PAVE 92

WEBB DOCK CONTAINER TERMINAL PAVEMENTS TEN YEARS ON

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SUMMARY

Various parts of the Webb Dock Container Terminal have been paved with heavy duty flexible crushed rock pavements, incorporating interlocking concrete segmental pavers for the surfacing. Webb Dock No. 5 Terminal, comprising 6 hectares of container stack area, was constructed in 1981, and the Webb Dock Rail Terminal, of a further 2 hectares, was completed in 1985. The performance of the pavements has been entirely satisfactory, despite loads on the pavements substantially exceeding the design loads over the life of the pavements. This paper reviews the design, construction and performance of these pavements up to ten years after being put into service.

1. INTRODUCTION

As part of the continuing expansion of the Port of Melbourne in the '70's and '80's, the Australian National Line (ANL) opened Webb Dock No. 5 Container Terminal in 1982 (Figure 1). This terminal comprises 6 hectares of heavy duty pavement for 3-high container stacking, and one hectare of equipment park, all surfaced with concrete segmental pavers. When constructed, this was the largest concrete segmental pavement in Australia. The terminal serves Berth No. 5, a wharf deck 350m in length fronting on to the terminal, within the Webb Dock complex. This complex comprises a total of about 22 hectares of open storage and transit sheds, four operating berths and three berth-mounted container cranes. All container movements within the No. 5 terminal are carried out with a combined truck/trailer and forklift operation.

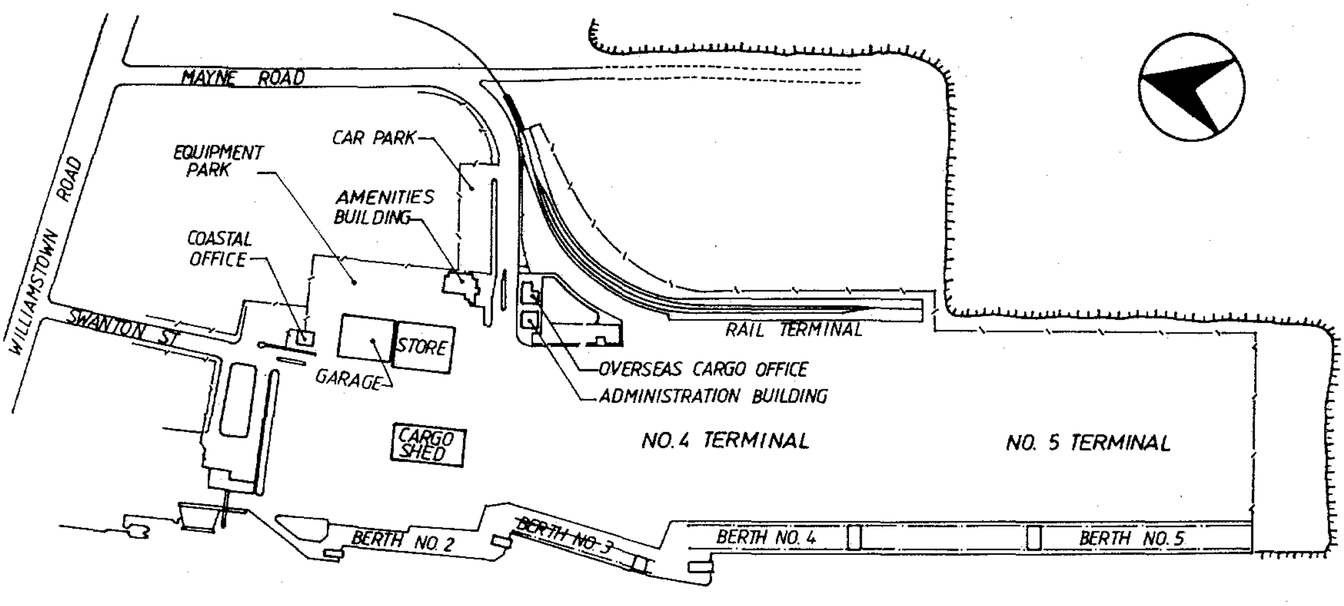

Figure 1 Webb Deck Container Terminal Layout

In 1985 a further 2 hectares of rail terminal area adjacent to Terminal No. 4 were completed. This area was paved in a combination of rigid concrete slab for the rail tracks and concrete segmental paver flexible pavement for container stacking. This arrangement provides a fully traffickable area for efficient movement of containers to and from block trains, using rubber tyred gantries across the trains and forklifts for container stacking.

