ANALYSIS OF THE PERFORMANCE OF A LONG LIFE PAVEMENT IN SOUTH AFRICA USING THE HVS

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ABSTRACT

This paper describes a long life pavement that has been in existence as an experimental section on a national highway in Gauteng, South Africa for the past 30 years. The section is part of a suite of test sections that have originally been constructed in 1968, but that required major rehabilitation of the base and surfacing due to stabilization cracks and deterioration during the first 2 years of its life. The base has been reworked through the addition of bitumen emulsion and a new surfacing added during 1976. For the past 30 years the section has received more than 11.5 million standard axles, and the performance during this period was excellent. Very little rutting or cracking is visible on the surfacing of the section.

Recently, a Heavy Vehicle Simulator (HVS) test has been conducted on the section to determine the ultimate failure condition and bearing capacity of the pavement. During this test, more than 40 million additional standard axles were applied to the pavement with little deterioration.

The history and background to the test section are provided in the paper, followed by a description of the pavement structure. The pavement design parameters are discussed and performance data over the last 30 years provided. The benefits of using the HVS as a successful option for the evaluation of the remaining life of the pavement are discussed. Finally, an assessment of the reasons for the good performance of this specific pavement are provided, that can be used to develop principles for perpetual / long-life pavements from. These principles would focus on both the pavement structure and the pavement materials used.

INTRODUCTION

The National Road 12 (N12) through the Gauteng province of South Africa was originally constructed in the late 1960s for large trucks transporting coal to industrial areas in Gauteng. A number of experimental sections were incorporated into the road (then called the S12) where various types of base courses and surfacings were studied to assess the effects of actual traffic on the performance of these layers and combinations of layers (1). Shortly after construction, two sections of the newly constructed road which were designed to evaluate the performance of a combination of a thin, flexible bituminous surfacing and a relatively thick, inflexible cement-treated layer failed dramatically through block cracking (1). These two sections were rehabilitated through reworking of the original base layer, during which bitumen emulsion was added to the original cement stabilized base layer material. The road was surfaced using a combination of two 25 mm asphalt layers and a 13 mm bituminous seal. This specific section provided exceptional performance under heavy traffic for the next 30 years (1975 to 2005). A rejuvenation “fog” spray was applied in 1991 as the only maintenance intervention over the life of the road. This paper focuses on this exceptional performance of Section 2 of road N12/19.

A brief history and description of the test road and original design objectives are firstly given. This is followed by a description of the performance of the road, based on both Long Term Pavement Performance (LTPP) and Accelerated Pavement Testing (APT) data. The construction processes as well as the maintenance performed on the road during its life are explained. Based on the data available and the performance of the road, the reasons why the road is deemed to be a success in terms of long-life pavements is discussed together with an interpretation of the combination of factors leading to the good performance of the road.

HISTORICAL AND DESIGN CONTEXT

HISTORICAL CONTEXT

Emulsified bitumen treated materials (EBTMs) have been used successfully in South African pavements for more than 30 years, with few reported failures. Eight experimental sections were constructed on the eastbound carriageway of the N12-19 (previously S12 and R22-P205-1) between August 1968 and March 1969 to assess the suitability of various pavement materials and pavement structures for carrying heavy traffic. The sections were opened to traffic in July 1969 and carried two-directional traffic until February 1976 when the westbound carriageway was opened to traffic. Two of the sections (one being the focus of this paper), both constructed with cement stabilized (4 per cent cement) crushed stone bases, failed prematurely through shrinkage and secondary cracks after pumping.

The base of the failed section was reconstructed in 1974 through ripping and emulsion treatment (0.5 per cent residual bitumen) of the original base material. This new base was surfaced with 50 mm continuously graded asphalt applied in two layers and a 13.2 mm single seal. A fog spray was applied in 1991 and limited surface patching was carried out in 2000 (2; 3). The supporting layers (subbase and selected layers) consisted of a cement stabilized (3 per cent) subbase layer and well compacted selected layers. In situ strength and stiffness evaluations of these layers indicated relatively high stiffness values (ranging between 100 and 400 MPa), even after 30 years of trafficking.

