Design, Maintenance and Sustainability of Container Terminal Pavements

(PIANC WG243)

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ABSTRACT

PIANC Working Group Report No.165-2015, Design and Maintenance of Container Terminal Pavements, is being updated to include consideration of the sustainability of Container Terminal Pavements. The work is being carried out by a team of international consultants forming Working Group 243 (WG243). The members comprise professionals from port authorities, terminal operators, consultants, contractors, and material suppliers with experience with port pavements. The report is scheduled for publication in 2025. It will provide information to the specifiers and designers of port terminal pavements to help reduce the quantity of new materials from natural resources used in a pavement, and the environmental factors in producing and transporting them to the project site. This paper discusses the various topics considered for addition to the original report. These include the use of sustainable and innovative materials and their carbon levels, and the effects of automation and alternative power for handling equipment on pavement requirements.

INTRODUCTION

In 2015 PIANC published Report No.165 - Design and Maintenance of Container Terminal Pavements. This publication highlights the critical aspects of port pavements compared to highway and airport pavements. Container handling equipment imposes very high wheel loads on port pavements where cornering, braking and other dynamic effects can increase the damaging effect on each vehicle pass. Corner castings on containers and sand pads or dolly wheel on chassis legs can apply very high point loads and surface stresses to the pavement and are not considered in highway or airport pavement design.

The publication also considers total and differential settlement that often affects marginal ground conditions encountered in port terminals owing to the significant load increase from fill materials placement and operational loading. These can affect drainage and equipment operations. The report discusses the expectations of terminal owners and operators to be able to continue profitable work.

Design methods and material properties are covered along with fatigue properties and failure mechanisms. Container terminal pavements comprise a major element in the capital cost of a container terminal and as such, their design needs to consider the construction cost and the cost of likely maintenance and the disruption that will result. The report provides information for the port pavement professionals to help minimize pavement failures and to adopt appropriate maintenance programs to achieve design expectations for the life of the pavement.

In 2022/2023, PIANC commenced work on an update to the report under the title of WG243 Design, Maintenance and Sustainability of Container Terminal Pavements to consider the sustainability of container terminal pavements. This will consider the availability of existing and innovative materials with reduced generation of carbon dioxide during manufacture and construction. The potential for recycling of materials will be explored to reduce the consumption of natural resources. It will also consider environmental factors and end of life impacts affecting the project vicinity.

The publication is expected to be completed later in 2025 and work is ongoing by a group of volunteers with expertise in each subject. It has been split into groups with an anticipated structure of thirteen sections as set out below:

- Chapter 1. Review of WG165
- Chapter 2. Consideration of sustainability at pavement design stage
- Chapter 3. Data on material and construction carbon levels
- Chapter 4. Innovative materials
- Chapter 5. Maintenance and extending pavement life without the need for full reconstruction
- Chapter 6. Sustainable drainage
- Chapter 7. Automated terminals
- Chapter 8. Sustainability from the employers' perspective
- Chapter 9. Pavement analysis/design optimization
- Chapter 10. Container Handling Equipment (considering its carbon and other environmental challenges)
- Chapter 11. Special issues for developing countries
- Chapter 12. Energy stored within pavements to recharge electric container handling equipment
- Chapter 13. Survey of port owners/operators

CHAPTER SUMMARY

At the time of writing, some sections of the report are only at the outline stage. The following sections summarize those chapters that are at final draft or complete stage.

Chapter 2, Consideration of Sustainability at Pavement Design Stage. BS EN 15978:2011 Sustainability of Construction Works considers Embodied Carbon to be categorized in four stages. These are (i) product stage, (ii) construction process stage, (iii) use stage and, (iv) end-of-life stage, which are further divided as shown in Figure 1:

