Safety in Mines Research Advisory Committee

Final Project Report

The Identification, Investigation and Analysis of End-of-wind Protection Devices for Vertical and Incline Shafts

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EXECUTIVE SUMMARY

The occurrence and cause of overwind and underwind events in underground mining were investigated in conjunction with devices, which are at present being applied to prevent and control such incidents. Proposals for in-shaft systems to protect personnel from excessive deceleration forces and subsequent injury or death in the event of underwind/overwind are discussed. The conclusion of the technology study is that a mechanical safety device is necessary to support current systems.

It was decided to concentrate on vertical shafts as these pose the bigger problem. However the solution has to be applicable for incline and vertical shafts.

Different concepts were generated for both the overwind and underwind protection systems. These concepts were evaluated against system requirements and specifications drawn up with the aid of a functional analysis study. The preferred concepts were then designed and built for testing in the 1:10 scale shaft model at the University of Pretoria. A full-scale functional design was done of both the overwind and underwind systems to retrofit them in the SV3 shaft of the South Shaft (South Deep Mine) if approved.

Both the overwind and underwind protection systems that have been developed were successfully demonstrated on an experimental scale. The following systems have been accepted by the relevant SIMRAC Technical Committee

Overwind protection system:
The system makes use of an alternative detaching mechanism. The existing detaching mechanism ("humble hook") is activated by a new mechanism at the beginning of sets of "Jack catches" placed in a specific area below the spectacle plate. When the conveyance enters this area with "Jack catches" the detaching mechanism detaches the cable from the conveyance. The conveyance is then decelerated under gravity and when it stops, it is caught by the "Jack catches" to prevent it from falling.

Underwind protection system:
The system makes use of energy absorption strips being pulled through rollers, similar to Selda strips. These strips are connected by means of by means of cables to both sides of the conveyance. Four systems are used per conveyance. Between the cable and the energy absorption mechanism a compression spring that fails to safety is placed inline with the cable to absorb the initial impact force while the absorption strip is being accelerated.

Full-scale tests need to be done for both the overwind and underwind protection systems to prove and demonstrate the integrity of the systems.

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1 INTRODUCTION

SIMRAC indicated that the annual frequency of overwinds has decreased but now remains approximately constant despite technical advances. Personnel are exposed to extremely dangerous situations and numerous fatalities and serious injuries have been sustained in conveyances during overwind and underwind situations. An investigation into the present safety measures, which have proved to be inadequate has been required as well as the development of a feasible solution to improve the safety of mine hoisting devices.

Mine transportation involves the movement of men, material and rock in both horizontal and vertical manner. Accordingly, transportation is a key issue in any mining operation. In addition, transportation has been acknowledged by industry and the Commission of inquiry into Safety and Health in the Mining Industry as the second largest causes of accidents in mines (*Maslen*, 1996:24-26).

Accidents relating to overwind and underwind were analyzed in an attempt to determine the factors that underlay such accidents. A literature survey was conducted in order to obtain more background on the mining transport safety devices implemented to ensure safe transport of men and material. Current devices were scrutinized as well as developments which could be pursued to improve the safety of hoisting in underground mines.

A functional analysis was done to determine the requirements of the end-of-wind protection devices. Different concepts were generated and evaluated. Scale models of the preferred concepts were then designed in detail and experimental development models (XDM's) were built. These XDM's were tested and evaluated in a one tenth scale mineshaft at the University of Pretoria. A full-scale functional design of the protection devices was then done for a typical mineshaft.

For both the overwind and underwind protection systems the concepts were successfully demonstrated and accepted by the relevant SIMRAC Technical Committee. The protection devices can now be further developed during the following phases of the project.

1.1 Methodology

The following methodology was followed during this project:

- A literature study was done to determine available technology for overwind and underwind protection devices.
- A preview was done on existing systems for end of wind devices.
- After gathering information from industry a functional analysis was done.
- From the functional analysis the requirements for the systems were concluded and the specification and design parameters drawn up.
- It was decided to concentrate primarily on vertical shafts as these installations have more stringent requirements but also to make sure that any solution can be applied to inclined shafts.

The two protection devices, for overwind and for underwind, were further developed separately as the requirements for the two systems are different:

- Different concepts were generated and evaluated against the specification and design parameters. The preferred concepts were then presented to the SIMRAC Technical Committee for approval.
- Experimental development models (XDM) were designed and built for testing in the 1:10 scale shaft at the University of Pretoria.
- The concepts were tested and evaluated.
- Design reviews were done and
- A full-scale functional design of the approved concept was done for a typical mineshaft layout.

The concepts were presented and demonstrated to the SIMRAC Technical Committee and other interested parties from industry.

Recommendations and concerns about the concepts were taken into account during the design review and the experimental models were subsequently changed and re-tested. The changed concepts were again presented to the SIMRAC Technical Committee and other representatives from industry.

The development of the concepts was an iterative process. As new concerns were raised or recommendations made, new or changed concepts were generated. Experimental development models were then designed, built and tested. These new concepts were again presented to the SIMRAC Technical Committee.

Both the end-of-wind protection devices for overwind and underwind that were developed were successfully demonstrated and accepted by the SIMRAC Technical Committee. These designs can now be further developed during a follow-up project if approval is obtained.

2 TECHNOLOGY AND ACCIDENT SURVEY

2.1 Accident survey

2.1.1 Statistics

The inspectors of mines of the various gold mining regions were contacted in an attempt to obtain accurate data pertaining to overwind accidents.

From the information obtained, it is apparent that a large number of overwinds have been reported over the past few years. Jeppe states that up to 1946 as a yearly average over many years there were 100 overwinds reported causing about 12 deaths. Deaths due to overwinds were about 2,99% of the total. (*Jeppe*, 1946)

The most significant circumstances relating to the overwinds are summarized below from information provided by Mr EA Coetzee. (*Coetzee*, 1999)

2.1.1.1 Lebanon Gold Mining Co., 7 Jan 1988. The driver of a man winder overwound the conveyance and pulled it into the headgear which activated the overwind trip.

2.1.1.2 Doornkop shaft, Randfontein Estates Gold Mining Co., 12 Jan 1988. While testing the overwind trip, the conveyance was pulled into the jack catches. It was found that the wire on the ultimate trip had broken.

2.1.1.3 East Rand Property Mine, 18 Jan 1988. A learner driver selected the wrong direction on the winder, causing a overwind and detachment.

2.1.1.4 Wes Driefontein Mine, 23 Jan 1988. During a headgear examination the timber man, while attempting to stop the conveyance, signaled to the driver on the locked bell of the wrong winder. The winder only tripped on slack rope after the detachment. Ostensibly the overwind protection system failed.

2.1.1.5 Simmergo North vertical shaft, 19 Feb 1988. A rock conveyance was overwound causing a detachment. No further explanations available.

2.1.1.6 Free State Saaiplaas Mine, 26 March 1988. Due to so called “false bank” during testing the underlay drum would be on slow braking while the overlay drum is on fast braking resulting in unequally raking modes on the respective drums. This caused the underlay conveyance to run at full speed into the headgear during testing.

2.1.1.7 East Rand Property Mines Ltd, 11 April 1988. A learner driver selected the wrong direction on winder controls. The conveyance was pulled into the ultimate limit trip. The directional protection device apparently failed.

2.1.1.8 Durban Roodepoort Gold Mining Co., 15 April 1988. A rock conveyance was overwind by a driver who has lost concentration at the end of the shift. Ostensibly overwind protection at the end of the systems had failed.

2.1.1.9 East Rand Propriety Mines, 20 April 1988. Whilst hoisting rock, the winder driver hoisted the conveyance past the ultimate limit trip.

2.1.1.10 East Rand Propriety Mines Ltd, 26 April 1988. While hoisting rock, the conveyance was overwind into the spectacle plate. Ostensibly overwind protection systems had failed.

2.1.1.11 Lebanon Gold Mining Co., 26 April 1988. A Laden rock conveyance pulled the upper conveyance into the headgear under gravity, and the brakes could not be engaged timorously.

2.1.1.12 Delokong Chrome Mine, 17 May 1988. The chain of the depth indicator came off, resulting in an overwind.

2.1.1.13 East Rand Propriety Mines, 16 July 1988. A power failure occurred which resulted in an overwind and a rope detachment. The automatic safety system had failed.

2.1.1.14 East Rand Propriety Mines, 16 July 1988. The bolt on the Coombes braking system selector stripped resulting in a loss of braking power, which caused a conveyance to overwind.

2.1.1.15 Hartebeesfontein Gold Mining Co Ltd, 3 October 1988. While the lower rock conveyance on a double drum rock hoist was being loaded with rock at the loading box, the sudden increase in weight of the lower conveyance pulled the upper conveyance into the spectacle plate causing a detachment there.

2.1.1.16 Durban Roodepoort Deep Mining Ltd, 18 February 1989. The winder selected the wrong direction and hoisted a rock conveyance from the tip into the jack catches.

2.1.1.17 East Rand Propriety Mines, 19 April 1989. The driver lost control of the winder and pulled a rock conveyance into the headgear, which caused detachment.

2.1.1.18 East Rand Propriety Mines, 2 July 1989. Excess grease on the rope caused the rope to advance one turn on the drum. This caused the driver to overrun a conveyance containing 16 persons.

2.1.1.19 Messina Diamonds Mine, 15 August 1989. The winder did not reduce the speed of a rock conveyance in time. The three turn warning bell possibly failed. Automatic retarding devices also failed.

2.1.1.20 Vaal Reefs Exploration and Mining Co., 11 September 1989. While testing the overwind on the man winder, the conveyance moved in the wrong direction into the spectacle plate and the rope was detached.

2.1.1.21 Messina Ltd Mine, 15 September 1989.The overwind trip on a man winder was in-operative. Apparently the winder driver also failed to retard and stop the conveyance timeously.

2.1.1.22 Hartebeesfontein Gold Mining Co., 19 October 1989. The retarding system failed to retard the ascending conveyance, which overtravelled into the spectacle plate, notwithstanding the fact that the winder tripped out on overspeed.

2.1.1.23 De Bruinsbank Mine, 26 October 1989. The automatic retarding devices and overwind protection devices were in-operative. The winder driver also failed to retard the conveyance manually.

2.1.1.24 Kinross Mine, 26 January 1990. The Lily controller and retarding cam were incorrectly calibrated, causing the winder driver to run a conveyance into the spectacle plate at full speed.

2.1.1.25 Dancarl Mine, 19 February 1990. The driver failed to retard the speed of the conveyance as it approached the bank. Apparently automatic retardation devices also failed.

2.1.1.26 Vaal Reefs Exploration and Mining Co., 10 May 1991. A rock winder was being operated in automatic mode. Notwithstanding a trip-out on overspeed/underwind/overwind ultimate, the ascending conveyance still overran the trip into the spectacle plate. Incident dynamic tests after the accident showed that the winder should have stopped long before the overwind ultimate, regardless of speed. No cause for overwind could be found.

2.1.1.27 Messina Diamonds Mine, 28 May 1991. A rock conveyance was hoisted past the tip position. The overwind trip did trip the winder engine out, but too late. The detaching hook ascended into the spectacle plate only partly and did not detach.

2.1.1.28 Majuba Colliery, 3 November 1991. Whilst doing repair work on the conveyance the overrun limit switches are bridged out in order to align the cage with the bank level. With the overrun limit switches bridged out, the conveyance was overrun.

2.1.1.29 Hartebeesfontein Gold Minning Company Limited, 22 March 1992. After disconnecting the Lily controller for repair work on the headgear, it was reconnected incorrectly, resulting in an incorrect calibration on the overwind protection systems. This caused registration in the conveyance to be one turn on the drum higher than actually registered on the indicator. This caused an overwind when the winder driver brought the conveyance to the bank level.

2.1.1.30 Messina Investments Limited, 22 June 1992. The hoist driver (on a rock hoist) realized he was approaching the tip too fast. He attempted to reduce speed by applying brakes and reversing power, which was unsuccessful. The driver struck the emergency stop, which was also ineffective due to short circuited contacts. As the conveyance passed the position of the overwind cam, the circuit was reset by an automatic resetting device. The conveyance continued to move despite the reversal of power, moved through the jack catches and spectacle plate and the rope was detached. (This particular mine uses the same conveyance for conveying personnel, although not simultaneously).

2.1.1.31 Durban Roodepoort Deep, 9 July 1992. A small stool fell into retarding cams of the winder, breaking the stool and throwing a piece against the driver’s cabin window giving him a fright. The driver left the controls and stepped back. The conveyance was overwound into the spectacle plate.

2.1.1.32 Western Platinum Mine, 21 September 1992. The driver of a rock hoist was momentarily not paying attention to his instruments. Although the Lily controller and overwind trips were activated, the conveyance was still overwind. In this event a directional switch failed, causing the overspeed safety devices to be overridden throughout the entire journey, instead of only during acceleration away from the trip.

2.1.1.33 East Driefontein, 16 January 1993. While the ultimate trips were being tested, a counter weight was pulled into the jack catches. The cause was found to be a lost bridle magnet allowing the cage to go past the trip mark.

2.1.1.34 Vaal Reefs Exploration and Mining Company 22 January 1993. Lightning caused the PLC to trip. (This is a sophisticated computerized electronic overspeed and overwind protection system). This caused the rock winder to overwind.

2.1.1.35 Consolidated Murchison Mine, 5 April 1993. The ascending conveyance was pulled into the jack catches by the out of balance load on the other conveyance on a double rum winder. The winder driver did not engage the brakes timeously. Automatic overwind protection ostensibly also failed.

2.1.1.36 Durban Roodepoort Deep, 14 May 1993. A conveyance was pulled into the ultimate by either a counterweight or another conveyance (no further particulars available) when the driver failed to apply the brakes timeously, as the overestimated the weight of the ascending conveyance.

2.1.1.37 Buffelsfontein gold Mining Company Limited, 17 May 1993. A rock winder was being used in automatic mode, when the upper conveyance over-travelled into the spectacle plate, detaching the rope. No cause for the overwind could be established. Various tests, including dynamic tests in automatic mode did not reveal any cause. Deceleration rates, brake operation and safety trips were found to be in perfect working order.

2.1.1.38 Western Holdings Gold Mine, 27 September 1993. The lower rock conveyance descended under gravity while being loaded at the loading box.

This pulled the higher conveyance into the spectacle plate, detaching the rope.

2.1.1.39 Vaal Reefs Gold Mine, 14 December 1993. While testing overwind trips, an overwind occurred. The overwind ultimate trip had failed.

2.1.1.40 Vaal Reefs East Mine, 16 January 1994. A rock conveyance was hoisted to the tip in the headgear and was overwound. Ostensibly, the overwind protection devices had failed.

2.1.1.41 Lorraine Gold Mine, 17 January 1994. While tests were being conducted, the winder driver selected the wrong direction on the power lever, causing an overwind. Ostensibly, the directional protection devices and overwind protection devices had failed.

2.1.1.42 Deelkraal Gold Mine, 20 January 1994. While the winder driver was checking the ultimate trips, the ultimate magnetic switch failed to trip. The cause was shorted wires in a cubicle, due to a heater situated next to the wire rack.

2.1.1.43 Messina Diamante Bellsbank Mine, 30 May 1994. In this event the conveyance was simply overrun into the spectacle plate and the rope detached. All overwind and overspeed protection failed.

2.1.1.44 Grootvlei Gold Mine, 3 June 1994. The winder driver selected the wrong direction on his controls, pulling the conveyance into the spectacle plate.

2.1.1.45 President Brand Gold Mine, 17 July 1994. After the front ends of the ropes on a double drum winder were cut off, the winder driver was in the process of recalibrating his indicator. While descending one conveyance to the loading box position, the other conveyance was pulled into the jack catches. Ostensibly, overwind protection devices had failed.

2.1.1.46 West Driefontein Gold Mine, 11 July 1995. The cam gear overwind switch failed and caused an overwind.

2.2 Records of fatal overwind accidents:

2.2.1 Hartebeesfontein Division

On Monday, 27 October 1997 at 17:15, the overlay conveyance was positioned at No. 5A Shaft Bank. The Winding Engine Driver was clutching the underlay conveyance from 78 level to 74 level so that he could start lowering material cars to the level. The Onsetter was already at 74 level. When the conveyance was just above 77 level, it tripped on overspeed and the driver was able to reset it. It tripped again when it was one turn away from 74 level station. The cage started running in the opposite direction. The Winding Engine Driver stated that he tried to apply the brakes but they would not come on. He stated that he also could not control the winder using dynamic braking. The conveyance ran all the way to shaft bottom and all the rope uncoiled from the drum, pulling tight at the hawse hole. From the driver's statement it was evident that he stopped the drum from rotating in the opposite direction by the application of dynamic braking.

The brake system was checked carefully from the calipers, to the brake engine towards the Winding Engine Driver's brake lever. It was observed that the clutch brake interlock counterweight was not in its normal brakes off position. It was hanging lower. Further investigation revealed that one of the levers that transmit motion from the Winding Engine Driver's lever to the brake engine had broken off at a welded joint. The valve for the brake engine was thus locked in the brakes off position and operation of the safety circuits could also not apply the brakes. When the lever was rewelded on, the system operated normally. (*Department of Minerals and Energy, 1997).*

2.2.2 Orangia Shaft, Buffelsfontein Gold Mining Co. Ltd, Klerksdorp.

16 Persons died in an overwind accident on 28 June 1973. The accident was due to the fact that the winding engine driver failed to retard the winding plant manually because he had fallen asleep. The safety devices were accordingly actuated at such a winding speed that effective stopping of the conveyance was impossible. Some unknown factor had rendered the overspeed device ineffective in overspeed protection near the end of wind when the winder was travelling at full speed at the time of the accident. *(GME,* Report 15).

2.2.3 Hartebeesfontein GM Co Ltd

On 24 December 1991 an overwind occurred at No 6 shaft while the No.1 man winder was hoisting in shift automatic mode from 78 level. Three persons in the ascending conveyance died instantaneously and four died later as a result of injuries sustained in the accident. Due to ‘n break in the oil pump coupling of the main and standby pumps mechanical emergency procedures were started. At a hoist speed of 5m/s while the cage was approaching the slow down area, the valve was fully opened, according to the operator. The winder speed continued to increase. He pulled both the clutch levers but with no effect. Operating the switches for the drum spraga had no effect. The conveyance struck the crash beams at approximately 9 m/s. Neither the operator nor the driver was properly trained to perform mechanical emergency procedures.

An investigation to determine the possibility of the brake lining losing its capability due to glazing caused by very light use over an extended period, fade at elevated temperatures and probable light contamination, indicated that the brake torque had reduced to 68% of the design value, but could nevertheless have brought the winder to rest in time. *(Dorbyl,* 1992) CAS. No. JK383/91

These accidents could have been avoided if a mechanical arresting device which came into operation when all else failed, had been in place.

2.3 Overwind accidents in Britain

2.3.1 Survey of data

From 1900 to 1973, overwinding has been the principal cause of shaft accidents. Table 2.3.3.1 lists several serious overwinds.

During the thirty years 1965 to 1995 surveyed for data, there had been a total of 99 overwinds on friction and drum hoists and 11 detachments. (Table

2.3.3.2). Errors on the part of winding engine men or persons maintaining, testing or commissioning the hoisting apparatus have been major contributory factors in overwind incidents over the past 20 years.

2.3.1.1 Limiting the deceleration rate

To provide a limit to the maximum rate of deceleration during emergency the following measures have been suggested:

2.3.1.1.1 Brakes should be so constructed that the engine man can **always** apply a braking effort not less than that of the brake when applied by the emergency devices. This would promote safety if some undetected fault in the system rendered the emergency brake ineffective. But the braking system should be so arranged that the braking effort at any time cannot exceed that which can be applied by either the engineman alone or the emergency devices alone, which ever is the greater.

2.3.1.1.2 Precaution against the effects of overwinding of an ascending conveyance moved by a drum winder can be provided if detaching gear of the necessary standard is installed. Where detaching gear can not be fitted, retarding guides in the head frame and sump can provide good protection against the effects of overwinding of the ascending and descending conveyances.

2.3.1.1.3 Safety catches fitted in the head frame can prevent the conveyance from falling down the shaft in the event of breaking away from the winding rope or suspension gear in an overwind.

2.3.1.1.4 The use of rubber tyred rollers on rigid cage guides have proved to be advantageous.

2.3.1.1.5 A British survey concluded that three designs of the detaching hook, Omerod, King and Humble have made significant contribution towards the safety of mine shaft hoisting systems in the UK. The success of the three designs has been clearly demonstrated on occasions in actual shaft overwinds. The results indicate that overwinds still occur in which detaching gear could save lives.

2.3.1.2 Problems with regard to overwind retardation devices are:

2.3.1.3 Arresting devices on cages or conveyance designed to automatically arrest it in the event of breakage of the rope or suspension gear are not reliable.

2.3.1.4 Keps can give rise to such dynamic shocks that their use should be avoided.

2.3.1.5 End fastenings or capping have proved to be unreliable.

Table 2.3-1: Major overwinds in Britian

YEAR	COLLIERY	*NO OF PERSONS KILLED*	*NO OF PERSONS REPORTABLY SERIOULY INJURED*
1909	*SILVERWOOD*	*0*	*29*
1926	*WEST ARDSLEY*	*2*	*14*
1932	*BICKERSHAW*	*19*	*1*
1934	*POLMAISE*	*2*	*11*
1934	*MURTON*	*0*	*42*
1937	*KILNHURST*	*1*	*17*
1939	*HATFIELD*	*1*	*70*
1958	*BROOKHOUSE*	*0*	*36*
1973	*MARKHAM*	*18*	*11*

Table 2.3-2: Number of overwinds/detachments in Britian 1965 to 1995

YEAR	NO OF OVERWINDS D = DRUM F = FRICTION	NO OF DETACH MENTS	REMARKS
1965	*8 (6D, 2F)*		*1 during manwinding*
1966	*8 (4D, 2F)*		
1967	*13 (4D, 4F)*	*1*	*4 during manwinding*
1968	*10 (6D, 4F)*	*2*	*1 during manwinding*
1969	*6 (3D, 3F)*	*1*	
1970	*8 (7D, 1F)*		*3 during manwinding*
1971	*6 (4D, 2F)*		*1 during manwinding*
1972	*5 (1D, 2F)*	*1*	
1973	*5*	*1*	*1 during winding (Markham Colliery)*
1974	*3*		*1 during manwinding*
1975	*5*	*1*	
1976	*2*		
1977	*5*		
1978	*5*		
1979	*4*		
1980	*5*		
1981	*4 (1D, 3F) 1*	*1*	
1982	*4 (1D, 3F)*		
1983	*1 (1D)*	*1*	
1984	*1*		
1985	*5 (2D,3F)*	*1*	*During manwinding*
1986	*3 (3F)*		
1987	*5 (2D, 3F)*	*1*	*Temporary winder*
1988	*5 (1D, 4F)*		
1989	*-*		
1990	*3 (3F)*		
1991	*-*		
1992	*1 (1F*		
1993	*-*		
1994	*-*		
1995	*-*		
TOTAL	***99***	***11***	

2.4 Technological survey

2.4.1 Introduction

In an address given by Dick Bakker, acting Government Mining Engineer and reported by Bill Krige (Krige) in the publication Mine Safety, Mr Bakker reasoned that it was “important to determine root causes of accidents so that effective meaningful preventative measures (could) be instituted to avoid repetition” as opposed to the concept of fault finding that pertained under the previous mining regulations. This technological survey of safety devices pertaining to underground transport, attempts to address the question of what is available and where improved measures could be implemented.

In deep mining, conveyances are used to hoist men and material to the surface. Partially balanced loading with two conveyances and two ropes is the normal practice on mines. Cylindro-conical, bi-cylindro-conical or cylindrical drums with round ropes are the usual methods for winding in deep shafts. (*Jeppe*, 1946 : 1093).

The methods of controlling speed and acceleration may be subdivided into (*Jeppe*, 1946 : 1100)

Braking – Mechanical and other
Governed speed and acceleration within specified limits and in relation to the position of the conveyance in the shaft.
Safety devices associated with the engine itself for :-

- Preventing of over speeding
- Preventing of overwinding
- Preventing of excessive acceleration
- Indicating the position of the conveyance in the shaft and the speed of travel of these conveyances
- Special purposes such as
    - giving a warning when the conveyance reaches a certain point in the shaft, when the hoist is being restarted in the wrong direction
    - differentiating between the hoisting of men and material or rock
    - preventing the un-clutching of drums unless the brakes are on, etc. by interlocking devices.

Safety devices associated with the braking equipment for preventing excessive deceleration

Safety devices associated with the shaft for:-

- Minimizing the effects of a) overwind – such as humble hooks
  b) rope breakage – jack catches, slack rope alarm
- Indicating when the conveyance comes off track in inclined shafts
- Indicating when there is excessive slack rope (in inclined shafts)

In addition there are a number of regulations governing such factors as:-

- The maximum load that can be carried
- The required power of the engine and of the brake
- The maximum speed of hoisting
- The duties of the driver, such as:-

- Not exceeding the permitted speed
- Avoiding shocks in starting, running and stopping the engine (with the exception of cases of emergency)
- Using all devices at his disposal to prevent overwinding
- Safety precautions in connection with hoisting operations and work in connection with shafts.

Speed and acceleration control devices are so closely interconnected with the braking system and its operation that it is difficult to differentiate between a braking system and a device to control braking speed and acceleration.

In spite of overlapping, certain devices are designed to serve particular purposes. The control of hoisting is thus devided into braking and safety devices.

2.4.2 Braking

A brake refers to any device applying artificial resistance to the motion of a machine or moving body. It either stops the machine, or retards it, or prevents its motion from accelerating.

2.4.2.1 Mechanical brakes

There are two types of mechanical brakes in use:

2.4.2.2 The band brake

The band covers the greater portion of the circumference of the brake drum (Figure 2.4.2.2-1)

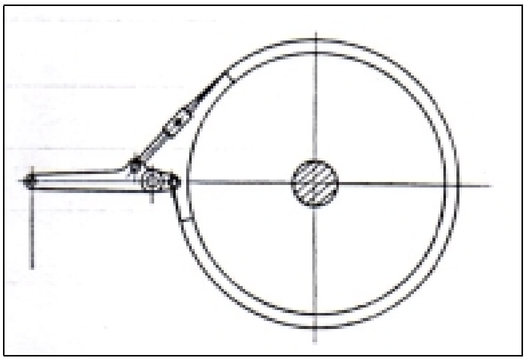

Figure 2.4-1: Band brake (Jeppe, 1946:1127)

If the brakes are applied suddenly when the hoist is in motion, the tension at the anchorage may be doubled or tripled: thus, with heavy loads the limit of band braking with applicable leverage ratios is soon reached

2.4.2.3 The Post Brake

Post brakes require a smaller movement for the necessary clearance from the brake ring, and a more uniform pressure along the whole of the brake path can be achieved.

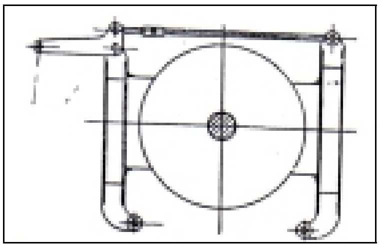

Figure 2.4-2: Straight Type Post Brake (Jeppe, 1946 : 1128)

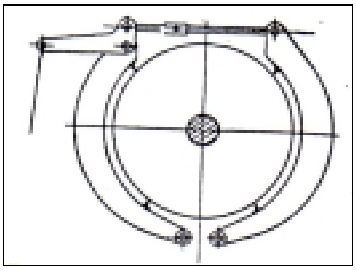

Figure 2.4-3: Curved Type Post Brake (Jeppe, 1946 : 1128)

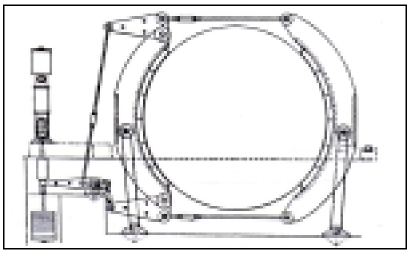

Figure 2.4-4: Suspended Type Post Brake (Jeppe, 1946 : 1128)

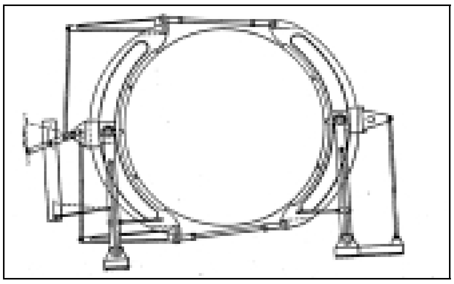

Figure 2.4-5: Parallel Motion Type Post Brake (Jeppe, 1946 : 1129)

The anchorage, regardless of the direction in which the rope winds upon the drum, always carries the load.

The frame of the post brake should be of parallel motion to secure uniform pressure over the entire surface of the brake shoe; supporting the frames on swinging links does this. This type is particularly suited for applying a considerable torque. Post brakes are almost universally used on large hoists.

Brake drums may be on the a) winding drum or b) the crankshaft.
If on the winding drum, there is danger of them getting loose on the winding drum shaft; they are more effective if placed on the crankshaft where they

are applied to the motive power itself, and lashing of the spur wheels is avoided.

The brakes of all larger hoists are applied by weighted levers, and are released by lifting of the weight, so that they are automatically set if the power fails.

Under emergency conditions, a winder must be brought to rest as quickly as possible and without unduly straining any parts of the machine. If undue strains are to be avoided the brake weight should not be rigidly connected to the brake rod. And it is for this reason that a spring box is introduced. It is necessary to damp the brake weight in such a way that its speed is reduced gradually when the brake blocks make contact.

On the majority of electric winders, brake engines operated from a constant oil-pressure supply from a hydraulic accumulator, are installed for lifting the brake weight. Cataract cylinders for damping and controlling the falling mass of brake weights when applying the brake are included (*Jeppe*, 1946 : 1131).

The operation of the emergency button in the case of an electric winder cuts off the current and applies the brakes. If a loaded conveyance is ascending at this moment the ascending loads as well as the brakes are acting in harmony, tending to stop the winder. If these conditions are reversed and there is a fully loaded conveyance descending, the shaft load acts against the brakes, the rate of absorption of kinetic energy will be lower and the number of revolutions performed before the winder comes to a standstill, will be higher. (*Jeppe*,1946 : 1140)

2.4.2.4 Control of braking

The large variation in rates of retardation that may occur when the full force of brake weights is applied (as is possible under emergency conditions) necessitates some control of braking force, so as to prevent high rates of deceleration, with large stresses and possible injury. (*Jeppe,* 1946 : 1140)

This is met by

- Mechanically controlled braking
- Electrically controlled braking
- A combination of both

2.4.2.5 Mechanical governor braking methods.

Mechanical governed braking methods use some form of inertia governor to the braking force. Most methods rely on the following principle:-

When brakes are applied, causing deceleration of the rotating mass, the action of an inertia governor driven from the drum shaft is such as to resist the change of speed. Advantage of this fact is taken by arranging that when a certain rate of deceleration is reached or exceeded, the governor limits any further increase of braking force by:-

- cushioning the rate in a cataract cylinder, or
- re-admitting oil to counterbalance the excess brake weight.

It is invariably stipulated in mechanical braking that the amount of braking force should correspond proportionally to the position of the drivers brake lever. With governed braking systems the same stipulation applies, with the provision that:-

Under emergency application such as (a) tripping of the safety circuit, or (b) when the driver's brake lever is brought to extreme "on" position, the braking force applied shall not cause the deceleration to exceed a predetermined maximum value controlled by the inertia governor action.

2.4.2.6 Electrical governed braking

With the large power required for ultra deep shafts, winders are commonly bi-cylindro conical drums. With such winders normal stoppage takes place only at the bank or with the conveyance in the tipping path even if the driver fails to perform the necessary lever movements. The usual cam gear would slow down the winder and obviate the necessity of severe braking at high speed. Under emergency tripping of the safety circuit opening of the safety circuit may result from:-

- failure of power supply
- automatic opening of AC circuit breaker by means of the overload releases
- operation of overload relay in the main DC circuit
- over speeding of the winder motor
- over speeding of the motor generator (MG) set
- opening of the driver's emergency switch.
- operation of overwind limit switch
- opening or operation of any safety devices connected in the safety circuit.

When such emergency conditions occur at high speeds, stoppage should be performed as rapidly as possible without the creation of undue stresses from rapid deceleration.

2.4.3 Safety devices

2.4.3.1 Safety devices associated with the engine

All such devices work on the principle of negative torque application by the winder brake or prime mover, and there are a variety of devices for applying this negative torque, these devices usually being incorporated in the safety equipment. (*Jeppe*, 1946 : 1150)

They fall under the following headings:-

- Overwind and over speed prevention
- Discrimination between men and rock hoisting
- Power failure protection
- Auxiliary devices
- Deceleration governing
- Clutch and brake interlocking

Such devices are designed for three main purposes:-

- the slowing down of the hoist when it reaches the end of the wind – such devices gives no over speed or retarding protection.
- the prevention of excessive speed at any point in the wind. These devices operate in every wind.
- the controlled retarding of speed in the event of an emergency - only comes into action when such an emergency occurs.

In earlier types of hoists the slowing down of the hoist at the end of the wind was effected by cutting off power and supplying the brakes. The operations were directly under control of the driver, who could assist retardation by reversing at the cost of appreciable waste of power.

To obtain automatic control two elements have to be coordinated:-

- a speed device
- a space element

The speed element is usually some form of governor directly driven from the winding drum shaft.

