TECHNO ECONOMIC EVALUATION
OF
ANCHOR PLATES IN PRESTRESSED CONCRETE SLEEPERS

BY

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Opsomming

Die tegniese sowel as die ekonomiese aspekte word in ag geneem met die evaluasie van ’n nuwe anker plaat. Die oorsprong van die dwarsleër sowel as die oorsprong van die ankerplaat wat in die “thosti” dwarsleër gebruik word, word breedvoerig verduidelik in die skripsie. Dit is noodsaaklik dat al die aspekte wat deel uit maak van die produksie van die dwarsleër in ag geneem moet word met die evaluasie van die ankerplate.

Daar is basies drie soorte dwarsleër wat gebruik word in die spoorbane van vandag naamlik:

- Hout
- Staal
- Beton.

Beton dwarsleër was voorgestel om hout te vervang. Die voorafgespande betondwarsleër wat op die “thosti” produksieproses vervaardig word, word gebruik gedurende die evaluasie. Die ankerplaat wat gebruik word in die produksie van die dwarsleër verseker dat die drukkrag wat onstaan as gevolg van die voorspanning voldoende tot die omliggende beton verplaas word.

Die ankerplate word met behulp van laboratorium toetse sowel as produksie toetse geëvalueer. Indien die toetse suksesvol is sal ’n ekonomiese evaluasie gedoen word. Die ekonomiese evaluasie sal die volgende aspekte aanspreek:

a) Materiaalkoste
b) Arbeid
c) Onderhoud
d) Gereedskapkostes

Die implimentasie van die produk sal volg indien die evaluasie suksesvol is. Die implimentasie van die produksie sal sekerlik nie sonder enige probleme afloop nie maar elke poging sal aangewend word om probleme te vermy.
Summary

The technical as well as the economical aspects were taken into account during the evaluation process of the anchor plates. The origin of the sleepers as well as the origin of the anchor plates used in the "thosti" production process is briefly explained. It is essential that a better understanding regarding the manufacturing process is created, for any aspect during the production could influence the outcome of the evaluation.

Three basic sleepers are used in the modern tracks today namely:
- Timber
- Steel
- Concrete

Concrete sleepers were introduced as a substitute for timber sleepers. Two types of concrete sleepers are explained namely:
- Reinforced twinblock sleeper
- Prestressed monoblock sleeper.

The prestressed concrete sleepers are manufactured in the "thosti" process as will be explained, and a long-line process. The anchor plates used for the evaluation are used in the "thosti" production process. The anchor plate is used to transfer the compressive stress induced by the prestressing to the surrounding concrete.

The anchor plates were evaluated by means of laboratory tests as well as production tests. The economic evaluation was only done after the tests have been done and proven successfully. During the economic evaluation the following aspects were recognizable:
- Material costs
- Labour costs
- Maintenance costs
- Tooling costs

The next step would be to implement the proposal.
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CHAPTER I

Introduction to anchor plate viability study

1.1 Introduction

Concrete sleepers, as we know them today have evolved significantly over the last century. They were introduced as a substitute for timber sleepers. The Railway Association became the main customer and their needs had to be met and still must be met today. The trains might be faster and the loads might be heavier, but the sleepers must still be adequate to withstand the forces and be reliable for ensuring the safety of every person travelling.

It is therefore of great importance to manufacture the sleepers cheaply and economically cost effective.

1.2 Approach

To determine whether a sleeper can be made cost effectively, it is of great importance that all the aspects for manufacturing, supplying etc., of the sleeper must be understood. The aim is to give the reader, a good understanding about the manufacturing of concrete sleepers and other aspects involved during the production as well as the research methodology used [Reference 8]. In chapter two railway in general will be discussed whereas in chapter three and four the manufacturing process of concrete sleepers.

1.3 Definition of anchor plates

The anchor plates are used for anchorage of the prestressing wire in the concrete sleeper. In the Prestressed Concrete Designer's handbook, [Reference 1], four anchoring systems for prestressing are explained.

The anchoring system that will be used for this investigation is a combination between the Mcalloy system, the BBRV system and the Prescon system. An
anchor plate is used to transfer the prestressing force to the concrete and is anchored with an anchor bolt and nut. [Reference 1]. The wires are anchored through the plate by means of a buttonhead, represented by BBRV and Prescon. The anchor plate that is used for positive anchorage of the stressing wire in the sleeper is of vital importance. The wire used in the sleeper is not indented and therefore cannot transfer the compressive force to the concrete very efficiently in bond. The compressive force is therefore transferred by means of the anchor plate.

The manufacturing process for the anchor plates can be an expensive and time-consuming operation. For this reason it was decided that the manufacturing process and the anchor plate would be investigated for the economical viability study.

1.4 Conclusion

Now that the investigated object is identified, as well as the use of the anchor plate, a more in-depth discussion of the sleeper, manufacturing process, as well as the investigation process can be done.
CHAPTER 2

Railway Sleepers

2.1 Introduction

The aim of this chapter is to introduce the reader to concrete sleepers and why they are used in railway lines today. In this chapter the design of sleepers will not be explained, for this is confidential information held by the supplier of the concrete sleepers. The components involved with the sleeper however will be explained.

2.2 Background

The first design in the United States for concrete sleepers was done in 1884 and the Reading Company in Germantown, Pennsylvania installed the sleepers in 1893. [Reference 2].

In 1902 the first reinforced concrete sleeper in Hungary was designed. [Reference 3] It was at the end of the forties that railway companies required crack-free sleepers. Various types of prestressed concrete sleepers evolved and changes and tests are still being done to accommodate the new technology trains with high speeds and axle loads.

It was only in 1957 that work was done on prestress concrete sleepers in the United States of America [Reference 2]. The first concrete sleepers were installed in 1960 and by 1967, 74 000 sleepers were installed in North America.