The overall original layout of the test sections is shown in Figure 1, with Section 2 (located on road N12-19 East, km 27.210) being the focus of this paper. In Figure 2 the structure of Section 2 is shown. Since the rehabilitation of the section, it has been monitored through various organizations and recently it became the topic of an Accelerated Pavement testing (APT) investigation where the ultimate failure mechanism and bearing capacity of the sections were investigated (3).

DESIGN AND TRAFFIC

One of the initial objectives of the construction of the test sections in the late 1960s was to use the information obtained from the tests to adapt the AASHO Road Test findings to South African conditions. The pavement design procedure was thus based on the AASHO Road Tests using a structural number of 4.5 and a design depth of 600 mm. Criteria were also set for limiting vertical and horizontal strains and stresses (1).

Early traffic counts indicated that the pavement carried between 800 and 2 200 80 kN standard axles (E80s) on the westbound lane per day with 35 per cent of the vehicles overloaded. Within two years 1 million cumulative E80s had traveled over the sections (1). The original service life assumption for the road could not be obtained. However, considering the specific circumstances shortly after construction (initial high number of coal trucks using the route and a subsequent major decrease in coal trucks on the route), the changes in alignment over the years, as well as following the general guidelines used at the time, this was probably a 20 year design life with a design traffic of between 10 and 15 million E80s.

CLIMATE

The region where the sections are located has an average annual precipitation of 760 mm of rain, mainly in the form of thunderstorms in summer (October to March). Dry winter months are normally experienced. Average maximum daily air temperatures of 27°C in January (summer) and 17ºC in July (winter) are experienced with average daily minimum temperatures of 13ºC in January and 0ºC in July. Average asphalt pavement surface temperatures measured during the recent APT evaluation (mainly summer) of the road was 23ºC.

CONSTRUCTION INFORMATION

Standard construction machinery and techniques were used for the original construction of the road in 1968 (1). Site diaries state that during the rehabilitation process of 1974, the contractor used a D8 bulldozer and a 15 ton grid roller to break down and rip the failed cement treated base. Between 0.5 per cent net bitumen was added in the form of emulsion. Density and moisture contents were determined for the lower layers, but not for the stabilized base (EBTM), as this layer was found to be too strongly cemented to undertake a sand replacement test. The relatively high densities and strengths in the base is perceived to be partly attributable to the improved compaction obtained after addition of the emulsion.. The base and surfacing for the specific section rehabilitated during 1974 consisted of the following layers (2):

- Base – constructed using the original cement treated base which had failed due to cracking, with the in-situ addition of diluted emulsion (ETB). No priming of the base was required;
- Bottom Asphalt layer – a 25 mm layer placed on top of the base, constructed using “hot mix / cold laid” asphalt. The binder used was MS150 and MS200 grade emulsions (high float emulsions);
- Top Asphalt layer – a 25 mm layer placed on top of the bottom asphalt layer, consisting of a standard medium continuously graded mix, and
- Single seal - After one season had passed, the asphalt layer was surfaced with a single seal.

The grading of the asphalt layers was deliberately chosen to coincide with the Fullers curve to attain maximum resistance to deformation. This grading target was achieved.

OPERATIONAL CONDITIONS

TRAFFIC

The experimental sections carried eastbound and westbound traffic between 1969 and 1976. Thereafter, the westbound carriageway was opened to traffic and only one direction of traffic was accommodated. In the seven years of bi-directional traffic, laden coal trucks (35 per cent overloaded) were the predominant heavy vehicles using the road. Traffic counts and estimates are based on information obtained from various sources, including comprehensive traffic observation stations, dedicated traffic counts and weigh-in-motion data. As at January 2005, the best estimates indicate that the road had already carried approximately 11.5 million E80s (2). This was before any APT commenced on the road.

