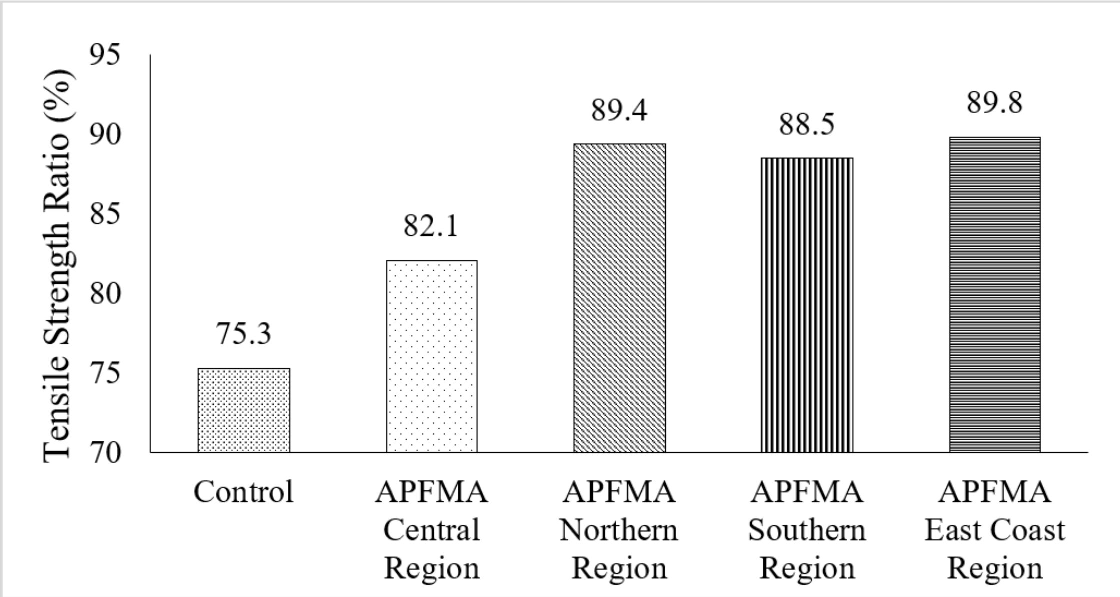

Figure 4: Tensile Strength Ratio for control and APFMA

Moisture damage to the pavement is mainly caused by water immersion, leading to the accumulation of water in the air voids within the mixture. The theory suggests that the bonding strength between the asphalt film and mineral aggregates is measured as the contact angle between the asphalt film and the aggregate surface (Wang et al. 2024). A smaller contact angle reflects a stronger adhesion between aggregates and bitumen, highlighting a higher degree of asphalt coating. Conversely, a larger contact angle means greater separation between asphalt molecules and aggregates. As this contact angle increases higher than 900, bitumen eventually completely separates from the aggregate, resulting in peeling of the asphalt film and stripping or raveling defects. When water penetrates the pavement and fills the voids, the water molecules disrupt the bonding energy by increasing this contact angle and accelerating the peeling phenomenon. However, as shown in Figure 2 , this moisture damage is minimized in fibre modified asphalt mixture. This is due to the presence of polyolefin and aramid fibre which has resulted in bridging effect, physically holding the asphalt film and mineral aggregates together. The fibres essentially ensure that contact angle is minimized and that the mineral aggregates are always coated with the asphalt. This is further amplified with the properties of aramid fibre being over 2,758 MPa in tensile strength.

Marshall Immersion Index

Similar to the TSR, Retained Marshall Stability can also demonstrate the resistance of asphalt mixtures to hot water damage. Figure 5 illustrates the Marshall stability for APFMA and control mixture after 30 minutes and 24 hours immersion in 60°C water bath. Figure 6 presents the resultant Marshall Immersion Index for all samples. After 30 minutes immersion, APFMA from east coast region shows the highest Marshall stability value, at 21% greater than conventional mix. However, APFMA from the southern region exhibits similar value to control sample. Interestingly, control mix reveals a significant drop in stability values after 24 hours immersion. APFMA from all regions exhibit higher stability values than conventional asphalt mix, with the east coast region showing the most significant improvement, exceeding values by over 54%. Consequently, the average Immersion Index for all APFMA regions was 89.41%, reflecting a 23% increase compared to the conventional mix.

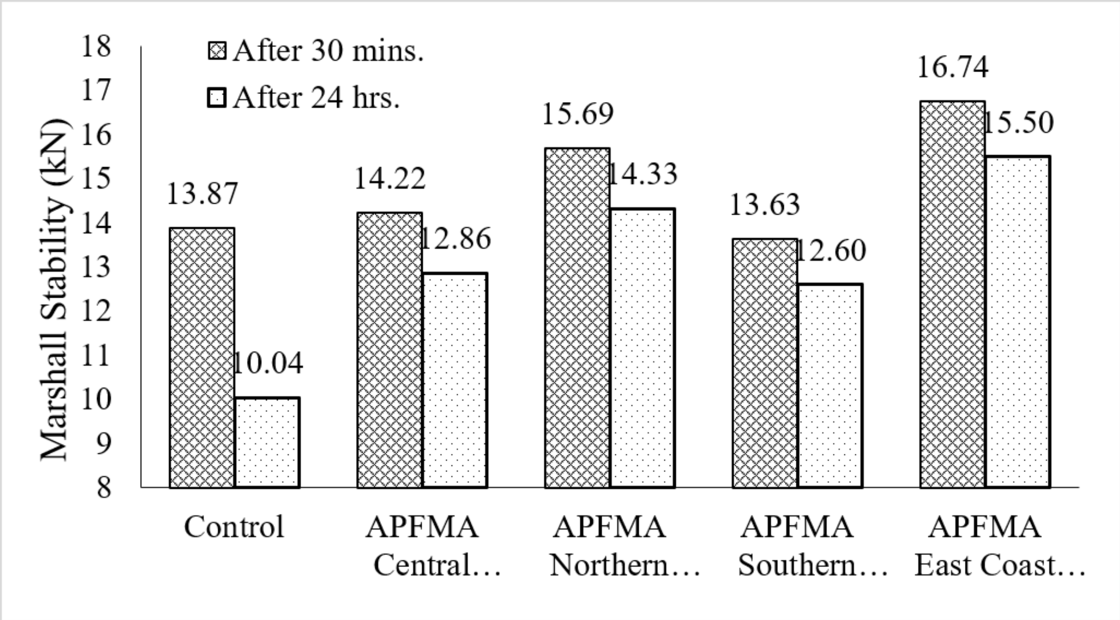

Figure 5: Average Marshall stability after 30 minutes and 24 hours immersion in water bath