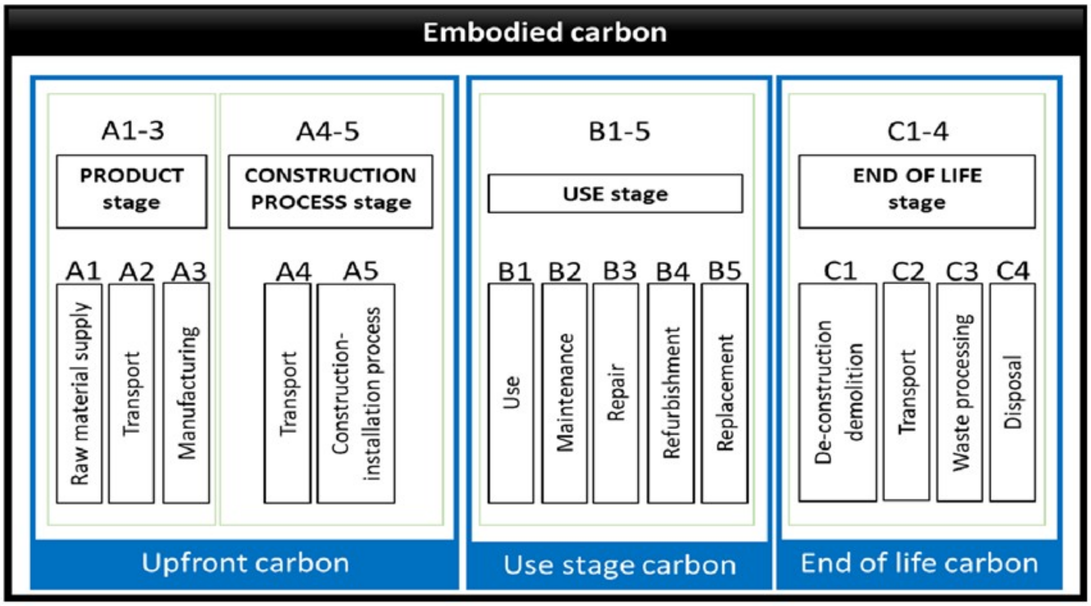

Figure 1. Embodied Carbon Stages

Once preliminary pavement sections have been developed based upon standard material properties, the sections can be interrogated for sustainability. For example, is there a ready supply of cement for concrete pavements that has supplementary cementitious materials that will be cost effective and more sustainable. A further example would be, can a recycled aggregate material be used in place of virgin aggregates without detriment to the performance of the related pavement layer.

Further consideration can be given to the end of life conditions. What will be the general condition of the pavement at the end of the design life? Will full depth demolition be required, or will alternative treatments enable a new surface to be used to extend the life while maintaining material lower in the pavement? How much of the demolition material can be recycled and how much will be wasted?

Chapter 3, Data on Material and Construction Carbon Levels. This section of the report provides typical data on embodied carbon values for material and construction. Accurate carbon assessment requires two key principles, as follows:

- It is preferable to calculate embodied carbon from the actual mix design rather than use a database. This is clearly not possible at early project stages and therefore databases have a role in carbon assessment.

- The cradle-to-site carbon should be assessed rather than the cradle-to-gate values given by databases. Otherwise, impacts from transport to site and placement are not allowed for.

Table 1gives typical embodied carbon values for pavement materials traditionally used on container terminals:

Table 1 - Typical Embodied Carbon Values

Material	**Description**	**Embodied Carbon ($kg/CO_2e/t$ unless stated)**
Asphalt -straight run bitumen	4% binder content	52
	5% binder content	54
	6% binder content	56
	7% binder content	58
Block pavers	Concrete pavers	132 kg/CO_2e/unit
C32/40 concrete	Portland cement only	149
	14% limestone	129
	30% fly ash	125
	25% slag	120
	50% slag	89
C8/10 CBGM	Portland cement only	97
C16/20 CBGM	Portland cement only	113
	14% limestone	97
	30% fly ash	92
	25% slag	87
	50% slag	62
Unbound crushed aggregates	-	5.2
Stabilized soil	2% lime + 6% cement	84

Note: CO_2e is Carbon Dioxide Equivalent (a unit of measurement that is used to standardize the climate effects of various greenhouse gases)

Chapter 4, Innovative Materials. Innovation is an ongoing process and materials that were once considered innovative have developed into well established pavement materials. For instance, geogrids, stone matrix asphalt, steel fiber reinforcement and roller compacted concrete are relatively new to the port pavement marketplace, but have been used in other paving work for several decades. Asphalt related paving materials that have yet to enter the port pavement environment include warm mix asphalt and synthetic fibers, reclaimed asphalt and waste materials such as roofing shingles and tire rubber. Concrete related paving materials include supplementary cementitious materials, reclaimed concrete and waste product aggregates, and chemical admixtures. There are also bio-based and synthetic binders for stabilizing soils and aggregates. This section of the report discusses some of these materials and provides details of their current development and use in paving.

Chapter 5, Maintenance and Extending Pavement Life Without the Need for Full Reconstruction. At the time of this paper, this chapter had not been written.

Chapter 6, Sustainable Drainage. Three aspects of sustainable drainage are considered in the report. These are environmental changes that will result in increased rainfall events, permeable pavement materials under equipment wheels and gravel bed systems under container stacks.