MAINTENANCE

Very little maintenance has been carried out on the sections until recently. According to official records no maintenance interventions were made on the sections between 1974 and 1990. A fog spray was applied in 1991 with no further record of any maintenance until 2005. Isolated crack sealing was also noted in the shoulders of both sections, however, no evidence of cracks or crack sealing was observed on the trafficked lanes.

PERFORMANCE DATA

LTPP DATA

The section (together with the surrounding sections) were monitored in the early years of operation through parameters such as visual, rutting, elastic deflection and riding quality measurements. In summary, these data indicated that the section did not develop significant permanent deformation, fatigue or any other significant failures during its 30 years of operation. The remainder of the road (outside of the specific section evaluated and with a different pavement structure), did, however, show signs of fatigue which probably related to overloaded conditions, permanent deformation and even some block cracking. Maintenance actions on these sections included crack sealing and local surface and base course patching.

APT DATA

In order to evaluate the expected remaining life of the specific section and to obtain an indication of potential future failure mechanisms it was decided to undertake an APT investigation using the Heavy Vehicle Simulator (HVS). During the test, all standard pavement response parameters (i.e. permanent deformation and elastic deflection etc) were monitored. A heavily overloaded test condition was applied (up to 100 kN dual tire load which is equivalent to a 200 kN axle load) during most of the test under essentially dry conditions. At selected phases, surface water was allowed onto the surfacing of the road, leading to specific behavior important for the evaluation of the pavement response.

The data in Figure 4 indicate the typical surface rut development on the section. The vertical scale is specifically indicated with a maximum value of 20 mm, as this is the typical failure value used for this type of road. The surfacing of the road only started to show fatigue, through stripping of the bitumen from the aggregate, after surface water was applied under high contact stresses. This type of fatigue, however, would not be expected under normal traffic, and it is thus viewed as an extreme condition. A gradual increase was observed in the surface deflection during trafficking with no exceptional changes during the test. Surface deflection (40 kN, 620 kPa load) started at 200 micron and increased to 450 micron after 130 000 load applications. This is mainly attributed to a change in the structure and bonds of the base layer during the excessively high applied stresses during the HVS test.

Analysis of the HVS data indicated that the pavement structure withstood in excess of an additional 30 million E80s during the HVS test, including a number of load applications during a wet phase test. This equates to total traffic load of more than 40 million E80s applied to the road since construction. To put this in context, it can be equated to at least an additional 15 years of traffic at the current traffic levels and growth rate. This translates to a total life of at least 45 years for this structure that was originally designed for a 20 year life.

The data from the HVS indicate that the trends observed during normal trafficking of the road were also observed under APT – very low permanent deformation rates and no fatigue development. The only significant failures that could be induced in the pavement were when water was allowed to run over the surface of the pavement while exceptionally high tire contact stresses were applied. This resulted in high pore water pressures that led to stripping of the bitumen from the aggregate on the seal in localized areas.

MATERIALS DATA

In order to evaluate the exceptional performance of the pavement as observed during both LTPP and APT, material from all the layers in the pavement were sampled and subjected to a series of laboratory tests. The details of these tests are reported elsewhere (3). Observations during profiling of trenches, laboratory testing of sampled material and scanning electron microscope evaluation all indicated that the good performance of the pavement is probably attributed to a number of factors. These include:

- The asphalt concrete/ single seal surfacing has proven to be a superior surfacing as it was well designed and constructed, which prevented cracking and hence the ingress of water.
- The binder in the asphalt layer was relatively fresh when the test pits were opened, and recovered binder samples were much softer than would have been expected for a 30 year old asphalt (softening point of 53°C). This exceptional condition of the binder in the asphalt could have been partly due to the protection provided by the seal that was used on top of the asphalt, and this good surfacing is perceived to have contributed to the exceptional performance of the pavement.
- The relative high densities (up to 90 per cent of bulk relative density) and strengths of the various pavement layers enabled the pavement to carry traffic loads without being overstrained.
- Although no cement or lime was added to the previously highly cement-stabilized, recycled base during construction of the test sections, the extracted cores showed the existing base to be stabilized through cementitious bonds between the aggregate/particles and the reaction products of free lime and/or cement assumed to have been released during the recycling of the original base.