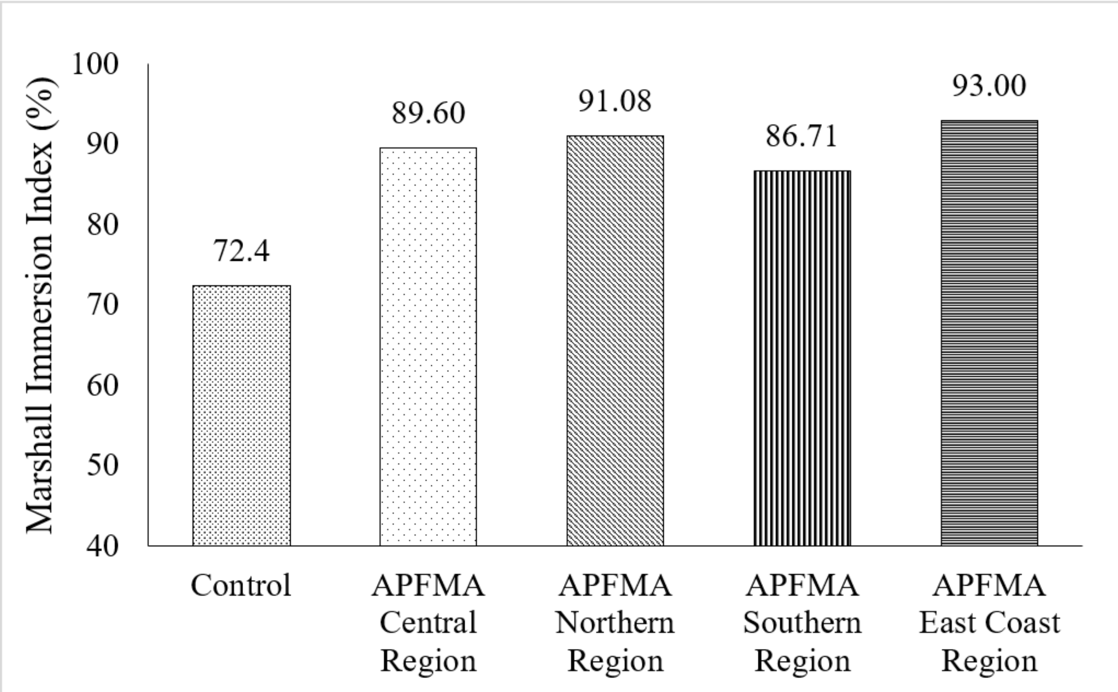

Figure 6: Marshall Immersion Index for control and APFMA

Beyond the contact angle theory, various approaches have been employed to elucidate the adhesion mechanism between asphalt and aggregates. These approaches include chemical reactions involving acids (present in asphalt) and alkalis. Alkaline aggregates, such as limestone, generally exhibit greater adhesion capacity with asphalt than their acidic counterparts (such as granite) (Tang et al. 2023).

However, when water infiltrates the interfacial layer, strong and stable hydrogen bonds will be formed between water molecules, asphalt and aggregates. These foreign molecules adsorbed onto the surface of aggregates can inhibit the contact between asphalt and aggregates, thereby significantly diminishing the adhesion properties of these two surfaces.

Despite successful adhesion work under dry conditions, research indicates that alkali aggregates have worse resistance to water damage compared to acidic aggregates (Tang et al. 2023). In Peninsular Malaysia, the majority of the aggregates used consist of acidic aggregates, or granite. Nevertheless, it is essential to recognize that, according to the World Bank 2020, Malaysia is one of the top ten wettest countries in the world, with average precipitation of 2,875 mm annually (Rao 2024). Consequently, prioritizing moisture-resistant asphalt materials remains crucial.

As shown in Figure 6, the improved Marshall Immersion Index for APFMA can be attributed to the three-dimensional reinforcement network contributed by aramid and polyolefin fibres. This translates into a stronger adhesion between the aggregates and bitumen, even when fully submerged. In other words, flexible pavements incorporating these synthetic fibres demonstrate enhanced resistance to moisture-induced damage, demonstrating an increased capacity to withstand a larger amount of stress before they fail compared to conventional asphalt mixtures.

Rutting Resistance – Hamburg Wheel Tracking

In contemporary road construction practices, the Hamburg Wheel Tracking (HWT) test has become a standardized method for assessing the rutting resistance and moisture susceptibility of asphalt mixes. The rut depth is usually reported on saturated specimens submerged underwater. However, previous studies have studied the potential of dry HWT to be the alternative test for measuring rutting resistance without confounding moisture effect (Chaturabong et al. 2017).

Figure 7 presents a comparison of the rut depths between APFMA and conventional asphalt mix after 20,000-wheel passes (data from APFMA East Coast region was not available). PWD Malaysia has set a maximum allowable rut depth of 12.5 mm for the HWT test (Jabatan Kerja Raya 2019). The rut depth in the APFMA from all regions was significantly lower after 20,000 passes. Overall, the APFMA exhibited an average rut depth reduction of 29% compared to the control, with the central region showing the best performance at 7.39 mm compared to 10.29 mm for the control mix.