The space element is a cam or nut and cam, where the position relative to the governor controller mechanism corresponds to the position of the cage or conveyance in the shaft.

A governor actuated member such as a latch, engaging with projections in a moving member whereby an emergency weight or spring is released thereby cutting of power and supplying brakes, causes an appreciable amount of lost motion and friction. Thus it is difficult to obtain sensitive and accurate adjustments and performance.

The chief disadvantage in purely mechanical controllers is that both time and travel to release auxiliary equipment are necessary after the latch engages with the moving element and frequently this delay is sufficient to defeat the purpose of the device.

2.4.3.2 Overwind devices

The two most commonly used overwind devices are:-

2.4.3.2.1 The Whitmore overwinder
2.4.3.2.2 The Job overwinder
2.4.3.2.3 The Lilly Controller

The action of the Lilly Controller is based on co-operated movement of the centrifugal governor and the dial mounted cams, the governor following the speed of the winding engine and the cams following the relative position of the cages or conveyances. (*Jeppe*, 1946 : 1154-1155)

By means of a suitable mechanism the resultant of the governor and cam action is transmitted to a compound electric circuit switch which in case of an emergency –

- first closes a circuit to sound a warning alarm
- with slight increase in speed or approach to end of travel within the retarding zone opens the overspeed switch and creates an immediate reaction by the auxiliary unit, which is held in reserve electrically to cut off the power and apply the brakes.

Two selective cam-operated limit switches are provided in the Lilly controller:-

- for top limit travel
- for bottom limit travel

If the hoist runs beyond the normal extreme limits in either direction, one of these switches will open, cutting off power and applying the brakes.

With the aid of a back-out switch these limit switches provide protection against applying power to the hoist in the wrong direction while at one of the limits of travel, and permit backout out of over travel with safety.

By this system it is possible to conform very closely to the desired maximum speed and retardation curves and when they are not followed within the limits of safety, the auxilliary equipment is promptly brought into action to stop the hoist. Lilly controllers utilise a weight or spring-operated auxillary equipment. Weights are always dependable. A group of springs may be used when very fast action is required since a single spring is not dependable as it may break.

The Lilly controller is a complicated mechanism which must be kept in perfect adjustment if it is to fulfil its duties as a safety device.

The Lilly device controls the speed of the winder throughout the complete wind as the cam translates the speed time curve of the equipment. (*Jeppe*, 1946 : 1155)

It provides for overspeed in the shaft, graduated speed of approach to the limit tripping and also man and rock selective tripping. In addition it provides for slow speed into the tip and fast speed out of the tip.

The outstanding feature of the Lilly controller is that it does not interfere with the driver in any way until he has a lapse, and then a warning gong sounds and if the driver does not respond, the winder is automatically shut down. (*Jeppe*, 1946 : 1157)

The sudden loss of power associated with a severe application of mechanical brakes is liable to create a most undesirable condition, so that any winder fitted with a Lilly controller must have suitable braking arrangements to obviate this hazard.

2.4.3.3 Deceleration governing

Deceleration governing is closely interconnected with the braking system. The form of deceleration governor most favoured has been one in which the brake engine is permitted to operate with mild office control until deceleraton actually takes place, at which point a form of inertia governor controls the engine.

The consistency with which such devices operate depends very largely on careful maintenance of the brake gear as a whole. All valves should be well made and free from leakage, and, above all, leakage past the piston of the cataract cylinder must be avoided. (*Jeppe*, 1946 : 1167)

2.4.3.4 Safety devices in shafts

2.4.3.4.1 Humble hooks

Humble hooks constitute the type of detaching hooks which detach the rope and hold the cage.

The top of the cage is connected to the lower part of the detaching hook and the rope to the upper part. The body of the hooks consists of three or four plates, the two outer ones carrying the load. When an overwind occurs, the hoisting rope, which passes through a ring hole in an iron plate or cylinder draws the detaching hook through the hole and the lower projections are forced inwards and shear the copper pin and the rope is detached: simultaneously jack catches come into action to support the cage.

2.4.3.4.2 Jack Catches

Humble hooks are used in conjunction with jack catches. Single post spring loaded type of jack catches is used in conjunction with slots cut into the bridle of the conveyance. The beams supporting the jack catch posts are designed to allow for a maximum deflection within safe limits, so that the work done on the beams in deflection is equal to the energy of the falling conveyance.

In the double post type springs are discarded and the operation is affected by the action of the bridle on successive catches, each of which positions the catch immediately below. In this arrangement the catches are accessible when supporting the conveyance and each catch is separately released as the conveyance is lowered out.

The jack catches are so arranged that the second catch from the top at each side support the conveyance with the wings of the open hook clear of the catch plate. By this means the jack catches are made the primary supporting device – not the catch plate. (*Jeppe*, 1946 : 1179).

The full value to personnel of Humble Hooks and jack catches is only obtained under non-violent conditions when the hook approaches the catch plate at a slow speed.

To obtain full benefit of protection in the case of a violent overwind it would be necessary to release the rope at a point some distance from the conveyance and arrange a series of jack catches over the whole of this distance.

At 15 – 17 m/s velocity, in order to allow retardation due to gravity to have its full effect, it would be necessary to release the rope when the conveyance is still 12 to 13 m from the catch plate; thus a further overwind distance of 12 to 13 m would be required over and above the normal overwind allowance and jack catches at say 10 cm intervals would have to be installed in order to provide for the varying conditions of overwinding at slow to full speed. A flexible connection e.g. chains between the detaching hook and the conveyance would be necessary, but dangerous features appear after an overwind e.g. damage to jack catches and humble hooks. Humble hooks have proved their value: in more than half the cases of overwind they have come into effective operation.

2.4.3.4.3 Bringing the guides together

By bringing the runners gradually closer together above the top landing, the conveyance, in the event of an overwind, is brought to rest without a severe shock (unless the overwind is violent) and wedges itself so that it cannot fall.

2.4.3.4.4 Overwind space

All headgears must be carried without obstruction to the cage or conveyanceway to such a height as to allow a clearance of at least 8m in which the cage, conveyance or other means of conveyance can travel freely above the highest passenger stopping place in case of an overwind. A similar 8m overwind allowance below the lowest passenger landing place in all shafts exceeding 330m with the exception of sinking shafts is required.

2.4.3.4.5 Limit strips

Limit strips have been installed in the conveyanceways to notify the engine driver when the conveyance has passed a certain point, beyond which there is a danger of overwind.

As a yearly average over many years there were about 100 overwinds reported causing about 12 deaths. Deaths due to overwinds were about 2,99% of the total of all <u>shaft</u> accidents.(*Jeppe*, 1946)

2.4.4 Causes of winding accidents

The main causes of overwinds are:-

2.4.4.1 Reversal of motion or application of power at the beginning of the wind.

In a great number of cases the driver fails to gauge the effort required to hold the load before releasing his brakes: or the driver fails to note that his reversing lever is set in the wrong direction.

2.4.4.2 Hoisting at full speed is carried too far.

Overwinding occurs when hoisting at full speed is carried too far in the wind or, in general, the conveyance travels at excessive speed beyond the limit point at which speed should be reduced.

Such accidents are thus due to:-

- error on the part of the driver
- a defect in the speed control apparatus, generally a maladjustment of the control devices which require great precision in setting.

An inherent defect in most safety devices
is the inefficiency of governers :–

- over a wide range
- at slow speeds

Other occasional causes of winding accidents are

2.4.4.3 Excessive deceleration by braking

2.4.4.4 Deceleration by compression in steam hoists

2.4.4.5 Complicated designs of safety devices.

Complicated designs of safety devices lead to accidents as they are often imperfectly understood. They are commonly subjected to wear and maladjustment.

The ideal is maximum simplicity with maximum effectiveness and automatic control until an emergency of any kind occurs, when the automatic safety devices should be brought into action and the driver warned of the emergency by a single common alarm device, with an indicator placed in the least distracting position showing the cause of the alarm. (*Jeppe*, 1946 :1186).

2.4.4.5.1 Time lag in braking equipment

Even when correctly set there is an inherent failing in the braking equipment itself: there is always a time lag, a delay between the tripping of the gear and the bringing of the conveyance to a stop.

This delay depends on a chain of circumstances
(*Jeppe*, 1946: 1185):-

- Movement of the emergency brake solenoid or emergency trip
- Action of the valve
- Lost motion of the brake tread
- Failing of the braking engine piston and of the brake weight
- Stretching of the rods

2.4.4.5.2 Other brake related causes:

- Contamination of brake paths or lining by oil or moisture or other matter (*NSC,* 1976 : 5).
- Failure of single line components in mechanical brakes (*NSC*, 1976 : 5)
- If brakes are suddenly applied when the hoist is in motion, the tension at the anchorage of a band brake may be doubled or trebled: thus with heavy loads, the limit of band braking with practical leverage is soon reached. (*Jeppe*, 1946 : 1128)
- Interruption of power supply in electrically or steam powered braking (*NSC,* 1976 : 5)
- Secondary bending stresses can exist in rods of mechanical brakes owing to eccentricity, friction and selfweight in addition to primary stresses. The addition of secondary bending could double the primary stress level. (*NSC*, 1976 : 62)
- Fatigue failure can occur in steel at stresses which are generally low particularly where there are points of stress concentration such as screwed threads, welds, sudden changes of section and small manufacturing defects. Secondary bending and fluctuating stresses in addition to primary stresses can be expected to occur in mechanical brake components and their effect must be considered. (*NSC*, 1976 : 6)
- High transient stresses many times greater than the primary stress changes in the normal brake operation can be caused in components when dead weights are allowed to drop. (*NSC*, 1976 : 6)
- If tight rope occurs when the cage moves up the shaft and jams, further attempts by the winder to pull the conveyance will either create a massive overwind with the cage shooting up the shaft and causing extensive damage; or the rope snaps and the cage falls to the bottom. (*NSC*, 1976)

2.5 Design specifications

From the technology survey the following overall specifications were compiled:

2.5.1 Mass

2.5.1.1 Mass of lift: 20 to 30 tons (65% payload) – (Western Areas Limited. Shaft and Winder Committee)

- Each person assesed at 70kg (*Jeppe*, 1134)
- Total load = Permanent load + rope load (17,7 kg/m for 64 mm dia.) + imposed load (SABS 0208-1:12). Formula for weight of rope according to Jeppe: 1,67 D^2.

- The load for standing personnel shall be taken as 6000 N per square meter. (SABS 0208-3:11)
- The load for seated personnel shall be taken as 4000 N per square meter. (SABS 0208-3)

2.5.2 Acceleration

2.5.2.1 Retardation should not exceed 1g in order to minimize risk of injury. Thus retardation of rope at drum should not exceed 4,9 m/s^2 and preferably be less than 3,7 m/s^2. (*NCS*, 1976 : 5).

2.5.2.2 (*Jeppe*, 1946 : 1149) Hoisting speed by depth

Table 2.5-1: Depth (m) vs. Safe hoisting speed

Depth(m)	Safe Conservative hoisting speed
155	6 m/s
155 – 305	8 m/s
305 – 610	10 m/s
610 – 915	13 m/s
Over 900	15 m/s

Assuming a one second braking interval, 8 m overwind allowance, and deceleration equal to g, the permissible speed is 5 m/s. With a deceleration of 1/2g, the practical limit of deceleration, the permissible speed is 4 m/s. (*Jeppe*, 1946 : 1150)

2.5.2.3 18 m/s maximum. On average 15 m/s (Other Mines)

2.5.2.4 Maximum allowable 15,25 m/s (Western Areas)

2.5.2.5 The ministry of mines for British Columbia specifies that a device be installed that in the event of overwind, will bring a conveyance to rest when it is being

2.5.2.5.1 raised, at a rate not exceeding 9,8 m/s2 (1g) or
2.5.2.5.2 lowered at a rate not exceeding 24,5 m/s^2 (2,5g)

2.5.3 Force applied on the lift by the gear

2.5.3.1 Rope strength must be such that the system does not fight the motor (Western Areas).

2.5.3.2 Starting friction should be taken as 25% of weight of one cage plus the weight of the rope. Running friction is taken as 0,6 of this, or 15% shaft friction and 10% windage. (*Jeppe*, 1946)

2.5.3.3 At high hoisting speed the shaft friction is much higher than the engine friction
(*Jeppe*, 1946 : 1100).

2.5.3.4 In practice it is usual to allow as much power for overcoming inertia as is required to lift the load (i.e. double the power to lift the load only) (*Jeppe*, 1946 : 1099)

2.5.3.5 Ascending loads and brakes act in harmony tending to stop the winder. During descending there is an increase in the static rope load of about 29% (*Jeppe*, 1946 : 1137).

2.5.3.6 Tests under emergency conditions have given the following results for a parallel drum winder 652 m wind, raising 6 ton rock load, lowering 54 persons. Motor rating 1244 kW, power of brake 3820 kW:

Table 2.5-2: Deceleration for different retardation power

	Brake force (kW)	Retarding (kW)	Deceleration (m/s^2)
At bank, lowering persons	3820	4036	3,6
At bottom lowering persons	3820	3048	2,72
At bottom raising rock	3820	5192	4,64
At bank raising rock	3820	4202	3,75

With uncontrolled braking under emergency tripping conditions a peak of 6,15 m/s^2 was reached equal to 162% normal static stress. (*Jeppe*, 1946 : 1214)

2.5.4 Rope and clearance

- Specifications of surroundings: Stopping distance 8m below lowest passenger landing place and a clearance of 8m above highest stopping place.
- For load combinations under emergency conditions, the design load effect, partial load factor for all loads when combined with the emergency rope load, the permanent load effect, governing work rope loads, and coefficient of friction between the rope and the winder drum is prescribed by the SABS document on Design of Structures for the Mining Industry (SABS, 0308-1).

2.5.5 Jack Catches

The downward load applied to jack catches and safety doors in case of an emergency shall be calculated in accordance with the resilience of the safety system of jack catches, safety doors and corresponding supports. The calculation shall assume a falling mass equivalent to that of the conveyance plus contents and any underslung load or tail rope (SABS 0208-1)

2.5.6 Braking Load

The conveyance breaking load E_{rC} shall be taken as 1,1 times the manufacturer's estimated rope breaking force. (SABS, 0208-1)

2.5.7 Emergency Arrestor

An arrestor which comes into operation when all else fails should be such as to:

- be ready for instant use independent of human initiation
- retard the traveling conveyance at a reliably predictable rate without exposing its occupants to the risk of injury
- avoid a high initial retarding force and ensure that the force remains constant
- dissipate energy – not store it – to avoid rebound
- be reliable, dependable and robust but cheap to make and install
- remain in a good working order with the minimum of maintenance

2.6 Available proposed monitoring, energy absorption, retarding and arresting devices

2.6.1 Visco-elastic shock absorbers

Bellamble Mining proposed the use of visco-elastic shock absorbers in the event of an accidental or anticipated shock. The energy of the mass, due to its velocity at impact, can be absorbed by a visco-elastic shock absorber and converted into heat. The viscosity (10 to 20 m^2/s) and the compressibility (15% at 400 MPa) of the specially formulated visco-elastic fluids allow a single device to function as a shock absorber and a spring, making any auxillary stroke-return mechanism unnecessary. (*Voith,* 1999)

2.6.2 Mine Hoist Monitor

Plessey Mining developed a Mine Hoisting Monitor suitable for both man cage and rock winder applications. This system uses a microwave communication link from the conveyance to the headgear with the capability to communicate via 20 digital and 4 analogue signals per conveyance. Being PC operated, the system can also be connected to the manufacturer's mine winder PLC, allowing automated control. The system also allows voice communication and signaling facilities between the cage and the surface. By using microwave signals, precise and accurate control can be achieved by the winder as the exact depth and travelling speed of the mine cages can be measured. Safety features include the ability to record bell signalling with the mine Hoist monitor system linked into a brake lock interface facility which locks the brakes until the correct signal is received. The driver monitors the cage position of the conveyance, depth, speed and tonnages. As the mine hoist Monitor accurately records the cage's true position and speed, situations where slack or tight rope occur, will immediately be detected, a warning display indicated and the conveyance brought to a halt. An accuracy to within 2 cm at a speed of 1 m/s is guaranteed for the monitor.

In addition a brake monitoring system is available which monitors wear on the winder brakes. The system is fitted with encoders which measure the brake to shoe distance and brake metal to metal on the brake drum. Through constant monitoring, the system will alert the winder driver to potential problem, e.g. if the brakes are running to hot. If the brake wear reaches maximum threshold set, the system will immediately trip the winder. (*Mining World* – November 1977 p.22-24)

2.6.3 Energy absorption by cyclic elastic bending

When a metal element is pulled through a set of rollers it is subjected “to a process of cyclic plastic bending deformation facilitating energy absorption. The cyclic plastic-bending energy absorber shows stable reliable and predictable behavior. The device has an almost ideal (square) force displacement characteristic, it is not maintenance intensive, and it can be constructed at relatively low cost. In emergency situations where a large moving object is out of control and has to be stopped at a controlled rate this device could find application.”(*Seltrust Engineering*, 1999)

In its simplest form the device consists of one roller around which the element is deformed, as well as a guide roller to force the element to conform to the roller radius. In the case of a three-roller configuration (Figure 2.6-1) the metal element is not subjected to any force prior to reaching the first roller.

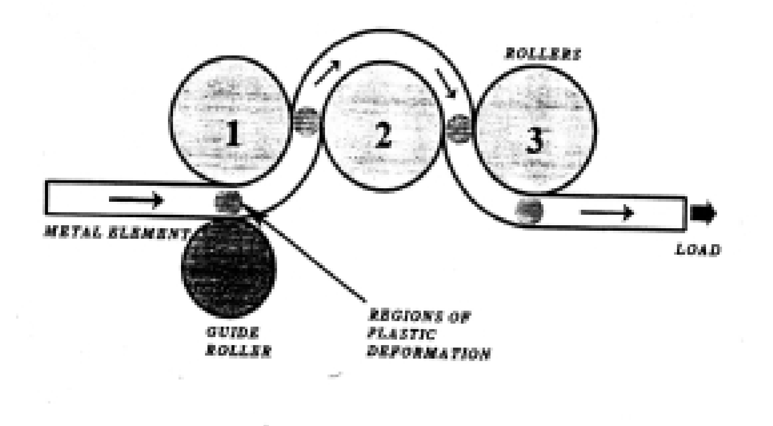

Figure 2.6-1: Cyclic plastic bending energy absorber (3 roller configuration). (*R&D Journal*, 1998 : 15-21)

Once it reaches the first roller every incremental section of the element is consecutively subjected to plastic bending and is deformed to conform to the roller radius. After the initial deformation the sections are not subjected to any deformation whatsoever over the arc of contact with the roller. At the moment when an incremental section leaves the first roller it is plastically unbent. This process repeats itself as each section passes from one roller to the next. Each fibre within the metal element is therefore subjected to cyclic plastic extension and compression the intensity of which varies from a maximum at the outside surfaces to zero at the neutral surface. A certain force is required to pull the element through the rollers and is called the resistance force of the energy absorption device. It is this resistance force acting over a certain displacement of the metal element which facilitates the absorption of energy. (*R&D Journal*, 1998 : 15-21)

Thus when a strip of ductile material is drawn through a series of rollers, being successively bent and straightened, the total energy converted is the product of the resistance and the distance pulled through. The retarding force consists of two distinct elements, namely the frictional resistance of the device and the deformation resistance of the strip material. In this application deformation resistance is much larger and it is this feature which ensures smooth operation and predictable results. (*Seltrust Engineering*, 1999)

A major advantage of the cyclic plastic bending device is that, due to the mechanism of operation, all the material participates in absorbing the energy through plastic deformation. No excessive localized plastic deformation that could lead to failure occurs. This implies that the device has a very high energy absorption capacity per unit mass and is highly reliable. Because it is a tensional absorber, directionality is not critical.

All the results obtained show that the device maintains an almost constant resistive force, virtually from the start of its stroke. This constant resistive force implies that a constant rate of deceleration is obtained which is advantageous if the object being decelerated contains passengers. By suitably choosing the parameters the resistance force can be reasonably well controlled. Only the deformed metal element needs to be replaced after being activated by an accident. (*R&D Journal,* 1998 : 15-21)

The principle of cyclic plastic bending was used in the development of the Strain Energy Linear Ductile Arrestor or SELDA. (*Seltrust Engineering*, 1999)

SELDA was promoted after the disaster at Markham Colliery where 18 miners were killed (1973) and at Moorgate where 43 passengers and staff lost their lives (1974). These accidents could have been avoided by an arresting device which came into operation when all else failed. A mechanism similar to a three roll bar straightening machine was adopted.

SELDA was originally conceived as a protective device on mine shaft winders for the prevention of overwind of friction hoist installations. SELDA units were recommended for use at both ends of the wind. On drum winding installation SELDA could be used at the top of the shaft in conjunction with conventional rope detaching mechanisms incorporated in the device. This combination ensures absolute safety in cases of accidental overwind, in arresting a conveyance approaching at high speeds and absorbing the shock loads, in reverse, resulting from the operation of the rope detaching mechanism when preventing runback. At the bottom of the shaft, SELDA not only arrests a conveyance but it provides a firm landing since it does not function unless the load is in excess of the brake away design figure, usually well above the weight of the full conveyance. (*Seltrust Engineering*, 1999)

The inventors indicated that although strips may be worked repeatedly the carriage is not easily “re-settable” as it requires the introduction of a reverse force. In mining accidents after an accidental overwind the strips should be discarded and replaced. This could be done at low cost.

2.7 Recommendations

In line with the British National Safety Commission who investigated the serious overwind accident at Markham Colliery in North Derbyshire the following guidelines are recommended in the search of a solution for the arresting of mine hoisting devices during overwind/underwind.

2.7.1 For all winding engines the mechanical brake shall be the ultimate means of retarding the winding system and this principle should apply even in the event of failure of one component.

2.7.2 Mechanical brakes should contain no single line component, the failure of which would prevent application of the brake either by the winding engine man or by a safety device.

2.7.3 To bring the winding system safely to rest means preventing the descending conveyance from passing the lowest landing at a speed greater than that at which the pitch bottom arresting devices can accept to bring the conveyance to rest at a specified rate. It also means ensuring that the ascending conveyance does not strike the head frame and that the detach cable is not wound into the winding engine house.

2.7.4 Single line components should be designed for infinite fatigue life but should be given a definite life. All single line components should be operated and maintained within their designed parameters and should be subjected to regular non-destructive testing.

2.7.5 Electrical braking should be retained as backup until the mechanical brake is proved sufficiently effective to retard the winding system.

2.7.6 The electrical torque and mechanical braking should not compound to produce either excessive or reduced rates of retardation.

2.7.7 AC winding engines not at present equipped with dynamic braking should be provided with dynamic braking.

2.7.8 Mechanical brake critical components should be made from materials with adequate guaranteed minimum notch impact values at temperatures likely to be encountered in service.

2.7.9 An arrestor which comes into operation when all else fails should be installed. This arrestor should be such that it :

- be ready for instant use independent of human initiation
- retard the traveling conveyance at a reliably predictable rate without exposing its occupants to the risk of injury
- avoid a high initial retarding force and ensure that the force remains constant
- dissipate energy – not store it – to avoid rebound
- be reliable, dependable and robust but cheap to make and install
- remain in a good working order with the minimum of maintenance

2.8 Protection device at Palabora mine

Towards the end of the project information was received that Palabora mine had protection systems for overwinds and underwinds. However a requested visit to the mine to gather more information about the protection devices was turned down as a moratorium was placed on all shaft visits until April 2001.

3 FUNCTIONAL ANALYSIS

A functional analysis was done on overwind and underwind protection devices. Taking into account the requirements for end-of-wind systems that were gathered visiting different mines and talking to people involved in mine hoisting and safety as well as information gathered through the literature study the functional analysis was compiled. Both platinum and gold mines were visited. In figure 3.1 the system level of the functional analysis is shown and the complete functional analysis is listed in Appendix A.

The results of the functional analysis were used to draw up the specification and requirements for the systems. The main system requirements can be summarized as follows:

- The end-of-wind protection devices are ultimate protection devices. An arrestor which comes into operation when all else fails.
- Be ready for instant use independent of human initiation.
- Be reliable, dependable and robust but cheap to make and install.
- Remain in a good working order with the minimum of maintenance.
- Mechanical devices are preferred (electrical or hydraulic are not recommended).
- The detaching hook must remain (?).
- Retard the traveling conveyance at a reliably predictable rate without exposing its occupants to the risk of injury. Avoid a high initial retarding force and ensure that the force remains constant. To prevent injuries to people transported the maximum deceleration for the conveyance traveling upwards is 9.81 m/s^2 1g and for the conveyance traveling downwards is 24.5 m/s^2 (2,5g).
- Dissipate energy – not store it – to avoid rebound.
- After stopping the conveyance, the device must prevent the conveyance from falling down the shaft.

3.1 Functional analysis flowchart

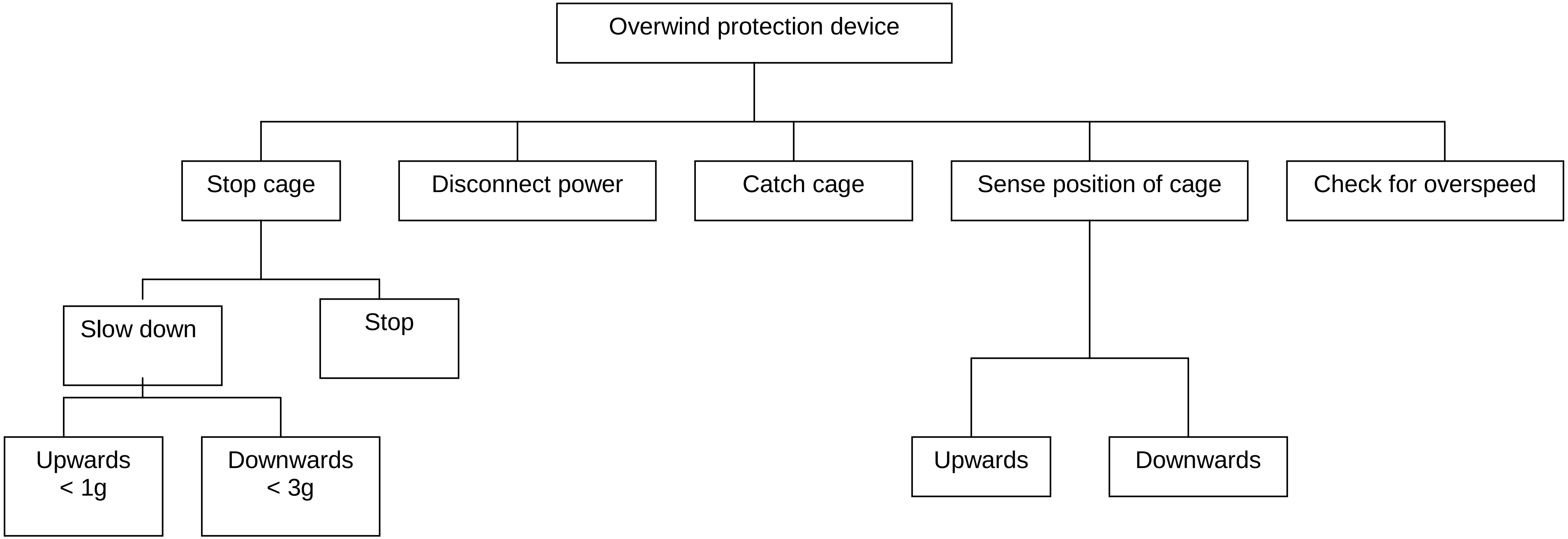

Figure 3.1-1: System level functional analyses

4 UNDERWIND PROTECTION DEVICE

4.1 Specification and design parameters

The functional requirements for underwind protection devices are:

- The maximum deceleration to prevent injuries to people transported in the conveyance is 24.5m/s² (2,5 “g”).
- After stopping the conveyance, the conveyance must be prevented from falling down the shaft.
- The system preferably has to be a mechanical device. Electricity or hydraulics can be affected by the primary cause of failure.

4.2 Concept design

Different concepts were generated and evaluated against the specifications and design parameters for the system. Although the design parameters state that the system should preferably be mechanical, other concepts, including hydraulic, electric, electro magnetic and pneumatic were also generated and evaluated. In figure 4.2-1, some of the initial concepts generated are shown.

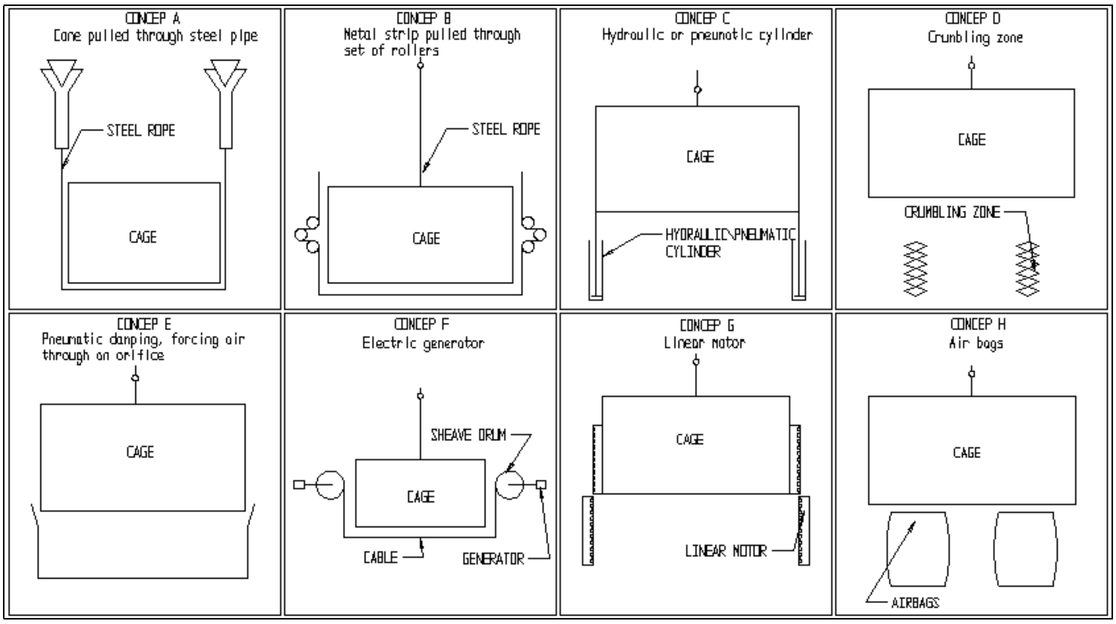

Figure 4.2-1: Selection of initial underwind concepts considered

During the initial evaluation of the different concepts it was concluded that only the mechanical concepts could meet the design requirements. In the following paragraphs the selected concepts are discussed.

4.2.1 Technogrid

Technogrid is a commercially available system, which is marketed by Horne Hydraulics cc. Although this is not a new concept this system is discussed as it presents a solution to energy absorption problems. The technogrid system provides a means of energy absorption with impact bodies. This is accomplished by deforming a steel grid section. See figure 4.2-2. The force applied is in tension. On impact, the individual elements of the grid are forced through an arc, causing double curvature bending. This deformation converts the kinetic energy into strain energy, which is safely dissipated in the form of low-grade heat.

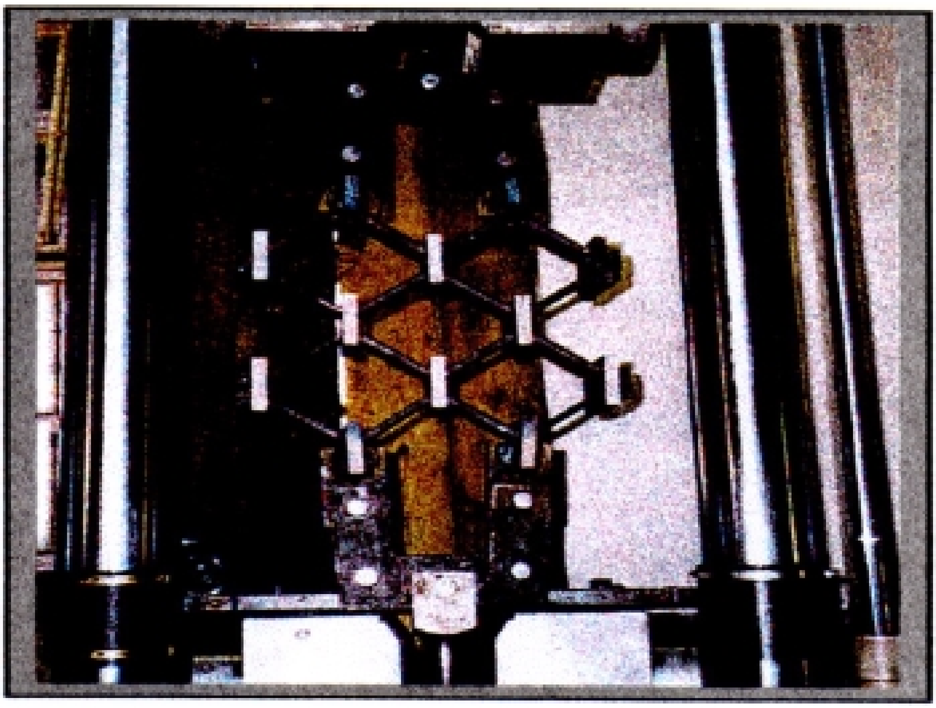

Figure 4.2-2: Technogrid energy absorption system

By varying the length of the bars, and the number of bars in the grid, and combining, duplicating and extending the grid, different shapes can be achieved. End forces, and safe deceleration, can be controlled for a wide range of potential energy.