This paper discusses the design, construction and subsequent performance over the past ten years of these pavements. The Webb Dock Container Terminal is currently operated by National Terminals (Australia) Limited (NTAL), a company jointly owned by ANL and Patricks. NTAL have expressed considerable satisfaction with the performance and condition of these concrete segmental pavements over the past ten years.

2. DESIGN

A detailed description of the design methods used for the Webb Dock No. 5 pavement was given by Towers (1). A similar design approach was used for the Rail Terminal flexible concrete segmental pavement.

The site comprises reclaimed land over soft silts and clays, the reclamation material being up to 12m thick. Initial global settlements across the site were substantial and some on-going settlement, particularly at the interface of the reclamation and the piled wharf deck continues to occur.

2.1 Material Properties

The pavement subgrade comprised predominantly hydraulically placed marine sourced sands, and design subgrade strength was based on laboratory soaked CBR tests on this material. The results of these ranged between 16 and 25%, tending to increase linearly with the density of the material. Plate load testing of the actual subgrade gave an elastic modulus of 100 kPa. A design subgrade CBR of 15% was adopted, with a corresponding subgrade elastic modulus of 150 MPa.

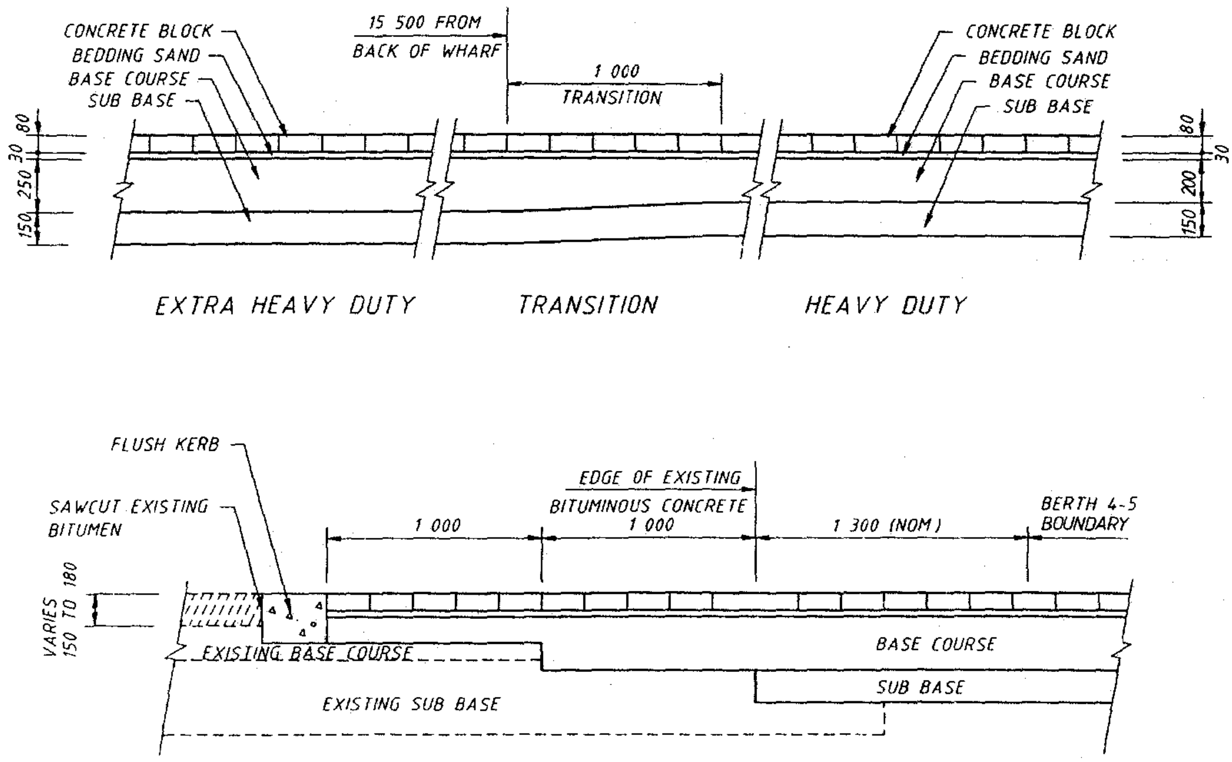

Figure 2 Terminal No. 5 Pavement Details

The flexible pavements were designed using elastic analysis, which was carried out with the computer program ELSYM from the University of California, Berkeley, based on multi-layered elastic theory. In this work, the stiffness of the concrete segmental paver layer was taken to be 1 000 vertical MPa, compared with