Various sleepers were manufactured in the world. These sleepers contained types like [Reference 3]:
- Twinblock sleepers
- Monoblock reinforced concrete sleepers
- Monoblock prestress concrete sleepers
Various production systems arose for manufacturing the concrete sleeper as quickly and as economically as possible.

The sleeper that will be used in this investigation is called a "Thosti" sleeper. This name originated from the manufacturing process used for these sleepers.

The "Thosti" sleeper is a prestressed monoblock sleeper. During the manufacturing the Mcalloy and BBRV systems as described in Chapter 1 are used for the prestressing of the sleeper. The "Thosti" production system will briefly be explained in further chapters.

2.3 Summary

It is clear that the use of concrete sleepers developed extensively during the 20th Century. The prestressed concrete sleepers are fairly new if one considers that the development of prestressed concrete sleepers in the United States of America only commenced in 1957. This was done to eliminate cracks in sleepers during working conditions. The next chapter will give the reader, a brief introduction on the manufacturing processes abroad for manufacturing prestressed as well as reinforced concrete sleepers.
CHAPTER 3

Literature Study

3.1 Introduction

Manufacturing processes that could produce high volumes of concrete sleepers at the most economical costs were needed due to the fast growth of rail transport and the need to run higher speeds and loads on the tracks.

Various parameters were used for investigating the most economical method of sleeper manufacturing. These parameters included the production capacity, location circumstances and the degree of automation. All these parameters were influenced by the complexity of design, handling of the product, size and weight of the product. [Reference 4].

3.2 Manufacturing of sleepers abroad

3.2.1 Netherlands production system

The system used in the Netherlands [Reference 5] is called a longline system, and will be explained briefly in the next few paragraphs.

The plant consists of a prestressing bed, 90 m long, with thirty-five 4 compartment moulds. This would mean that 140 sleepers can be produced in one line. The line with the moulds placed in position can be seen in figure 3.1.
Figure 3.1  Prestressing beds with moulds in position.

The prestressing wires are placed through the active and passive ends of the prestressing beds. The active end is the point where the wires will be stressed and the passive end is the fixed end of the line where no movement of the wire will take place. The sleepers are cast as shown in Figure 3.2.

Figure 3.2  Casting process of sleepers in the Netherlands.
The concrete is cured using steam injection that is situated beneath the moulds. The sleepers are suspended at the same height by means of transport carriages, whereafter the mould is lowered. The stress is released and the sleepers are forwarded to the cutting station, whereafter they are turned 180°.

Figure 3.3 illustrates a flow diagram for the longline production system. The wire is cut in lengths of 100 m each. At the same time the moulds are cleaned from concrete spillage and dust. The release oil is sprayed to the inside of the mould to act as a release agent when demoulding. The fastening systems, reinforcing wire and other inserts such as ferrules are placed in the moulds.

The casting process is done by placing the concrete with an overhead concrete skip and vibrating the concrete mechanically.

Curing blankets then insulate the moulds. After the curing process the moulds are lowered from the product. The reinforcing between the products are cut and transported to the turning station, where they are turned 180°. The products are transported to the stockyard where they are despatched to various sites.

Figure 3.3 Flow diagram of longline production for manufacturing of sleepers.
3.2.2 Twinblock sleeper production in Belgium [Reference 4]

The production system uses a pallet tilt-up forming machine. The machine is connected to an automatically controlled pallet circulation system and take-off arrangement.

The concrete is supplied to a conveyor which in turn delivers the concrete into a transfer bucket. The bucket moves via an overhead rail to the casting area whereafter the concrete is discharged in the casting machine. The casting process can be seen in Figure 3.4.

![Discharging of concrete into casting machine.](image)

Each mould is prepped before casting. The prepping process will involve the cleaning, oiling and placing of the reinforcing in the mould.
The casting machine is divided into simple stationary parts which comprise of a metering system as well as a concrete distributor. When the reinforcing is placed in the mould the casting can be done. The concrete is compacted using two vibrator motors. A hydraulic charging truck fills the mould whereafter the trimming and smoothing beam finishes the casting stage. [Figure 3.5]

![Figure 3.5](image)

**Figure 3.5**  
Trimming and smoothing being done of top concrete surface of the mould

The mould is lifted, turned and demoulded onto a pallet. Figure 3.6 illustrates the lifting and turning process.
Figure 3.6  Lifting and turning of mould.

The sleepers are transported by means of a conveyor whereafter curing; cleaning and shipping will take place.

3.3 Conclusion

Two different production systems as well as two different sleepers are recognisable in this chapter. The monoblock prestressed concrete sleeper is produced on a longline system where curing is done before destressing and demoulding whereas the twinblock reinforced concrete sleeper is manufactured on a pallet tilt-up forming machine, where the demoulding is done before curing.

Prestressed concrete needs a certain release strength to be able to transfer the prestressed force to the sleeper whereas the reinforcing sleeper does not need as high strengths, such as 30 - 35 MPa cube strength, for demoulding. This will be explained in greater detail in Chapter 5.
CHAPTER 4

A South African Production System for the Manufacture of Prestressed Concrete Sleepers

4.1 Introduction

The sleepers manufactured in South Africa are mainly monoblock prestressed concrete sleepers. Two systems are used for the manufacturing of prestressed concrete sleepers namely:
- Longline
- Thosti

The longline system will not be explained further in this chapter for the system is based on the longline system used in The Netherlands as explained in Chapter 3.

The "Thosti" production system will be explained briefly in this chapter but for confidentiality reasons the system is explained in greater detail in the Grinaker Duraset Report. [Reference 6]

4.2 Thosti production system

Figure 4.1 below illustrates the various stages in the production system.