Based on the available data, the following general conclusions are drawn regarding performance of the test section:

- The test section performed well (both during normal trafficking over 30 years and under accelerated loading conditions) when evaluated using permanent deformation, fatigue resistance and visual condition criteria. The data indicate that the pavement structure provides more than adequate resistance to both traffic and environmental loads;
- All observations from the section indicate that the pavement structure provides a strong support for the traffic that the road is carrying, with little indication of the potential for sudden failure due to traffic or environmental influences, and
- The materials analysis indicated that the materials used in the structure performed optimally by providing the required support from the lower layers and protecting the structure against moisture ingress from the surfacing.

ASPECTS IMPACTING ON COSTS

An analysis of the costs of a pavement, especially one that performs well over an extended period, is always important in order to understand whether or not it is worth constructing similar pavements in the future. In the context of this project, there are a number of uncertainties that renders the calculation of a life cycle cost for the specific pavement impractical, most importantly the lack of clear construction costs for the original pavement. However, in order to obtain an indication of the financial implications of the parameters that most probably contributed to the relatively good performance of this specific pavement, the following are important:

- Use of an impervious seal over a newly constructed asphalt layer - it appears that the additional cost to a new layer of asphalt should have benefits that outweigh the initial costs of the action.
- Maintenance - according to available records, a fog spray was applied to the surfacing in 1991. The merits of such a fog spray may be debated, but in this specific case it may have contributed to the fact that the surfacing remained flexible and impervious for a period of 30 years. Again, the benefit of reduced fatigue cracks and water penetration into the pavement structure for the limited additional cost of a fog spray need to be considered.
- Good supporting layers in the pavement structure - indications are that the support that was provided by the various layers in the pavement structure enabled the pavement to withstand traffic loads. This can only be achieved through the use of appropriate materials, good construction techniques (i.e. optimal compaction of all materials) and quality control measures throughout the pavement structure.

REASONS FOR EXCEPTIONAL PERFORMANCE

Various different definitions exist for perpetual or long life pavements internationally. These definitions depend on the level of traffic normally experienced in the region, the typical expected life of pavement structures in the region and the experience with similar pavement structures under different conditions. In this case, the PIARC definition has been adopted for Long Life Pavements (LLP):

"A pavement is considered as a "success story" when it has proved to behave better than expected when it was designed. Such a pavement must be clear of structural maintenance and still be in good shape, despite the fact that it has sustained a cumulated traffic higher than the one contemplated at its design".

Based on this definition, the N12 Section 2 discussed in this paper is seen as a success story. This is based on the evaluation of the initial design of the road, the performance of similar roads in the vicinity (refer to Figure 5) and the lack of maintenance actions on the road during its life. The most significant findings from the HVS and laboratory tests conducted and discussed in this paper are:

- The road was most probably designed for between 10 and 15 million E80s over a 20 year life, and it withstood more than 40 million E80s of which a percentage was in a wet condition over a life of more than 30 years.
- The performance during real trafficking (LTPP phase) and the APT test was similar with respect to the main performance parameters (i.e. permanent deformation and fatigue).
- The results of all parameters evaluated (materials, structural and performance) were in agreement and indicated that the pavement should perform relatively well.
- Analysis of the asphalt surfacing indicated that the asphalt/single seal surfacing was well designed and constructed, which prevented cracking and hence the ingress of water.
- The relative high densities and strengths of the various pavement layers enabled the pavement to carry traffic loads without being overstrained (see previous bullet for details).