To achieve a deceleration of less than $24.5 m/s^2$ a system for a conveyance travelling at a maximum speed of 15m/s has to have a deformation capability of at least 4.6m, which necessitates a long system that will be relative costly. To counter rust relative expensive materials like stainless steel will have to be used.

4.2.2 Energy absorption strip

If an underwind situation occurs, the conveyance runs into cables connected via a shock absorbing system to the energy absorption mechanisms. The system is duplicated on both sides of the conveyance so that no relative motion between the conveyance and the cable takes place. See figure 4.2-3. The cables then pull a metal strip through a set of three rollers (energy absorption mechanism). This system is similar to the “Selda strip”. See figure 4.2-4. The kinetic energy of the conveyance is dissipated through the deformation of the metal strip.

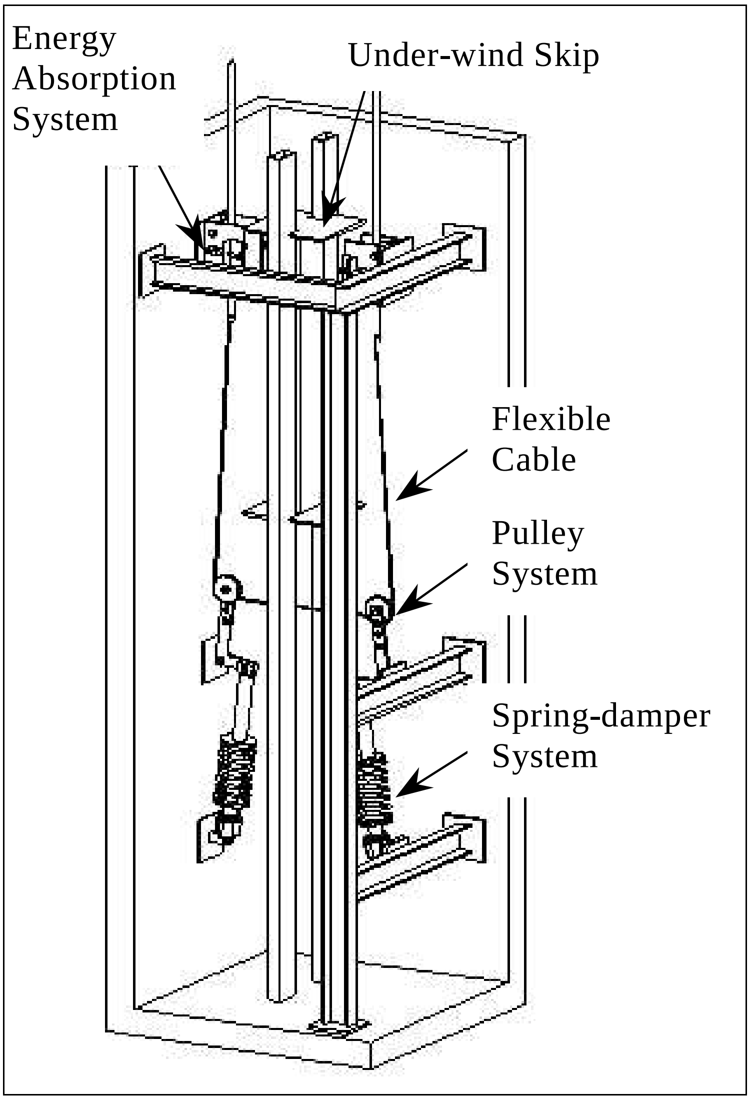

Figure 4.2-3: Energy absorption underwind protection system

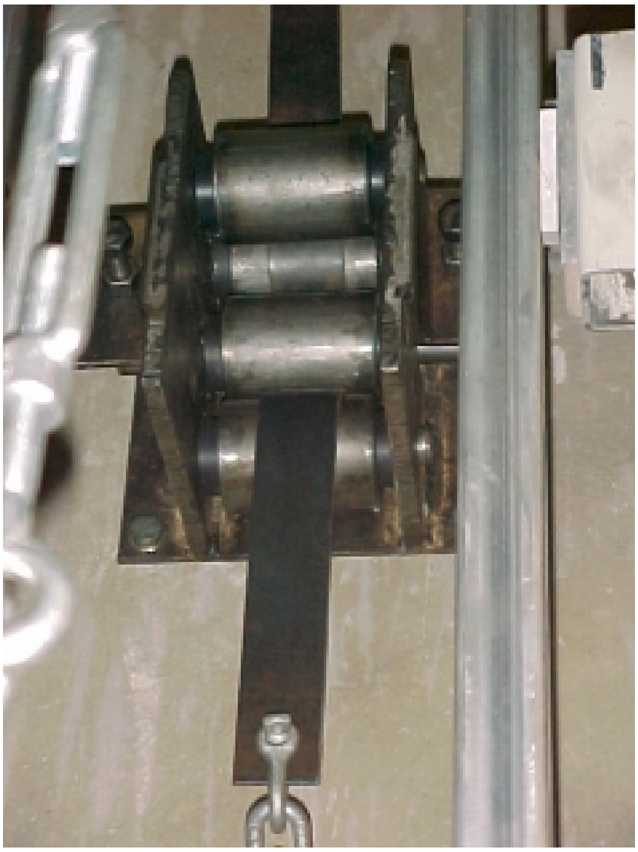

Figure 4.2-4: Metal strip energy absorption mechanism

The operation of the material deformation mechanism is based on the strength of material theory. A metal strip, as an example, requires a specific applied forced to deform the material elastically. This force is a function of the material properties in example the yield stress or elastic limit of the material. The principle operation of the material deformation mechanism is based on a metal strip that is pulled through a set of offset rollers. See figure 4.2-4. The forced deformation of the metal strip is the mechanism that is used to absorb the energy.

To absorb the initial impact when the conveyance hits the cable two concepts were developed. The one concept makes use of a spring/damper system connected via a bell crank to the cable and the other has a compression spring connected in series with the cable and the energy absorption mechanism.

4.2.2.1 Energy absorption strip with spring/damper and bell crank

To absorb the initial impact when the conveyance hits the cable, a spring/ damper system connected via a bell crank to the cable that pulls the metal strip through the energy absorption mechanism is used. The operation of the spring/damper system is similar to that being utilized in the suspension configuration of an automotive vehicle. In figure 4.2-5 the layout of the underwind protection system with the spring/damper and bell crank is shown while in figure 4.2-6 the spring/damper and bell crank sub-system is shown.

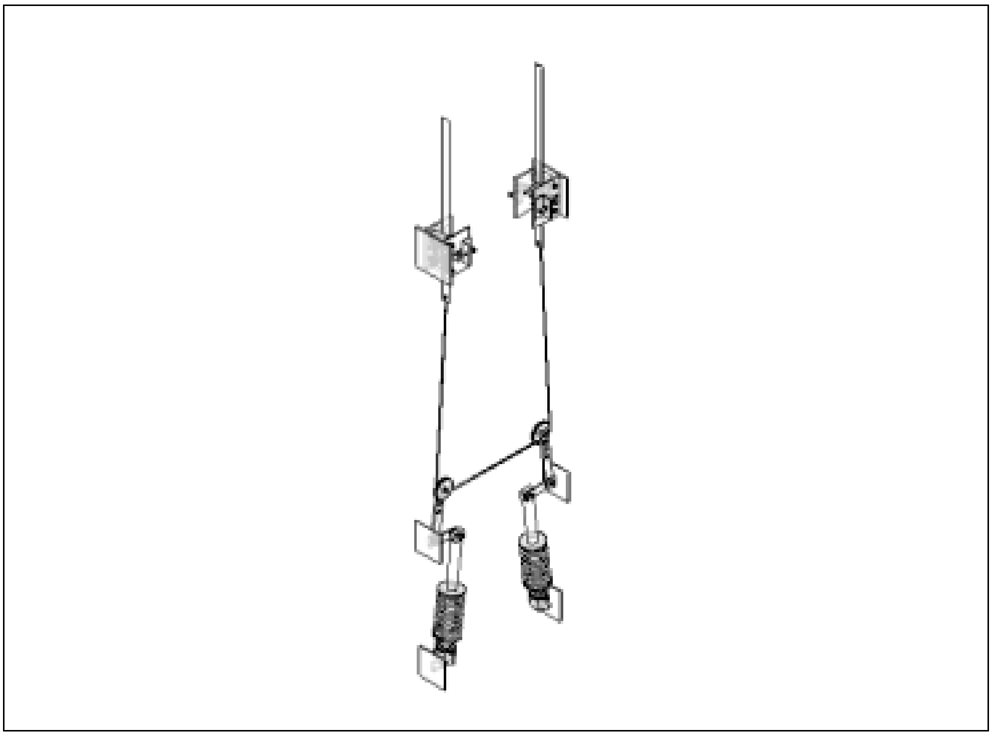

Figure 4.2-5: Layout underwind protection system: Energy absorption strip with spring/damper and bell crank

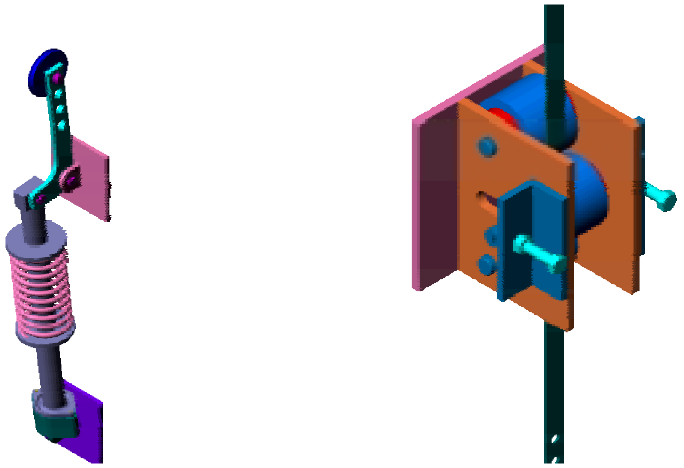

Figure 4.2-6: Spring/damper and bell-crank sub-system

The advantage of this system is that all the energy is absorbed and no rebound takes place. The disadvantage is that the bell-crank takes a lot of space, which was subsequently found not to be available in all the shafts. This system can thus not be fitted in all the shafts.

4.2.2.2 Energy absorption strip with compression spring

To absorb the initial impact when the conveyance hits the cable an in-line compression spring is placed in series with the cable to absorb the first impact while the energy absorption strips are accelerated. The spring is a compression spring, which will fail to safety. Figure 4.2-7, shows the layout of the underwind protection system.

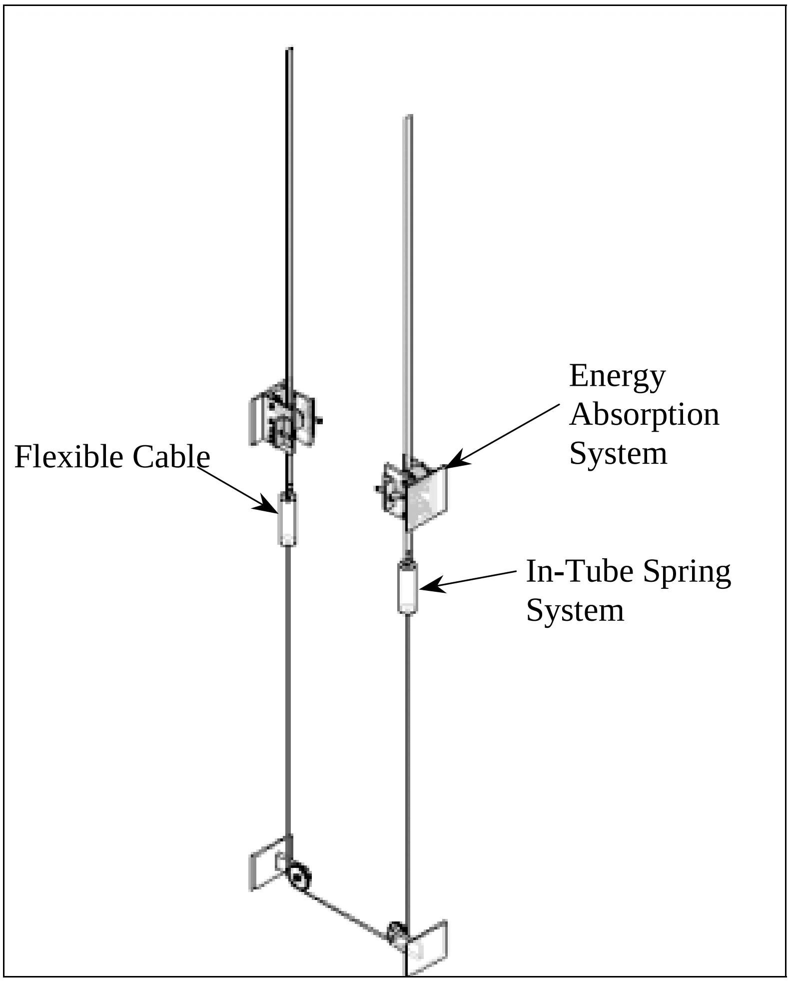

Figure 4.2-7: Layout of underwind protection system: Energy absorption strip with in-line compression spring

The advantage of this system is that it is very compact and can be fitted in the limited space available at shaft bottom. If the compression spring fails, the spring fails to safety and the strip is still pulled through the energy absorption mechanism. The disadvantage is that some energy is not dissipated and stored in the compression spring, which will result in a small amount of rebound. If this does pose a problem a damper can be used to reduce the rebound. A damper would however increase the maintenance requirement of the system.

4.2.3 Proposed concept

The proposed concept for the underwind protection system is the energy absorption strip, as described in paragraph 4.2.2, with the two different systems to absorb the initial impact when the conveyance hits the cable. This concept can also be used in incline shafts.

4.3 Design of Experimental model

Experimental models of the energy absorption strip concept, as described in paragraph 4.2.2, with the two different systems to absorb the initial impact when the conveyance hits the cable, were designed for the 1:10 scale experimental mine shaft at the University of Pretoria. The two initial impact absorption systems are the spring/damper system connected via a bell-crank to the catching cable, as described in paragraph 4.2.2.1, and the compression spring in-line with the cable, as described in paragraph 4.2.2.2.

4.3.1 Energy absorption strip with spring/damper and bell crank

A detail design was done for the energy absorption strip system with spring/damper and bell crank, from which the system was built. Detail drawings for all the components were made. In figure 4.2-8 the assembly of the energy absorption system is shown.

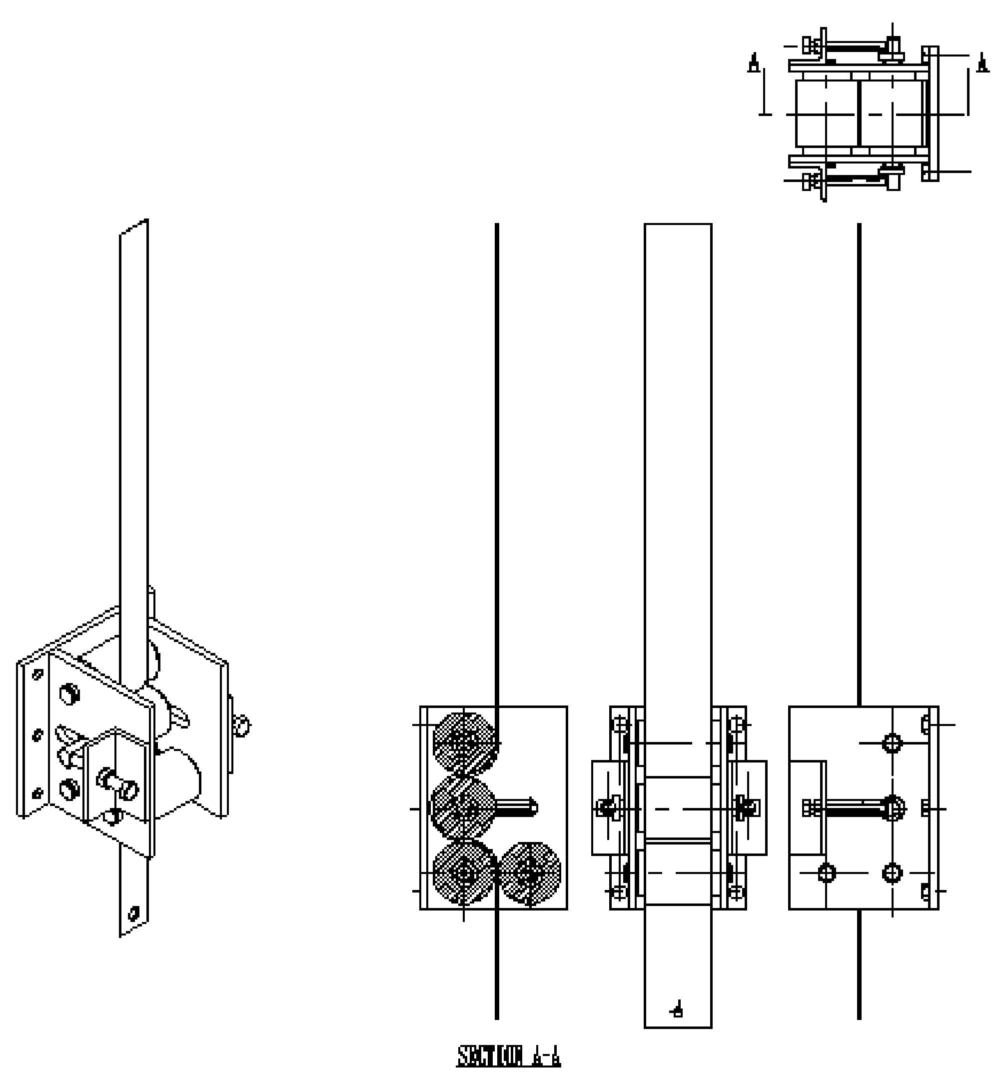

Figure 4.3-1: Assembly of energy absorption mechanism

4.3.2 Energy absorption strip with compression spring

A detail design was done for the energy absorption strip system with in-line compression spring, from which the system was built. Detail drawings for all the components were made. The drawings correspond with the ones described in paragraph 4.3.1 with the exception that the spring/damper and bell crank is replaced by the compression spring.

4.4 Laboratory testing of experimental models

For the concept as described in paragraph 4.2.2, the energy absorption strip was tested with the two different systems to absorb the initial impact when the conveyance hits the cable. These two systems are the spring/damper system connected via a bell-crank to the catching cable and the compression spring in-line with the cable.

4.4.1 Laboratory test methodology

4.4.1.1 Test system instrumentation

The system was instrumented with piezoelectric accelerometers that enabled the measurement of acceleration with regard to the three main axes (x, y and z). Two normally open switches were also placed a specific distance (100 mm) apart to enable the speed measurement of the falling conveyance before impact. The accelerometers were connected to a signal conditioner that enabled the conditioning and amplification of the accelerometer signals. The normally open switches were connected to an external voltage source that emitted a specific voltage level when the switch was closed. The accelerometer and switch voltage signals were digitally sampled through an analogue-to-digital system.

Figure 4.4-1: Acquisition equipment

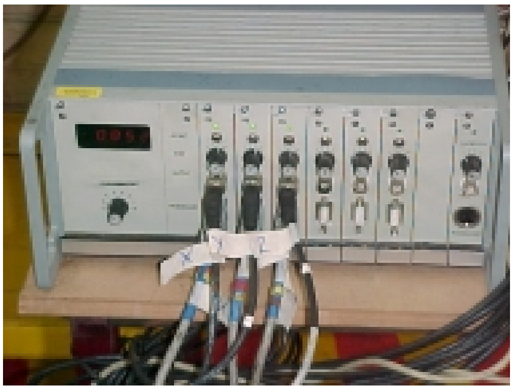

Figure 4.4-2: Signal conditioner

4.4.1.2 Experimental procedures

The experiment was divided into three different phases:

The first phase of the testing involved the rectification of the simulation system and instrumentation related problems. The second and third phases of testing were used to determine the correct dimensions of the energy absorption mechanisms to ensure that the maximum peak deceleration does not exceed the prescribed value of 2,5g.

The experimental procedures utilised during the different test phases were the same.

The conveyance, which was connected to a quick release mechanism, was lifted to a pre-defined height via a cable and pulley system. This height is a function of the speed of the conveyance required. The recording of the accelerometer data was initiated prior to the triggering of the release mechanism. The conveyance was thus allowed to free fall up to the point of impact. At the point of impact the energy absorption system would then dissipate the kinetic energy of the free falling conveyance (A step-by-step test procedure is depicted in table 4.4.-1).

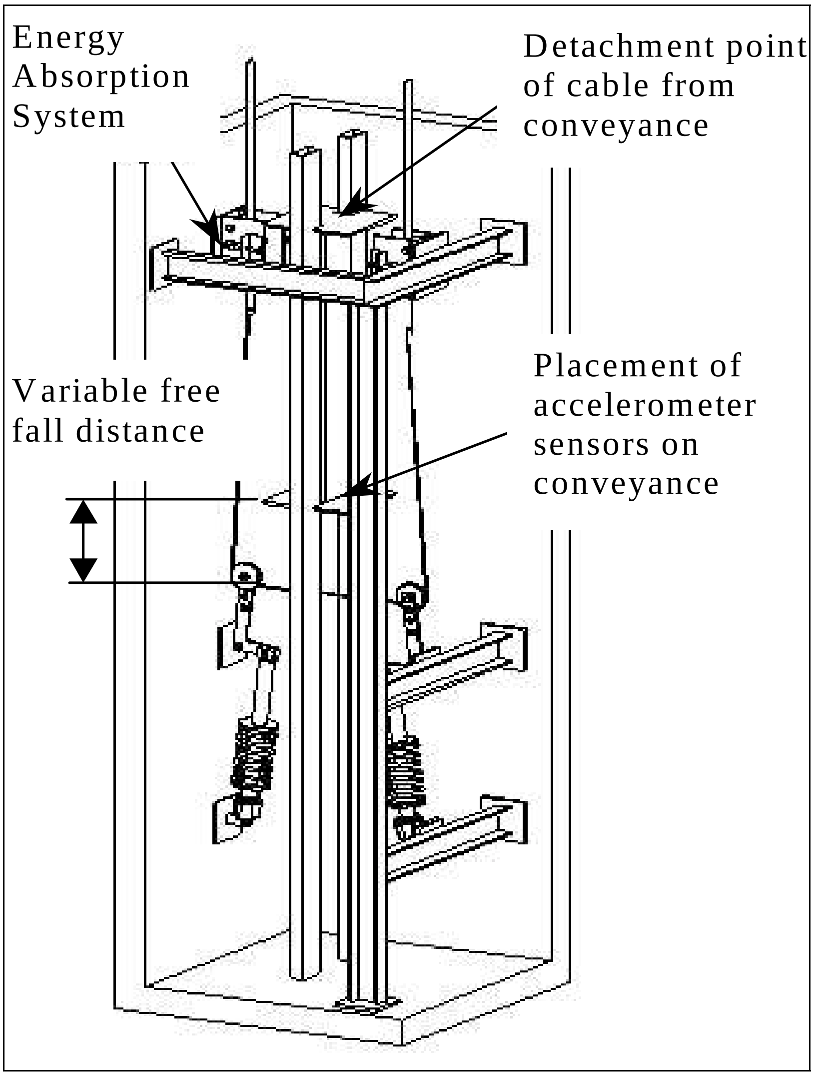

Figure 4.4-3: Tenth scale mine shaft test set-up.

Table 4.4-1: Experimental procedure

- Secure conveyance in a safe fixed position above the underwind system.
- Insert metal strips into the energy absorption system and connect and check test instrumentation.
- Connect steel cable through pulley system to the inserted metal strips.
- Connect quick release mechanism to the conveyance.
- Move the conveyance to the pre-determined test height.
- Activate quick release mechanism and data acquisition system.
- Disconnect conveyance from cable.
- Take measurements.
- Connect conveyance to cable.
- Return conveyance to a safe position above the underwind system.

4.4.2 Discussion of results

The data recorded during the first phase of the research project will not be presented in this report because the data is deemed not to be relevant to the primary objective of the report. The results obtained from the first phase will however be discussed in brief because it impacts on the second testing phase.

4.4.2.1 System configuration – test results

The results obtained from the first phase of testing highlighted the following points:

4.4.2.1.1 The stiffness of the spring-damper system used within the energy absorption mechanism to assist in the dissipation of the initial impact energy was incorrect. The stiffness was too low. During the first testing phase it was observed that the pulley system (refer to Figure 4.4-3) knocked against the under-wind conveyance during the operation of the absorption mechanism. The stiffness of the spring-damper system therefore needed to be increased.

4.4.2.1.2 The piezoelectric accelerometers used during the first phase of testing were found to be limited in range and sensitivity and thus not suitable to the testing application required for this project. The acceleration signals recorded during the first phase were not representative of the theoretically calculated accelerations. A different type of accelerometer was therefore used in the second testing phase. The problem was that only one of the three axis directions could be measured accurately. The z-axis (vertical direction) was therefore selected for the placement of the a more robust accelerometer.

4.4.2.1.3 It was observed during the first phase of the testing that the under-wind conveyance might run through the absorption mechanism during the iterative testing phase. To ensure that this does not happen the pre-set release height for the second phase tests were adjusted to a lower position and a rubber wheel (bump stop) was placed at the bottom of the shaft. This was also done as a precautionary step to ensure the integrity of the measuring equipment.

4.4.2.2 Spring-damper system – test results

(Determination of metal strip size)

The accelerometer data was recorded digitally through the use of an analogue-to-digital system. The data was sampled at a sampling frequency of 1600 Hz with a cut-off frequency of 150 Hz. The data was calibrated and the data presented in graphical format. The results obtained from this testing phase are depicted in Appendix B. The maximum peak deceleration values presented in Table 4.4-2 are discussed in the following paragraph.

Table 4.4-2: Peak deceleration values (concept no. 1)

Test no. (Concept 1)	Strip dimensions (width x depth)	Maximum peak deceleration (g)	Stopping Distance (mm)
1	10 x 3	5,80	Run through to bump stop
2	12 x 2	3,45	Run through to bump stop
3	20 x 2	3,79	Run through to bump stop
4	15 x 1,6	3,17	Run through to bump stop
5	20 x 1,6	2,47	710
6	20 x 1,6	2,62	690
7	20 x 1,6	2,53	710

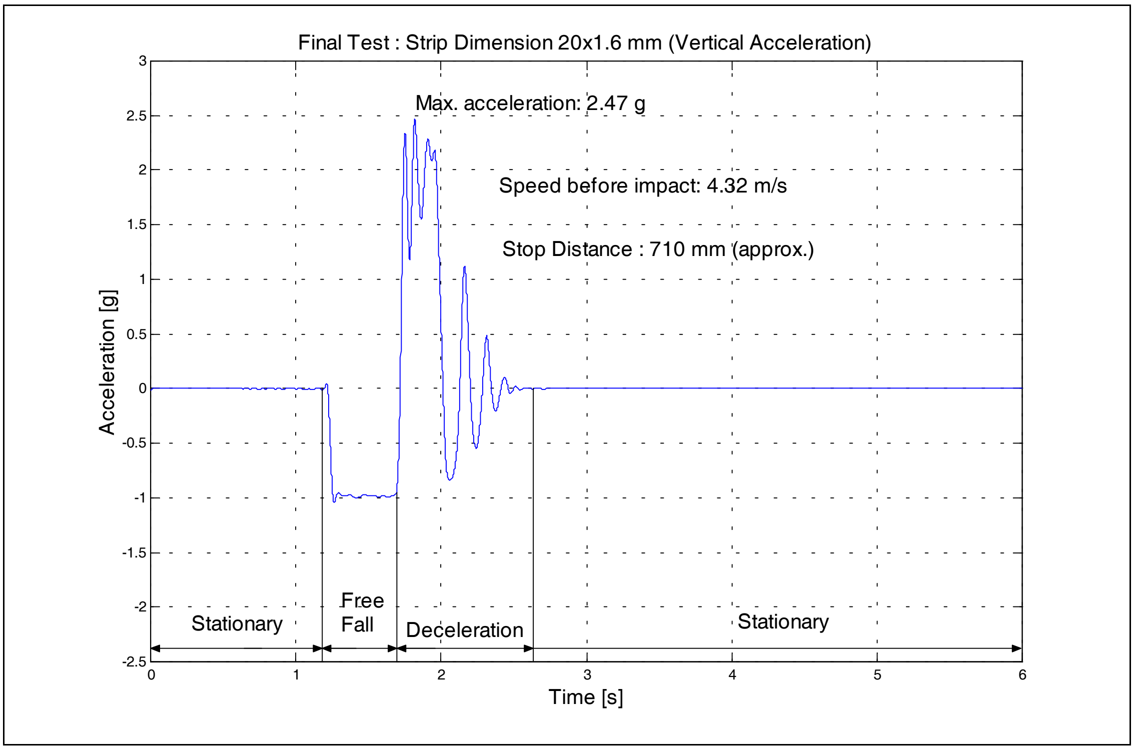

Figure 4.4-4: Spring-damper system test result graph

Figure 4.4-4, shows the different phases in the underwind test. The conveyance is stationary before activation of the release mechanism. Activation of the release mechanism enables the conveyance to fall down the simulation shaft to the activation point of the underwind mechanism. The underwind mechanism then decelerates and stops the moving conveyance. The graph shows that the maximum deceleration obtained during the testing of the system was approximately 2.5g.

4.4.2.3 In-line spring system– test results

(Determination of metal strip size)

The accelerometer data was recorded digitally through the use of an analogue-to-digital system. The data was sampled at a sampling frequency of 1600 Hz with a cut-off frequency of 150 Hz. The data was calibrated and the data represented in a graphical format. The results obtained from this testing phase are also shown in Appendix B.

Table 4.4-3: Peak deceleration values (concept no. 2)

Test no. (Concept 2)	Strip dimensions (width x depth)	Maximum peak Deceleration (g)	Stopping Distance (mm)
1	34 x 1.6	3.18	610
2	33 x 1.6	3.04	637
3	27 x 1.6	2.77	680

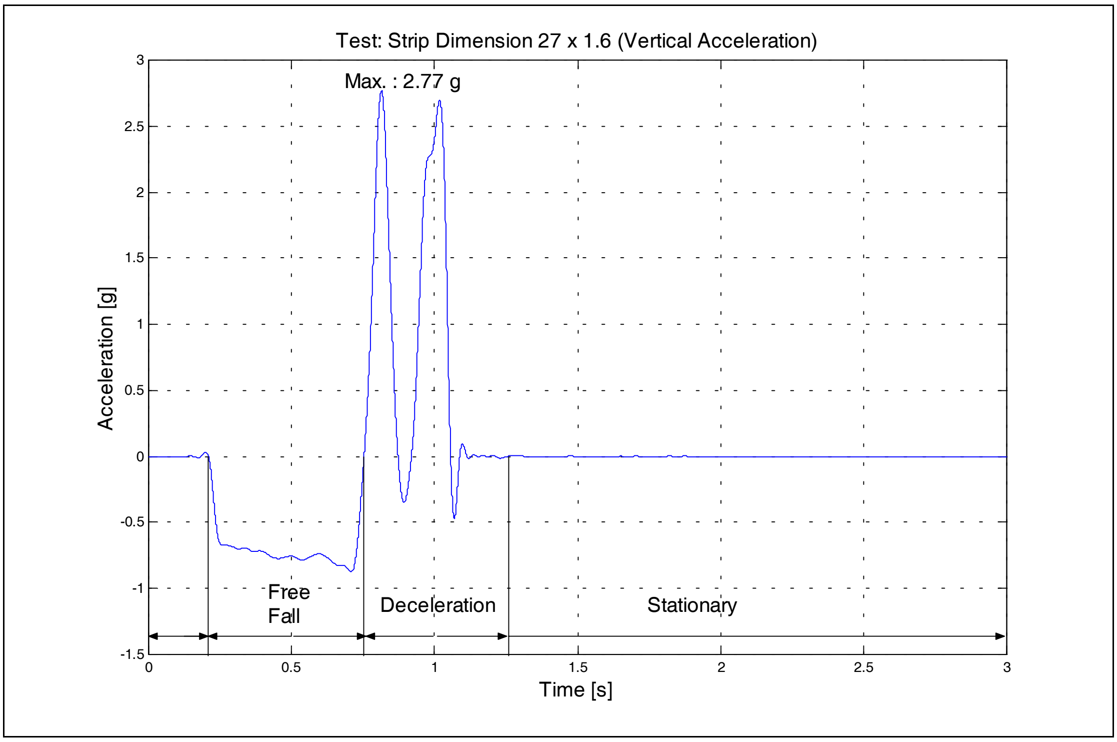

Figure 4.4-5: In-line spring system test result graph

The graph depicted in the figure 4.4-5, shows the deceleration during a test performed to determine the metal strip size for the in-line spring system. The graph follows the trend that has been observed from the spring-damper tests with the different phases: stationary, free fall, deceleration and stationary phase. A maximum 2.77g deceleration value was obtained from the test. This is approximately 10% above the set norm of 2.5g deceleration but with a slightly smaller strip size the deceleration will be below 2,5g as required.

4.4.3 Conclusion

The arresting of the conveyance was successfully demonstrated. A deceleration of less than 2,5g was achieved during the test.

A number of tests have been performed. The results obtained from these tests show the repeatability of the system.