FLOW CHART

Figure 4.1 Flow chart of Thosti production system
Each stage will be explained briefly.

Stage 1. Cleaning and oiling of the mould. The oil is used as a release agent for demoulding.

Stage 2. The fastenings as well as the reinforcing wire is placed into the mould. The bolts are tightened for straightening the wirepair before stressing.

Stage 3. The reinforcing is stressed and anchored at the correct stressing force.

Stage 4. The concrete is fed to the mould by means of an overhead discharge bucket. The mould is placed on a vibrating table during the casting process.

Stage 5. The moulds are transported to the curing chambers after the casting process is complete.

Stage 6. Curing takes place until the required release cube strength has been reached. The sleepers are demoulded by turning the mould 180°.

Stage 7. The bolts are detensioned when the required release cube strength has been reached.

Stage 8. The empty moulds are turned over for cleaning and oiling.

Stage 9. The sleepers are transported to the finishing stage where the corking of the bolt holes take place.

Stage 10. The finished sleepers are transported to the stockyard whereafter they are dispatched to the client.

4.3 Conclusion

This process may seem very simple but a lot of process planning, time management and sophisticated equipment goes into this process. The anchor plates that are explained in the next chapter are only one small part of this process.
CHAPTER 5

Production System for Anchor Plate Manufacturing

5. Introduction

During this chapter the manufacturing process of the flat anchor plate, that is currently used, is explained. The investigation of the proposed anchor plate as well as the shortcomings are explained in this chapter.

5.1 Flat anchor plate

In the current production of Thosti concrete sleepers a flat anchor plate is used. The anchor plate is manufactured from a flat strip of steel with various dimensions. The second paragraph of this chapter will illustrate the production of the flat anchor plate.

5.1.1 Production layout

The production of the flat anchor plate is a very simple process. Although it is simple it is also a labour intensive process. The manufacturing of the anchor plate is not the only process for the manufacturing of wire pairs. The wire is of no use without the anchor plate and the anchor plate of no use without the wire. The total wire pair consists of the following:

- 2 lengths of wire
- 2 anchor plates

The anchor plate is secured with a buttonhead on each end of the wire. The buttonhead is a ball-shaped head formed on the end of the wire. The buttonheading system is adapted from the BBRV or Prescon system as was described before. The buttonheading method is a simple process but uses fairly sophisticated machines. The process involves two stages namely:

- Clamping of wire
- Button forming
The button former is used to press the wire tip, forming a ball form at the tip. This process is done just after the wire clamping stage. The clamping stage is used to prevent any slippage or movement of wire when the tip is formed.

Figure 5.1 illustrates a typical wire pair.

![Figure 5.1](image)

Figure 5.1 | Typical wire pair

Now that some of the processes are understood, the production layout for the manufacturing of a complete wire pair can be explained. Figure 5.2 illustrates using a block diagram, what processes are involved in the production of a wire pair.
Each of these processes will be explained briefly:

a) During the punching stage for the anchor plate the flat bar is fed into a die-set where the plate is cropped to the required length and a hole punched in the centre of the plate which will accommodate the stressing and anchor bolt.

b) The cropped plate is taken to the drilling process where two small holes are drilled for locating the wire.

Each of the processes needs at least one worker. The drilling process is a repetitive process.

c) The cropping of the wire is done during the same time as the anchor plate production. The wire is cut to the required length during the cropping stage.

d) The cut wires and the complete anchor plates are assembled in the assembly stage. Two workers are required if a production rate of 4000 wirepairs/day is to be achieved.
e) The wire is buttonheaded at each end finishing the wire pair production cycle.

f) The wire pairs are stacked in bundle form in the stockyard whereafter they are sent to various sleeper production plants.

Due to various problems that are explained in the next section it was decided that a new anchor plate should be developed.

5.1.2 Problem description

Various problems occurred during the production of the anchor plates. These problems included aspects like:

a) Maintenance
b) Structural integrity
c) Labour

a) Maintenance

Because no preventive maintenance plan existed, it caused excessive downtime when maintenance needed to be done. The drilling operation was a very costly operation due to maintenance. Seals had to be replaced from time-to-time causing unacceptable downtime rates and high productivity losses. The press used for punching the anchor plates had a very low downtime rate due to the low maintenance required during production.

It is however essential to determine what the requirements for maintenance should be during the running operation of the press. Troubleshooting might be done but no formal procedure as described in Reference 7, page 441 – 451 exists. The maintenance analysis data cover basically two aspects:

i) all significant repairable items as well as,

ii) all requirements for maintenance.

This problem needs to be addressed when a new system of manufacturing is implemented. If a new system is not implemented it is essential that data should be
collected and in turn, be used for setting up a detailed maintenance plan that would address aspects like downtime, MCT (mean corrective maintenance time), MTTR (mean time to repair) etc.

b) Structural integrity

The structural strength of the flat anchor plate was too low to resist the bending forces imposed on the plate. These results were gathered from deflection and load-tests performed in Phase 1 of the project and this report can be seen in Appendix 2 of Reference 6. The results will be explained in greater detail in the next chapter. The imposed forces caused the plate to deflect in such a way that there was reason to believe that stress-loss in the prestressing occurred during the bending of the anchor plate. The stress-loss is the reduction in stress or force if a constant load is applied over a finite time period. This time period could be minutes, hours, weeks and even years.

c) Labour

Using labour is no longer a very cost effective method of manufacturing. It is also important that labour should be trained to fulfil a higher skilled operation that could in turn, assist with gathering new ideas or systems. It could generate new products that could then produce work for other labour whereafter they can also be trained and create other opportunities. This could be a huge chain reaction that would benefit both parties, namely the employer and employee.