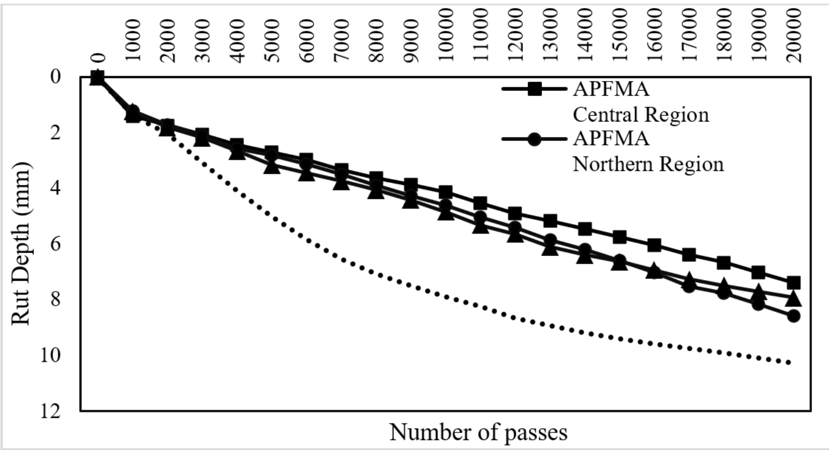

Figure 7: Rut depth in APFMA after 20,000 passes

As the temperature rises, the rut depth will increase as the asphalt binder softens and loses its resistance to rutting. The critical temperature zone for the rut resistance of asphalt mixes typically occurs around 3°C near the softening point of the asphalt binder (Pan et al. 2023). Both mixes utilized penetration grade 60/70 bitumen, which has a softening point ranging from approximately 49°C to 56°C (Santhanasamy et al. 2023). This indicates that, at a test temperature of 50°C, the bitumen had already commenced to soften, resulting in an increase in rut depth. However, the incorporation of aramid and polyolefin fibres mitigated this detrimental effect by enhancing the cohesive energy between asphalt molecules. The findings demonstrated that rutting resistance is significantly improved with APFMA incorporated into the mix compared to conventional asphalt.

Dynamic Creep Modulus

Similar to HWT test, dynamic creep behavior focuses on the continuous time-dependent plastic deformation characteristics of asphalt concrete under repeated loading. Dynamic creep modulus measures the ratio of applied stress to the cumulative axial strain. Figure 8 shows the dynamic creep modulus calculated for APFMA and control mixtures after subjecting the specimens to compressive haversine loading. APFMA exhibited creep modulus values between 17% and 149% higher than the conventional mix, with batching plants in the east coast region demonstrating the most significant improvement.

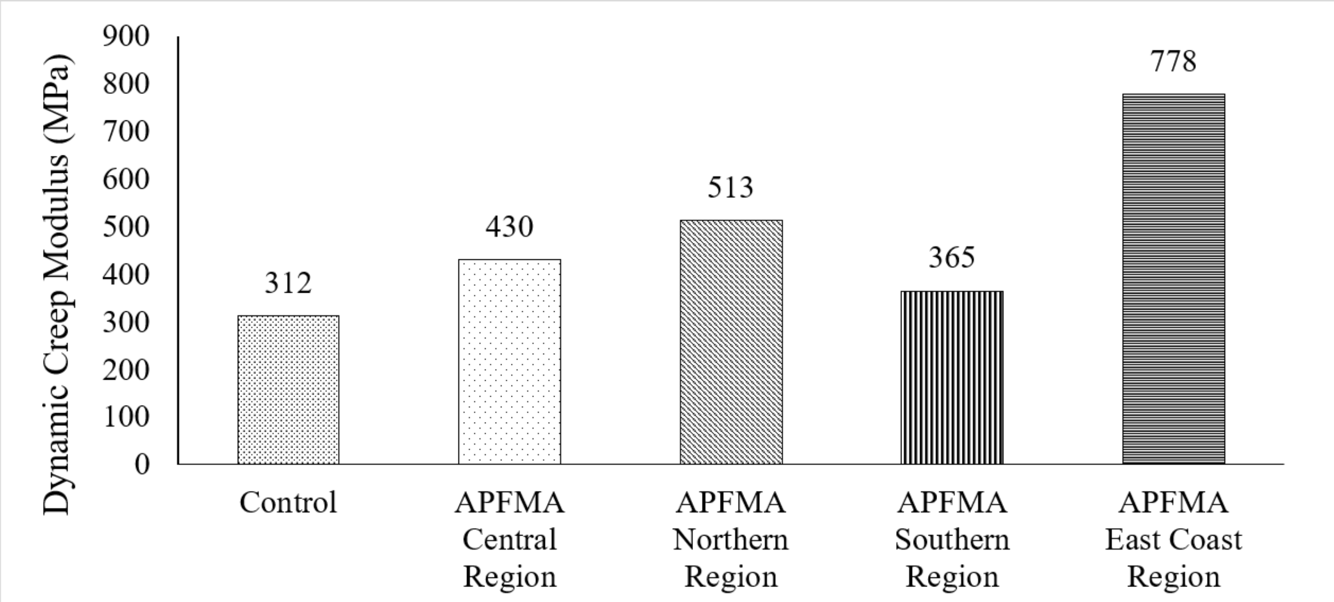

Figure 8: Dynamic creep modulus calculated between 2000th and 3600th load cycles

Research studies have shown that traffic loading significantly impacts the permanent deformation performance of asphalt pavements (Pan et al. 2023). The deformation rate can change from moderate to rapid, depending on the load intensity. Overloaded vehicles can thus significantly jeopardize asphalt pavement stability. Based on statistics by Malaysia's PLUS expressway, heavy vehicles loading can go up to 33 tons per axle, as opposed to the standard 18 tons per axle (Ab Wahab 2024). Furthermore, the recorded 8% to 9% of overloaded heavy vehicles contributed more than 80% of the annual traffic loading calculated in equivalent standard axles. Hence, these findings clearly demonstrate that modified mixes such as APFMA are crucial for rutting resistance, outperforming conventional mixes. Continued reliance on conventional asphalt materials may no longer be sufficient to achieve the current desired design life, particularly in areas subjected to heavy vehicular traffic.