- The bitumen added to the base layer during construction contributed to improve the densities in this layer, mainly through acting as a compaction aid (see previous bullet for details).
- The large lumps of cemented aggregate retained from the original road and tightly bound by the original highly cemented matrix, supported by the cement stabilized subbase, probably influenced the bearing capacity and stiffness of the base layer positively.
- Based on the above it is clear that the lower layers of the pavement structure (subbase, selected and subgrade) provided good support for the base and surfacing, while the exceptional structural performance of the base protected the lower layers against over-stressing and over-straining. The asphalt further performed its role of adequately protecting the base against traffic and environment, allowing the entire pavement structure to withstand a large number of loads as well as environmental stresses over a considerable period.
- Further studies are being performed in South Africa on bituminous stabilization of granular materials, focusing on forensic information to improve the understanding of the mechanisms governing the exceptional performance obtained from this type of pavement in this and similar pavements.

GUIDELINES FOR LLP

It has to be appreciated that the pavement structure evaluated during this project is probably somewhat unique due to the method by which the original cemented base layer was reworked, and the resulting combination of parent materials, cement and emulsion. In addition, the wearing course consisted of a hot-mix/cold laid combination protected from environmental influences by a relatively impervious seal. However, it also has to be appreciated that this project (and the actual road that still functions well at the time of writing this paper) has shown that a pavement structure can be designed and constructed to carry relatively large loads for considerable periods. The idea of long-life or perpetual pavement structures is thus, at least in the South African traffic and environmental context, not an impossible dream. The applications that are valid to practice from this project can be summarized as follows:

- The following principles of pavement engineering still remain valid:
    - Keep the pavement layers dry;
    - Support the various pavement layers well;
    - Ensure good strength-balance between the various layers in the pavement;
    - Design and construct a deep pavement structure with the various layers each providing adequate support to the overlaying layers;
    - Select an appropriate aggregate grading to prevent permanent deformation, and
    - Select a binder that does not age quickly to prevent fatigue;
- The optimal use of large aggregate (larger than the currently specified maximum aggregate size for a base layer) should be further investigated, as it appears that the large cemented lumps from the original base had a significant influence on the good performance of the road.

CONCLUSION

Based on the information provided in this paper, the following main conclusion is drawn:

- It is possible to construct high quality (long-life) stabilized-base pavements which will provide exceptionally long structural lives if basic principles such as impermeable surfacings, high density pavement layers and good construction control techniques are obtained.