A labour saving can have a huge benefit and this aspect was used as one of the aspects in the economic evaluation and will be explained in Section 5.2.

5.1.3 Conclusion of flat anchor plate

In the discussion of the above section it was aimed to give the reader, a better understanding of what is involved in the production of the flat anchor plates, and also what the problems were which indicated that a new anchor plate with maybe a new production system, should be investigated. The problems such as labour, structural integrity and maintenance might not be the only problems but they were the main driving factors for this evaluation. It is rightfully so that economics play a big role in the
evaluation process, but the economic evaluation cannot be used as a measuring tool when the current product is structurally inferior. Now that these aspects are better understood, one can continue to propose solutions and evaluation.

5.2 Proposed solution

It was felt that a more cost effective solution had to be found for the manufacturing of anchor plates. It was decided that an external search will first be conducted to determine if and what anchor plates are used in similar production systems throughout the world. The purpose of this section is to give the reader, an overview of evaluations and tests performed to eliminate as many variables as possible.

5.2.1 Production layout

One critical aspect in the production is to save labour and time. This should in turn increase productivity. A search was conducted and it was found that various anchor plates are used in Europe for the manufacturing of concrete sleepers. It was decided that the evaluation of which anchor plate to use will be done using the following criteria:

- Increase productivity
- Reduce labour
- Reduce maintenance
- Cost effective
- Structurally correct

Based on the above criteria it was decided that a channel shape anchor plate would be investigated. It was realised that no drilling operation is involved in the anchor plate production when a channel anchor plate is manufactured for the holes could be punched. This was seen as a great opportunity to save labour and in turn increase productivity. The press operation was found to be a lower maintenance function as the drilling machine. This would in turn reduce maintenance and maintenance costs.

A proposed production layout for the manufacturing of 4000 wirepairs/day can be seen in Figure 5.3. The proposed production layout would save on labour due to the fact that no drilling operation is required as for the case in Figure 5.2. The proposed anchor plate can
be produced in one press operation, and it is for this reason that the worker used for the drilling of the flat anchor plate can be used in another operation.

![Diagram of anchor plate production](image)

**Figure 5.3** Proposed channel anchor plate production

5.2.2 Tests and results

The evaluation process for selecting the correct anchor plate is a long process for technical tests have to be performed to determine if the structural integrity of the plate is efficient. Only then can an economic evaluation be done.

The first aspect that had to be clarified is what steel should be used. It was decided to use the chemical analysis, done on the German plate that was received and compare it with the proposed 300WA flatbar.

The chemical analysis has shown that the quantity of each chemical element in the German plate complied with the 300WA specification. There were however elements such as:
- Molybdenum
- Nickel
- Copper
- Aluminium
- Vanadium

that were slightly higher than the 300WA specification [Reference 6]. The chemical composition of the German anchor plate relative to the 300WA specification can be seen in Appendix 2.

It was therefore decided that 300WA will be used during the two proposed test procedures namely:

- laboratory testing
- production testing

5.2.2.1 Laboratory testing

It is very important that the shortcomings that occurred during the tests conducted in previous evaluations would be addressed and corrected.

These shortcomings included the following:

1. High relaxation losses caused by the length of wire used in system. The relaxation loss is the reduction in stress or force in the wire when kept under load.
2. Temperature changes during each test.
3. Possible stress losses due to stressing and anchor bolts used in the system.

It was therefore important that a proposal should be done to eliminate these variables.

Design proposal for testing

1. The relaxation of the wire should be tested to see what effect the relaxation of the wire will have on the stress-loss in the system. If the relaxation of the wire is known then this value can be subtracted from the total stress loss in the system where the anchor plates are being used.

2. The method of stressing with anchor bolts must be taken out of the system for the reason that the thread of the bolts can cause a stress loss in the system. This stress
loss cannot always be ignored and therefore it is better to take the bolts out of the system when the anchor plate must be isolated or to increase the thread so much that no slip or stress loss could take place.

3. The initial stress and the temperature of the working environment must be kept constant throughout the total duration of the test.

4. Figure 5.4 shows a proposal of how the anchor plates could be tested to minimise the variables in the system.

---

**Figure 5.4** - Proposed testing apparatus

1. The loadcell is used to measure the applied load on the wirepair.
2. The test frame is used to locate or situate all the equipment and the wirepair. It is designed to resist the maximum applied force that would act on it if the wirepair is under load.
3. The anchor plate under investigation.
4. The stressing plate is used to anchor the wirepair. There are no anchor plates situated in the plate. The stressing plate is placed in the stressing box whereafter the stressing operation can be done.
5. The stressing box is pulled using a stressing bolt and shaft. It slides on plate during the jacking operation.
6. The jack is a hollow-core jack. The stressing bolt is placed through the jack and located and locked with a nut.

7. The anchor bolts are used to lock the stressing box in position when the correct load on the wirepair is applied.

8. The stressing shaft or bolt is used to connect the jack and stressing box. The shaft is the link for the stressing operation between the jack and stressing box.

The laboratory test is conducted on the following basis:

1. Manufacture nine current 300WA flat anchor plate samples.
2. Do comparison tests between the 300WA and German plate using the criteria and apparatus in the design proposal for testing.

The comparison tests are done at 70%, 75% and 80% of 1700 MPa UTS. The UTS is the ultimate tensile strength of the wire. Three plates of each type are tested at each stress percentage.