Calculation of TOPSIS

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a highly regarded, applied and adopted multi-criteria decision analysis method with close to 13,000 citations in various fields. It revolves around a simple, underlying concept that the best solution is the one closest to the positive ideal solution and furthest from the negative ideal solution (Chakraborty 2022). In this study, TOPSIS is used to compare the performance test performed on control and APFMA samples from all regions (Table 4 and Table 5).

With regards to the Hamburg Wheel Tracking test, the difference between each reported rut depth and the maximum allowable rut depth of 12.5 mm is used. For instance, since the control mix exhibited a rut depth of 10.29mm after 20,000 wheel-passes, value of 2.21 is employed for the TOPSIS calculation. Additionally, as data for the rut depth of APFMA East Coast region was not available, the average rut depth of APFMA from Northern, Southern and Central region is utilized. Consequently, APFMA East Coast is assigned a Hamburg Wheel Tracking value of 4.53 for the TOPSIS analysis. Every performance test is attributed with equal weight for the evaluation matrix (wj). The following equations are used:

$$n_{ij} = \frac{z_{ij}}{\sqrt{\sum_{j=1}^{m}\left(z_{ij}\right)^2}}, \qquad j = 1, \dots n, i = 1, \dots m \tag{5}$$

$$v_{ij} = w_j * n_{ij} \tag{6}$$

$$A+ = \max(v_{ij}), \qquad A- = \min(v_{ij}) \tag{7}$$

$$d_i^+ = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2}, \qquad d_i^- = \sqrt{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2} \tag{8}$$

$$R_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{9}$$

Based on the TOPSIS analysis considering Marshall Immersion Index, tensile strength ratio, dynamic creep modulus, and Hamburg rut depth, the ensuing ranking of laboratory performance is as follows: APFMA East Coast Region > APFMA Central Region > APFMA Northern Region > APFMA Southern Region > Control mix.

Table 4: Normalized evaluation matrix for control and APFMA mixes

Mix/Performance Test	Marshall Immersion Index, z_i	Tensile Strength Ratio, z_i	Dynamic Creep Modulus, z_i	Hamburg Rut Depth, z_i	Normalized evaluation matrix, n_{ij}			
Control Mix	72.40	75.3	312	2.21	0.373	0.395	0.275	0.185
APFMA Central Region	89.60	82.1	430	5.11	0.461	0.431	0.379	0.552
APFMA Northern Region	91.08	89.4	513	3.92	0.469	0.469	0.453	0.423
APFMA Southern Region	86.71	88.5	365	4.57	0.446	0.464	0.322	0.493
APFMA E. Coast Region	93.00	89.8	778	4.53	0.479	0.471	0.687	0.489
Weighted evaluation matrix, wj	0.25	0.25	0.25	0.25				

Table 5: Laboratory performance test ranking for control and APFMA mixes

Mix	Weighted normalized evaluation matrix, v_i				Euclidean positive separation measure, d_i^+	Euclidean negative separation measure, d_i^-	Overall preference score, R_i	Rank
Control Mix	0.093	0.099	0.069	0.046	0.142	0.000	0.0000	5
APFMA Central Region	0.115	0.108	0.095	0.138	0.078	0.098	0.5588	2
APFMA Northern Region	0.117	0.117	0.113	0.106	0.067	0.080	0.5457	3
APFMA Southern Region	0.112	0.116	0.081	0.123	0.093	0.082	0.4695	4
APFMA E. Coast Region	0.120	0.118	0.172	0.122	0.016	0.132	0.8940	1
Positive ideal solution, A+	0.120	0.118	0.172	0.138				
Negative ideal solution, A-	0.093	0.099	0.069	0.046				

Field Performance

Due to the addition of the fibres, the initial construction cost of APFMA is generally slightly higher than a conventional mix. However, multiple road maintenance projects in Malaysia have demonstrated that it is more economical in the long run owing to its superior performance and durability. Tan example is a field trial conducted in August 2021 for APFMA on FT 029, Section 46.00-48.00, Jalan Puchong-Putrajaya, Sepang District, Selangor, Malaysia. In this trial, a 200 m long section was selected for both the wearing course and binder layer replacement, involving a total milling depth of 110 mm. Specifically, 60 mm of the binder layer was replaced with conventional AC 28, while the 50 mm wearing course was either replaced with conventional asphalt (AC14) or APFMA. Prior to the resurfacing work, severe crocodile cracking and rutting could be observed along the wheelpath, as shown in Figure 9. Falling Weight Deflectometer (FWD) testing was performed on the trial site, and the deflections obtained showed that there was no structural issues with the lower unbound layers.

Figure 9: Site conditions prior to resurfacing work (August 2021)

In December 2021, a tropical depression unleashed unprecedented volumes of rainfall onto the west coast of Peninsular Malaysia. The rainfall persisted for four days, equivalent to a month's worth of precipitation in the region (Rahman 2022). During this event, the site was submerged in water for 1-2 days. In March 2024, a visual inspection of both sections was performed, marking two years and seven months since the installation date, as shown in Figure 10 and Figure 11. As anticipated, the control section exhibited multiple block cracking along the wheelpath, affecting approximately 50% of the 200 m length. In contrast, the APFMA section exhibited virtually no defects.

The incorporation of aramid and polyolefin fibres in the asphalt mix has proven to be ideal in terms of increasing the pavement's susceptibility to moisture damage and rutting. For this specific site, the HWT test yielded a rut depth of 8.37 mm, the Tensile Strength Ratio (TSR) was 97.20% and the dynamic creep modulus in the APFMA was 244 MPa. These results underscore APFMA's superiority not only in controlled laboratory settings but also in real-world conditions.