asphaltic concrete at 25°C of 4 000 to 10 000 vertical MPa. It is well known that stiffness of the block surfacing increases in the first year or so of the life of the pavement, as lock-up occurs, but it is difficult to measure the elastic properties of concrete segmental paver surfacing. Values of up to 7 500 MPa (2) have been suggested, and stiffness as high as this may be appropriate, in the light of the excellent performance of these Webb Dock pavements.

The other layers of the pavements are made up of various qualities of crushed rock products with Melbourne basalt as the source rock. In the Rail Terminal, the 200mm thick basecourse layer was treated with 3% cement to increase its stiffness for better resistance to rutting. The forklift movement patterns within the Rail Terminal were expected to be rather more channellised than in the No. 5 Terminal, hence the concern for rutting. Figures 2 and 3 show the pavement profiles used in the No. 5 Terminal and the Rail Terminal.

2.2 Pavement Loads

The pavement design loadings were developed using Luxford and Lees 40 tonne forklifts, a loading spectrum for 20 ft. containers, and an average annual throughput of 50 000 TEU's (twenty foot equivalent units). As detailed in Table 1, container loads have, in fact, been substantially greater than was used in the design load spectrum.

Table 1 CONTAINER LOADING SPECTRA

Container Status	Design Loads			Actual Loads		
	Weight Range (tonne)	Average Weight (tonne)	Proportion (%)	Weight Range (tonne)	Average Weight (tonne)	Proportion (%)
full	17-22.5	22.5	30	18-24	24.0	39
average	11-17	16.0	19	12-18	17.0	21
half	4-11	10.0	12	4-12	11.0	11
light	2-4	4.0	14	2-4	4.0	7
empty	2	2.0	25	2	2.0	22

Note : The actual load spectrum has been estimated following discussions with the Webb Dock Terminal Manager.