4.5 Design Review

As the development of the concepts was an iterative process, a design review was held more than once. As new concerns were raised or recommendations made, a design review was held and new or changed concepts were generated. These new concepts were then again presented to the SIMRAC Technical Committee.

After the successful testing of the concept described in paragraph 4.2.2.1, the energy absorption strip with the spring/damper mechanism connected via a bell-crank to the catching cable, different mine shafts were visited to investigate the possible application of the system. It was found that not enough space exists between the wall of the shaft and the area where the conveyance travels, to install the spring/damper and bell-crank mechanism. The design was subsequently changed to include a compression spring instead of the spring/damper and bell-crank combination. This new concept is described in paragraph 4.2.2.2. This system was then presented and demonstrated and comments from industry were very positive. The system was also presented to the relevant SIMRAC Technical Committee, which accepted the concept.

4.6 Full scale design (functional)

A full-scale functional design of the concept for the underwind protection device was done for the SV3 shaft of the Western Areas Gold Mining Co Ltd South Shaft (South Deep Mine). A layout of this design can be seen in figure 4.6-1 and the detail drawings are attached in Appendix C. Two sets of underwind protection systems are placed to balance the loading on the conveyance when an underwind situation occurs. The energy absorption systems as well as the rollers holding the cable are connected to the shaft wall by rock bolting into the rock. The cable to be used will be of Stainless Steel to prevent any rusting. The spring, which is a contained unit, can be packed with grease to protect it against rust. The deformation strip is placed inside a square tube which is also packed with grease to prevent rust. Since all the different components of the system are protected against rust, very low maintenance if any will be required.

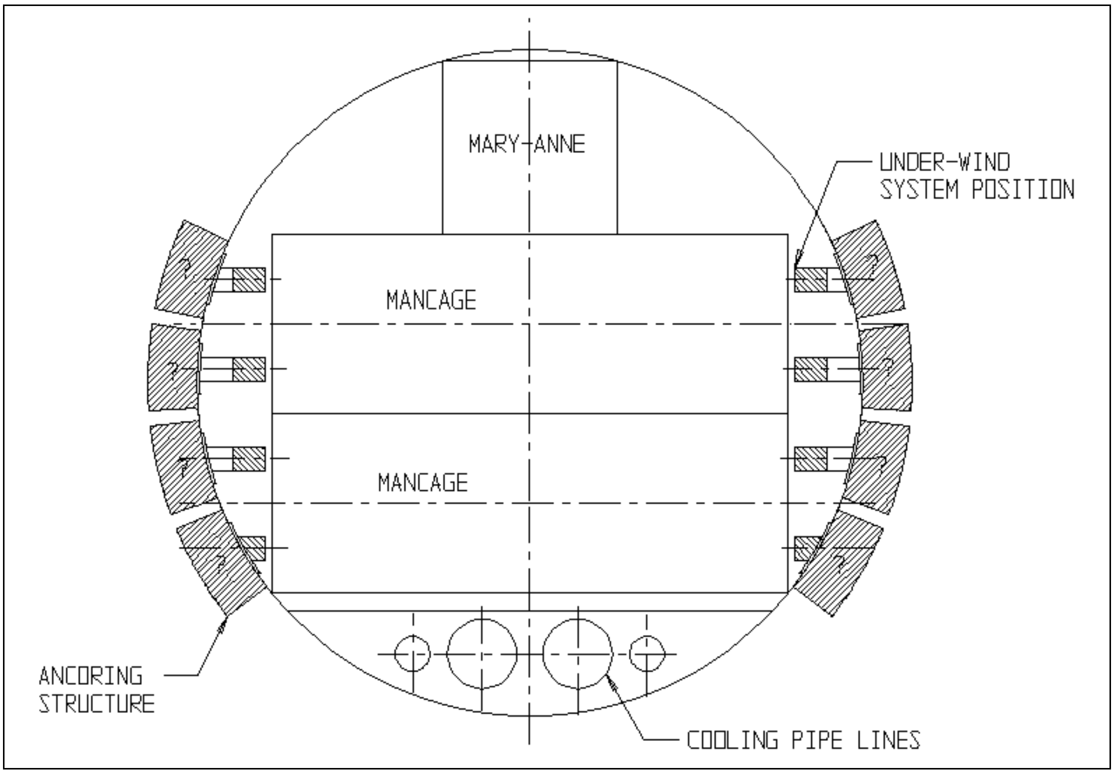

Figure 4.6-1: Layout of full-scale design (functional) of underwind protection system for the SV3 shaft of the South Shaft (South Deep Mine)

4.7 Retrofit possibilities

The space required above the crash bar at the shaft bottom for a conveyance traveling at 18 m/s is 6,6 meters. Since this is small in comparison to the space available in most mines, retrofitting the system in existing shafts should not pose any problem. The system can be fitted in incline as well as vertical shafts.

5 OVERWIND PROTECTION DEVICE

5.1 Specification and design parameters

The functional requirements for overwind protection devices are:

- The maximum deceleration to prevent injuries to people transported in a conveyance is 9.8 m/s^2 (1 “g”).
- After stopping the conveyance, the conveyance must be prevented from falling down the shaft.

5.2 Concept design

To prevent a deceleration of more than 9.8m/s^2, the conveyance has to be detached from the hoisting cable and be allowed to decelerate under gravity alone. No brake system can be incorporated since this will increase the deceleration to higher than 9.8m/s^2 and will cause the occupants in the conveyance to get airborne, which may cause head or neck injuries.

The overwind protection can be divided into two different operations. The first operation is the cable detachment, which is performed by the “humble hook” (See paragraph 2.4.3.4.1). The “humble hook” mechanism, referred to in figure 5.2-1, operates on a scissors principle. It is kept closed by a shear pin, that is sheared when the hook assembly is pulled into a hole in a plate (spectacle plate) at the top of the shaft headgear. This detaching mechanism is currently used in mines.

Figure 5.2-1: “Humble hook” assembly

5.2.1 Catching mechanism

After detaching the conveyance, the conveyance has to be caught to prevent it from falling down the shaft. To catch the conveyance a series of “Jack catches” (See paragraph 2.4.3.4.2) are placed downward from the spectacle plate for a distance larger than the stopping distance required. See figure 5.2-2. The stopping distance is related to the maximum speed of the conveyance. As can be seen in table 5.2-1, the stopping distance required and thus the height that has to be fitted with “Jack catches” increases exponentially with increase in maximum speed of the conveyance.

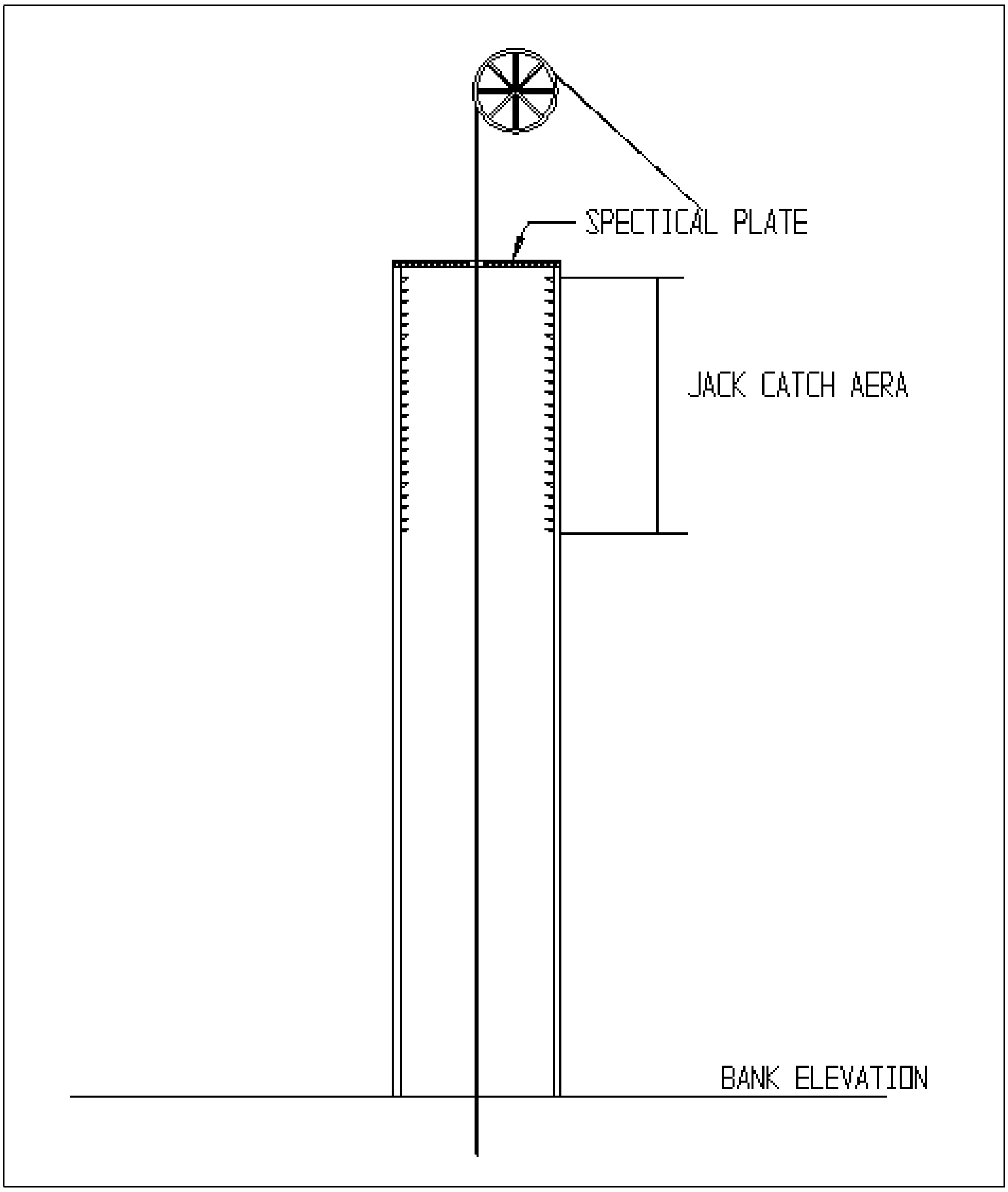

Figure 5.2-2: Placement of “Jack catches” in shaft headgear

Table 5.2-1: Stopping distance required for maximum conveyance speeds

Maximum conveyance speed	Stopping distance required/ Jack catch area
6 m/s	1.8 m
8 m/s	3.3 m
10 m/s	5.1 m
12 m/s	7.3 m
14 m/s	10.0 m
16 m/s	13.0 m
18 m/s	16.5 m

Since the speed at which the conveyance travels into an overwind situation may vary from slow to the maximum speed of the conveyance, the stopping distance can also vary from zero to the stopping distance required for maximum speed. Due to the varying possible stopping distances, a series of “Jack catches” have to be placed a distance below the spectacle plate that is larger than the maximum stopping distance required. The distance has to be larger than the maximum stopping distance to ensure that the detaching of the conveyance only takes place after the conveyance has entered the “Jack catch” area.

The catching mechanism, a series of “Jack catches” as described above, is the same for all the different concepts that have been generated. The detaching mechanism of the conveyance of the concept described in the following paragraph differ.

5.2.2 Detaching of conveyance

5.2.2.1 Cable between detaching hook and conveyance

A detaching hook is placed away from the conveyance with a piece of cable between the detaching hook and the conveyance. The length of the piece of cable depends on the maximum speed of the conveyance with the corresponding stopping distance required (see paragraph 5.2.1). If an overwind situation takes place the conveyance is detached via the detaching hook to stop it from being pulled further and the conveyance decelerates at $9.8 m/s^2$ due to gravity. Since the speed at which the overwind situation takes place varies, the stopping distance varies and provision must be made to catch the conveyance at the different stopping distances. A series of jack catches are proposed to catch the conveyance (see paragraph 5.2.1).

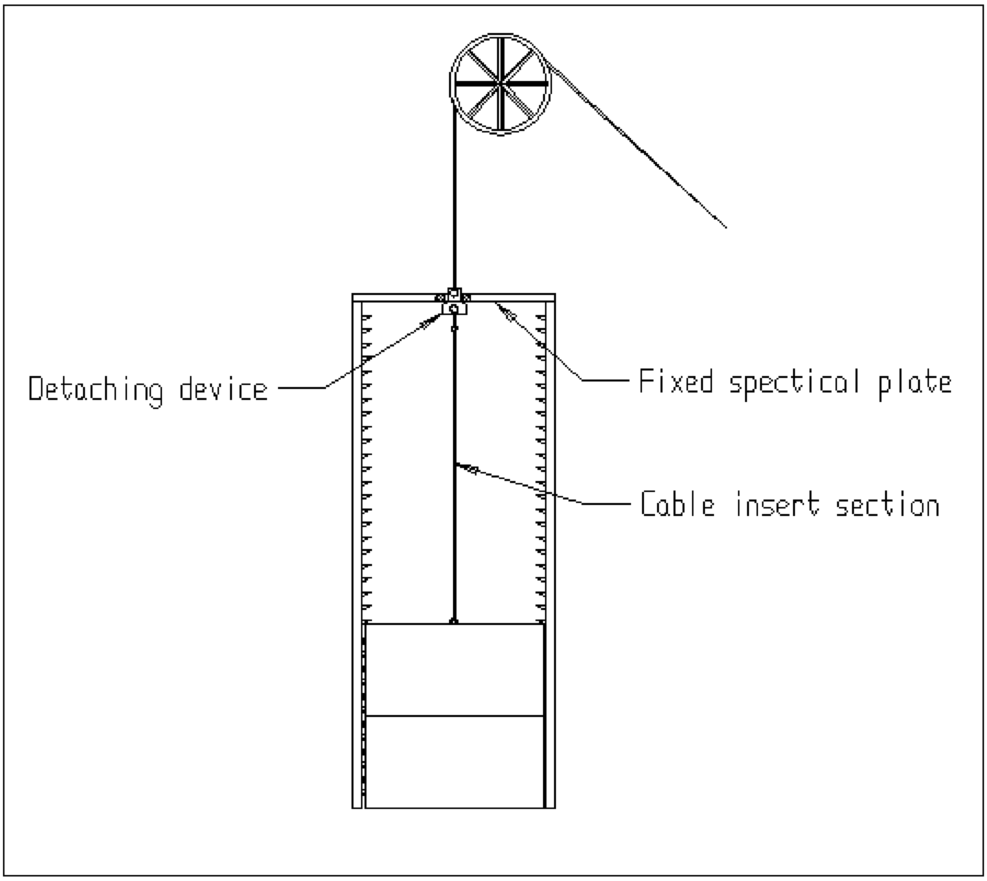

Figure 5.2-3: Schematic layout of overwind concept with piece of rope between detaching hook and conveyance.

This concept is not acceptable since the detaching hook can hit the side of the shaft under slack rope conditions causing it to disconnect. Another disadvantage is that the inspection of the detaching hook, which has to take place at regular intervals, will be very difficult, as the detaching hook hangs a distance above the conveyance.

5.2.2.2 Cable between detaching hook and conveyance and spectacle plate that can be de-activated

In headgears where not enough height is available to install the series of "Jack catches", a variation of the concept described in paragraph 4.2.2.1 was developed. To make provision for slinging operations a spectacle plate, which can be de-activated by the engineer is proposed. This alternative spectacle plate has an automatic mechanical return to operational mode. See figure 5.2-4.

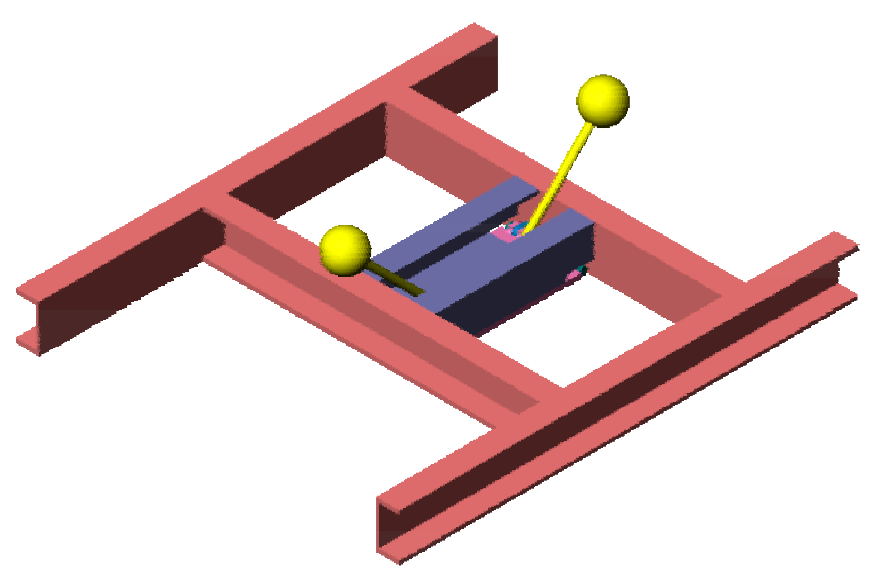

Figure 5.2-4: Spectacle plate that can be de-activated

In addition to the disadvantages of the concept described in paragraph 4.2.2.1 this variation has the disadvantage that it is human dependant and human error may be the cause of the system to fail. This concept is not acceptable.

5.2.2.3 Floating spectacle plate

This concept has the detaching device ("humble hook") placed on top of the conveyance as is current practice. A floating "spectacle plate" is placed at the bottom of the "Jack catch" area. If an overwind situation occurs the "humble hook" hits the floating spectacle plate just after the conveyance has entered the "Jack catch" area. The conveyance is disconnected from the cable and decelerates under gravity. It is prevented from falling back by the "Jack catches". The floating spectacle plate travels with the conveyance. The spectacle plate is held in positions by shearing pins so that even if the conveyance runs into the floating spectacle plate at a low speed the humble hook is still disconnected as the force needed to shear the shearing pins will be sufficient to disconnect the detaching hook. Figure 5.2-4, shows the layout of the overwind protection system with a floating spectacle plate.

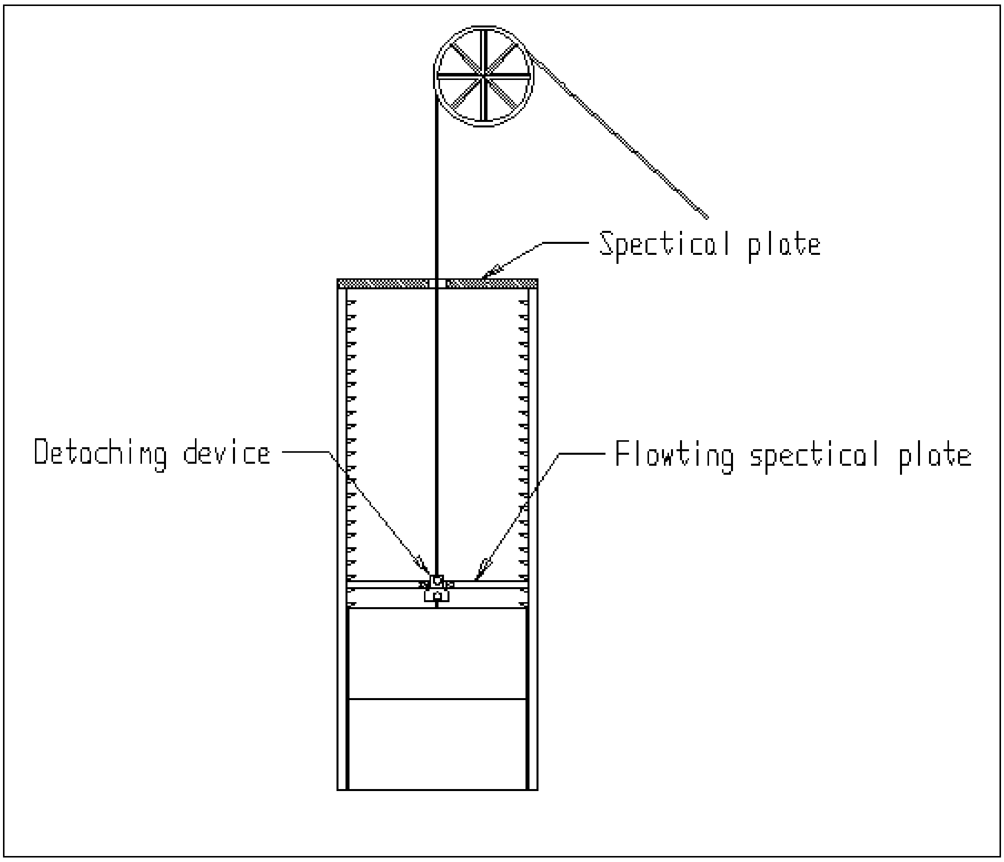

Figure 5.2-4: Layout of overwind protection system with floating spectacle plate.

The disadvantage of this system is that the conveyance will be decelerated at a deceleration of more than 9.8m/s^2. This is because the floating spectacle plate has to be accelerated to the speed of the conveyance. Although this is for a short time it may cause the people in the conveyance to lift off the floor and hit their head against the roof of the conveyance.

5.2.2.4 Alternative detaching mechanism at start of “ Jack catch” area.

A detaching device (“humble hook”) is placed on top of the conveyance, as is current practice. An alternative detaching device activation system is placed at the bottom of the “Jack catch” area. If an overwind situation occurs, the detaching device (“humble hook”) it activated just after the conveyance enters the “Jack catch” area. The conveyance is disconnected from the cable and decelerates under gravity. It is prevented from falling back by the “Jack catches”. Figure 5.2-5, shows the layout of the overwind protection system with the alternative detaching device.

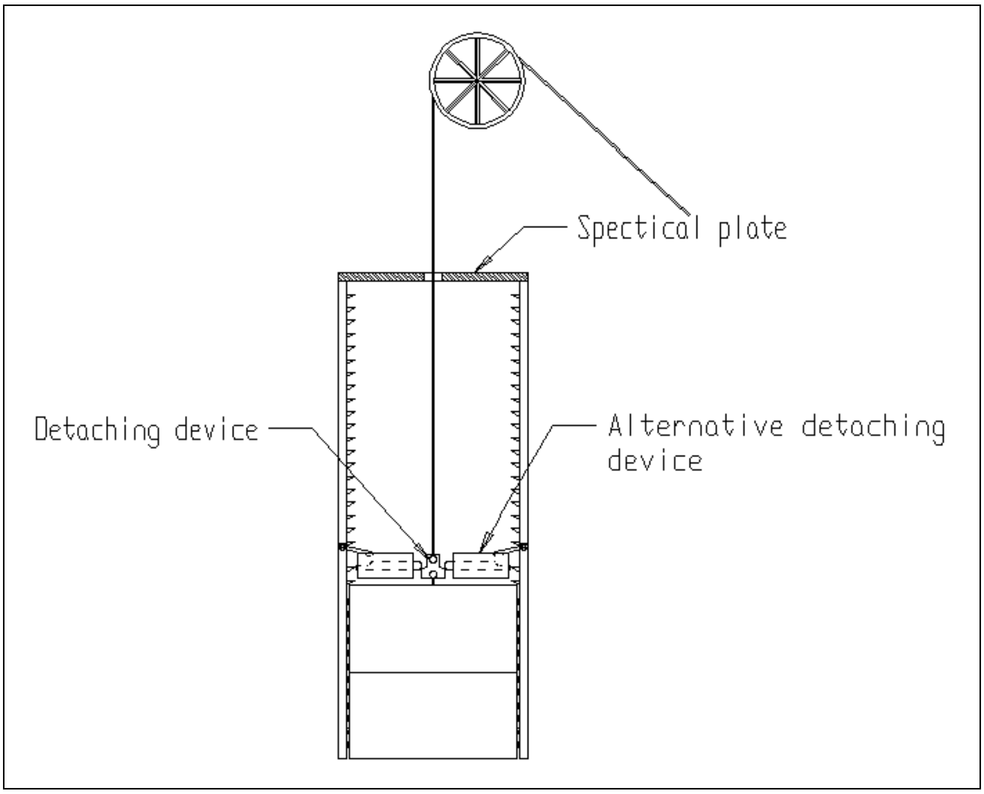

Figure 5.2-5: Layout of the overwind protection system with alternative detaching mechanism at bottom of the jack catch area.

The alternative detaching mechanism does not make use of the spectacle plate to activate the "Humble hook". A horizontal force on the scissor plates is used to activate the detaching hook. Horizontal forces and not the vertical force of the spectacle plate activate the scissor plates of the detaching hook. The alternative detaching mechanism is shown in figure 5.2-6.

Figure 5.2-6: Alternative detaching mechanism

The mechanism has two pivoting arms connected to the structure of the headgear. On the conveyance, next to the detaching hook, the two activation bars are placed that can only move horizontally. As the conveyance moves through the pivoting arms, the arms lock into the activation bars. As the conveyance moves further upward, the pivoting arms push the activation bars inward, which in turn force the scissor plates of the detaching hook inwards to activate the detaching hook and detach the cable. Figure 5.2-7, schematically shows the working of the alternative detaching mechanism. As the mechanism is positive the detachment action will be effective at low and high speed.

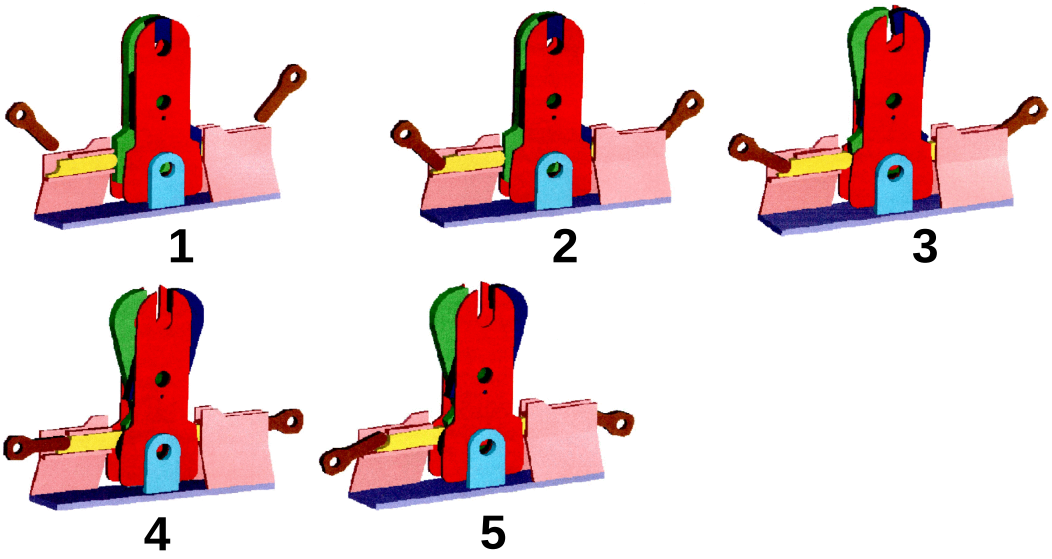

Figure 5.2-7: Working of alternative detaching mechanism.

5.2.2.5 Functional working of detaching mechanism

A casing to protect the activation arms and prevent any accidental activation encapsulates the activation arms. No accidental detachment can take place, as the pivoting arms first have to pierce the casing before the activation arms can be moved. Low maintenance is needed as the casing can be packed with grease to prevent rust. The casing also protects the scissor plates of the detaching hook and prevents a falling object to accidentally activate detachment.

5.2.3 Proposed concept

The different concepts as described in the above paragraphs were evaluated against the system specification. The concept with the alternative detaching mechanism is proposed as the preferred concept. This concept has been presented to the SIMRAC Technical Committee, which accepted the concept.

5.3 Design of experimental models

Experimental models of the concept with the cable between the detaching hook and the conveyance, as described in paragraph 4.2.2.1, and the concept with the alternative detaching mechanism placed at the beginning of the jack catch area, as described in paragraph 4.2.2.4, were designed. The design was done for the 1:10 scale experimental mineshaft at the University of Pretoria.

5.3.1 Cable between detaching hook and conveyance

A detail design was done for the concept with a piece of cable between the detaching hook and the conveyance, from which the system was built. Detail drawings for all the components were made.

5.3.2 Alternative detaching mechanism at start of “ Jack catch” area

A detail design was done for the concept with the alternative detaching mechanism at the start of the “ Jack catch” area, from which the system was built. Detail drawings for all the components were made. In figure 5.3-1 the assembly of the system is shown.

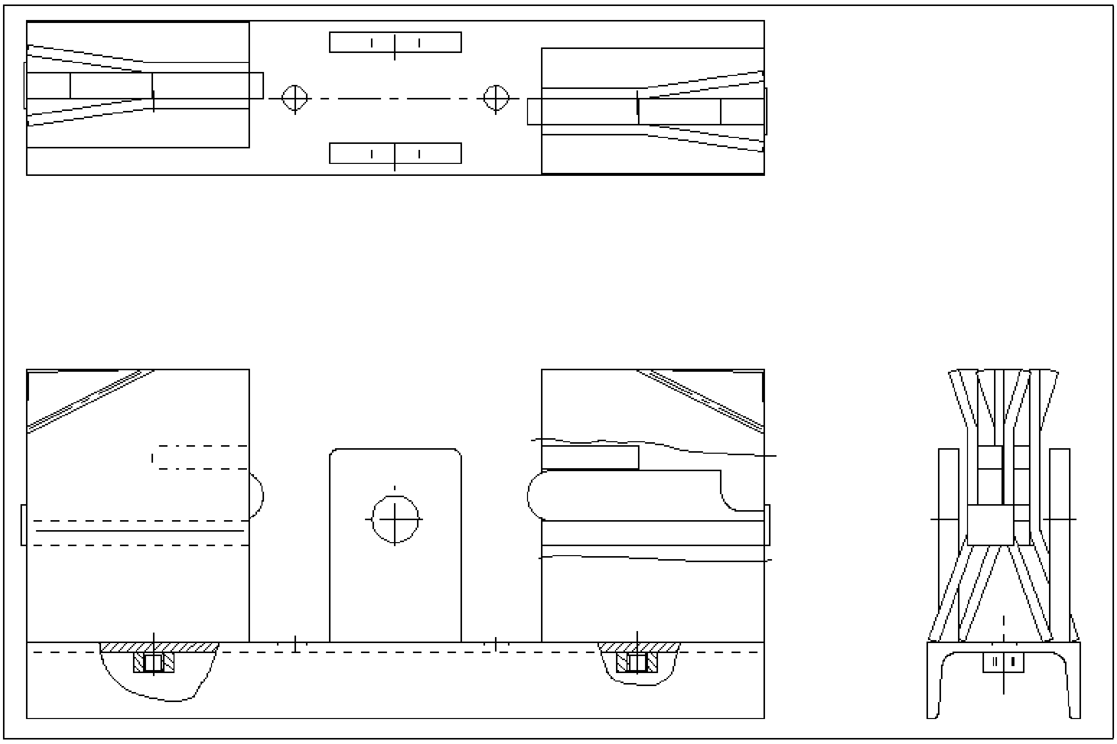

Figure 5.3-1: Assembly of alternative detaching mechanism

5.4 Laboratory testing of experimental models

The experimental models of the concepts with the cable between the detaching hook and the conveyance, as described in paragraph 5.2.2.1, and the concept with the alternative detaching mechanism placed at the beginning of the jack catch area, as described in paragraph 5.2.2.4, were tested. The tests were done in the 1:10 scale experimental mineshaft at the University of Pretoria.

5.4.1 Laboratory testing methodology

5.4.1.1 Test system instrumentation

The system was instrumented with piezoelectric accelerometers that enabled the measurement of acceleration with regard to the three main axes (x, y and z). The accelerometers were connected to a signal conditioner that enabled the conditioning and amplification of the accelerometer signals.

Two switches were placed at specified positions to enable the disconnection of the electric motor drive and the activation of the pneumatic braking system respectively. The electric motor was disconnected to ensure that the lifting cable was not pulled into the pulley system. The simulation system has a counter weight and the activation of the pneumatic braking system was used to stop the counter weight from falling to the bottom of the test simulation set-up (once the electric motor drive is disconnected the counter weight is free to fall). A signal was relayed from a switch (the electric motor disconnection switch was used for this purpose) that indicated the exact point in time at which the detachment system was activated. The voltage signal was obtained via a connection to an external voltage source that emitted a specific voltage level when the switch was triggered. The accelerometer and switch voltage signals were digitally sampled via an analogue-to-digital system.

5.4.1.2 Experimental procedures

The experiment was divided into two different phases.

The first phase of the testing involved the setting of the test simulation system (the setting of the disconnection and braking switches). The second phase of testing was used to capture the relevant acceleration data. (A step-by-step test procedure is depicted in the subsequent table).

Table 5.4-1: Experimental procedure

- Secure conveyance in a safe position at the bottom of the simulation shaft.
- Insert humble hook assembly and connect data acquisition equipment.
- Connect driving/pulling cable to the humble hook assembly.
    - 13 m cable between conveyance and humble hook assembly
    - alternative detaching device incorporating humble hook assembly.
- Activate hoisting mechanism and data acquisition system.
- Hoist till conveyance disconnected.
- Conveyance securely falls back on to the jack catch mechanism
- Return conveyance to a safe position.

Table 5.4-2: Overwind tests performed

Concept tested	Number of tests performed	Approximate deceleration (g)	Successful activation
13 m dummy cable	10	1	Yes
Alternative detachment device	10	1	Yes

5.4.2 Discussion of results

5.4.2.1 Overwind concept(s) – test results

The accelerometer data was recorded digitally through the use of an analogue-to-digital system. The data was sampled at a sampling frequency of 1600 Hz with a cut-off frequency of 150 Hz. The data was calibrated and the data represented in graphical format. The test results of the two different concepts evaluated are depicted in Appendix D.