Recent rainfall events have broken records in some areas, exceeding 1:50 and 1:100 year storms that are typical design events. Climate models are indicating that rising temperatures will intensify the earth's water cycle increasing evaporation in some areas resulting in increased frequency and intensity of storms in other areas. Port pavements typically have shallow falls (generally less than 2%) and are subject to ponding and flooding, and runoff generally picks up contaminants from the pavement surface. Attenuation systems are generally included in designs to trap these contaminants before water is discharged into the sea. It is important that future design/construction includes for the increased volumes and water flows.

Permeable pavements of unit pavers, concrete areas slabs and asphalt have been used successfully in streets, parking and pedestrian areas, but only in a limited number of experimental applications. These include test areas of permeable concrete pavers at the Port of New York and New Jersey in the US, and at Port Santos in Brazil.

The Port of New York and New Jersey project (Figure 2) included a 1,000 m^2 area of 80 mm concrete pavers on 25 mm of sand bedding, 125 mm of permeable plant mix macadam on 75 mm of impermeable asphalt, 450 mm aggregate base on the 150 mm subgrade reinforcement. The design provided for vertical flow of water through the aggregate filled openings and joints of the permeable interlocking pavers and through the drainable layers of bedding and plant mix macadam. Horizontal flow along the impermeable asphalt surface transmits the water to a piped collection system at the perimeter. The pipes connect to the storm water drainage system and include access points for any future sampling or flow monitoring.

Figure 2. Port of New York and New Jersey Pavers

The Port Santos project (Figure 3) comprised 132,000 m^2 of 8 cm thick pavers on 5 cm of sand bedding and 50 cm of cement stabilized no fines gravel over 1.5 m of sand fill. The pavers had integral 6 mm proud spacers providing an estimated 1 mm/sec permeability. The system reduces runoff to drainage inlets and quickly clears surface ponding.

Figure 3. Port Santos Pavers

Chapter 7, Automated Terminals. Automated terminals achieve many sustainability benefits including safety and health of workers, reduced equipment emissions, denser stacking arrangements with less land use, and increased efficiency and security. However, they have very different pavement requirements compared to manually operated equipment terminals. Some container handling equipment such as Automated Stacking Cranes (ASCs) operate on rails, such that the pavement area is reduced. These can also reduce the pavement requirements under the container stacks, which can be wider and higher. Automated straddle carriers can work over flexible container row positions such that the number of repetitions over each point in the pavement is reduced, resulting in thinner pavement sections. Other equipment operating in these terminals includes automated guided vehicles (AGVs) used for transporting containers rather than stacking them.

The automated equipment must remain in contact with the Terminal Operating System (TOS) and other management and safety systems. This can be achieved by GPS tracking, over the air transmissions, in-pavement transponders and other proprietary systems. The former two allow the equipment to follow any designated path around the terminal, whereas transponders can cause channelizing of wheel paths and localized dead spots if a transponder is damaged or moved. Safety systems can shut down sections or all the terminal if unauthorized foot or vehicular traffic enters the working area which is typically fenced off.

ASCs typically operate on rails mounted to a structural beam that is ground or pile supported depending on ground conditions. With some situations, the rail is supported on rail ties. Container stacks in such facilities are supported at each end of the containers using structural beams or on occasion, concrete pads with gravel between. At either end of each ASC block there is a transfer area that can be paved with concrete or asphalt, although the former is more common. Waterside pavements can be designed for 4-, 6-, or 8-wheeled AGVs and automated straddle carriers, or for manually operated equipment. Landside paving is generally for highway tractor-trailer systems.

Automated straddle carriers operate on pavement. There will be areas of the terminal such as roadways where the straddle carriers may be highly channelized. This can result in rutting in flexible pavements. Channelization can also happen in the stacking rows, but some systems include row and route relocation to even out wear by offsetting wheel paths at regular intervals. This is not possible where transponders are used, and rigid pavements are more appropriate in these applications.

When ASCs are introduced into an existing terminal, it may be possible to repurpose a significant area of the exiting pavement if it is in an acceptable condition. Detailed condition inspection and testing of the existing pavement should be carried out when this option is considered

Chapter 8, Sustainability from the Employers' Perspective. From the terminal operators' perspective, a sustainable pavement is one that will remain serviceable throughout its design life with minimal maintenance such that the impacts on terminal operations are negligible. At present and in the near term, there is a significant push to decarbonize terminal operations. Carbon data from daily operations are monitored and tracked for annual reporting, but this is not the case for construction and maintenance materials and work over the pavement's design life.

Terminal operators prefer tried and tested materials and construction methods when planning a paving project rather than adopting untried materials that claim improved sustainability. As such, providing the operator with performance information on alternative materials and methods in a similar situation will be an important part of the development of more sustainable port pavements.