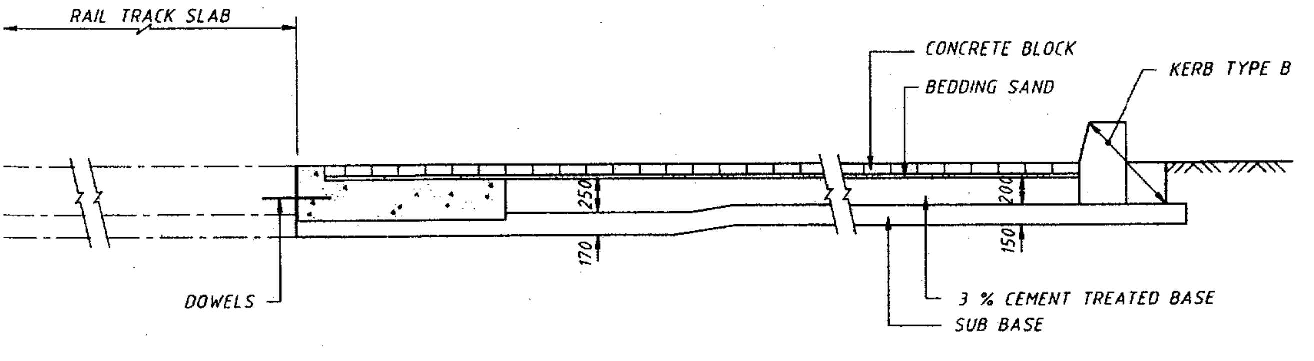

Figure 3 Rail Terminal Pavement Details

There is no doubt that container users have, over the years, become more adept at packing a 20 ft. container efficiently, so that more containers weight close to the statutory limit of 24 tonne than was expected ten years ago, and considerably fewer containers are light. It should also be noted that the statutory weight limit for 20 ft. containers has been increased from 22.5 to 24 tonne. Very few 40 ft. containers pass through Webb Dock, and for this exercise they were converted to TEU's.

Also, new heavier Valmet forklifts were purchased by NTAL in 1986, so that the vehicle load contributions used for the design pavement loads are not accurate. Moreover, the annual throughput of containers has been greater than expected, remained virtually static over the past ten years at 55 000 TEU's.

Design loading of the pavements was based on the concept of Port Area Wheel Load (PAWL) which is described in detail in the British Ports Federation Heavy Duty Pavement Design Manual (2). The No. 5 Terminal pavement was designed for a load calculated to be equivalent to 8.7 PAWL's. However, the actual historical loading of the pavement in the ten years of operation is estimated to be equivalent to 14.1 PAWL's, an increase of 62%. The number of load repetitions of the PAWL per year which was used for the original design was 50 000, based on container throughput, the layout of the container yard and expected operating patterns. Taking into account the 10% increase in throughput, the heavier containers and introduction of the Valmet forklifts, this annual number of load repetitions of the PAWL is estimated to be 89 000.

The single most influential change to the design criteria for the Rail Terminal pavement in practice is the fact that only about 8% of all containers, or about 9 000 TEU's per year are transported to and from the terminal by rail, compared to the design proportion of 23% or 25 000 TEU's per year.

2.3 Failure Criteria

The failure criteria used in the application of the elastic analysis to determine the allowable strains within the pavement structure were based originally on work for the design of asphalt road pavements (3), (4). Because this work related to road pavements, it was considered appropriate for the purposes of designing the Webb Dock heavy duty pavements that the allowable vertical compressive strain of the subgrade could be increased by 25% for failure to be deemed to have occurred.

The allowable vertical compressive strain was defined as

$$Ev = \frac{1.25 \times 28000}{N^{0.25}}$$

where N is the design number of load repetitions over the design life of the pavement. Using the original design parameters, an appropriate pavement with a design life of 30 years was selected.

The British Ports Federation Manual (2) uses a more stringent requirement for allowable vertical compressive strain of the subgrade of

$$Ev = \frac{21600}{N^{0.28}}$$

Applying this to the revised pavement loading, the estimated design life is revised to only seven years. Failure of this pavement is clearly not yet apparent after ten years, so either the failure criteria originally used for design more accurately predict the behaviour of this particular heavy duty pavement, or other parameters used in the design process have been set incorrectly.

If the design input parameters are modified by increasing the subgrade stiffness by 20%, the stiffness of the pavement layers is increased by 10% and the stiffness of the concrete segmental paver layer increased to 7 500 MPa, then the predicted design life of the pavement can be revised up to 14 years, based on BPF failure criteria. As discussed below, the standard of construction of these pavements was very high and it is not unreasonable to expect that the elastic properties of the pavement materials are better than was predicted at the design stage.

2.4 Design Detailing

Some important details which were incorporated in the design of these pavements, and which have enhanced the overall performance of these pavements, include :-

(i) surface slopes of at least 2% to facilitate drainage of surface water from the pavement;

(ii) regularly spaced grid of subsoil drains within the sandy subgrades to maintain subgrade moisture equilibrium;

(iii) strict adherence in the specifications to established overseas practices for manufacture and laying of the pavers;

(iv) positive measures in the Rail Terminal pavement to overcome the problems associated with differential settlement, which had become evident in the No. 5 Terminal pavement.