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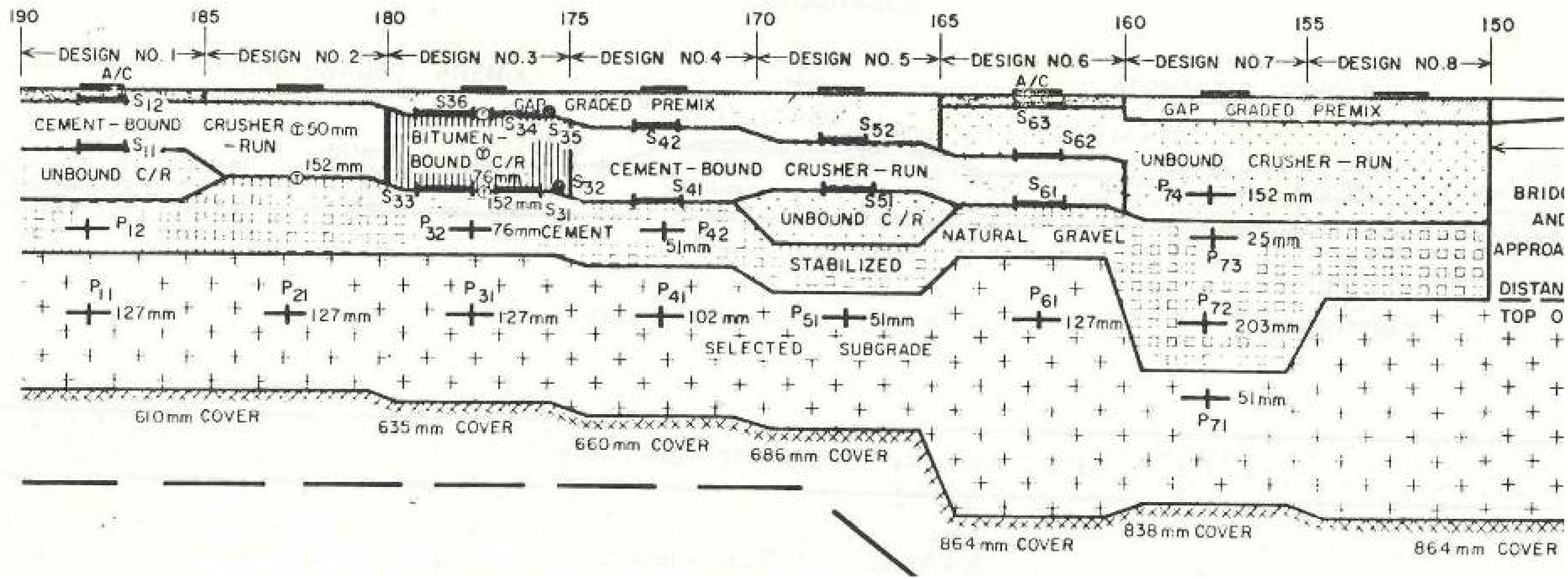

Figure 1: **Detailed layout of original sections – Design no 2 indicates the location of the section described in this paper. The crusher run base layer was replaced by the stabilised base layer indicated in Figure 2.**

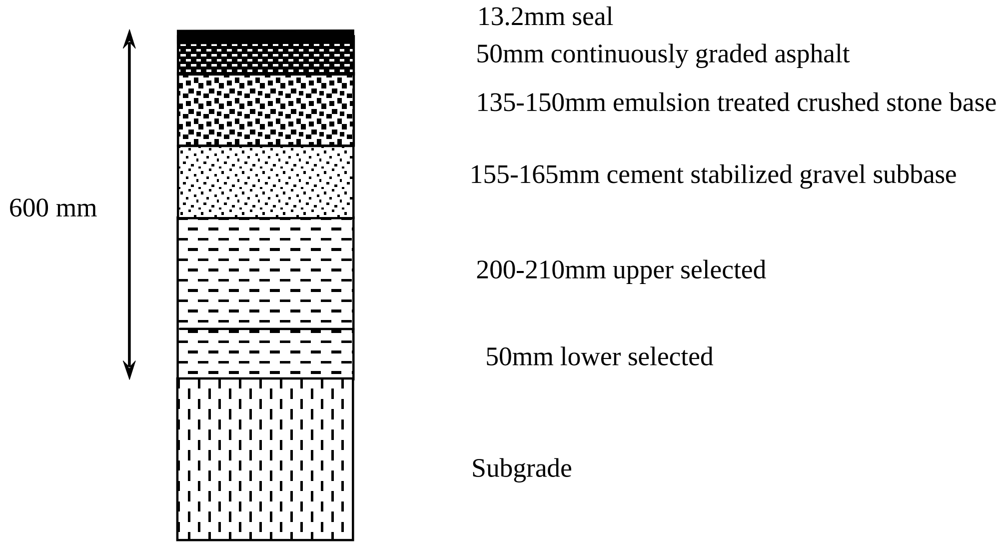

Figure 2: Structure of the pavement.

Figure 3: Photo showing the pavement surfacing and test pit.