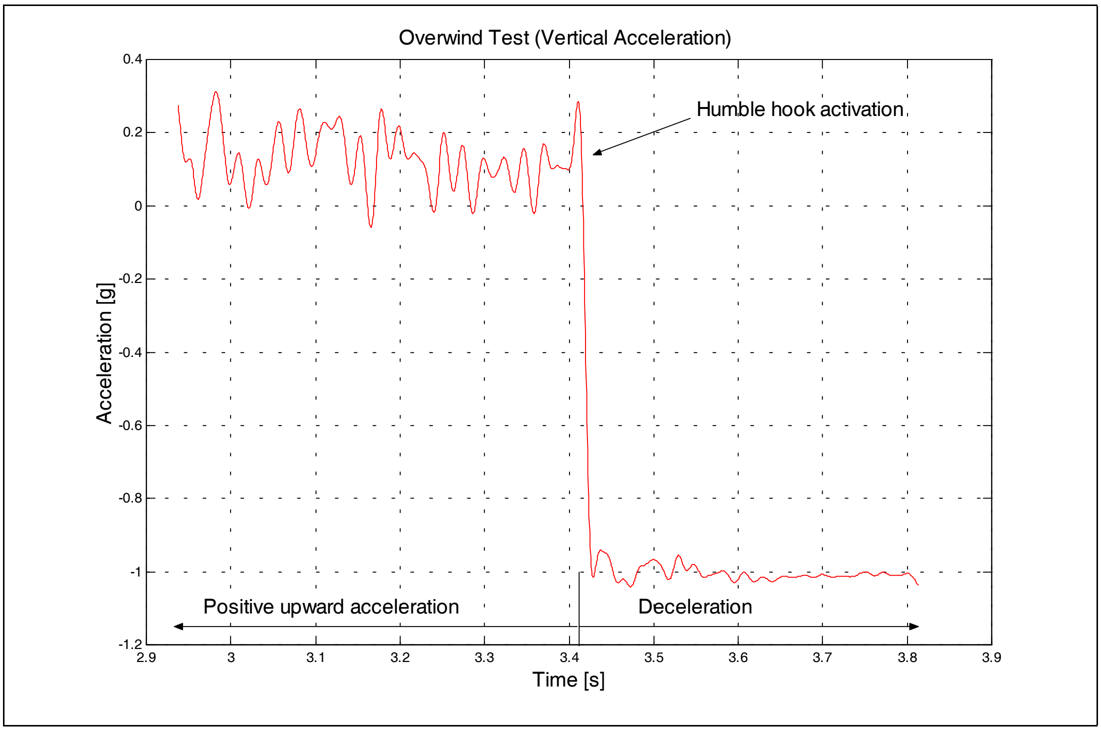

Figure 5.4-1: Overwind test result - dummy cable

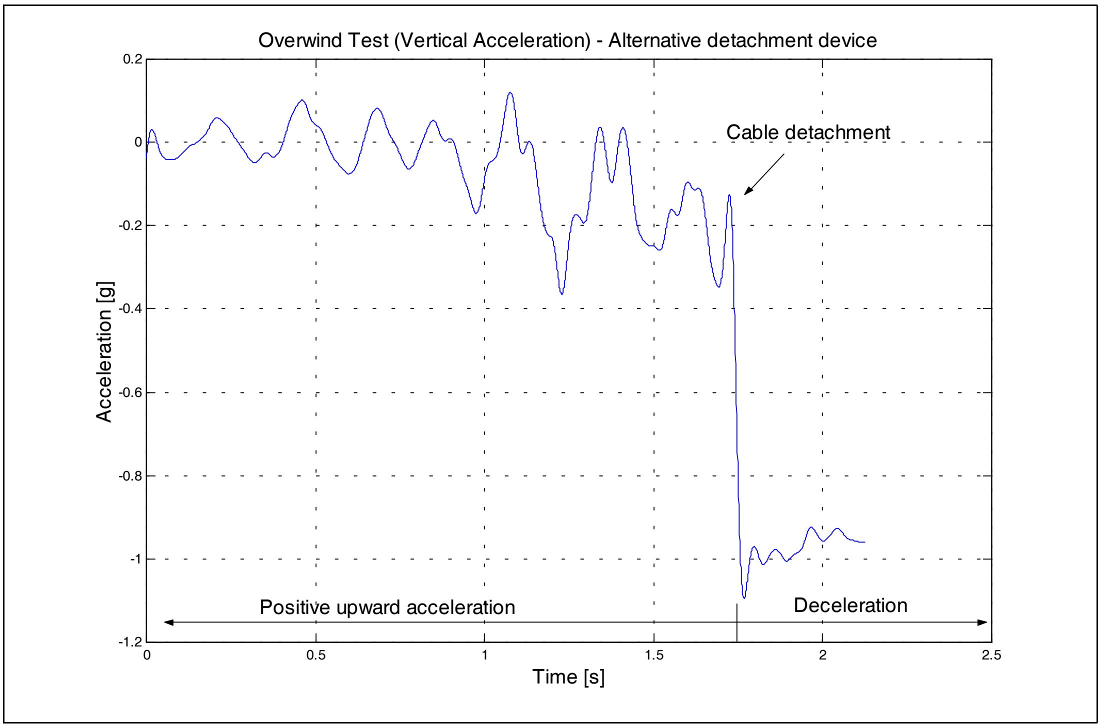

Figure 5.4-2: Overwind test result - Alternative detachment device

5.4.3 Conclusion

As can be observed from the graphs depicted in this section it is clear that the two concepts tested, both comply with the set test criteria. The system can be fitted in incline as well as vertical shafts.

5.5 Design Reviews

As the development of the concepts was an iterative process, design reviews were held more than once. As new concerns were raised or recommendations made, a design review was held and new or changed concepts were generated. These new concepts were then again presented to the SIMRAC Technical Committee.

The first concept that was developed was the one with the detaching hook connected to the conveyance by means of a piece of cable, as described in paragraph 4.2.2.1. This concept is not acceptable as the humble hook can hit the side of the shaft under slack rope conditions causing it to disconnect.

The next concept that was developed is the one with the floating spectacle plate, as described in paragraph 4.2.2.3. This concept can work however the deceleration will be higher than 9.8m/s², which will cause the occupants of the conveyance to get airborne and hit the top of the conveyance. This may however not be severe and still acceptable because the deceleration will only momentarily be above 9.8 m/s².

The following concept that was developed is the one with the alternative detaching mechanism, as described in paragraph 4.2.2.4. This system was accepted by the SIMRAC Technical Committee.

5.6 Full scale design (functional)

A full-scale design of the concept with the alternative detaching mechanism at the beginning of the jack catch area was done for the SV3 shaft of the Western Areas Gold Mining Co Ltd South Shaft (South Deep Mine). A layout of this design can be seen in figure 5.6-1 and the detail drawings are attached in Appendix C. The headgear of the shaft was inspected and it was found that with certain modifications to the headgear structure, the overwind protection mechanism can be fitted. No structural changes are proposed in this design since the design is only a functional design. In figure 5.6-1, the layout of the overwind protection system for the SV3 shaft is shown.

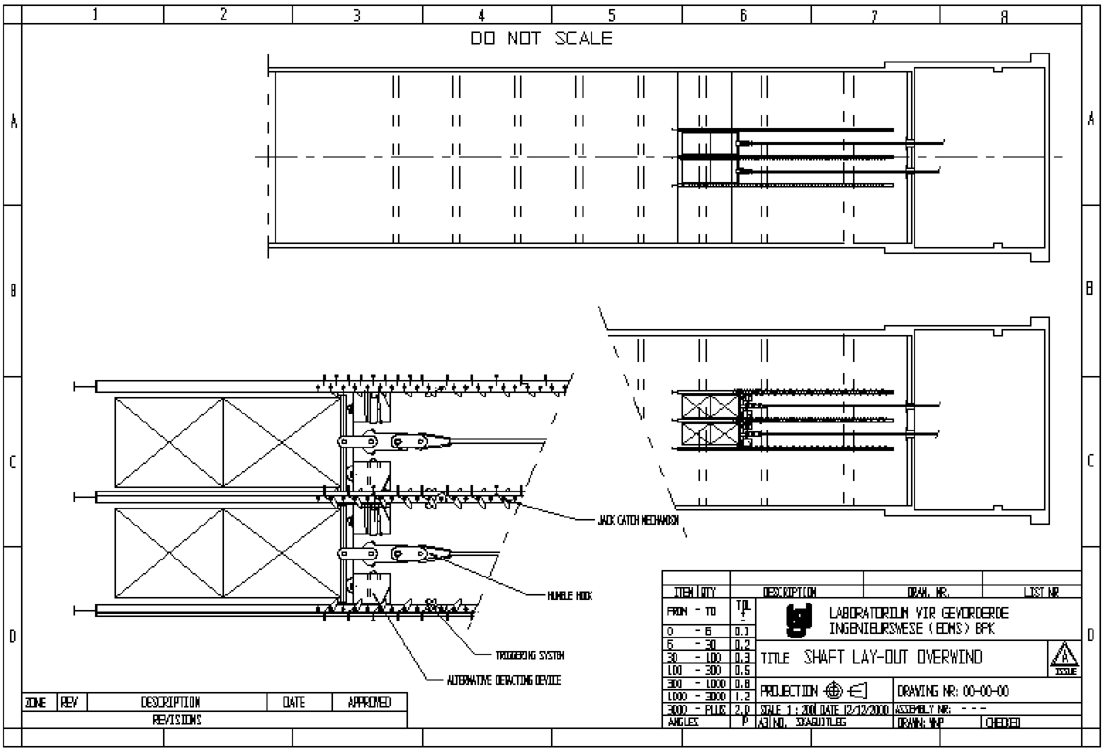

Figure 5.6-1: Layout of full-scale design (functional) of overwind protection system for the SV3 shaft of the South Shaft (South Deep Mine)

5.7 Retrofit possibilities

A survey of different headgears was conducted to determine which headgear could be retrofitted with the overwind protection system. To comply with the 9.8 m/s² deceleration a certain stopping distance is required. In paragraph 5.2.1 the stopping distance required is discussed. In order to determine whether there is enough space the minimum height of the spectacle plate above ground level that is required has to be calculated:

Distance of collar to spectacle plate required = Height of conveyance
+ Space required for slinging
(± 13m)
+ Height of detaching hook
(± 1m)
+ Stopping distance required

In table 5.7-1 headgear information of some mines as well as the space available for retrofitting the overwind protection system is shown. As can be seen from table 5.7-1. The maximum speed of most of the conveyances, calculated from the space available to fit the system exceeds the actual speed of the conveyance. This shows that most headgear can be retrofitted.

For headgears where not enough space is available, retrofitting the system will however still have certain advantages. The conveyance will have decelerated in the space available and will not crash into the spectacle plate at full speed. The reduced speed will result in fewer injuries. To reduce the space required, slinging into the cage and not under the cage can also be considered.

From the above-mentioned it can be deducted that a great number of the headgears currently in operation can be retrofitted with the proposed overwind protection system.

Table 5.7-1: Retrofit possibilities of the overwind protection system in some headgear

MINE	SHAFT	COLLAR TO SPECTACLE PLATE(mm)	CAGE HEIGHT (mm)	SPACE AVAILABLE (mm)	MAX SPEED TO STOP SAFE (m/s)
Elandsrand G.M.	Man & Matl. Shaft	30845	7875	8970	13.3
	Sub Shaft	37500	8120	15380	17.4
Mponeng	Main Shaft	51050	7700	29350	24.0
	Service Shaft	38730	7600	17130	18.3
	SS1 Shaft	57200	7600	35600	26.4
Bambanani East	Main Shaft	37620	10650	12970	16.0
Matjabeng Nyala	Main Shaft	53650	8540	31110	24.7
Elandsrand G.M.	Man & Matl. Shaft	30845	7875	8970	13.3
	Sub Shaft	37500	8120	15380	17.4
Mponeng Mine	Main Shaft	51050	7700	29350	24.0
	Service Shaft	38730	7600	17130	18.3
	SS1 Shaft	57200	7600	35600	26.4
Bambanani East	Main Shaft	37620	10650	12970	16.0
Matjabeng Nyala	Main Shaft	53650	8540	31110	24.7

Table 5.7-2: Retrofit possibilities of the overwind protection system in some headgear (Continue)

MINE	SHAFT	COLLAR TO SPECTACLE PLATE(mm)	CAGE HEIGHT (mm)	SPACE AVAILABLE (mm)	MAX SPEED TO STOP SAFE (m/s)
RPM-R Rustenburg	Frank No 1	31500	7400	10100	14.1
	Frank No 2	29500	5470	10030	14.0
	Townlands	31500	7400	10100	14.1
	Paardekraal	31500	7400	10100	14.1
	Turffontein	31500	5400	12100	15.4
	Bleskop	20900	5070	1830	6.0
	Brakspruit	20700	4950	1750	5.9
RPM-U Union	Richard Shaft	20700	4950	1750	5.9
	Spud Shaft	31500	7400	10100	14.1
RPM-A Amendelbult	No 1 Shaft	45500	6000	25500	22.4
	No 2 Shaft	37900	5790	18110	18.8
LPM- Atok	No 1 Shaft	21500	5150	2350	6.8
Beatrix	No 2 Shaft	37800	5470	18330	19.0
Leeudoorn G.M.	No 1 West Man	57220	9012	34208	25.9
	No 1 East Man	39455	9012	16443	18.0
	No 1 S/V No 1 Man	64000	9012	40988	28.4
	No 1 S/V No 2 Man	64000	9012	40988	28.4

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of a survey done showed that overwind and underwind incidents with injury to or death of people still happen. The end-of-wind protection devices suggested, are ultimate protection devices with low maintenance, which must be ready for instant use independent of human initiation.

Although certain specifications and requirements for ultimate protection devices for overwinds and underwinds was found in literature no solutions were found during the technology survey. To prevent injuries to people transported the maximum deceleration for the conveyance travelling upwards is 9.81 m/s^2 and for the conveyance travelling downwards 24.5 m/s^2 as specified by the Ministry of Mines by British Colombia. The energy must be dissipated to avoid rebound and after stopping the conveyance it must be prevented from falling down the shaft.

Both the overwind and underwind protection systems that have been developed were successfully demonstrated on experimental scale.

The underwind protection system makes use of energy absorption strips being pulled through rollers, similar to Selda strips. These strips are connected via cables to both sides of the conveyance. Four systems are used per conveyance. Between the cable and the energy absorption mechanism a compression spring that fails to safety is put inline with the cable to absorb the initial impact force while the absorption strip is been accelerated.

For the overwind protection system different concepts were developed. The preferred concept makes use of an alternative detaching mechanism where the existing detaching mechanism (“humble hook”) is activated by a new mechanism at the beginning of sets of “Jack catches” placed in a certain area below the spectacle plate. When the conveyance enters this area with “Jack catches” the detaching mechanism detaches the cable from the conveyance. The conveyance is then decelerated under gravity and when it stops it is caught by the “Jack catches” to stop it from falling down the shaft.

Both the overwind and the underwind protection systems can be installed in vertical as well as incline shafts. The protection systems can be retrofitted in a number of existing shafts. Enough space is available at shaft bottom above the crash beam, for the underwind protection system. The headgear of most shafts has enough space below the spectacle plate to install the series of “Jack catches” and the detaching mechanism. If the system is installed in a headgear where there is not enough space available, the conveyance is decelerated in the available space which will reduce possible injuries. If the conveyance enters the overwind system at maximum speed, the conveyance will decelerate and hit the spectacle plate at a lower speed, which will result in less injuries. If however, the conveyance enters the “Jack catch” area at a lower speed it may decelerate to standstill before it hits the spectacle plate.

6.2 Recommendations

Overwind and underwind incidents are an are of concern and end-of-wind protection devices should be installed to prevent injuries or loss of live to people travelling in conveyances.

Since the two systems are totally different it is recommended that they be handled as two separate projects.

6.2.1 Underwind protection system:

- Perform full-scale surface tests to determine all the parameters and make sure the system works.
- Perform full-scale tests in a mineshaft to demonstrate the effectiveness of the system.

6.2.2 Overwind protection system:

- Perform full-scale testing on surface to determine all the parameters and make sure that the system is safe.
- Perform full-scale tests in a mineshaft to demonstrate the effectiveness of the system.
- The structure of the headgear has to be investigated to make sure that the overwind system can be retrofitted.
- Since the jack catches form an integral part of the overwind system, a design review as well as tests of the “Jack catches” have to be done to determine the safety and compliance of the “Jack catches”.

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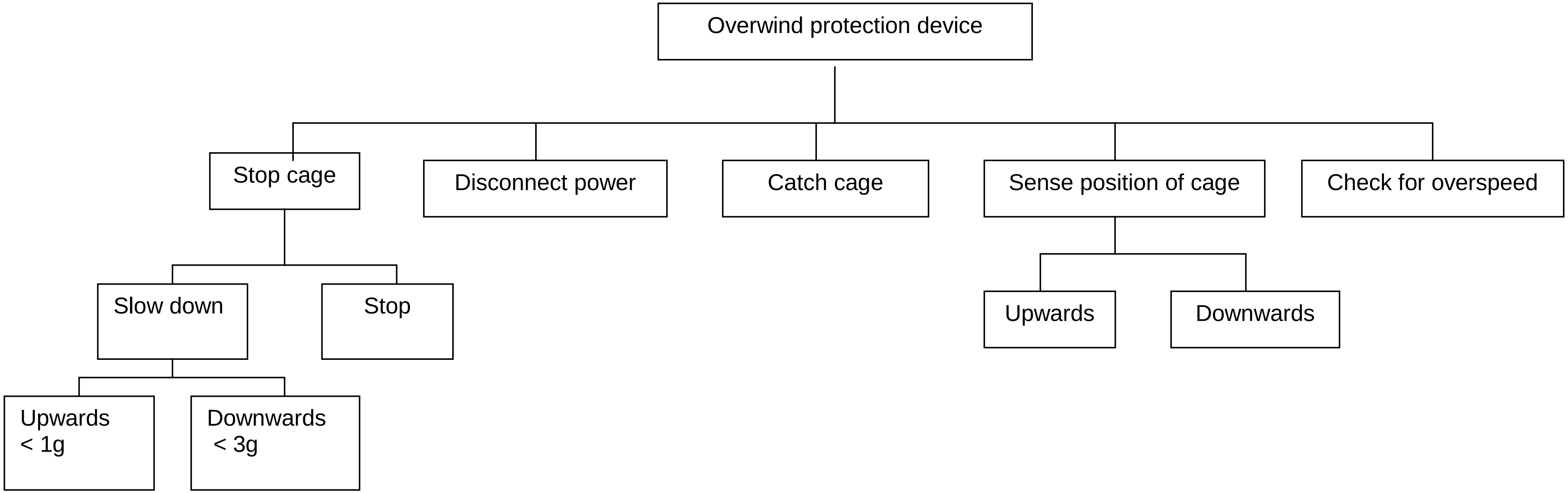
Appendix A: Functional analysis

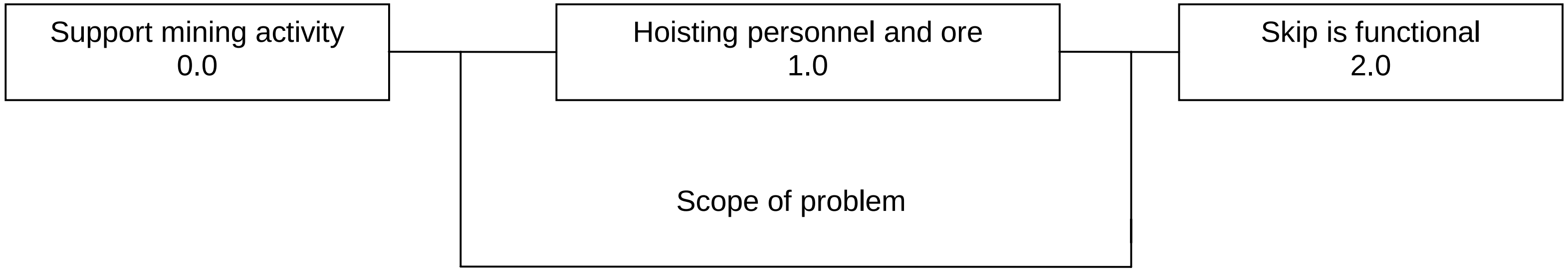
SYSTEM LEVELS



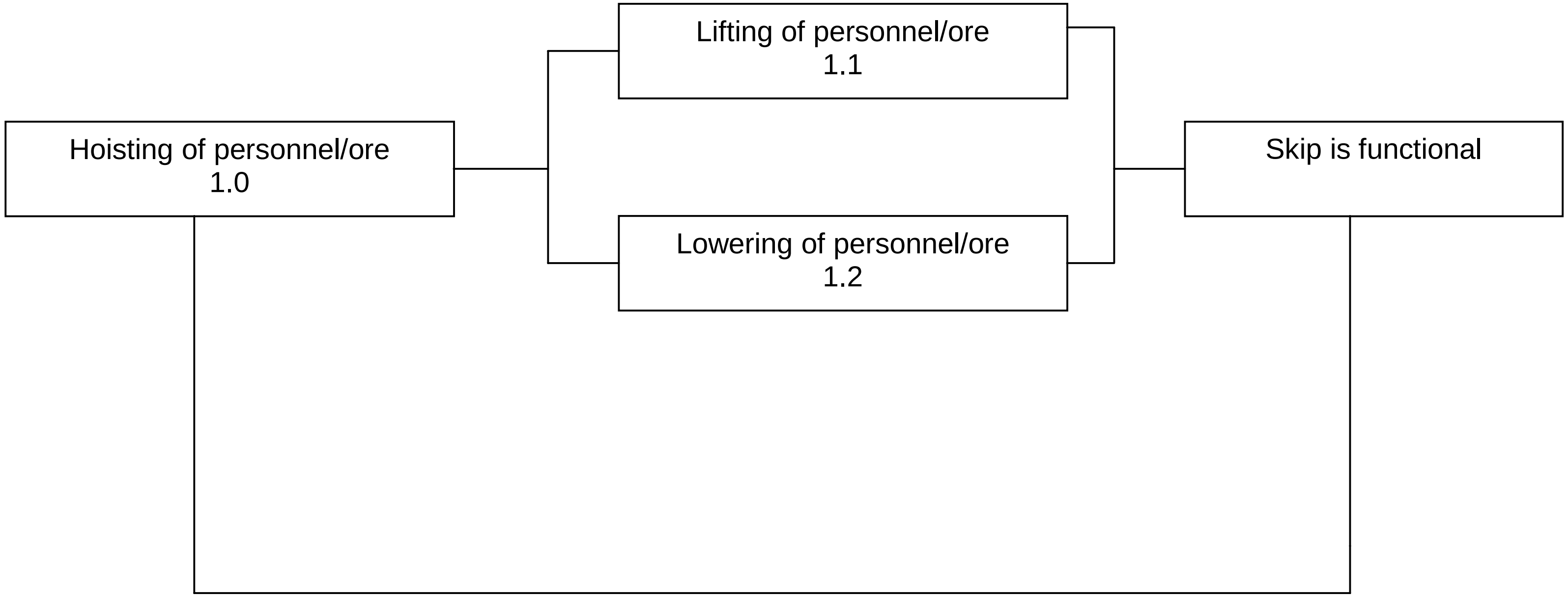
MISSION LEVEL

- Use of proven equipment
- Compatible
- Acceptable life expectancy
- Low maintenance
- Robust
- SAFE
- Reliable
- Tamper proof

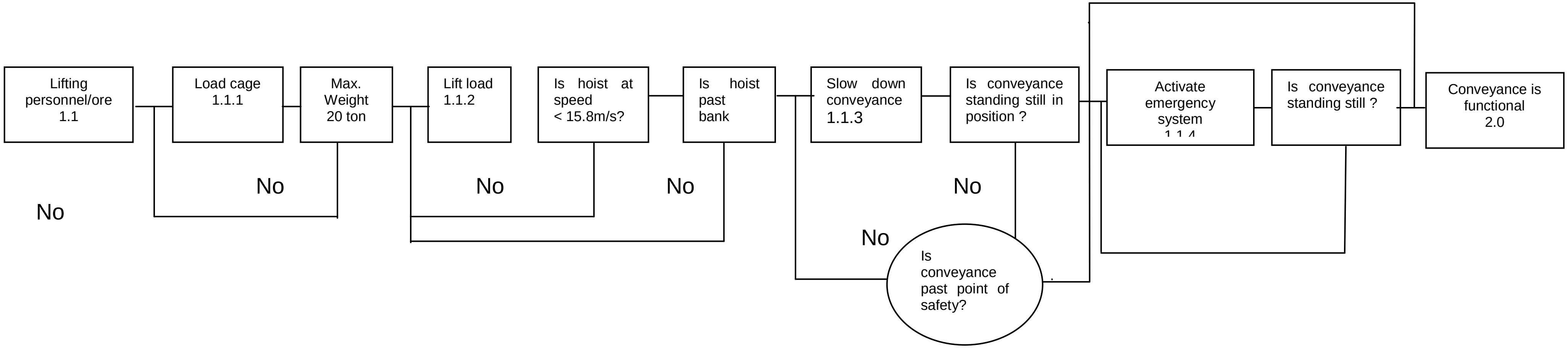
DESIGN PARAMETERS



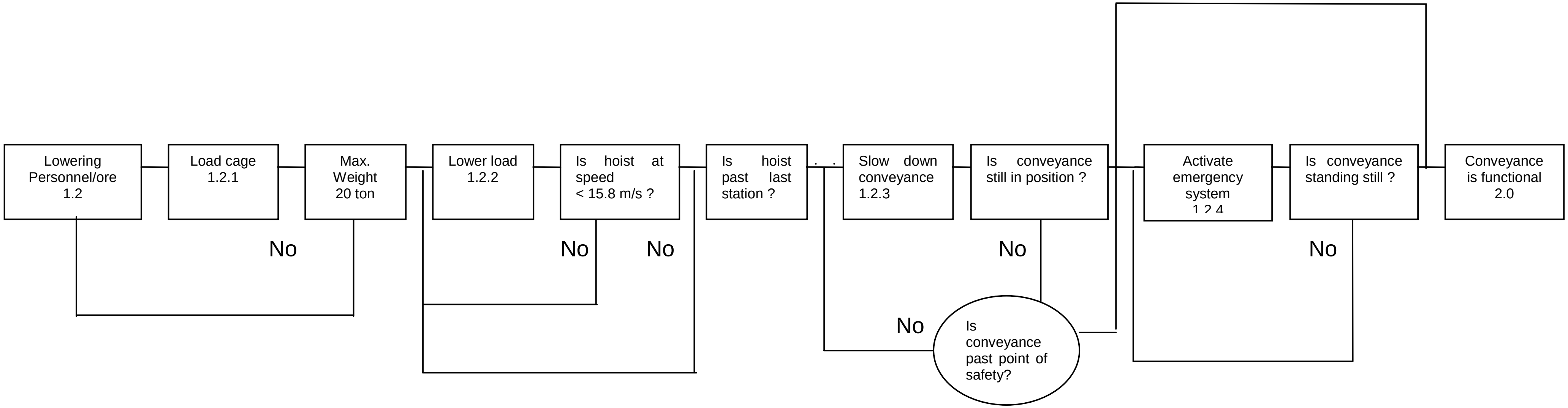
SYSTEM LEVEL : FUNCTIONAL DIAGRAM



FIRST LEVEL



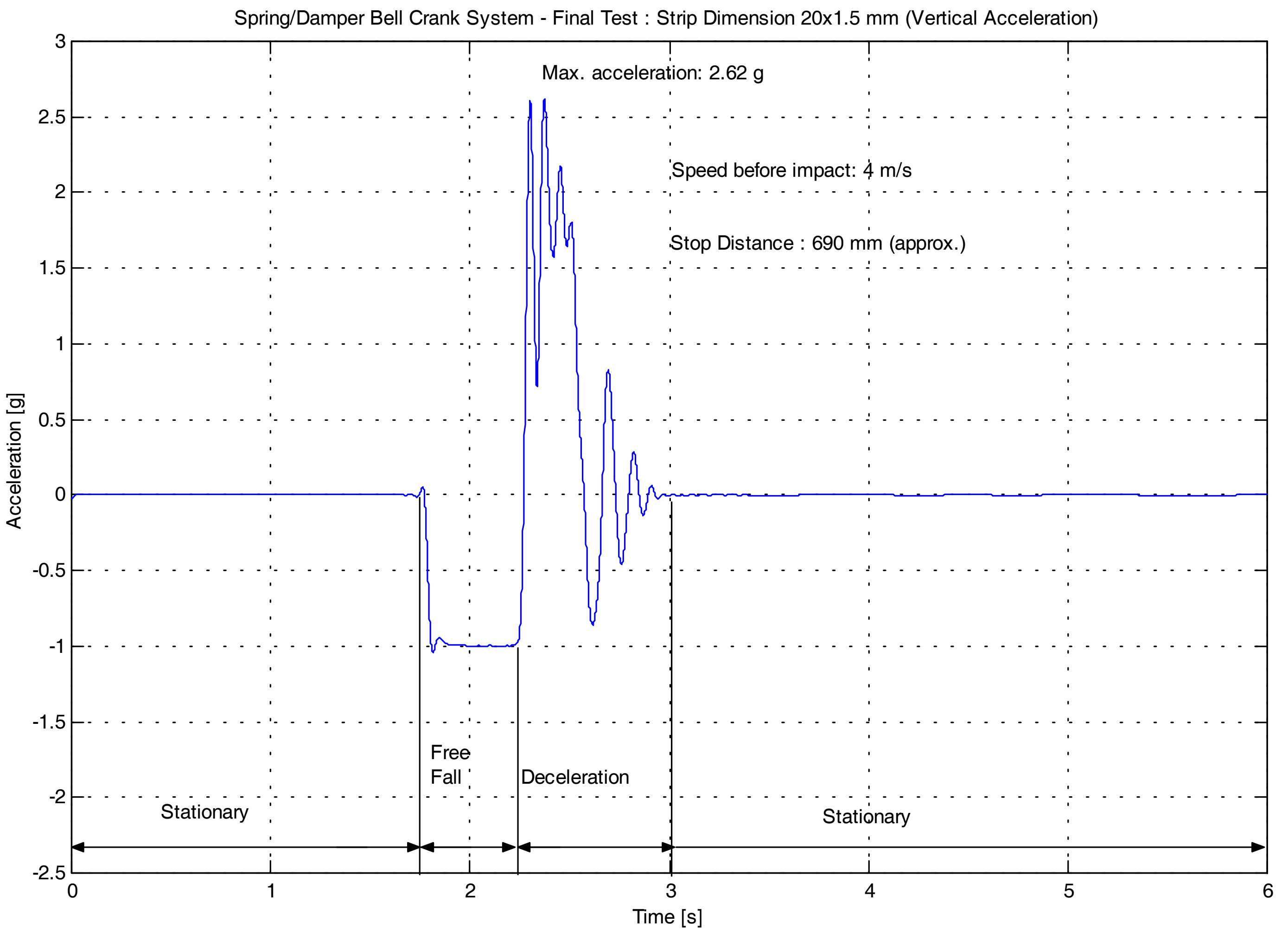
Lifting personnel/ore 1.1
Load cage 1.1.1
Max. Weight 20 ton
Lift load 1.1.2
Is hoist at speed < 15.8m/s?
Is hoist past bank
Slow down conveyance 1.1.3
Is conveyance standing still in position ?
Activate emergency system 1.1.4
Is conveyance standing still ?
Conveyance is functional 2.0
No
No
No
No
No
No
Is conveyance past point of safety?