3. CONSTRUCTION ASPECTS

The satisfactory performance of these pavements can be attributed not only to the approach used to design these pavements, but also to the construction techniques adopted, which ensured that the quality of the finished product was adequate to deliver the desired performance.

During the preparation of tender documentation for both the No. 5 Terminal and the Rail Terminal projects, designs for both concrete segmental and asphalt concrete pavements were prepared. With the lack of a sound long term performance history for heavy duty concrete segmental pavements in Australia, it was decided to call tenders with two pavement alternatives. Project cost estimates had identified the asphalt concrete pavement to be cheaper, but with the recognition that a concrete segmental pavement would be more durable in the long term (asphalt concrete was predicted to require overlaying after eight years), a decision could best be made on the basis of comparative construction costs. Prior to signing of a contract, the concrete segmental pavement alternative was selected on both occasions.

3.1 Quality Control

The specification for each pavement area required that the top pavement layer beneath the concrete segmental paver surfacing be placed by a tamper spreader paving machine. This ensured that the best possible surface finish and tolerance to level for this layer was obtained, and that a uniform grading of material, with minimal segregation through this layer, was achieved. Control of the paving machine was with stringlines, which gave an excellent finish well within the specified tolerance over a surface with complex contouring.

Laying the basecourse layer with a tamper spreader paving machine was found to be of particular value for the cement treated crushed rock basecourse in the Rail Terminal pavement. This material has a limited time available for reworking and compaction, making spreading and achieving the required tolerance difficult with a grader. Field densities in this material consistently exceeded the specified densities by a substantial amount.

Quality control of concrete segmental paver manufacture comprised sampling of ten pavers from each batch of 20 000 pavers or less, with five pavers making up one test sample for compressive strength testing. On the basis of a method for compression strength testing similar to the method described in the Concrete Masonry Association of Australia's MA20 (5), with a specified paver strength of 45 MPa, no failures of the strength specification were ever detected in the 2.5 million pavers manufactured for these contracts. No requirement for abrasion resistance was specified for these pavers, since, at the time, abrasion was not commonly recognised as a problem in this type of pavement.

3.2 Construction Techniques

All concrete segmental pavers for both the No. 5 Terminal and the Rail Terminal contracts were laid by hand. During the laying, it was found to be essential for the full construction sequence of spreading the bedding sand, placing the pavers, initial compaction of the pavers, spreading of jointing sand and further compaction to be completed for an area within the day's work. On at least one occasion when this was not done in the Rail Terminal contract, where bedding sand and pavers were left uncompacted, rain overnight caused considerable damage to the new work, saturating and washing out some of the bedding sand. The entire affected area was subsequently pulled up and completely relaid, as efforts to remedy the damage proved futile.

It is essential to recognise the distinct difference in grading between the bedding sand and the joint sand. The required gradings are well defined in various specifications, and economies must not be sought by using bedding sand in joints nor joint sand for bedding. Furthermore, it is vital to ensure that on-going attendance is provided for topping up the joint sand for up to a year after commissioning, as the joint sand tends to degrade and crush between the pavers, as lock-up of the pavers develops under operating conditions.

All pavers in these Webb Dock pavements were specified to be laid notionally hard up against each other. The ability to do this depended on the size tolerance of pavers, as the moulds used to manufacture the pavers wore considerably over time, and pavers tended to "grow" during the production cycle. No detrimental effects from placing pavers in contact with each other were apparent in the Webb Dock pavements. However, more recent laying practice recommends using a gap of about 2mm between pavers, and some pavers have ribs cast in their side faces to facilitate this. The intention of this is to distribute the compressive loads between the pavers evenly, and therefore reduce the possibility of pavers spalling at the corners from high localised loads. Specifications now usually reflect this current practice, although for heavy duty pavements, this change in practice is not believed to be critical to satisfactory performance of a concrete segmental paver layer. For road and light duty pavements, where aesthetics is an important factor, any measures which guard against pavers spalling should be adopted, and leaving small gaps between pavers is therefore recommended for these applications.