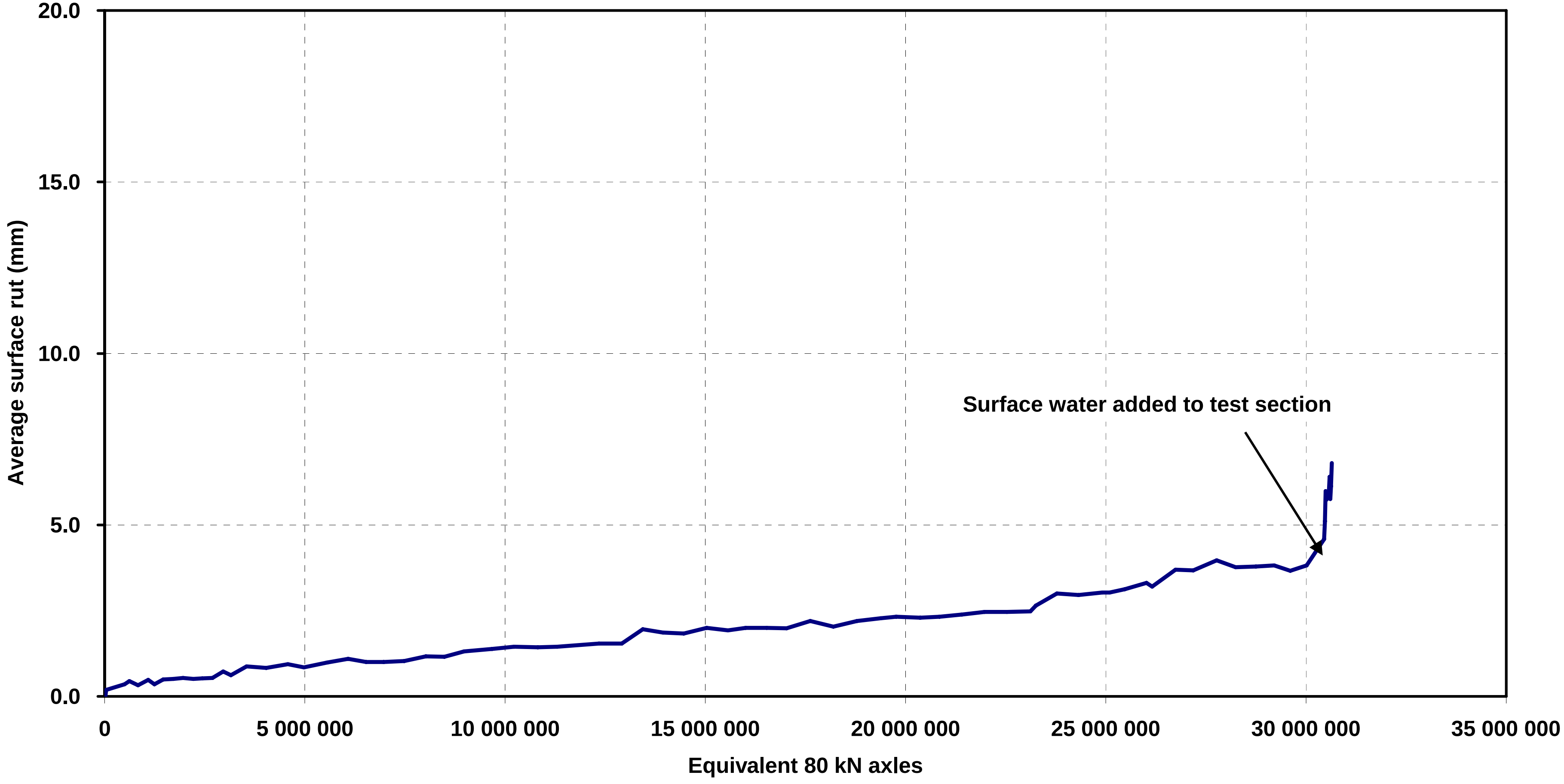

Figure 4: Trend in permanent deformation from HVS.

Figure 5: **Comparison between portions outside Section 2 and Section 2.**