5.2.2.2 Production testing

Sleepers should also be tested to evaluate the effects of the different anchor plates in the sleepers. Therefore twelve P2 sleepers with the flat anchor plates that are currently used, and 12 P2 sleepers with the anchor plates that are used in Germany were manufactured. Two moulds were cast with one batch of concrete so that the concrete strength in the two moulds is the same. Each of the two moulds were cast with different anchor plates. The one mould was cast with the normal flat anchor plate and the other was cast with the German type anchor plate. Six concrete batches were prepared for the total amount of sleepers. Every two moulds had the same concrete strength but different anchor plates so that the concrete strength as a variable can be eliminated for the purpose of the comparison testing between the two types of anchor plates. Equivalent moulds and the same stressing equipment should be used. Bending tests were performed after 28 days to determine if there is any difference in the bending ability of the sleeper.
5.2.3 Test results

The laboratory testing that was described in the previous section was done using the current 300WA flatbar and the German plate. Although the chemical analysis was done and concluded that the 300WA plate compared very well against the German plate, it was still decided that 18 samples using 300WA plate would be manufactured to the dimensions of the German sample. The test results will be explained in two sections:

- Laboratory tests
- Production tests

5.2.3.1 Laboratory test results

Three wire samples are used to measure the relaxation of the wire during a 4-hour period. One sample is tested at each of the three percentage stress levels, 70%, 75% and 80% UTS of the wire, respectively.

A typical test set-up can be seen in Figure 5.5 and 5.6.

Figure 5.5 : Top view of test apparatus
The stress-loss in the system would include the relaxation of the wire as well as the stress-loss caused by the continuous deflection of the anchor plate. The relaxation of the wire is subtracted from the system stress loss. These results can be seen in Table 5.1.
Table 5.1  Stress loss due to bending of the anchor plate

UTS of wire [ MPa ] = 1700

Area of wire [ mm $^2$ ] = 28.274

<table>
<thead>
<tr>
<th>Type of plate</th>
<th>Percentage stress of UTS</th>
<th>Test number</th>
<th>Load [ KN ]</th>
<th>Duration of test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70</td>
<td>75</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>German Plate</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>15 min</td>
<td>16</td>
<td>59</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>14</td>
<td>64</td>
<td>-4</td>
</tr>
<tr>
<td></td>
<td>45 min</td>
<td>12</td>
<td>63</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>60 min, 1 hour</td>
<td>15</td>
<td>72</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>75 min</td>
<td>16</td>
<td>73</td>
<td>-3</td>
</tr>
<tr>
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<td>90 min</td>
<td>16</td>
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<td>-6</td>
</tr>
<tr>
<td></td>
<td>105 min</td>
<td>17</td>
<td>78</td>
<td>-6</td>
</tr>
<tr>
<td></td>
<td>120 min, 2 hours</td>
<td>16</td>
<td>78</td>
<td>-9</td>
</tr>
<tr>
<td></td>
<td>135 min</td>
<td>19</td>
<td>80</td>
<td>-9</td>
</tr>
<tr>
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<td>150 min</td>
<td>19</td>
<td>81</td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td>165 min</td>
<td>19</td>
<td>80</td>
<td>-14</td>
</tr>
<tr>
<td></td>
<td>180 min, 3 hours</td>
<td>21</td>
<td>83</td>
<td>-17</td>
</tr>
<tr>
<td></td>
<td>195 min</td>
<td>22</td>
<td>86</td>
<td>-20</td>
</tr>
<tr>
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<td>210 min</td>
<td>21</td>
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<td>-25</td>
</tr>
<tr>
<td></td>
<td>225 min</td>
<td>24</td>
<td>85</td>
<td>-27</td>
</tr>
<tr>
<td></td>
<td>240 min, 4 hours</td>
<td>27</td>
<td>85</td>
<td>-30</td>
</tr>
</tbody>
</table>

It can be seen from Table 5.1 that a negative stress loss, or stress gain occurred in some of the tests. This would mean that there would be a gain in stress. A relaxation test was done using wire samples from the same batch as the sample used for the tests in Table 5.1. The relaxation test only measured the stress loss which occurred in the wire alone, no anchor plate was present during this test. If a stress gain as in Table 5.1 occur, it
would mean that the total system, anchor plate and wire, has less stress loss than the wire alone. This however is not possible. Although the same wire from the same roll was used, there were still differences. The continuous deflection, as well as the initial deflection, of the anchor plate was also determined [Reference 6].

The stress-loss that did occur however, without the plate deflecting continuously could have been due to:

1. Relaxation of wire
2. Indentation caused by the buttonhead. This is illustrated in Figure 5.7.

![Indentation caused by the buttonhead in the German anchor plate at 80% stress.](image)

**Figure 5.7** : Indentation caused by the buttonhead in the German anchor plate at 80% stress.

It was decided that the stress loss in the system would be used as a basis for evaluation and not the stress-loss due to the continuous deflection of the anchor plate. The newly formed anchor plate is shown in Figure 5.8 and 5.9.
Figure 5.8 : Top view illustration of 300WA channel anchor plate.

Figure 5.9 : Indent caused by buttonhead on channel anchor plate at 80% stress.
Table 5.2 indicates the stress-loss in the system for the newly formed plate with 300WA plate (channel system).