Once an area of pavement had been completed, it was beneficial to allow light construction traffic to use the pavement prior to handing over for full operation. This helped to settle-in the pavement and promoted early lock-up. Heavy vehicles such as concrete trucks were not permitted on the newly completed pavements. If, however, the pavement was to be handed over for operations immediately, it was vital that five or more passes of a 35 tonne pneumatic tyred roller were completed before handover. In any event, this final heavy rolling was done on all completed areas of pavement prior to handover, this being essential for heavy duly concrete segmental pavements. If this final compaction is not done, gross migration of bedding sand can occur under heavily loaded wheels, causing localised rutting and heaving (6).

4. PERFORMANCE IN SERVICE

The performance of the concrete segmental pavements in the No. 5 Terminal, the Rail Terminal and the Equipment Park since commissioning has been exceptionally good in all but isolated problem areas. Virtually no maintenance has been needed on any of the concrete segmental pavements in the past ten years, and no maintenance in the immediate future is envisaged. This contrasts with the regular maintenance programme scheduled by NTAL for the asphaltic concrete surfacing in Webb Dock No. 4 Terminal which is subjected to similar operating conditions as the No. 5 Terminal.

The Equipment Park shows exceptional performance under severe conditions, due in particular to the considerable amount of hydraulic and lubricating oil spilled on the pavement. This area is not subjected to the same heavy axle loads applied to the main terminal pavements, with only empty forklifts and other equipment using this area. Regardless of this, it is likely that an asphalt pavement would have suffered considerable degradation under these conditions.

Nowhere in the terminal's concrete segmental pavements is there any evidence of rutting or other movement which might indicate onset of failure. The surfacing is well sealed and no penetration of rainwater run-off through the pavers is apparent. Minor problems have arisen at some locations in the pavements. In particular, settlement at structures continues to be a problem, especially at the pavement/wharf deck interface and to a lesser extent at the deep drainage pits. This problem is, of course, a consequence of settlements in the subgrade and the underlying fill and is not attributable to the use of concrete segmental pavers as the surfacing medium. The effects of settlement have been better catered for in the Rail Terminal by incorporating a special run-on slab detail (Figure 3), which has also more recently been adopted at pavement/wharf interfaces on other projects.

The other clearly evident problem is the localised surface degradation of pavers beneath container corner pads. This is most advanced in the area directly behind the wharf deck where containers have been dropped onto the pavement by container cranes, resulting in substantial impact loads. Pavers have in some cases cracked into a number of pieces, and about 10 to 15mm of the paver thickness has been lost. However, inherent compression within the layer of concrete segmental pavers ensures that joints and cracks remain tight, and failure of the pavement cannot yet be considered to have occurred. Further degradation of pavers in this area will not occur, because, for unrelated reasons, operating procedures have been modified recently, so that all containers are now lowered to the concrete deck of the wharf, between the legs of the container crane. A similar problem, although less severe in the level of damage, is the cracking and wear of pavers under the corners of containers in the stacks. While this damage is a little unsightly, maintenance of these areas is not necessary.

5. CONCLUSIONS

The various heavy duty concrete segmental pavement areas constructed at Webb Dock over the past ten years are performing at least as well as originally expected, with no areas of actual or potential pavement failure yet identified. Actual loadings in the No. 5 Terminal pavement have exceeded the design loadings by an estimated 75 percent, and the failure criteria used were less stringent than the criteria currently recommended for this type of pavement. These factors are likely to have reduced the design life of this pavement by half.

Attention to detail in the design and specification, and the application of established construction practices from Europe and North America have assured the satisfactory long term performance of these relatively large areas of heavy duty container terminal concrete segmental pavements.

The excellent performance of these pavements over the past ten years, under more severe loading conditions than was anticipated at the design stage, vindicates ANL's decision to proceed with this type of heavy duty pavement. These pavements now serve as a model for the design and construction of heavy duty concrete segmental pavements for container terminals with forklift operation in Australia.

6. ACKNOWLEDGEMENT

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