Figure 10: Block cracking in control mix (March 2024)

Figure 11: No visible defects on APFMA test section (March 2024)

Life Cycle Cost Analysis

Figure 12 illustrates the life cycle cost analysis over a 5-year period, spanning from 2021 to 2026. The site in question is a protocol road characterized by heavy vehicle traffic, necessitating recurrent maintenance work. Based on previous work history, a conventional asphalt mix would require an additional 110 mm milling work followed by replacement with conventional AC14 and AC28 asphalt every two years. In contrast, resurfacing using APFMA is projected to require zero maintenance during the life cycle cost analysis period. This conclusion is supported by the material's exceptional resistance to moisture-induced damage and rutting. Specifically, only the cost of the 110 mm milling work, the supply and installation of the asphalt materials, and the application of prime/tack coat was considered. Commercially, adopting the use of APFMA would yield a substantial (61%) cost saving for the PWD compared to conventional asphalt.

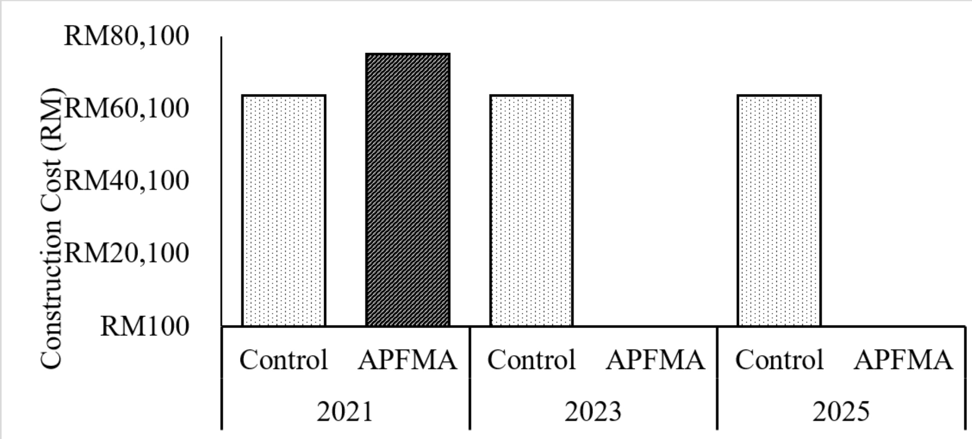

Figure 12: Life cycle cost analysis – 2021-2026

Conclusions

The superior laboratory test results, field performance and cost analysis demonstrated that APFMA presents a more cost-effective maintenance alternative, not only for government agencies, but also for any road application in Malaysia, including highways. The APFMA mix can be easily integrated into existing road construction operations due to its similar construction process to conventional asphalt. This eliminates the need for contractors to adapt to new technologies typically required for specialty mixes. By incorporating aramid and polyolefin fibres, APFMA significantly enhances the durability and pavement life of asphalt, ultimately leading to a more resilient road infrastructure.

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Enhancing the Management of Federal Road Maintenance in Peninsular Malaysia through Performance-based Contract: Evaluation at the Halfway Mark

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Introduction

Background of Federal Roads Maintenance

The Federal Road network in Malaysia is a vast network of roads approximately 18,117 km in length, It plays a crucial role in providing accessibility to a wide variety of commercial, economic and social activities (JKR 2021). It is under the purview of Ministry of Works (KKR) as the asset owner and Jabatan Kerja Raya (JKR) as the asset manager. Federal Roads in Malaysia can be categorized into main federal roads, secondary roads, industrial roads, federal institution roads, FELDA federal roads, federal territory road and tollways. These roads are vital to the country, as they form a network connecting districts and states all over the country. They provide transportation connectivity and reduce the distance between people, ser-vices, markets and knowledge (i.e. universities and, colleges). A good and well-maintained network of roads is often seen as a positive indicator on the economic development of a country.

Before 2000, the Malaysian Federal Roads were maintained by the JKR using annual funding provided by the Federal Government. Following the signing of the Privatization Agreement for Federal Roads in 2000, a maintenance concession of Federal Roads was granted to the relevant concession companies to undertake Federal roads maintenance (FRM) and all other activities incidental to the performance of the works. Cur-rently, and under the Privatization Agreement in relation to the maintenance of Federal Roads in Peninsular Malaysia, the Government has granted Concessions to four companies: Belati Wangsa Sdn. Bhd (Perak), THB Maintenance Sdn. Bhd. (Perlis, Kedah & Penang), Roadcare Sdn. Bhd. (Selangor, Pahang, Kelantan and Terengganu) and Selia Selenggara Selatan Sdn. Bhd. (N.Sembilan, Melaka & Johor). The concession companies were granted the rights to undertake routine maintenance work, periodic maintenance work, emergency work and other activities incidental to the performance of works until the expiry of the conces-sion period on 16 February 2026 (JKR 2018).

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Current Maintenance Practice

Currently, the maintenance of the Federal Roads is generally output-based with the works undertaken based on specified cycles, controlled quantities, and methodology with a corresponding Schedule of Rates (SOR). The expected output standards are specified, together with activities on specified cycles; they are limited to routine maintenance work only. Meanwhile, the periodic repair and rehabilitation works would only be undertaken based on available and approved funding provided by the Ministry of Finance. Emergency works are conducted according to approved activities together with the SOR, with the works implemented under Notification of Emergency (NOE (KOAV-JKR 2015).

Due to the lack of funding, the current practice of road asset maintenance for the Federal Roads in Malay-sia is based on reactive maintenance. This method of maintenance has many disadvantages, including no specific LoS or asset maintenance management plan, reduced life expectancy of assets, and uneconomical and unpredictable long-term costs. The condition of the pavement deteriorates over time due the lack of intervention treatments, the increasing number of traffic loadings, and environmental effects. The delay in repair and rehabilitation processes will eventually increase the agencies' financial commitments in the longer run.

Current maintenance contracts also lack a database system to store key data, such asset condition data, and database management, deterioration modelling and scenario analysis, works planning and management to enable the agency to have a detailed understanding of the life cycle of the relevant assets. The failure to provide consistent LoS to the road users will compromise safety and riding comfort. These factors contribute directly to the rising number of complaints from road users and other stakeholders. On the other hand, damaged vehicles, injuries and fatalities due to the condition of the roads contrib-ute significant losses socially and economically to the country (KOAV-JKR, 2015).