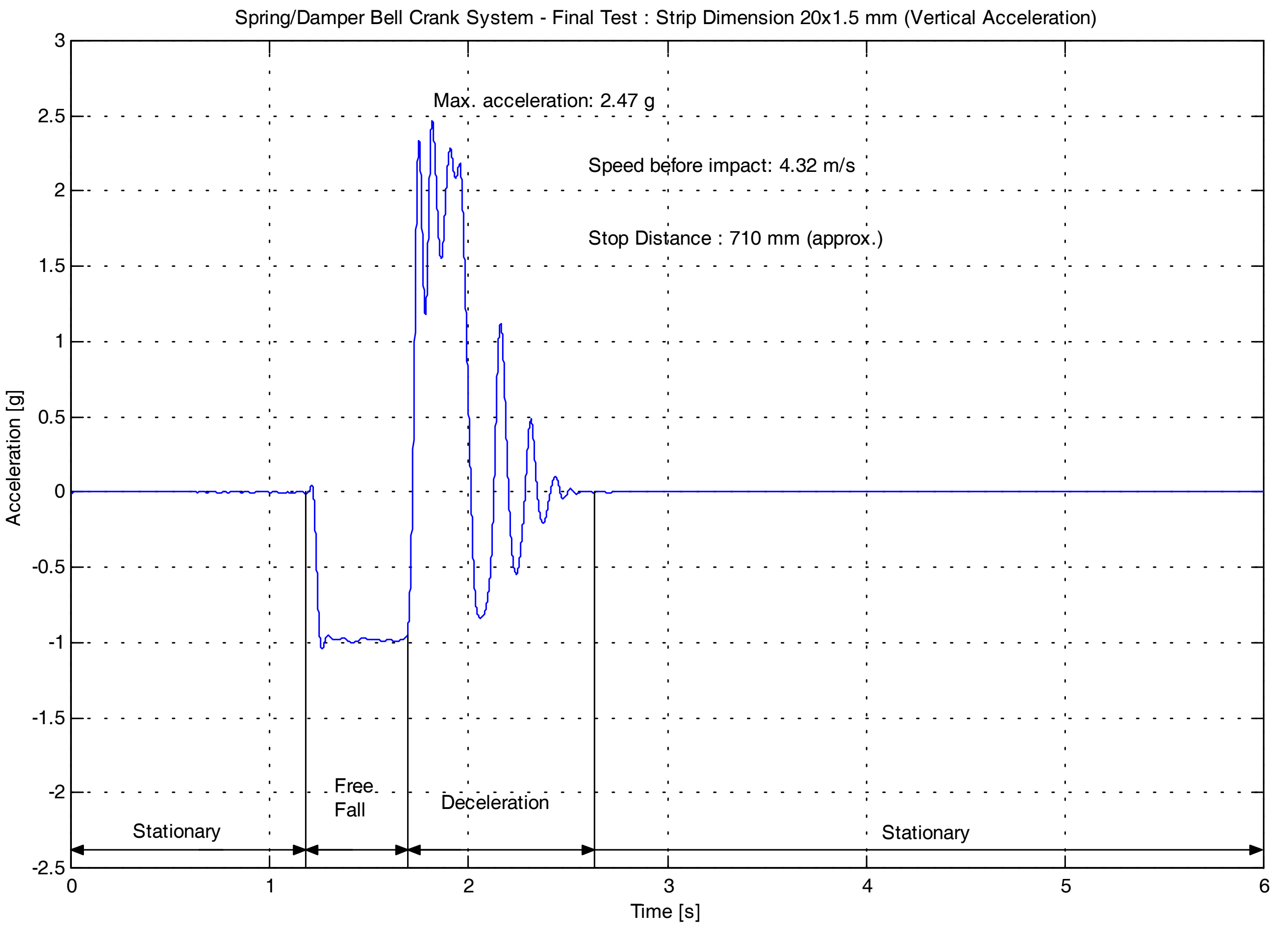


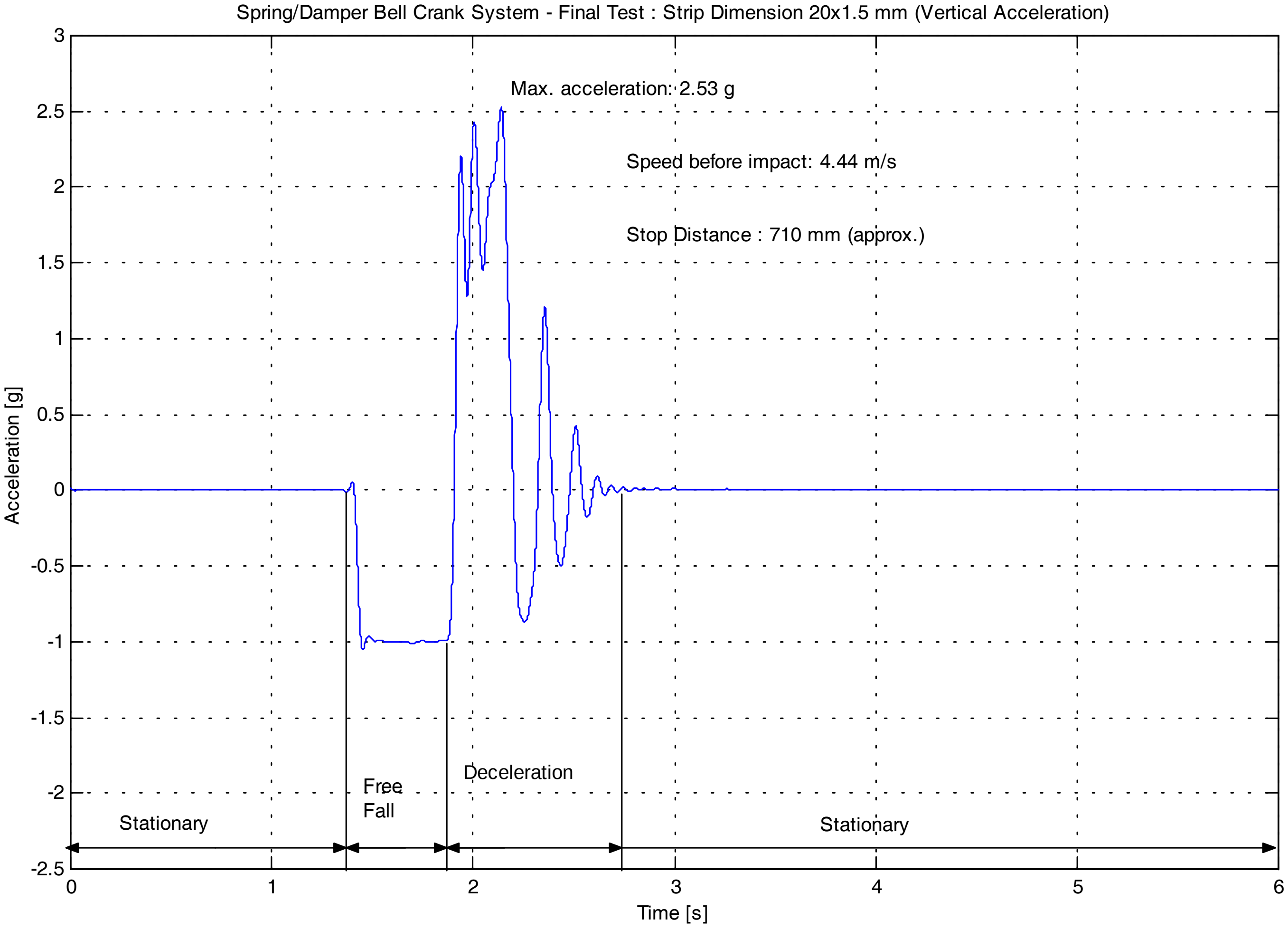
Lowering Personnel/ore 1.2
Load cage 1.2.1
Max. Weight 20 ton
Lower load 1.2.2
Is hoist at speed < 15.8 m/s ?
Is hoist past last station ?
Slow down conveyance 1.2.3
Is conveyance still in position ?
Activate emergency system 1.2.4
Is conveyance standing still ?
Conveyance is functional 2.0
No
No
No
No
No
No
Is conveyance past point of safety?

	FUNCTION	DESIGN PARAMETER
1.1	Lifting personnel/ore	
1.1.1	Load cage	Max weight < 20 ton Max weight (loaded) < x ton Max height of cage : x mm Max width of cage : x mm Construction of cage
1.1.2	Lift load	Max lifting speed < 18m/s Max acceleration < x g
1.1.3	Slow down skip	Sense position of skip Max deceleration < 0.5 g Max deceleration distance: xmm
1.1.4	Activate emergency system	Max speed of cage < 15.8 m/s Max deceleration < 1g Max deceleration distance < 13 m Disconnect power Disconnect cage from main cable Engage catching system
1.2	Lowering personnel/ore	
1.2.1	Load cage	Max weight < 20 ton Max weight (loaded) < x ton Max height of cage: x mm Max width of cage: x mm Construction of cage
1.2.2	Lower load	Max lowering speed < 18 m/s Max acceleration < 1 g
1.2.3	Slow down skip	Sense position of skip Max deceleration < 0.5 g Max deceleration distance : x mm
1.2.4	Activate emergency system	Max speed of cage < 18 m/s Max deceleration < 2.5 g Max deceleration distance < 13m Disconnect power Disconnect cage from main cable Engage catching system
x: Shaft dependant information		

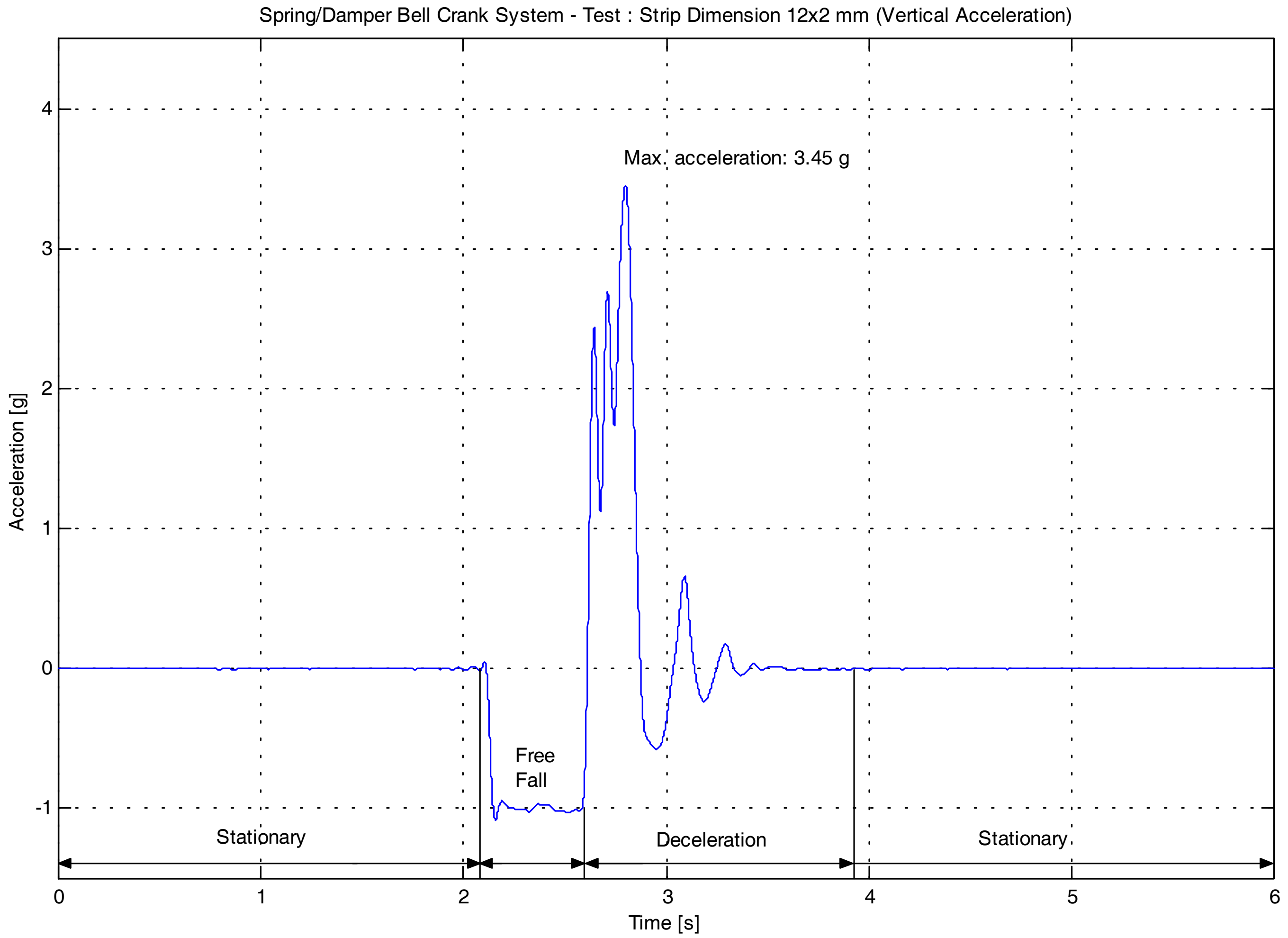
Appendix B: Test results: Underwind System

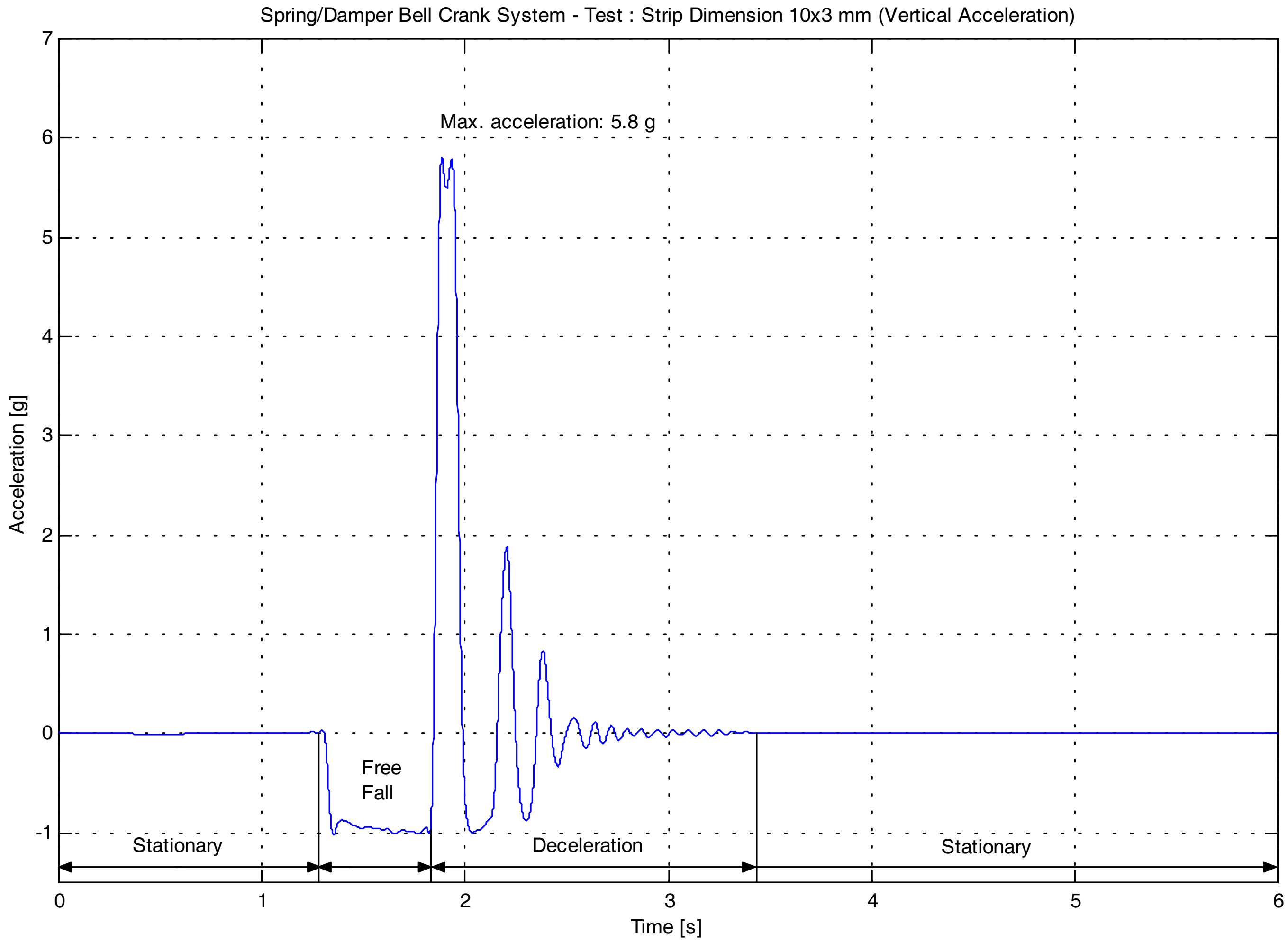

Spring/Damper Bell Crank System - Final Test : Strip Dimension 20x1.5 mm (Vertical Acceleration)
Max. acceleration: 2.62 g
Speed before impact: 4 m/s
Stop Distance : 690 mm (approx.)
Acceleration [g]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Free
Fall
Deceleration
Stationary
Stationary
0
1
2
3
4
5
6
Time [s]

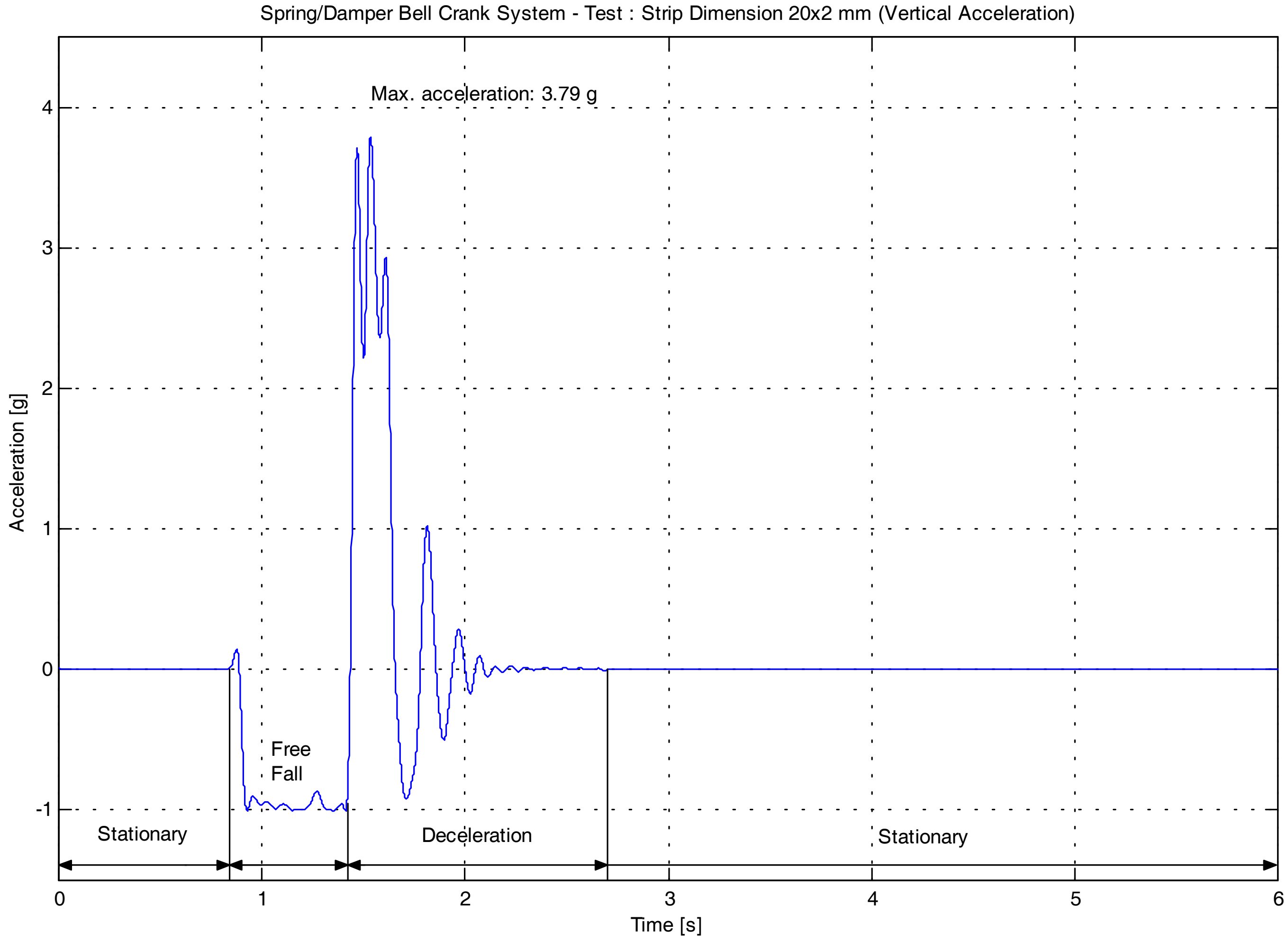

Spring/Damper Bell Crank System - Final Test : Strip Dimension 20x1.5 mm (Vertical Acceleration)
Max. acceleration: 2.47 g
Speed before impact: 4.32 m/s
Stop Distance : 710 mm (approx.)
Acceleration [g]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Stationary
Free
Fall
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]

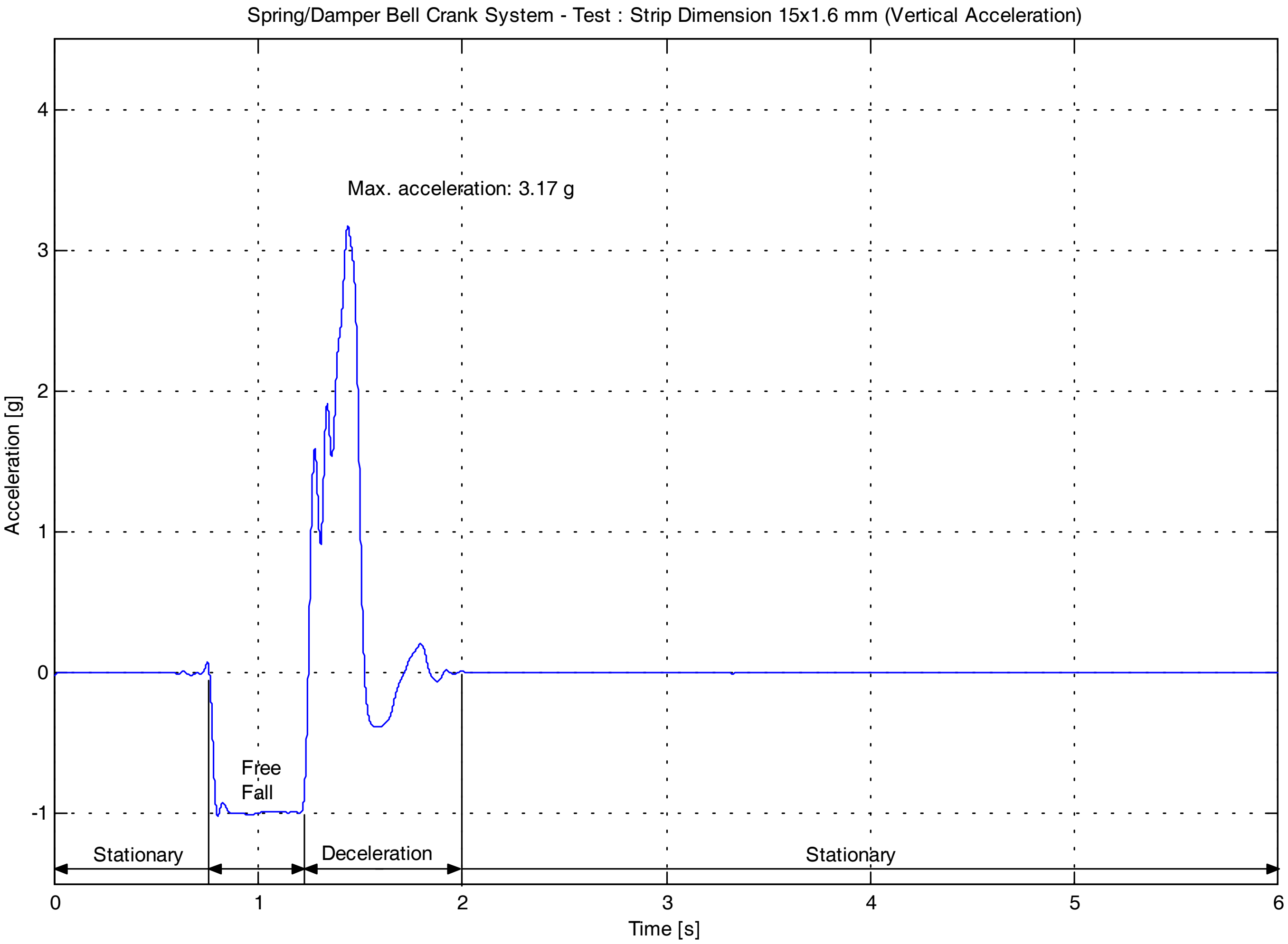


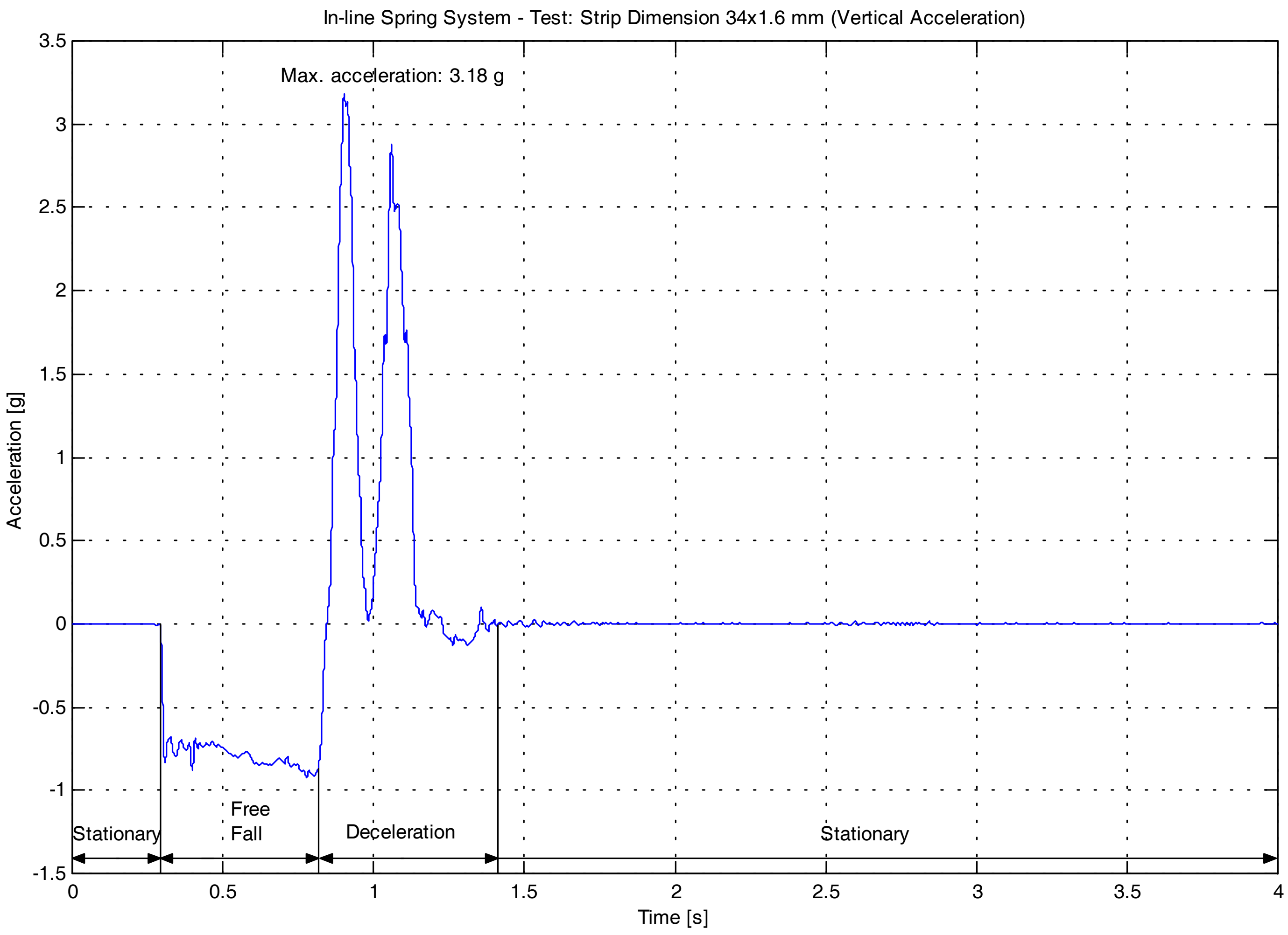
Spring/Damper Bell Crank System - Final Test : Strip Dimension 20x1.5 mm (Vertical Acceleration)
Max. acceleration: 2.53 g
Speed before impact: 4.44 m/s
Stop Distance : 710 mm (approx.)
Acceleration [g]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
Stationary
Free
Fall
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]

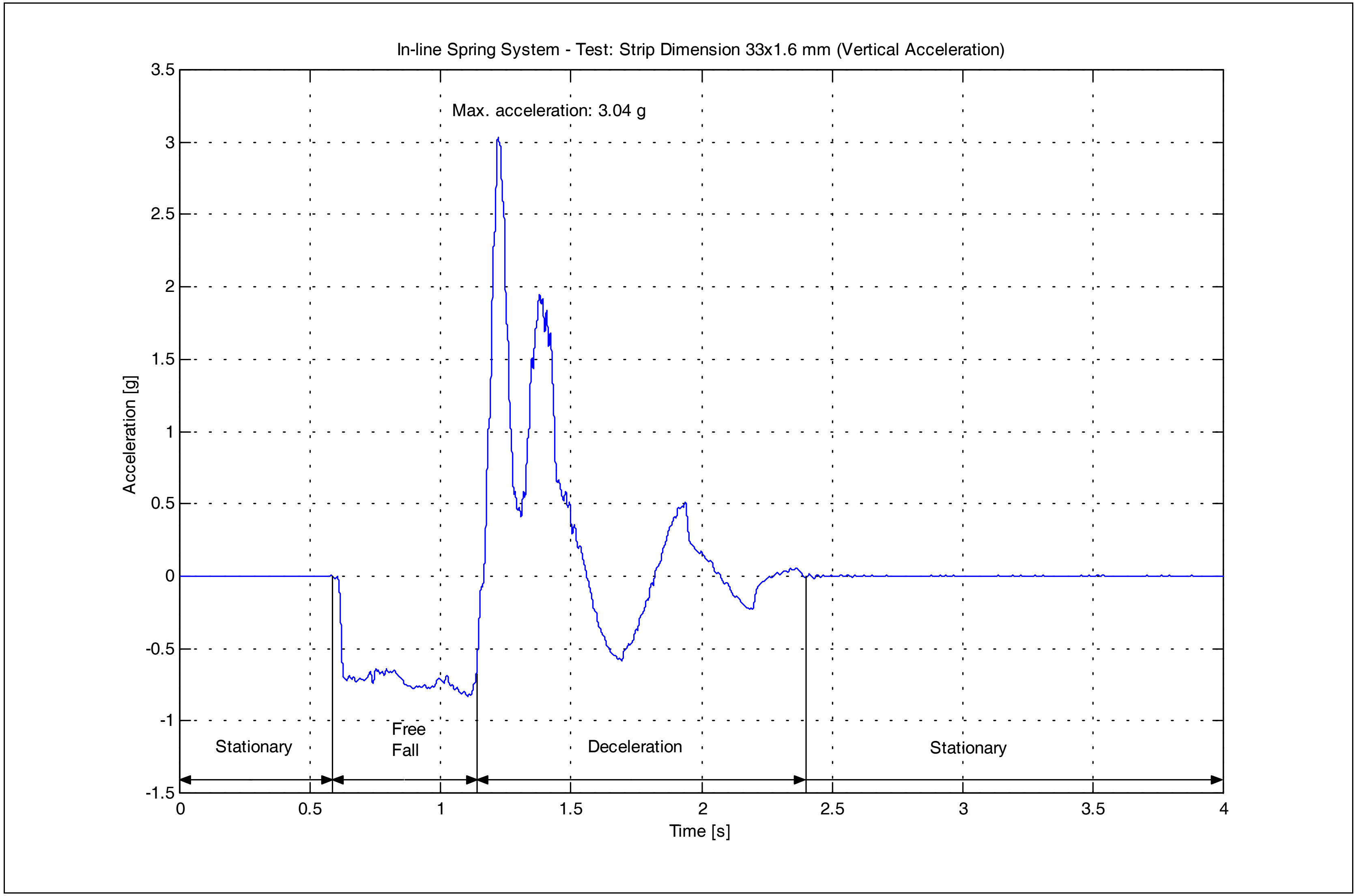

Spring/Damper Bell Crank System - Test : Strip Dimension 12x2 mm (Vertical Acceleration)
Max. acceleration: 3.45 g
Acceleration [g]
4
3
2
1
0
-1
Free
Fall
Stationary
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]