This section of the guide discusses considerations of the operator for three issues as follows for achieving a sustainable pavement using materials and methods familiar to the operator:

- How design will meet the objective.
- How construction will eliminate risk
- Maintenance expectations for the pavement

Pavement Design. Pavement must be designed for the equipment expected to use it, the expected operational modes including required flexibility, and the projected site conditions. Appropriate design methods must be adopted, such as those discussed in the PIANC Report 165. The operator should provide all available information on proposed operations and potential future developments, particularly if automation is envisaged at some future date. The pavement designer should produce a full design report, which should be reviewed alongside the construction documents by the operator's in-house expertise or suitably qualified peer review consultants to ensure that the design intent meets the operator's requirements.

Pavement Construction. The pavement must be constructed to meet or exceed the design intent to achieve the operator's requirements. A robust QA/QC program should be used to identify and correct deficiencies before the pavement is placed into service. This can be achieved with experienced on-site personnel and testing facilities. The scope should not be limited to the pavement layers, but should also include proper preparation of the subgrade under the pavement and the quality of fill and backfill work. In addition to the QA/QC program, a clear warranty document is required to ensure that any defects are addressed in an appropriate manner to minimize disruption to ongoing terminal operations.

Pavement Maintenance. PIANC's Declaration on Climate Change recommends employers "Prioritize inspection and maintenance to optimize the resilience of existing infrastructure". All pavements require some level of pavement maintenance and repair if they are to remain serviceable through their design life. Maintenance starts with regular inspection of the pavement to monitor wear and tear or identify problems. There are formal pavement management systems (PMS) that can aid in pavement maintenance by establishing a data base of pavement inspections and condition assessments to monitor changes over time. The PMS should include the designer's pavement performance model to forecast future performance with and without the various maintenance items. A good understanding of distress development is necessary to plan maintenance work to prevent localized failures that could restrict terminal operations.

Chapter 9, Pavement Analysis/Design Optimization. At the time of this paper, this chapter had not been written.

Chapter 10, Container Handling Equipment (Considering Its Carbon and Other Environmental Challenges). At the time of this paper, this chapter had not been written.

Chapter 11, Special Issues for Developing Countries. Port paving projects in developing countries and in some island communities are often restricted in access to locally available high quality materials and construction equipment and experience, and have to import these or resort to lower quality materials and available equipment. In some cases, operational equipment may be older without the latest technology such that wheel loads and dynamic effects are greater, potentially causing premature failure, necessitating repairs to be made with locally available materials and equipment.

Sustainable pavements can be achieved in these locations by adopting careful sequencing of pavement layers using materials that will be durable under the stresses imposed within each layer, increasing in strength the closer to the surface that they are. Low quality materials can be stabilized with various binders to improve their properties. Surface layers can be constructed by importing durable materials such as concrete pavers that can be hand laid rather than setting up an asphalt or concrete plant and bringing in large construction equipment. Maintenance work can therefore use the same materials that are locally available.

Chapter 12, Energy Stored Within Pavements to Recharge Electric Container Handling Equipment. Container handling equipment is typically powered by diesel engines when free running and by bus bar or cable reel electricity when rail mounted. However, diesel emissions are under pressure for reduction. Battery pack electrical power is gaining a foothold in a few terminals for their free running equipment such as tractor units, forklifts, AGVs, etc. This can lead to problems with availability of equipment if a battery is nearly depleted and requires recharging, which is a much longer process than refueling equipment with diesel. Some AGV systems include special facilities for charging batteries outside of the equipment after it has been swapped out with a fully charged battery.

This section discusses some potential options for recharging batteries while the equipment is operating. These approaches are being introduced in limited scale for highway vehicles or in some cases are still on the drawing board. Others are more suited to automated areas where there is no foot traffic or onboard operators. In all cases, these systems will require increased stationary time for the equipment.

Induction is one potential system where equipment will stop in designated areas with induction cables buried in the pavement like placing a cell phone on an induction charger. The cables would only be live when equipment is correctly located. There are still concerns about efficiency due to AC-DC conversions. A further option would be connecting directly to shore power outlets where accurate docking will be required, or a busbar type connection could be made. Other options may include elements of solar cells and regenerative charging.

Chapter 13, Survey of Port Owners/Operators. At the time of this paper, this chapter had not been written.

CONCLUSION

PIANC Working Group 243 (WG243) are preparing Report 243 titled Design, Maintenance and Sustainability of Container Terminal Pavements. When completed, the report will address design approaches, construction materials and other considerations to achieve more sustainable pavement construction and operations thereon for heavy duty pavements. The report is scheduled for publication in 2025. The working group members comprise professionals from port authorities, terminal operators, consultants, contractors, and material suppliers with experience with port pavements.

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