The current level of Federal road maintenance funding is insufficient to address the increasing demands from the public while at the same time keeping the costs of road maintenance affordable and providing val-ue for money. The adaptation of methodologies incorporating best international practices from current ac-tivity-based contracts to outcome-based contracts will assure the appropriate preservation of the asset . There is also a pressing need to justify and secure multi-year financing throughout the contract period (KOAV-JKR 2015).

Performance-based contracts (PBC) which priorities outcomes are relatively a new concept in Malaysia. They are designed to increase the efficiency and effectiveness of road maintenance management. They aim to ensure that the physical condition of the roads under contract is adequate for the needs of road us-ers over the period of the contract. The pilot PBC for the maintenance of Federal roads was signed in June 2022. It includes FT001 (Jalan Johor Bahru-Senai-Gemas–Seremban–Kuala Lumpur), FT003 (Jalan Johor Bahru–Endau) and FT005 (Jalan Johor Bahru–Pontian–Batu Pahat–Muar–Melaka–Masjid Tanah–Lubok Cina–Port Dickson-Sepang) in the Southern zone involving Negeri Sembilan, Melaka and Johor (JKR 2022). The length of the roads involved in the study was approximately 748 km (JKR 2022).

Methodology

With the implementation of the pilot project of PBC for Federal Roads Maintenance Contract (Southern Zone) this paper aims to show the halfway results of.

a. achievement of the set performance criteria, e.g. roughness

b. customer satisfaction index

c. management of public complaints.

In determining the functional condition assessment to measure International Roughness Index (IRI) the data was collected using a network survey vehicle. The data was processed and analyzed using the Hawkeye processing toolkit and was reported in Sistem Pengurusan Aset Jalan (SPAJA). The SPAJA report for roughness will be presented in this paper. In terms of the method set by JKR Malaysia regarding the Customer Satisfaction Index for Federal Roads Maintenance, a questionnaire was used to record the responses from 850 respondents using these Federal routes in 17 districts. As for the public complaints management, the data from Sistem Pengurusan Aduan Awam (SISPAA) JKR was collected and analyzed to compare the number of complaints recorded prior to, and after, the implementation of PBC.

Results and Discussion

Roughness – International Roughness Index (IRI)

A Pavement Condition Assessment (PCA) by the concession company was carried out in 2020 to determine the current functional and structural condition along the mainline FT001, FT003 and FT005 and to generate the Planned Periodic Maintenance Work (PPMW) based on HDM-4 analysis. The findings from PCA 2020 were used to establish the Network Health Service Level and establish a performance curve modelling measured by using the IRI as a main performance indicator for network health throughout the contract period. Based on the PCA 2020 data, HDM-4 analysis with constrained budget was conducted. A planned periodic maintenance works as shown in Table 1 was generated for four years duration, starting from 2022 to year 2025 (JKR 2022). Other factors such as geotechnical issues, soft ground and bridges and culverts approaches were also considered. The baseline data for average roughness for the whole network based on PCA 2020 was 3.50 IRI. A total of six treatment types (regulation 50 mm, regulation 100 mm, mill and pave 50 mm, mill and pave 110 mm, mill and pave 200 mm and reconstruction were agreed to be used as rehabilitation method of the Planned Periodic Maintenance Works.

Table 1: Summary of PPMW at FT001, FT003 and FT005

Treatment Year	Total treatment of Periodic Maintenance Work (Quantity – lane.km)						
	REG 50 mm	REG 100 mm	MP50	MP110	MP200	RECON	Total
2022	179.30	16.00	158.10	15.00	12.80	14.20	395.40
2023	96.20	8.00	185.90	56.40	15.90	104.50	466.90
2024	146.50	16.00	192.40	50.70	13.10	61.50	480.20
2025	90.00	8.00	190.40	55.90	23.10	100.30	467.70
Total (km)	512.00	48.00	726.80	178.00	64.90	280.50	1810.20

According to the PBC agreement, the average roughness of the paved surface of the network is deemed as an important Performance Measure and the concession company must ensure that the roughness of the paved surfaces constructed under the agreement conforms to targeted criteria as specified in Table 2 at the end of each concession year. Pavement condition assessment (PCA) was carried out by the concession company at the end of each concession year and the results are also shown in Table 2.

Table 2: Overall Average Roughness Performance Measures

Average (50th Percentile) Roughness (using 100 lane.m data): Conformance threshold values				
Contract category	Year			
	2022	2023	2024	2025
Targeted overall pavements – primary and protocol	3.44 IRI	3.37 IRI	3.31 IRI	3.20 IRI
Results of overall – primary and protocol	3.39 IRI	3.25 IRI	NA	NA

* NA – Not available.

The results of the PCA carried out by the concession company in year 2020 (baseline) and at the end of concession year 2022 and 2023 against the targeted value is shown in Figure 1.