Table 5.2  Stress loss in system

<table>
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<th>Type of plate</th>
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<th>75</th>
<th>80</th>
<th>70</th>
<th>75</th>
<th>80</th>
<th>70</th>
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<td>Load [kg]</td>
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<td>7350</td>
<td>7840</td>
<td>6860</td>
<td>7350</td>
<td>7840</td>
<td>6860</td>
<td>7350</td>
</tr>
<tr>
<td>Load [kg]</td>
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<td>7350</td>
<td>7840</td>
<td>6880</td>
<td>7350</td>
<td>7840</td>
<td>6860</td>
<td>7350</td>
</tr>
<tr>
<td>Test number</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Duration of test</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>15 min</td>
<td>6841</td>
<td>7322</td>
<td>7809</td>
<td>6860</td>
<td>7329</td>
<td>7822</td>
<td>6848</td>
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<td></td>
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<td>7310</td>
<td>7797</td>
<td>6860</td>
<td>7324</td>
<td>7813</td>
<td>6842</td>
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<tr>
<td></td>
<td>45 min</td>
<td>6830</td>
<td>7305</td>
<td>7789</td>
<td>6856</td>
<td>7319</td>
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<td>6838</td>
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<tr>
<td></td>
<td>60 min, 1 hour</td>
<td>6827</td>
<td>7301</td>
<td>7783</td>
<td>6852</td>
<td>7317</td>
<td>7802</td>
<td>6836</td>
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<tr>
<td></td>
<td>75 min</td>
<td>6823</td>
<td>7301</td>
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<td>6846</td>
<td>7314</td>
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<td>120 min, 2 hours</td>
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<td>7289</td>
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<tr>
<td></td>
<td>150 min</td>
<td>6803</td>
<td>7285</td>
<td>7756</td>
<td>6839</td>
<td>7305</td>
<td>7781</td>
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<tr>
<td></td>
<td>165 min</td>
<td>6802</td>
<td>7284</td>
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<td>6837</td>
<td>7302</td>
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<tr>
<td></td>
<td>180 min, 3 hours</td>
<td>6798</td>
<td>7284</td>
<td>7748</td>
<td>6834</td>
<td>7301</td>
<td>7778</td>
<td>6824</td>
</tr>
<tr>
<td></td>
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<td>6832</td>
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<td>7278</td>
<td>7743</td>
<td>6832</td>
<td>7300</td>
<td>7772</td>
<td>6819</td>
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<tr>
<td></td>
<td>225 min</td>
<td>6795</td>
<td>7282</td>
<td>7741</td>
<td>6829</td>
<td>7296</td>
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<td></td>
<td>240 min, 4 hours</td>
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<tr>
<td>Stress loss [kg]</td>
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<td>100</td>
<td>31</td>
<td>56</td>
<td>70</td>
<td>40</td>
<td>66</td>
</tr>
<tr>
<td>% Stress loss</td>
<td>0.95</td>
<td>0.93</td>
<td>1.26</td>
<td>0.45</td>
<td>0.76</td>
<td>0.89</td>
<td>0.58</td>
<td>0.90</td>
</tr>
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</table>

In Reference 6 a detailed discussion is given on the results for the investigation of the flat, German and channel anchor plate. The stress loss for the flat, German and channel anchor plate at 75% stress were 2.93%, 1.91% and 0.86% respectively for the total
system. It can now be concluded that the German and channel anchor plate had less stress loss than the flat anchor plate [Reference 6].

5.2.3.2 Production test results

Twenty-four sleepers were cast, twelve of which consisted of the German anchor plate and twelve the flat anchor plate. These sleepers were tested at the University of Pretoria, and the results can be seen in Reference 6. No significant difference in the bending resistance was noticeable between the sleepers manufactured with the German anchor plate and those with the flat anchor plate.

5.2.3.3 Conclusion of laboratory and production test

To finalise the results it was decided that a second test should be done. Four sleepers were cast, two of which consist of the 300WA flat plate and two with the new channel plate [Reference 6]. There was no significant difference in the strength of the sleeper during the bending tests, but the manufacturing process for the channel anchor plate is simpler than the current flat anchor plate production.

It was therefore decided to continue with the economic evaluation of the anchor plates using the channel plate made from 300WA flatbar.

5.2.4 Economic evaluation

The economic evaluation was based on the standard of a wirepair. It was decided that two options must be investigated.

- Importing
- Local manufacturing

Quotations were submitted for the importing of anchor plates from Germany. The costs of importing anchor plates were not economically feasible and this option was rejected. The cost for manufacturing the anchor plate in South Africa was investigated.
The cost of a wirepair would include:
- all material costs
- write-off costs of tooling, parts and punches
- labour and supervision

The material cost of a wirepair would include the prestressing wire and anchor plate material.

The write-off for tooling, parts and punches, is based on two factors:
- cost of replacing tool, inserts and parts
- time before replacement

The time to replace could be determined accurately if a good maintenance plan exists. This however is not the case and estimations based on the experience of the tooling experts were used for the calculations of the write-off costs.

The labour cost as well as the supervision includes a mark-up percentage to compensate for increases and overtime.

A more detailed breakdown of the evaluation can be found in Appendix 8 of Reference 6. For this report a detailed discussion can be seen in Appendix 1.

It was found that a 2.25% saving can be achieved. This however could increase to approximately 3.15% if a higher productivity rate with less labour is reached.
CHAPTER 6

CONCLUSION

6.1 Introduction

The manufacturing of prestressed concrete sleepers may seem simple, but detailed planning and problem solutions are needed during production. Two production systems for the manufacturing of concrete sleepers were discussed namely;

- Longline
- Thosti

The Longline production is used when huge volumes are required. The Longline system is not economical when small quantities and big variations need to be manufactured. The Thosti system on the other hand is much more adaptable to small quantities as well as for big variations of concrete sleepers.

Although the anchor plates are such a small element in the total production system, they can cause huge problems when not used correctly or if they fail. This could easily result in production losses. The anchor plates were therefore tested in such a way that the variables, which occurred during the previous evaluations, could be eliminated.

6.2 Summary of results

6.2.1 Technical results

During an evaluation conducted by Holtz [Reference 6], it was found that the 300WA flat anchor plate deflected more than the “Castro bar” used at that time. "Castro bar" was a $32 \times 9.54$ mm flatbar with a yield strength of 525 MPa. The "Castro bar” was used for the manufacturing of flat anchor plates at that time. The deflection of the anchor plate however caused great concerns, namely;

- the plate might shear under load
the reduction of steel area of the anchor plate's front face might reduce the degree of prestress reached under the railseat
- the yield in the anchor plate due to stressing might cause further reduction in prestress.

The concerns were proven unnecessary for the plates did not fail during testing. It was found that a 6.3% saving in material costs alone could be achieved. Shortcomings however did occur during T.Holtz's evaluation and Phase I [Reference 6]. It was therefore necessary that Phase 2 [Reference 6] must be aimed at eliminating as many variables as possible.

During this investigation it was found that the German plate as well as the 300WA channel plate induced less stress-loss than the flat anchor plate. The anchor plates did not deflect continuously, and could not have induced any stress loss due to bending. The stress loss however could occur due to the following:

- Higher relaxation of wire
- Indentation caused by buttonhead

It was found that no significant difference in bending moment resistance occurred between the sleepers using the channel or German anchor plate and those using the flat anchor plates.

6.2.2 Economical results

In the evaluation by Holtz, the material cost was the only saving considered [Reference 6]. In Holtz’s report no consideration was given to labour savings, maintenance and tools. The material cost for the anchor plate production reduced by 6.3% when a 300WA plate was used instead of the “Castro bar” [Reference 6]

Only during this investigation the economical and technical considerations were taken into account during the anchor plate production. Labour, tooling life, time and material costs were considered during the evaluation. It was found that a saving of between 1.8% and 2.7% could be achieved if a 300WA channel plate is used instead of the 300WA flat anchor plate.
6.3 Implementation of channel anchor plate production process

A progressive tool for the manufacturing of the channel was made and tested to determine whether the tool would produce the channel anchor plate within specification. A progressive tool is a single tool which has multiple stages. Each stage will do a certain operation to ultimately, when the plate has been through various stages, would be completed within specification.

The tests however did not prove to be very successful for cracks occurred on the outside of the bend of the anchor plate. Various steel suppliers were contacted for advice on solving the problem. This investigation is an ongoing process and can be considered for future research.

6.4 Recommendations

It must be noted that stress-loss could occur during wire relaxation, bending of anchor plate, as well as the indentation of the buttonhead into the anchor plate.

With these considerations in mind, it would be recommended that a new test procedure or test equipment be used, which would enable one to test the relaxation, bending and indentation more accurately.

Other considerations would be:

- Conducting a good maintenance plan by gathering data on the maintenance done in production.
- Evaluate other production systems.
- Update standard when a detailed maintenance plan exists and write-off costs can be predicted more accurately.

To conclude, it can be said that the evaluation for the manufacturing and use of the 300WA channel anchor plate proved positive, but consideration must be given to the indentation and tooling for manufacture.
References

1) B.K Bardhan-Roy, P.W Abeles; Types of prestressing steel: Prestress concrete designers handbook; Third edition; page 72

2) Amir N. Hanna; A century of ties; Concrete International; August 1990

3) Janos Beluzsar, Gyula Fogarasi; Manufacturing of railway sleepers and special sleepers for switches and crossings in Hungary; FIP '90 XI congress; Volume II; 4 - 9 June 1990

4) Siegfried Schwarz; Two plants for the production of concrete sleepers and cable channel elements in Belgium; Betonwerk + Fertigtei + Technik; Issue 8; 1993

5) Siegfried Schwarz; Modern production plant for prestressed concrete sleepers in the Netherlands; Concrete precasting plant and technology; Issue 9; 1991

6) H. Jansen van Vuren; Techno economic evaluation of anchor plates in prestress concrete sleepers; Grinaker Duraset Report; Grinaker Duraset Brakpan Branch; November 1998

7) Benjamin S. Blanchard; Logistics Engineering and Management; Fourth Edition; Prentice Hall, Englewood Cliffs; 1992

8) Donald R. Cooper, C. William Emory; Business research methods; Fifth Edition; Irwin; 1995
Appendix 1:

Detailed discussion on wirepair cost evaluation

Note: Only the principles and aspects that were used for the evaluation are explained. This report does not show any values or final calculation.
Anchor plate project

The cost saving between the German anchor plate and the Flat anchor plate was based on the P2 wirepair. The standard cost for the P2 wirepair using the flat anchor plate is calculated in the next few pages.

Standard cost for P2 wirepair based on a flat anchor plate

Anchor plate material

Length_of_plate = 53.1
L = Length_of_plate
Anchor_plate_material = 2L

Anchor_plate_material = 106.2
Am = Anchor_plate_material

6 mm wire

Price = value
Cost_of_material = Price x Anchor_plate_material / 1000

Punch write-off

For the punch, drill and die write off a few aspects have to be considered. The first aspect for the production of the anchor plates is the cropping and punching of the flat bar. The punch for the hole in the plate could last for 10 production days. This was based on a production of 4000 wirepairs per day. This would mean that the punch can last for 80000 punches before it must be replaced. This value could well vary on the quality of plate that is used for the anchor plates. The cost of a punch and blade for the cropping of the plate must also be depreciated for the production of anchor plates. These blades can last for a production period of 120 production days. The cost of these blades is depreciated over 960000 cuts.

Cost_of_punch = value
Cost_of_blade = value

Punch_write_off = Cost_of_punch / 80000
Blade_write_off = Cost_of_blade / 960000

Total_punch_write_off = Punch_write_off + Blade_write_off

NB. The above write off is calculated for one anchor plate.