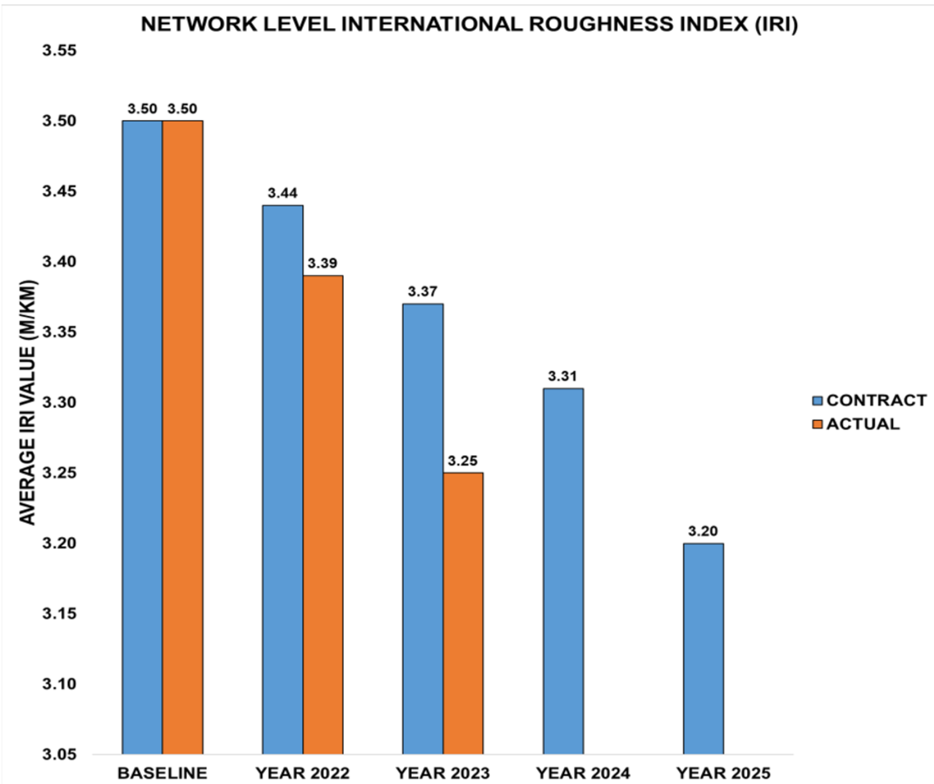

Figure 1: Overall average roughness

From Figure 1, the baseline data for average roughness for the whole network based on PCA 2020 was 3.50 IRI. After the completion of the PPMW in the year 2022 and 2023, the results of the overall average roughness performance measures for the network health in year 2022 are 3.39 IRI against the targeted 3.44 IRI. Meanwhile, for the year 2023, it can be observed that the average roughness recorded is 3.25 IRI against the targeted 3.37 IRI (SPAJA 2024). This is because various rehabilitation works that were carried out in 2022 and 2023 contributed directly to reducing the average roughness (IRI) and increasing the riding comfort along FT001, FT003 & FT005 in the Southern zone.

Customer Satisfaction Index (CSI)

The JKR CSI survey is the primary measurement method used by JKR to assess the Federal Road Maintenance effectiveness. The questionnaire that was used in this research is a controlled document that is a part of Prosedur Komunikasi, Aduan Dan Kepuasan Pelanggan, Sistem Pengurusan Bersepadu JKR. According to JKR procedure the CSI survey will be done twice a year, and the questionnaire is sent to JKR Districts engineers through an official letter with the survey implementation timeline. The preset respond-ents must be a minimum for 50 people for each of the Federal Roads surveyed and for this research data from the survey was conducted by JKR District personals on selected locations along FT001, FT003 & FT005 involving 17 districts was used. The JKR districts personnel acted as researchers in doing the sur-vey by distributing the questionnaire to the random road users while explaining the content of the question-naire. The actual sample size is estimated to be 850 respondents. The findings from the JKR CSI survey done along FT001, FT003 and FT005 for the year 2021,2022 and 2023 are shown in Figure 2.

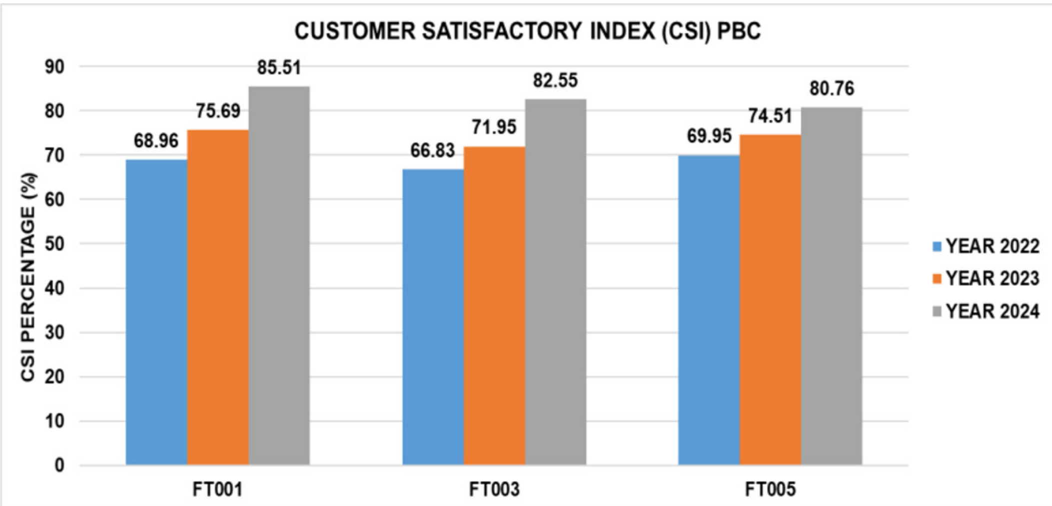

Figure 2: Customer satisfaction index by routes and years

From Figure 2, the average calculated CSI for FT001 was 68.96% in 2022. In the year 2023 the average CSI gradually improved to 75.69% and for the CSI done in the first half of the year 2024 it increased to 85.51%. For FT003 it recorded 66.83% in 2022. In the year 2023 the average CSI gradually improved to 71.95% and for the CSI done in the first half of the year 2024 it increased to 82.55%. For FT005 it recorded 69.95% in 2022. In the year 2022 the average CSI gradually improved to 74.51% and for the CSI done in the first half of the year 2024 it has increased to 80.76%. The increase of CSI in the year 2023 & first half of 2024 can be due to the fact the road conditions have improved significantly compared to the state they were in year 2022 because of the pavement rehabilitations and PBC routine maintenance works that were carried out in the year 2022 and 2023.