Flat anchor plate costs RAU.MCD

2/12/99
APPENDIX 1
Drill write-off

The second aspect that must be considered is the drilling operation for the two 6.5 mm holes. This is the bottle neck in the production line. The drilling machine takes of 30 drill bits. These drill bits are priced at a certain value. The total number of holes that can be drilled before the drill bits must be replaced is 40000. The drill bits have to be sharpened every day before production. This operation is also a high maintenance operation. The write off on the drill bits would be the following:

\[
\text{Cost of drill bits} \times \text{Quantity of drill bits} = \text{30} \times \text{40000}
\]

\[
\text{Total cost of drill bits} = \text{Cost of drill bits} \times \text{Quantity of drill bits}
\]

\[
\text{Drill write off} = \frac{\text{Total cost of drill bits}}{\text{Number of holes}}
\]

**NB.** The drill write off is calculated for one plate.

Buttonhead write-off

The third operation for the wirepairs is the buttonheading. Two machines are used for this operation. Each machine buttonheads one side of the wirepair. The plates are then placed on the wirepair and closed at the other end by means of a buttonhead. The machine has three moving parts that must be replaced after a certain production period. These are the following:

1) Clamping jaws
2) Upset hammer
3) Profil form insert

These items should be replaced after a production period of 80000 punches.

1) \[
\text{Cost of clamp jaw} = \text{value} \\
\text{Clamp jaws write off} = \frac{\text{Cost of clamp jaw}}{80000}
\]

2) \[
\text{Cost of upset hammer} = \text{value} \\
\text{Upset hammer write off} = \frac{\text{Cost of upset hammer}}{80000}
\]

3) \[
\text{Cost of profile form insert} = \text{value} \\
\text{Profile form insert write off} = \frac{\text{Cost of profile form insert}}{80000}
\]

The Buttonheading write off will be based on one machine. This would mean that the write off is for one end of the wirepair.

\[
\text{Total Buttonheading write off} = \text{Clamp jaws write off} + \text{Upset hammer write off} + \text{Profile form insert write off}
\]

**NB.** The write off for the buttonheading is for one end of the wirepair.
Cropping write-off

The write off for the wire cropping is also important for this is still part of the manufacturing process for a wirepair. A set of jaws for the wire cropping machine could last for 40 production days. The production rate for the wirepairs is 4000 wirepairs per day. This would give a total number of 320000 cuts before a set of jaws would be replaced.

\[
\text{Cost for insert} = \text{Cropping write off} \times \frac{\text{Cost for insert}}{320000}
\]

\textbf{NB. The cropping write off is based on one wire}

Total write-off

The total write-off cost for the wirepair can now be calculated. This would take the following write-off values into account namely:

1. Total punch write-off for the punching of the anchor plate
2. Drilling write-off for the drilling of the 5.5 mm holes in the anchor plate
3. The total buttonheading write-off
4. The cropping write-off for the cutting of the wires.

It must be remembered that for each wirepair there is two of each namely:

1. \(2 \times \text{Wires}\)
2. \(2 \times \text{Anchor plates}\)
3. \(2 \times \text{Ends}\)

This would mean that the write-off values that were calculated must be multiplied by 2. By adding these values the total write for a wirepair can be obtained.

\[
\begin{align*}
\text{Punching} &= \frac{\text{Total punch write off}}{2} \\
\text{Drilling} &= \frac{\text{Drilling write off}}{2} \\
\text{Buttonheading} &= \frac{\text{Total Buttonheading write off}}{2} \\
\text{Cropping} &= \frac{\text{Cropping write off}}{2}
\end{align*}
\]

\[
\text{Total write off per wirepair} = 2 \left( \frac{\text{Punching} + \text{Drilling} + \text{Buttonheading} + \text{Cropping}}{2} \right) \left( 1 + \frac{2}{100} \right)
\]

Supervision

The next cost that is used for the standard cost of a wire pair is the supervision. This would not change for different wirepairs. This value is fixed at:

\[
\text{Supervision} = \text{hours supervision cost}
\]
Direct labour cost

The direct labour would vary on the number of wirepairs that are produced per man per day. The direct labour is based on a production of 500 wirepairs per man per day. The hours that are worked in one day are used as 9 hours and a 3 percent allowance.

\[
\text{Wirepairs\_per\_man} = 500 \\
\text{Hours\_per\_day} = 9 \left( \frac{3}{100} + 1 \right) \\
\text{Direct\_labour} = \frac{\text{Hours\_per\_day}}{\text{Wirepairs\_per\_man}} \\
\text{Direct\_labour} = 0.01854 \\
\text{Cost\_of\_labour} = \text{value} \\
\text{Direct\_labour\_cost} = \text{Cost\_of\_labour} \times \text{Direct\_labour}
\]

A layout of the production procedure and amount of men working for a production rate of 4000 wirepairs per day can be seen in Figure 1A.

---

Figure 1A: Production layout for 4000 wirepairs/day
Total standard cost

The total standard cost of a wirepair can now be determined. This is shown in the next calculation.

\[
\text{Total standard cost} = \text{Cost of material} + \text{Cost of wire} + \text{Total write off per wirepair} + \text{Supervision} + \text{Direct labour cost}
\]
Appendix 2:

Chemical composition of German Anchor plate
Grinaker Duraset (Pty) Ltd.
PO Box 365
BRAKPAN
1540

Attention: Mr C A Keyser

19 May 1997

Certificate of Analysis. No. 970452

<table>
<thead>
<tr>
<th>Element</th>
<th>Nominal Specification</th>
<th>Sample No. - Composition in Mass %</th>
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<td>300 WA</td>
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<tr>
<td>Carbon</td>
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<td>Manganese</td>
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<td>0.004</td>
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<td>Phosphorus</td>
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</tr>
<tr>
<td>Hardness</td>
<td>HRB</td>
<td>92 - 95</td>
</tr>
</tbody>
</table>

Description of Samples: 5mm Plate

Whilst making every effort to ensure that our services are of the highest standard, they are nevertheless without guarantee or warranty.

PLEASE NOTE: SAMPLES WILL BE DISCARDED AFTER 3 MONTHS.