Management of Public Complaints

JKR Malaysia to date has 12 official channels to receive public complaints regarding the delivery of services by the department. Sistem Pengurusan Aduan Awam (SISPAA) is a public complaints management system that was developed by Public Complaints Biro under the Prime Ministers Department and is the primary public complaints management system used by JKR which has been officially in place since 1 May 2021. The system is compulsory to be used by the JKR Headquarters, branches, state JKR and JKR dis-tricts. Any public complaints regarding JKR or assets maintained by the department and being in this case the Federal Roads are received through the official complaints will be automatically and manually regis-tered in the SISPAA JKR. All these complaints will be systematically managed through the SISPAA JKR portal. The management of these public complaints data through SISPAA JKR enables the department to manage the complaints effectively, especially by delivering agreed performance standards. For this research the data from Sistem Pengurusan Aduan Awam (SISPAA) JKR was collected and analyzed to compare the number of complaints recorded prior and after the implementation of PBC and the results are shown in Figure 3.

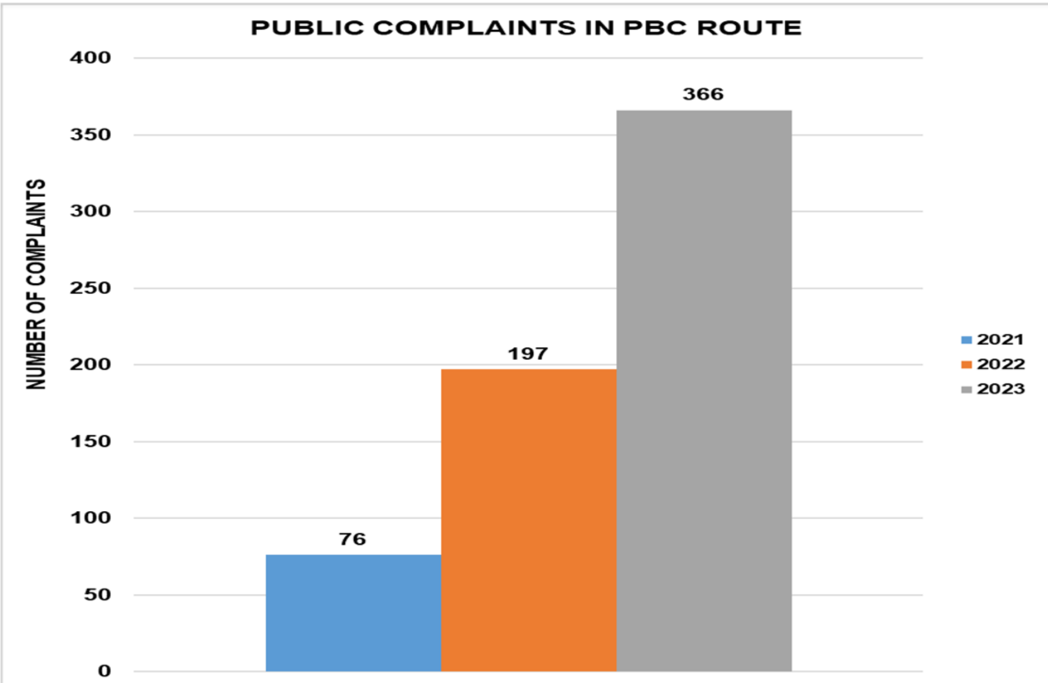

Figure 3: Public complaints along PBC routes

From Figure 3, the total number of complaints recorded involving the PBC routes was 639. In the year 2021, 76 complaints were recorded, in the year 2022 it jumped to 197 and in the year 2023 it increased to 366. From the data that was collected and analyzed to compare the number of complaints recorded prior and after the implementation of PBC and the results have surprisingly shown that the number of complaints has increased after the implementation of PBC. The complaints data was further analyzed and has been tabulated according to the PBC scope of works as shown in Table 3.

Table 3: Complaints on PBC routes according to works category

Works category	Year			Total
	2021	2022	2023	
Routine maintenance works (RMW)	25	62	131	218
Planned periodic maintenance works (PPMW)	41	75	106	222
Emergency works	0	5	1	6
Additional works (any other work other than RMW or PPMW as approved by the government)	2	8	22	32
Non-PBC scope	8	47	106	161
Total	76	197	366	639

Based on the data in Table 3, it can be said that most of the complaints recorded are within the PBC scope. These complaints will be also recorded in the Performance Based Contract Management System and the contractor will need to take action to resolve it within the stipulated time as per the contract, failing that it will be recorded as nonconformance. As for the non-PBC related complaints, it will be channeled to the relevant agencies/authorities for further action.

The increase in the number of complaints recorded can be due to three main reasons, one being the per-formance of the maintenance contractor in terms of maintenance planning and prioritizing repair works, response time for maintenance activities involved and delayed on the approval of additional works to due budget restraints. The other factor can be due to the successful campaign and promotion by Kementerian Kerja Raya regarding complaints medium such as the MyJalan KKR and Responds Rakyat smart phone application to provide better people-oriented services which has provided easier methods at their fingertips for the public to convey their complaints.

Conclusions

The results obtained lead to the following conclusions:

1. Periodic maintenance works with is an important scope of the PBC agreement has been successful in reducing the average roughness (IRI) for the network health and increasing the riding comfort along FT001, FT003 & FT005 in the Southern Zone.
2. The JKR Customer Satisfaction Index survey done along FT001, FT003 & FT005 for 2023 and the first half of 2024 has shown significant improvement compared to 2022. It can be concluded that this is be-cause of the pavement rehabilitations and PBC routine maintenance works that have improved the road asset conditions.
3. Most of the complaints recorded in 2022 and 2023 involved the RMW and PPMW scope and it can be resolved with better planning and prioritization of the repair work by the appointed contractor.

Based on the findings to date, the pilot project PBC Agreement has managed to enhance the management and increase the level of service along FT001, FT003 & FT005 at the halfway point.

It is suggested that the PBC can be further expanded to other main trunk roads from south to north and west to east of Peninsular Malaysia and the Pan Borneo Highway in Sarawak to further enhance the management of Federal Roads.

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