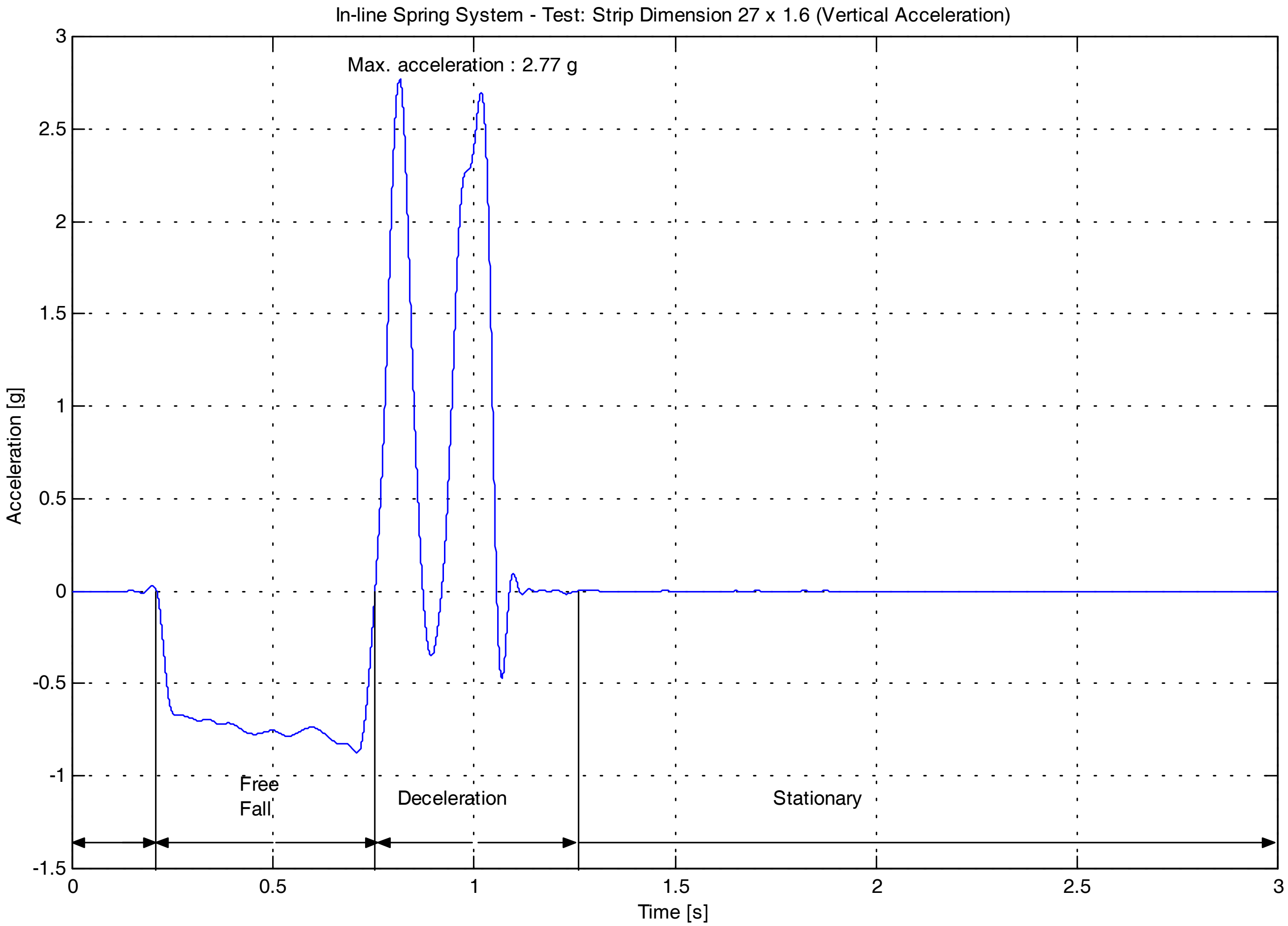

Spring/Damper Bell Crank System - Test : Strip Dimension 10x3 mm (Vertical Acceleration)
Max. acceleration: 5.8 g
Acceleration [g]
7
6
5
4
3
2
1
0
-1
Free
Fall
Stationary
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]


Spring/Damper Bell Crank System - Test : Strip Dimension 20x2 mm (Vertical Acceleration)
Max. acceleration: 3.79 g
Acceleration [g]
4
3
2
1
0
-1
Free
Fall
Stationary
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]

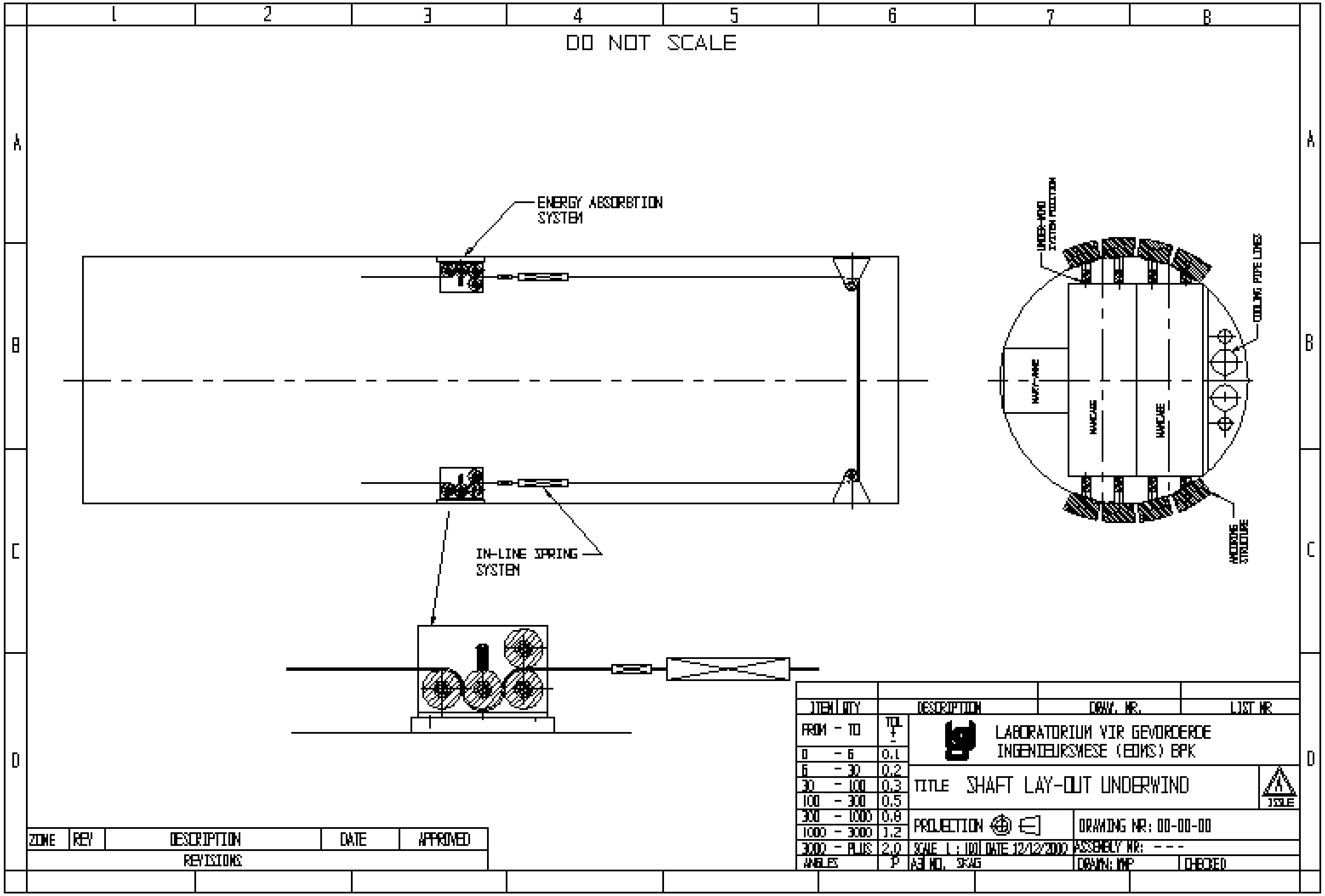

Spring/Damper Bell Crank System - Test : Strip Dimension 15x1.6 mm (Vertical Acceleration)
Max. acceleration: 3.17 g
Acceleration [g]
4
3
2
1
0
-1
Free
Fall
Stationary
Deceleration
Stationary
0
1
2
3
4
5
6
Time [s]

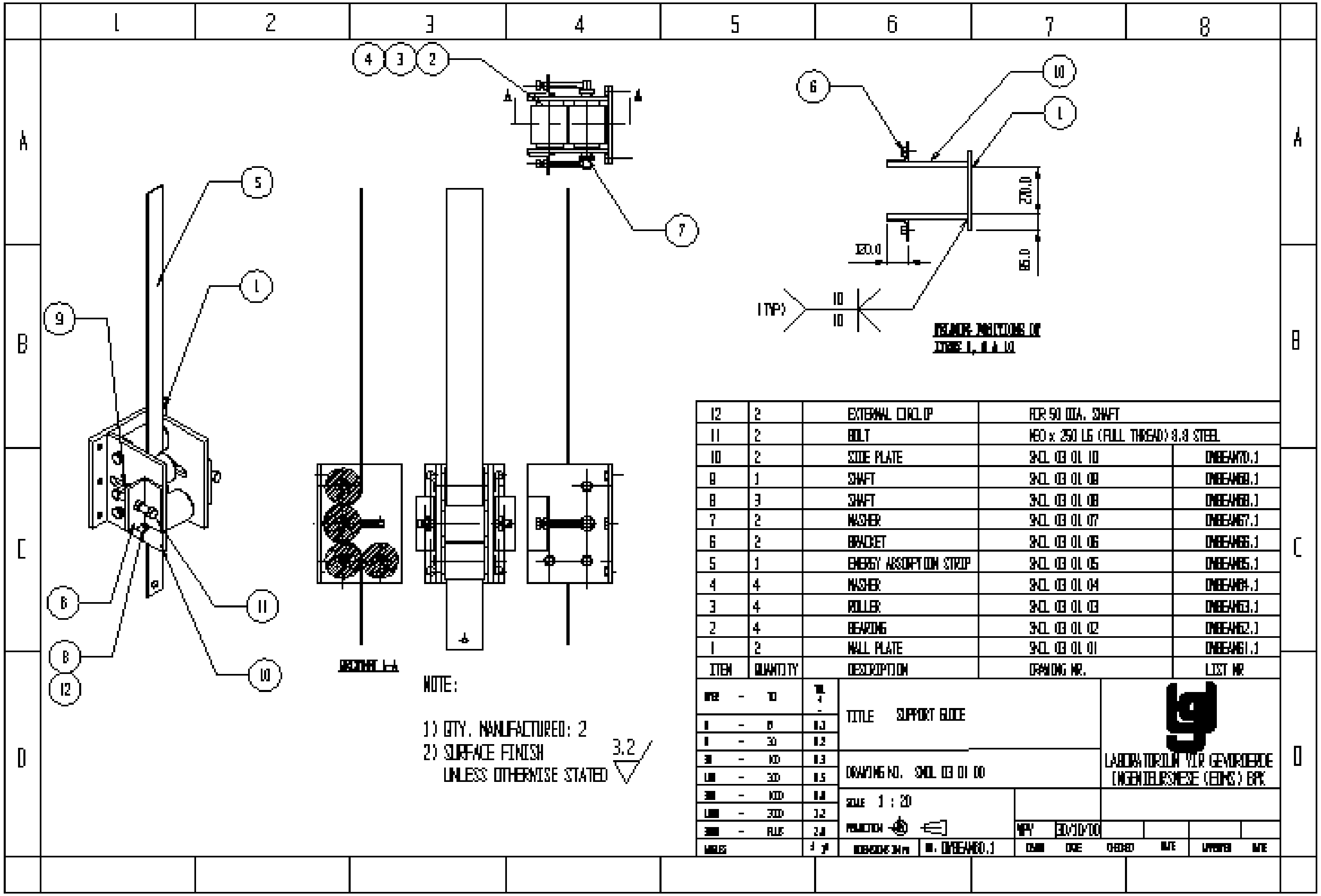

In-line Spring System - Test: Strip Dimension 34x1.6 mm (Vertical Acceleration)
Max. acceleration: 3.18 g
Acceleration [g]
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
Stationary
Free Fall
Deceleration
Stationary
0
0.5
1
1.5
2
2.5
3
3.5
4
Time [s]


In-line Spring System - Test: Strip Dimension 33x1.6 mm (Vertical Acceleration)
Max. acceleration: 3.04 g
Acceleration [g]
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
Stationary
Free
Fall
Deceleration
Stationary
0
0.5
1
1.5
2
2.5
3
3.5
4
Time [s]


In-line Spring System - Test: Strip Dimension 27 x 1.6 (Vertical Acceleration)
Max. acceleration : 2.77 g
Acceleration [g]
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
Free
Fall
Deceleration
Stationary
0
0.5
1
1.5
2
2.5
3
Time [s]

Appendix C: Drawings of full-scale underwind system


1
2
3
4
5
6
7
8
A
B
C
D
DO NOT SCALE
ENERGY ABSORBTION SYSTEM
IN-LINE SPRING SYSTEM
UNDER-WIND SYSTEM POSITION
COOLING PIPE LINES
ANCHORING STRUCTURE
MANCAGE
MANCAGE
ITEM
QTY
DESCRIPTION
DRAW. NR.
LIST NR
FROM - TO
TOL ±
0 - 6 0.1
6 - 30 0.2
30 - 100 0.3
100 - 300 0.5
300 - 1000 0.8
1000 - 3000 1.2
3000 - PLUS 2.0
ANGLES
LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK
TITLE SHAFT LAY-OUT UNDERWIND
ISLE
PROJECTION
DRAWING NR: 00-00-00
SCALE 1 : 100
DATE 12/12/2000
ASSEMBLY NR: - - -
A3 NO. SKAG
DRAWN: MNP
CHECKED
ZONE
REV
DESCRIPTION
DATE
APPROVED
REVISIONS



NOTE:

1) QTY. MANUFACTURED: 2
2) SURFACE FINISH
UNLESS OTHERWISE STATED 3.2

ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR
12	2	EXTERNAL CIRCLIP	FOR 90 DIA. SHAFT	
11	2	BOLT	M20 x 250 LG (FULL THREAD) 8.8 STEEL	
10	2	SIDE PLATE	SHCL 03 01 10	DNBEAM70.1
9	1	SHAFT	SHCL 03 01 09	DNBEAM69.1
8	3	SHAFT	SHCL 03 01 08	DNBEAM68.1
7	2	WASHER	SHCL 03 01 07	DNBEAM67.1
6	2	BRACKET	SHCL 03 01 06	DNBEAM66.1
5	1	ENERGY ABSORPTION STRIP	SHCL 03 01 05	DNBEAM65.1
4	4	WASHER	SHCL 03 01 04	DNBEAM64.1
3	4	ROLLER	SHCL 03 01 03	DNBEAM63.1
2	4	BEARING	SHCL 03 01 02	DNBEAM62.1
1	2	WALL PLATE	SHCL 03 01 01	DNBEAM61.1

OVER	–	TO	TOL ±
[illegible]	–	6	0.1
[illegible]	–	30	0.2
[illegible]	–	120	0.3
[illegible]	–	315	0.5
[illegible]	–	1000	0.8
[illegible]	–	2000	1.2
[illegible]	–	PLUS	2.0
ANGLES			± ½°

TITLE SUPPORT SLIDE

DRAWING NO. SHCL 03 01 00

SCALE 1 : 20

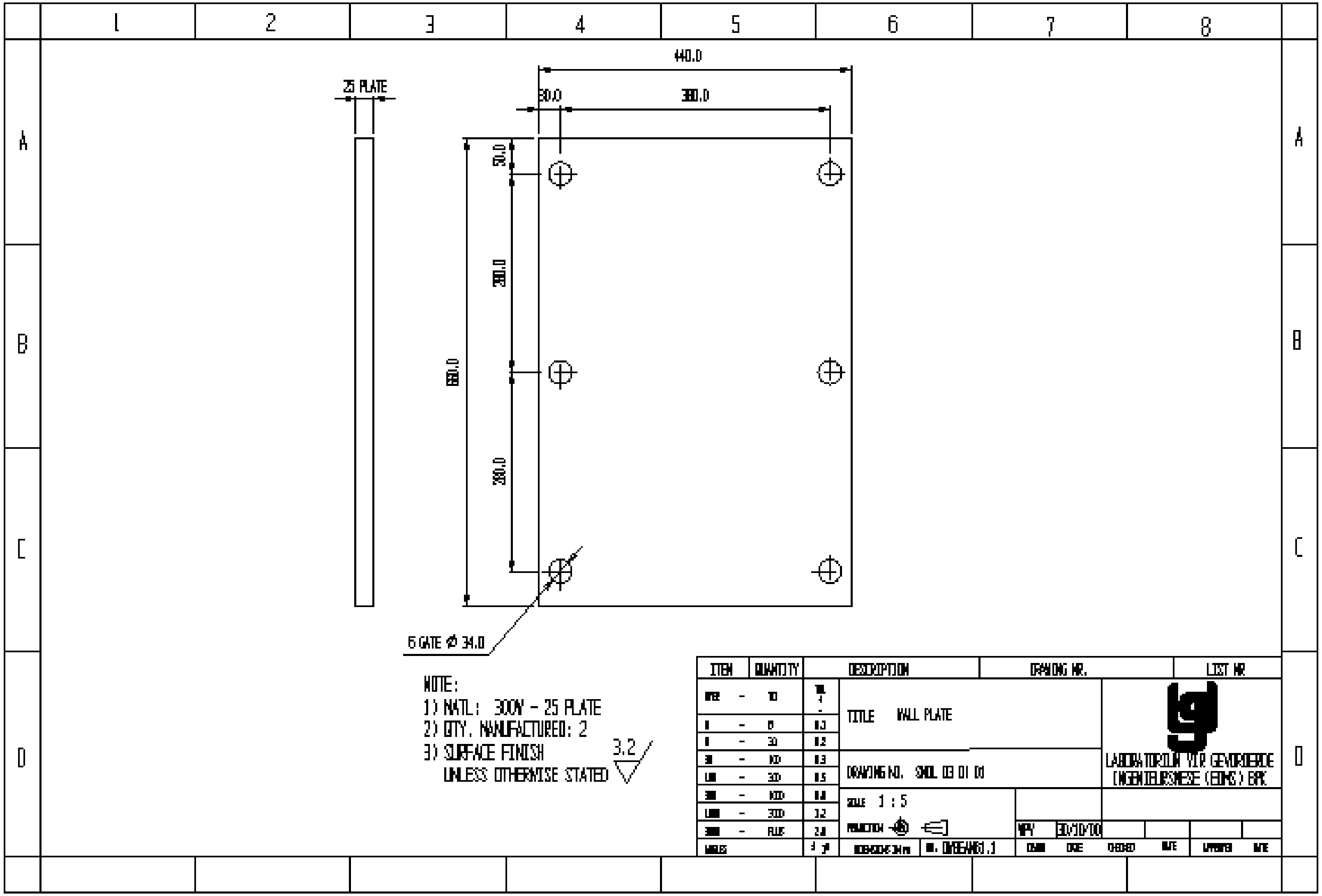
PROJECTION

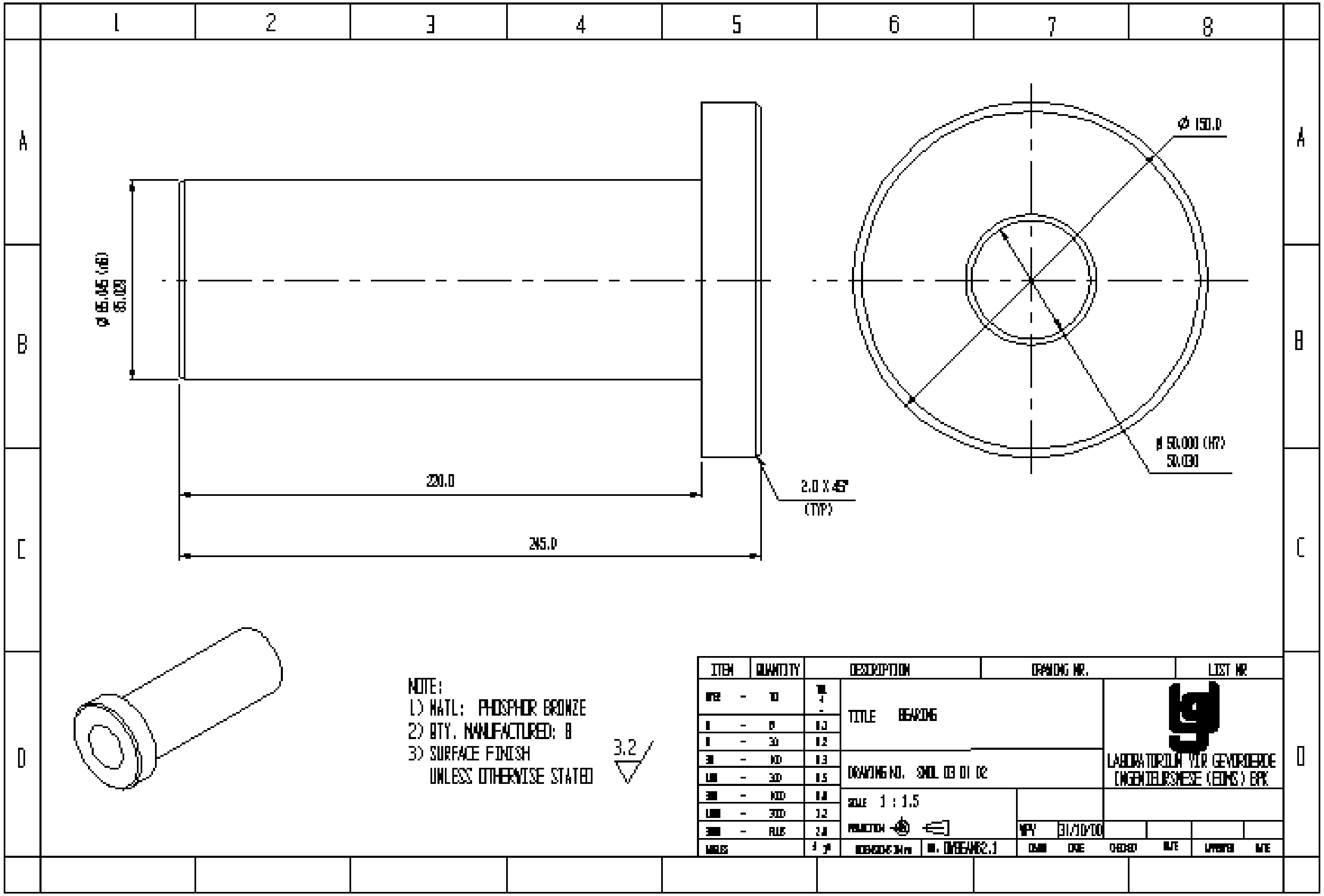
DIMENSIONS IN mm

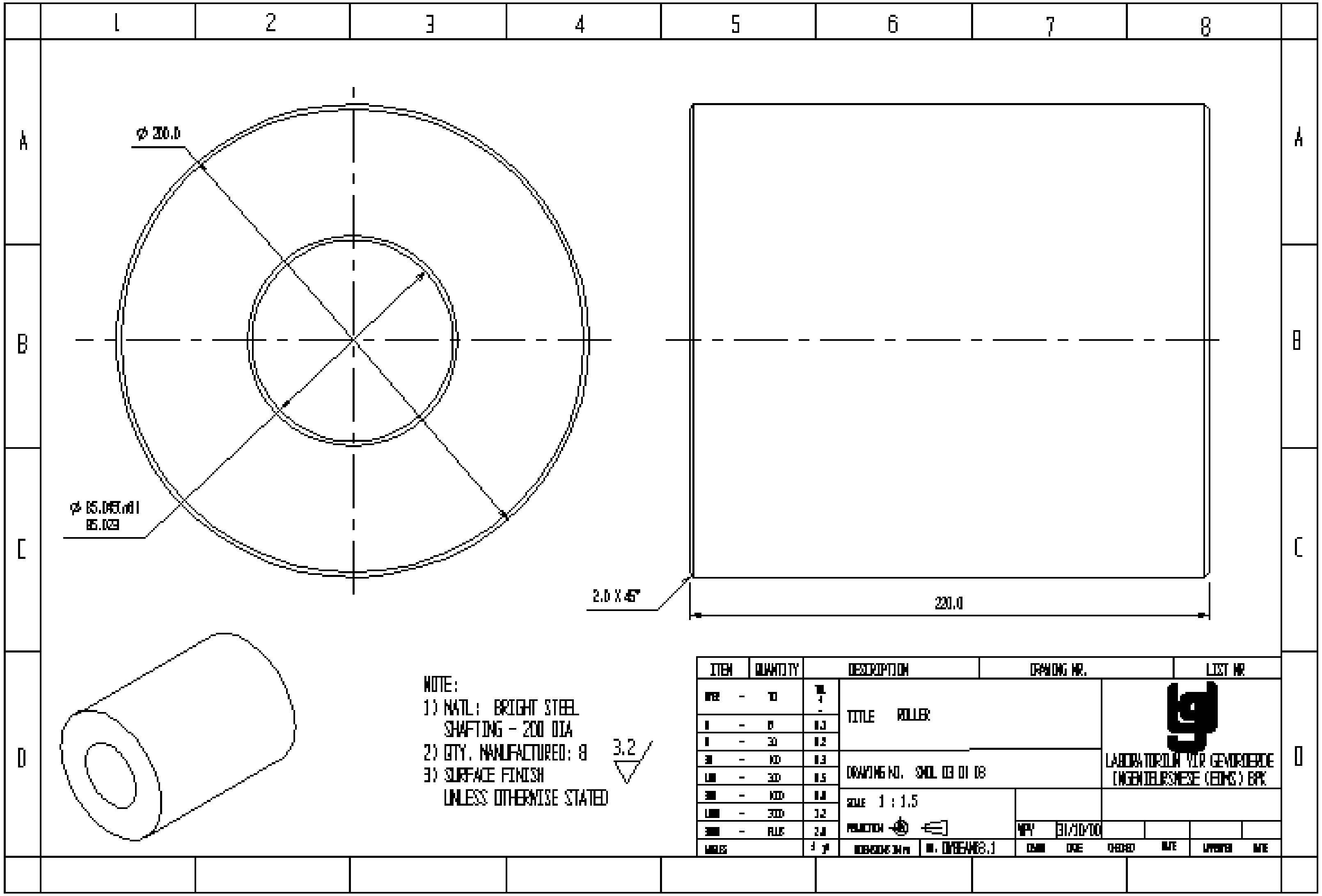
NR. DNBEAM60.1

LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK

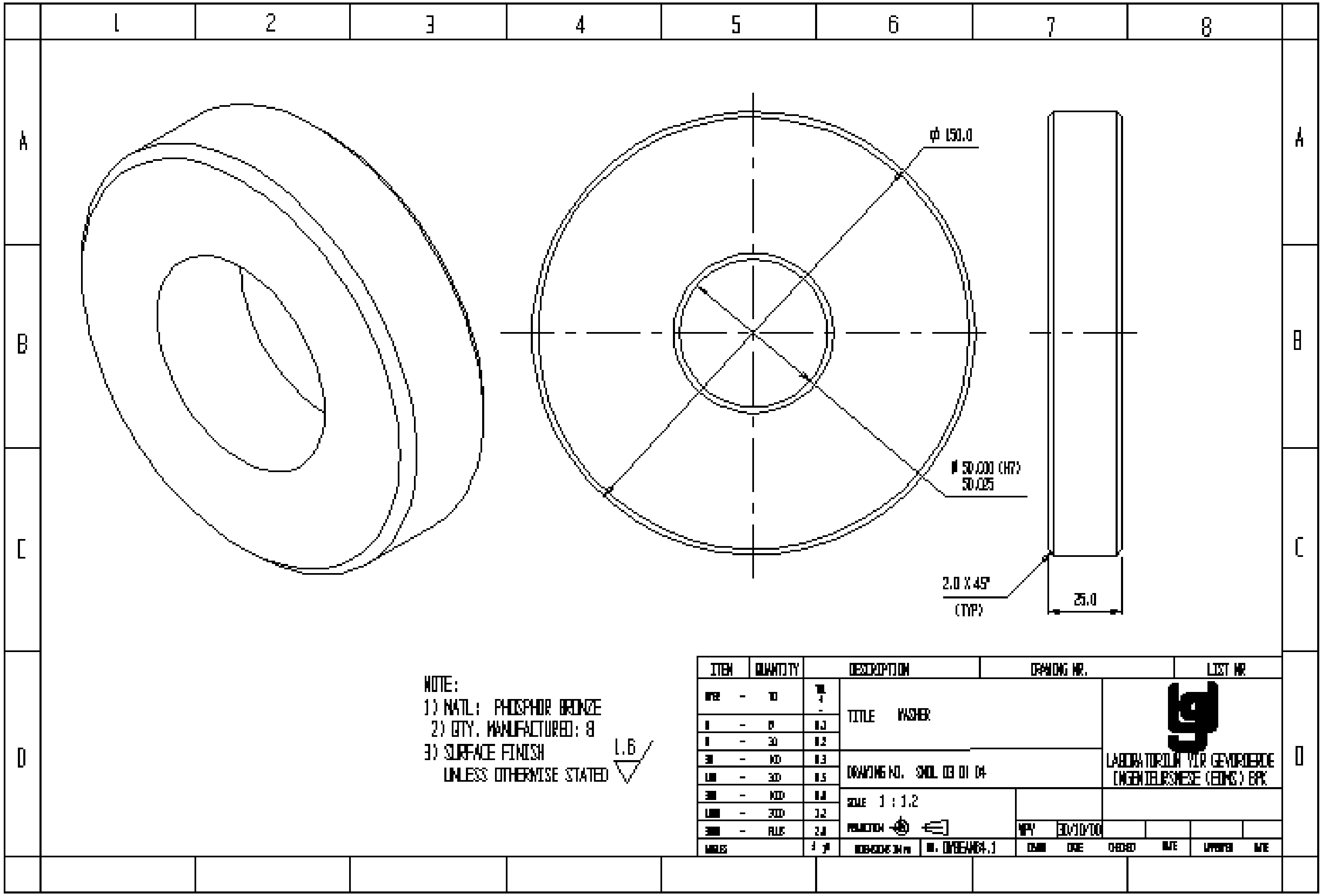
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
MPV	30/10/00				

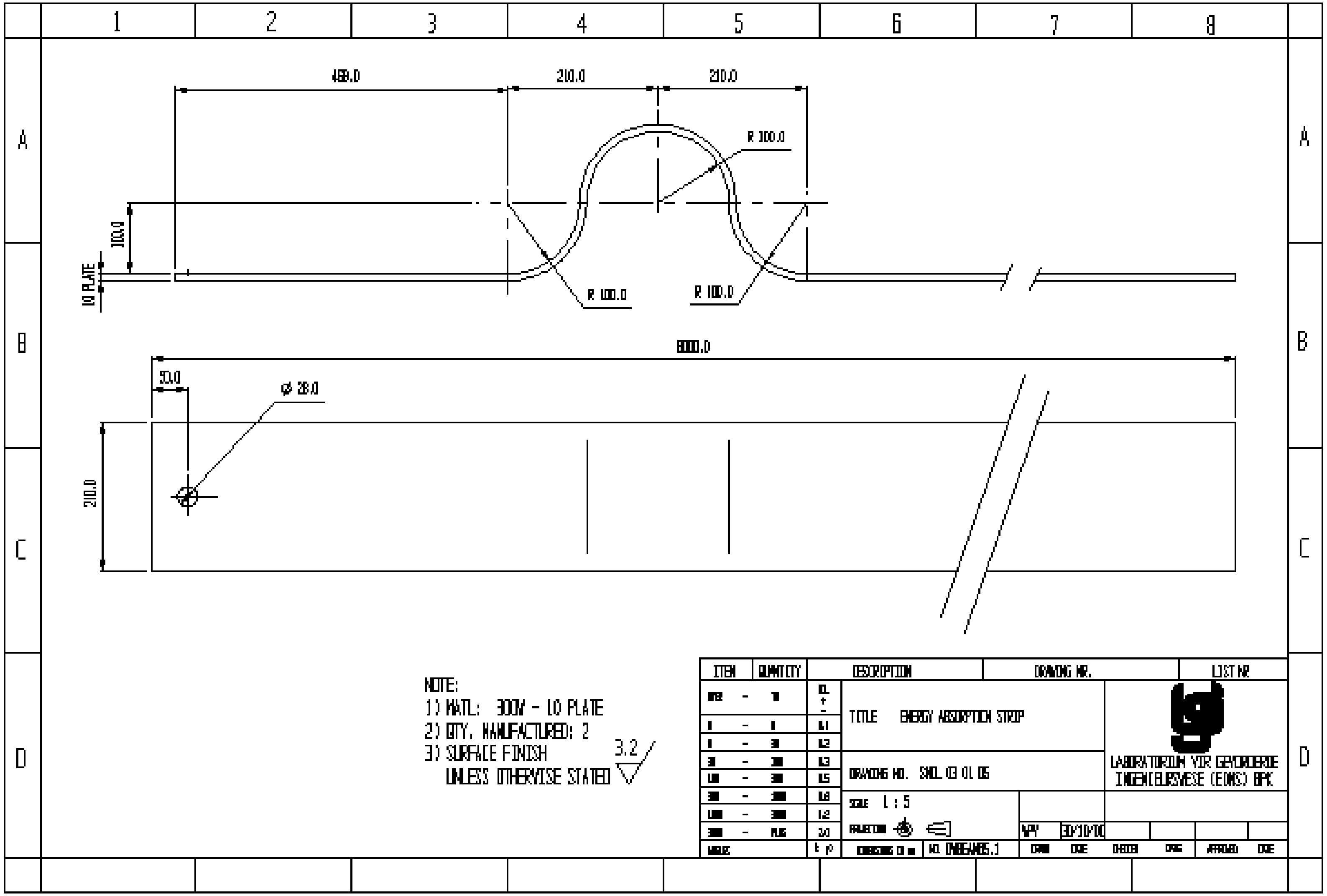

1
2
3
4
5
6
7
8
A
B
C
D
440.0
30.0
380.0
25 PLATE
50.0
280.0
280.0
660.0
6 GATE ⌀ 34.0
NOTE:
1) MATL: 300W - 25 PLATE
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE WALL PLATE
DRAWING NO. SMDL 03 01 00
SCALE 1 : 5
PROJECTION
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK
NPV
30/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE

1
2
3
4
5
6
7
8
A
B
C
D
Ø 85.045 (n6)
85.023
220.0
245.0
2.0 X 45°
(TYP)
Ø 150.0
Ø 50.000 (H7)
50.030
NOTE:
1) MATL: PHOSPHOR BRONZE
2) QTY. MANUFACTURED: 8
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
OVER - TO
TOL ±
0 - 6 0.1
6 - 30 0.2
30 - 120 0.3
120 - 300 0.5
300 - 1000 0.8
1000 - 3000 1.2
3000 - PLUS 2.0
ANGLES ± 1°
TITLE BEARING
DRAWING NO. SMDL 03 01 02
SCALE 1 : 1.5
PROJECTION
MPV 31/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK



1
2
3
4
5
6
7
8
A
B
C
D
Ø 200.0
Ø 85.045
85.023
2.0 X 45°
220.0
NOTE:
1) MATL: BRIGHT STEEL
SHAFTING - 200 DIA
2) QTY. MANUFACTURED: 8
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
OVER - TO
0 - 6 0.1
6 - 30 0.2
30 - 120 0.3
120 - 300 0.5
300 - 1000 0.8
1000 - 2000 1.2
2000 - PLUS 2.0
ANGLES
TITLE ROLLER
DRAWING NO. SMDL 03 01 08
SCALE 1 : 1.5
PROJECTION
DIMENSIONS IN mm
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK
NPV
31/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE


1
2
3
4
5
6
7
8
A
B
C
D
ϕ 150.0
ϕ 50.000 (H7)
50.025
2.0 X 45°
(TYP)
25.0
NOTE:
1) MATL: PHOSPHOR BRONZE
2) QTY. MANUFACTURED: 8
3) SURFACE FINISH
UNLESS OTHERWISE STATED
1.6
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE WASHER
DRAWING NO. SMDL 03 01 04
SCALE 1 : 1.2
PROJECTION
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (LGI) BPK
DRAWN
CHECKED
DATE
APPROVED
DATE



NOTE:
1) MATL: 300W - 10 PLATE
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH 3.2
UNLESS OTHERWISE STATED

ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR

TITLE ENERGY ABSORPTION STRIP

DRAWING NO. SNL 03 01 05

SCALE 1 : 5

PROJECTION

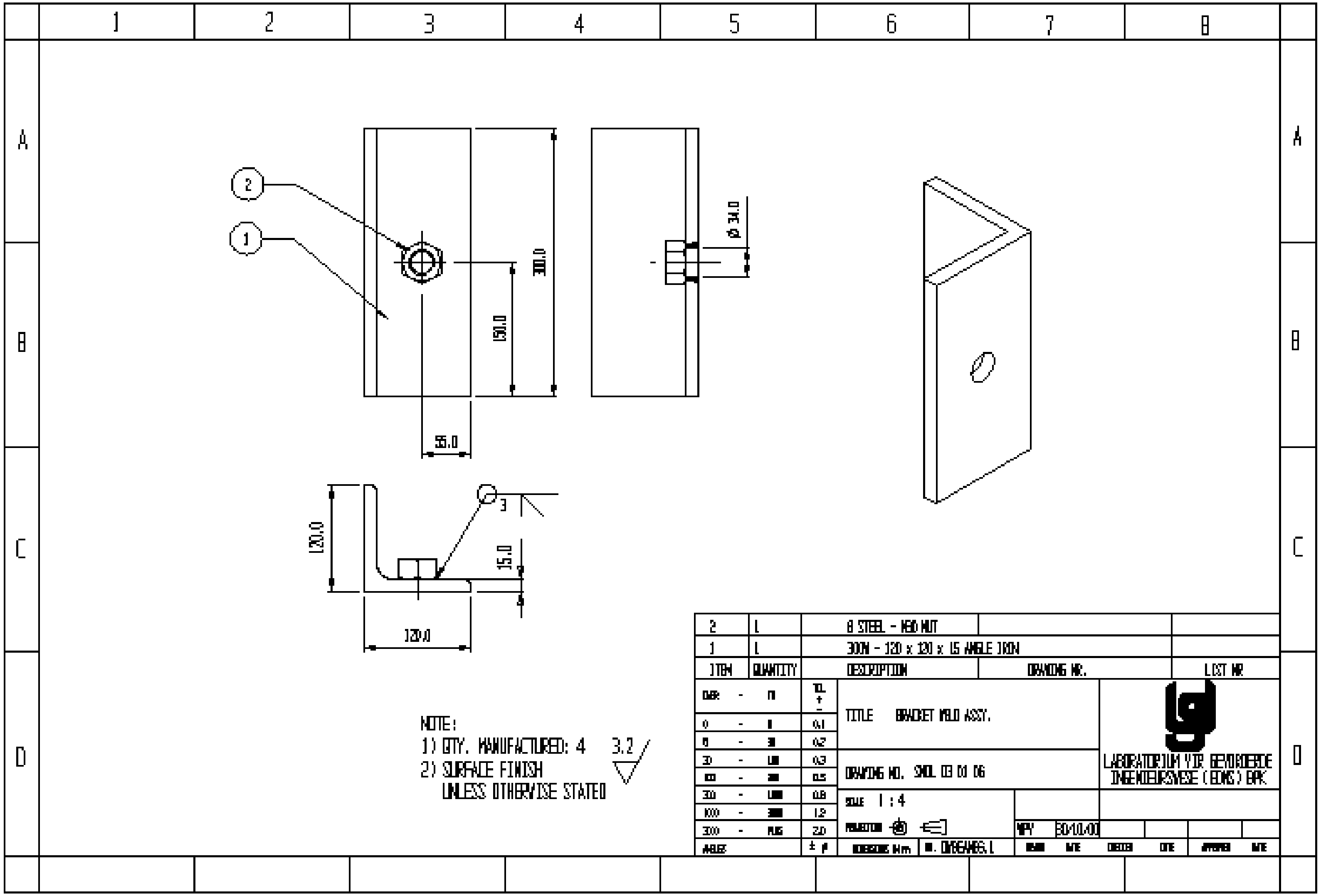
WPV 30/10/00

DRAWN DATE CHECKED DATE APPROVED DATE

NO. [illegible]

LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK

[illegible]	0.1
[illegible]	0.2
[illegible]	0.3
[illegible]	0.5
[illegible]	0.8
[illegible]	1.2
[illegible]	2.0



2	1	8 STEEL - WELD NUT		
1	1	300M - 120 x 120 x 15 ANGLE IRON		
ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR

NOTE:
1) QTY. MANUFACTURED: 4
2) SURFACE FINISH
UNLESS OTHERWISE STATED

OVER - TO	TOL. ±
0 - 6	0.1
6 - 30	0.2
30 - 120	0.3
120 - 300	0.5
300 - 1000	0.8
1000 - 3000	1.2
3000 - PLUS	2.0
ANGLES	±

TITLE BRACKET WELD ASSY.

DRAWING NO. SMDL 03 01 06

SCALE 1 : 4

PROJECTION

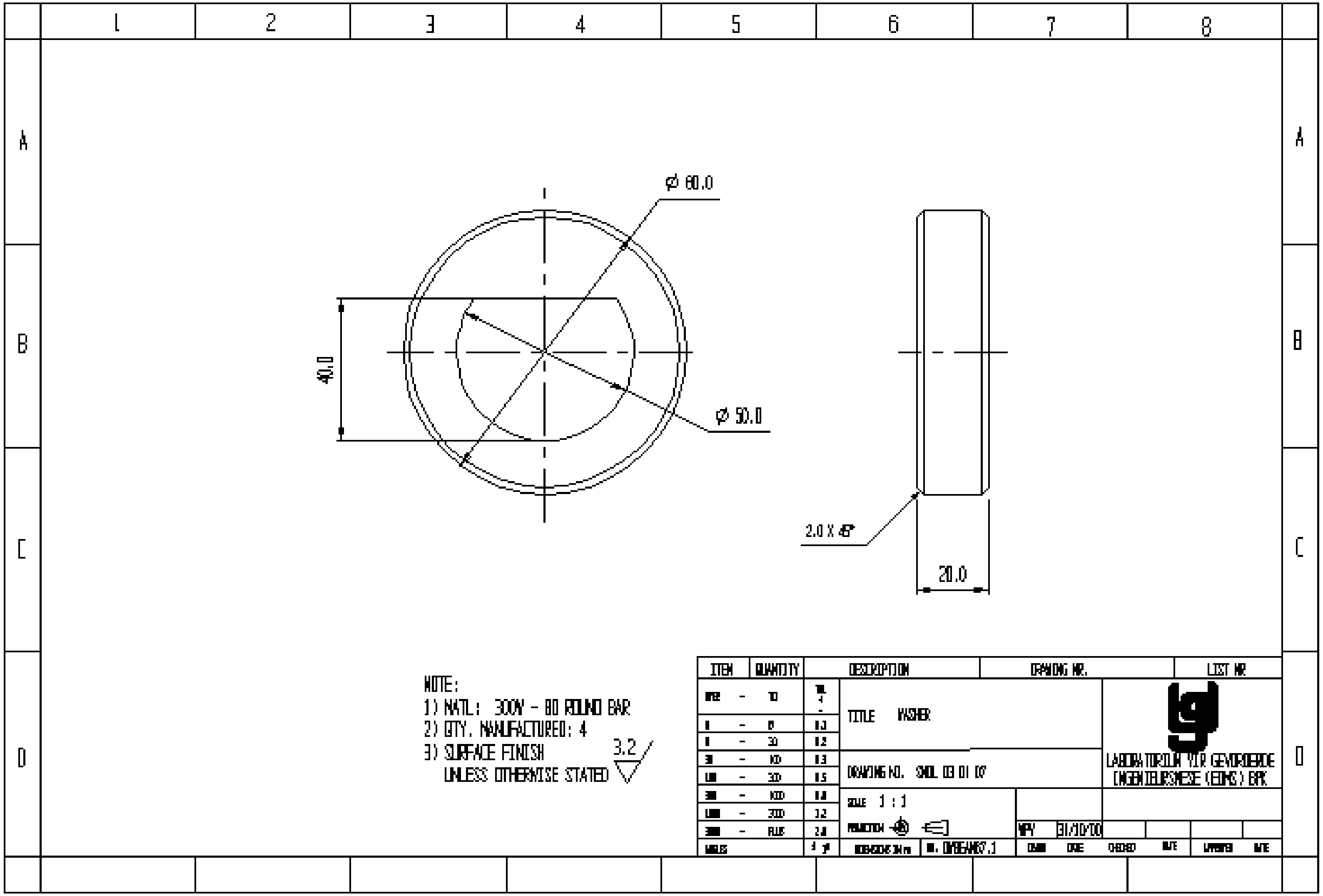
NPV 30/10/00

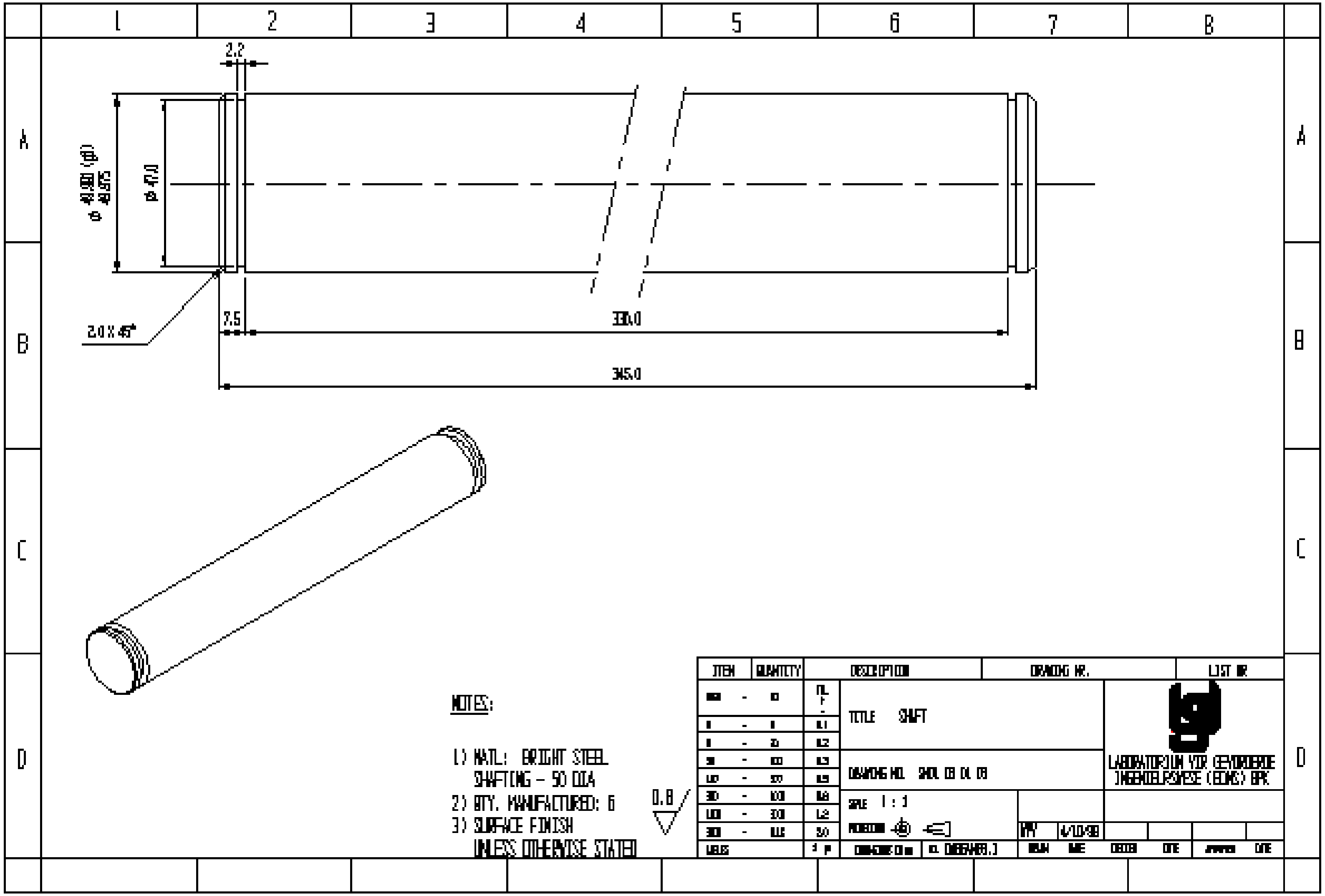
DIMENSIONS IN mm

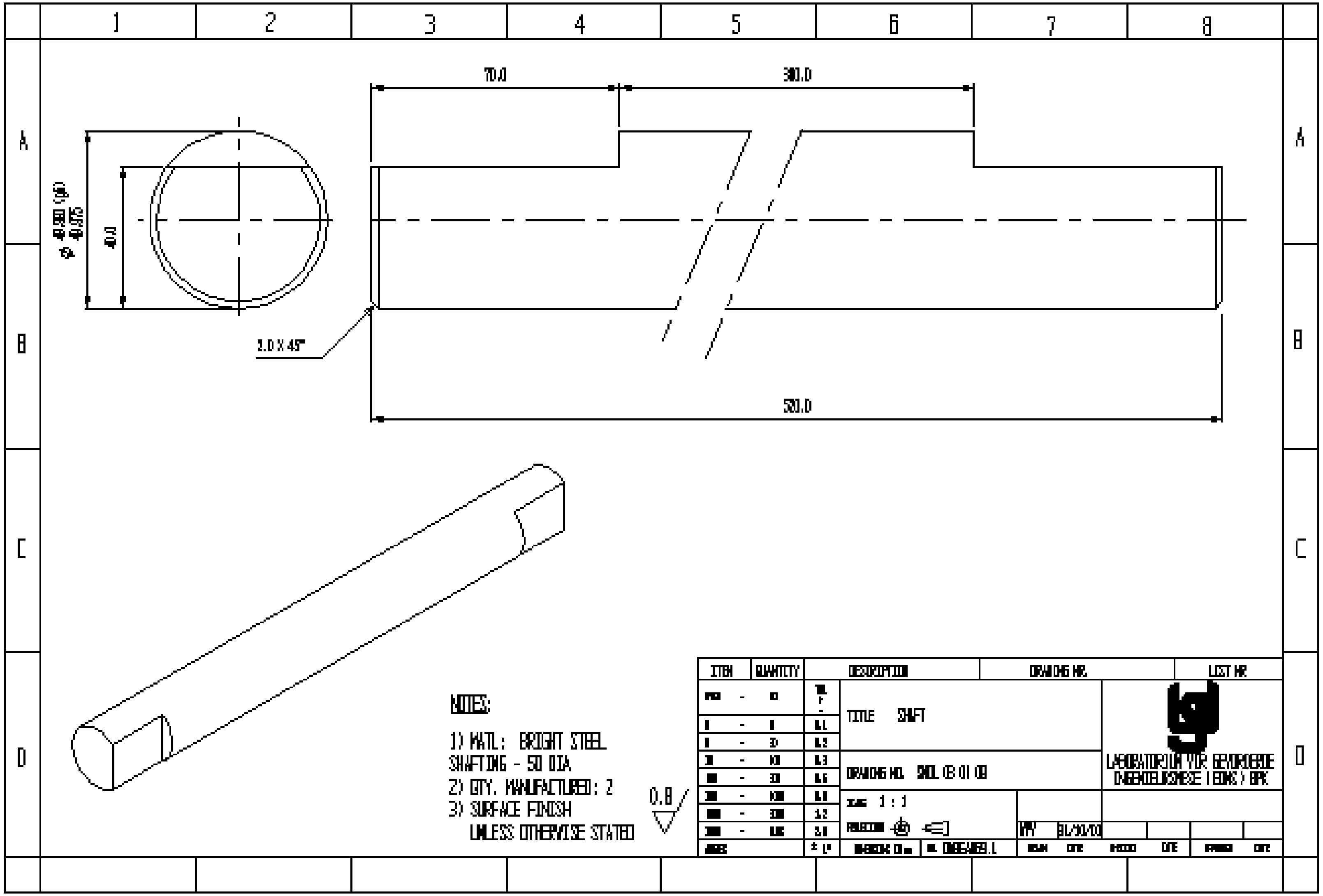
FN. DWGBEAMS.1

DRAWN DATE CHECKED DATE APPROVED DATE

LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK

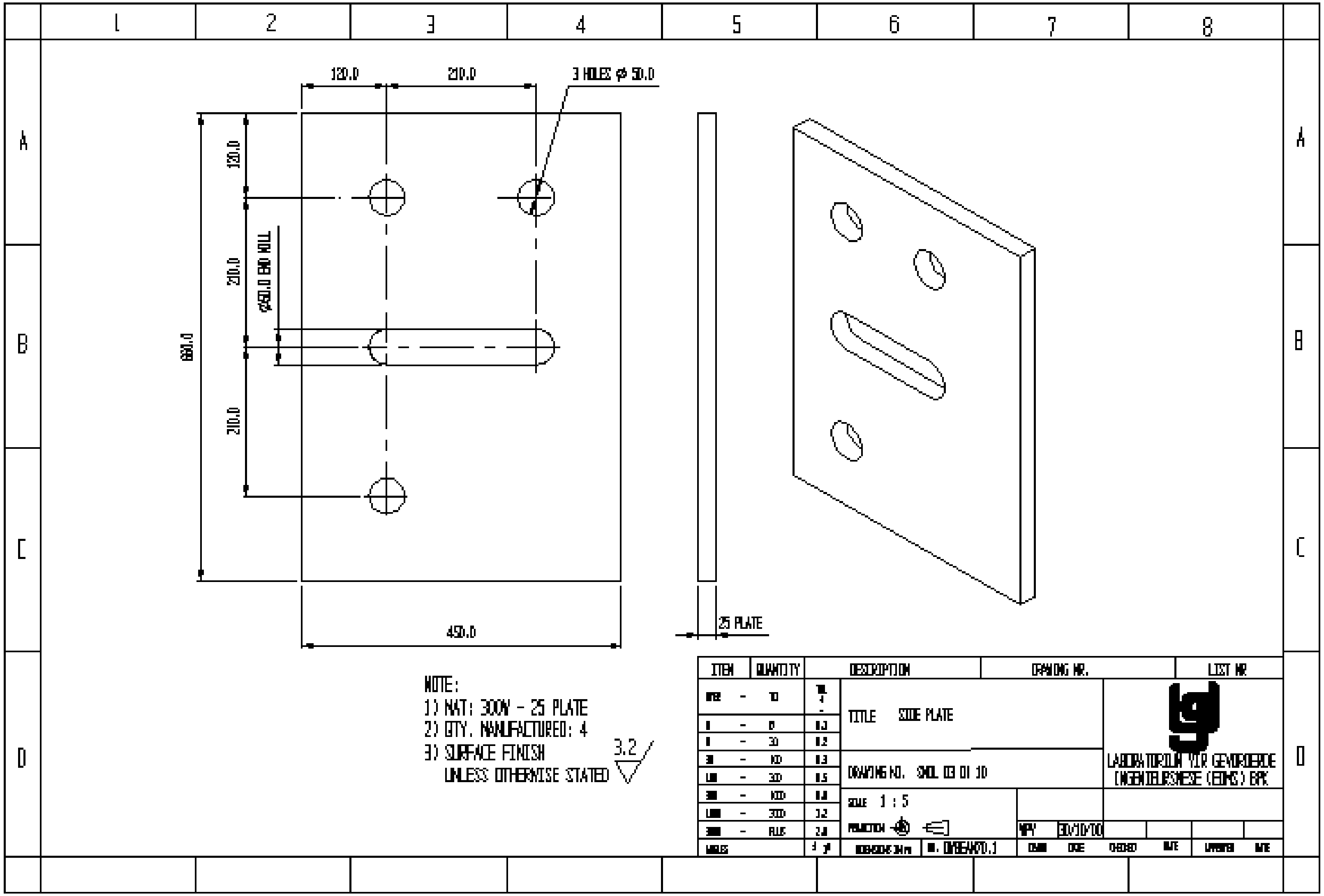

1
2
3
4
5
6
7
8
A
B
C
D
Ø 60.0
Ø 50.0
40.0
2.0 X 45°
20.0
NOTE:
1) MATL: 300W - 80 ROUND BAR
2) QTY. MANUFACTURED: 4
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE WASHER
DRAWING NO. SMDL 03 01 07
SCALE 1 : 1
PROJECTION
WPV 31/10/00
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (LGI) BPK
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE


2.2
⌀ 47.0
(g6)
49.975
2.0 X 45°
7.5
330.0
345.0
NOTES:
1) MATL: BRIGHT STEEL
SHAFTING - 50 DIA
2) QTY. MANUFACTURED: 6
3) SURFACE FINISH
UNLESS OTHERWISE STATED
0.8
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE SHAFT
DRAWING NO.
SCALE 1 : 1
PROJECTION
4/10/98
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK
A
B
C
D
1
2
3
4
5
6
7
8

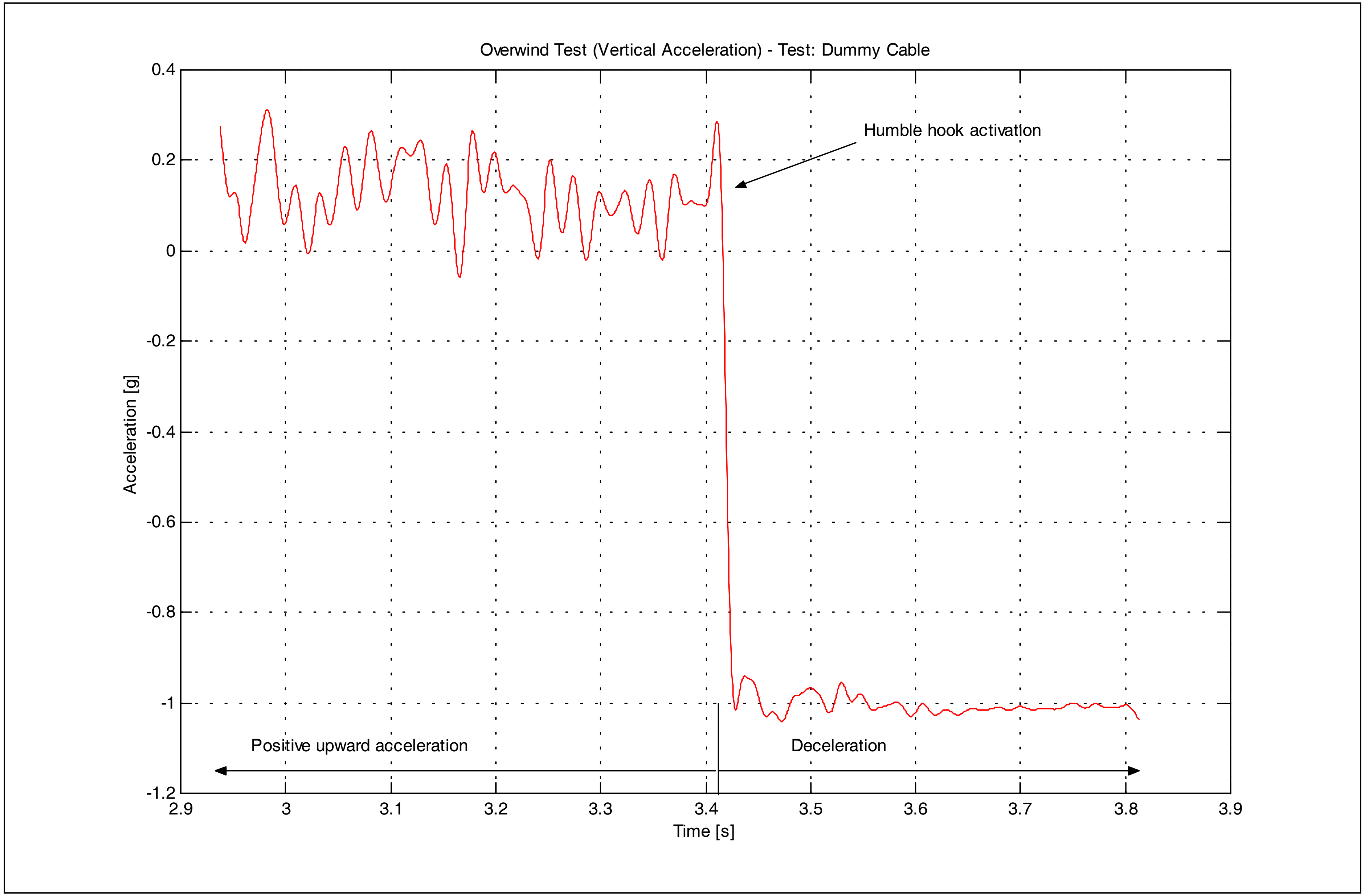


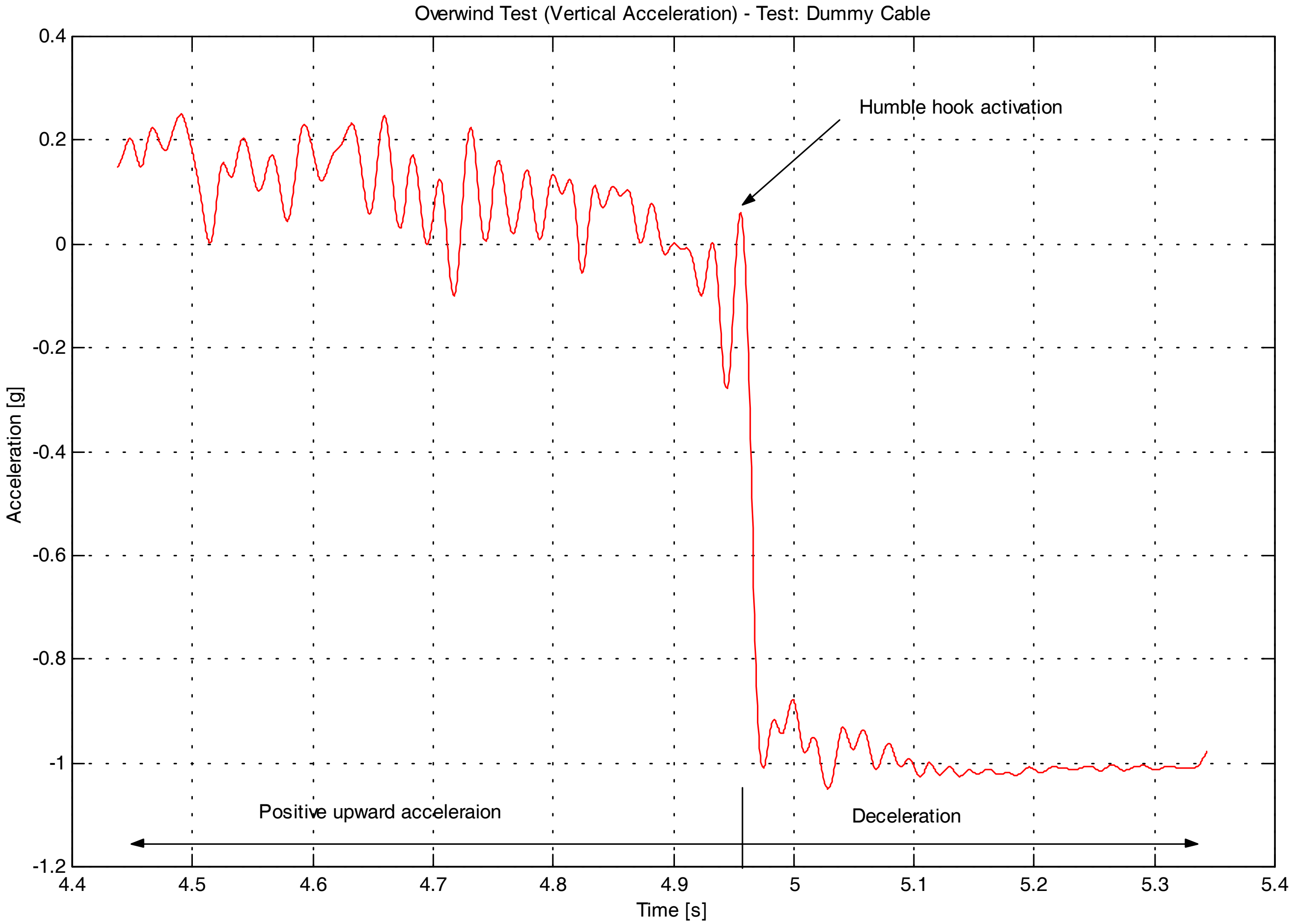
NOTES:

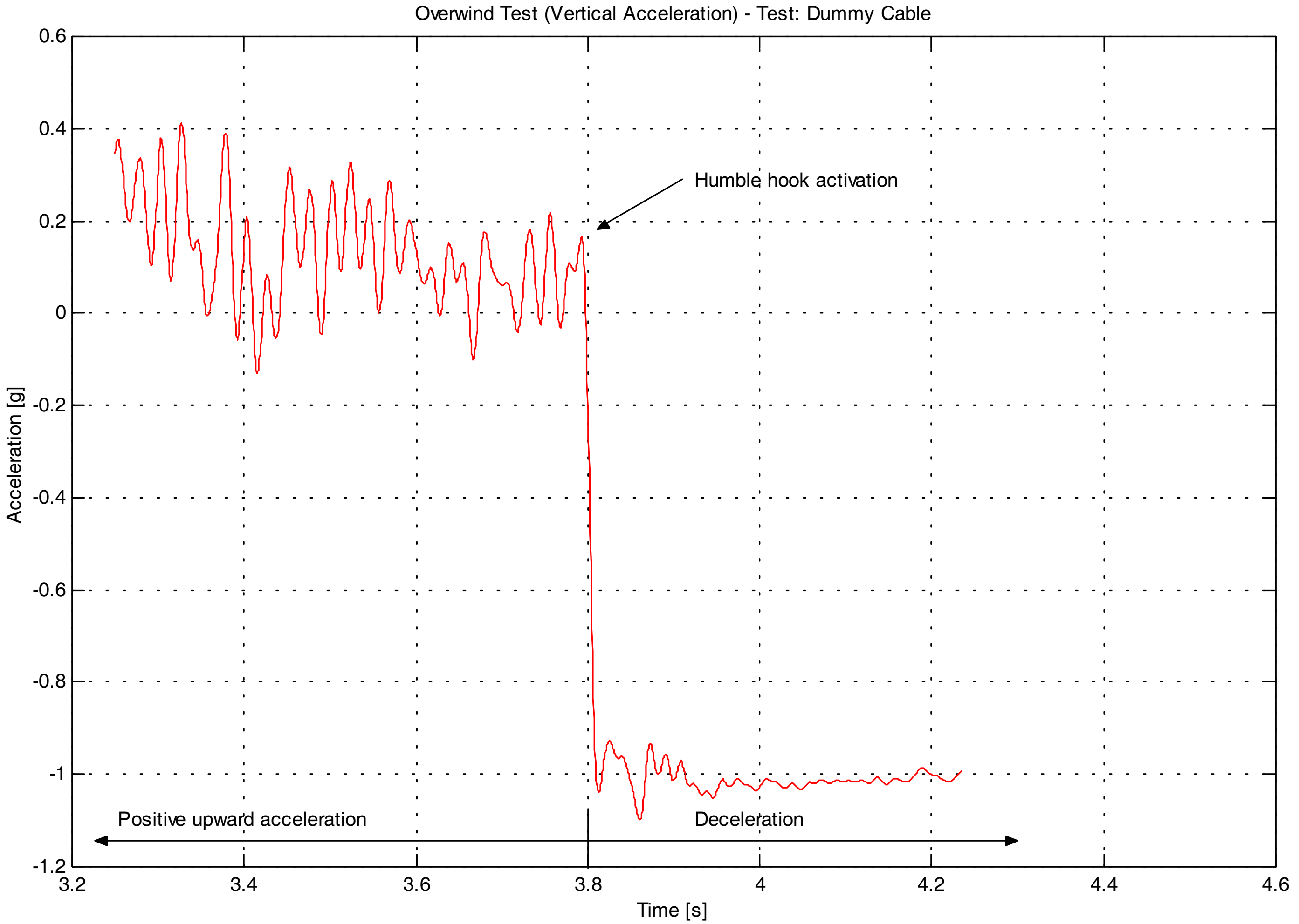
1) MATL: BRIGHT STEEL
SHAFTING - 50 DIA
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED

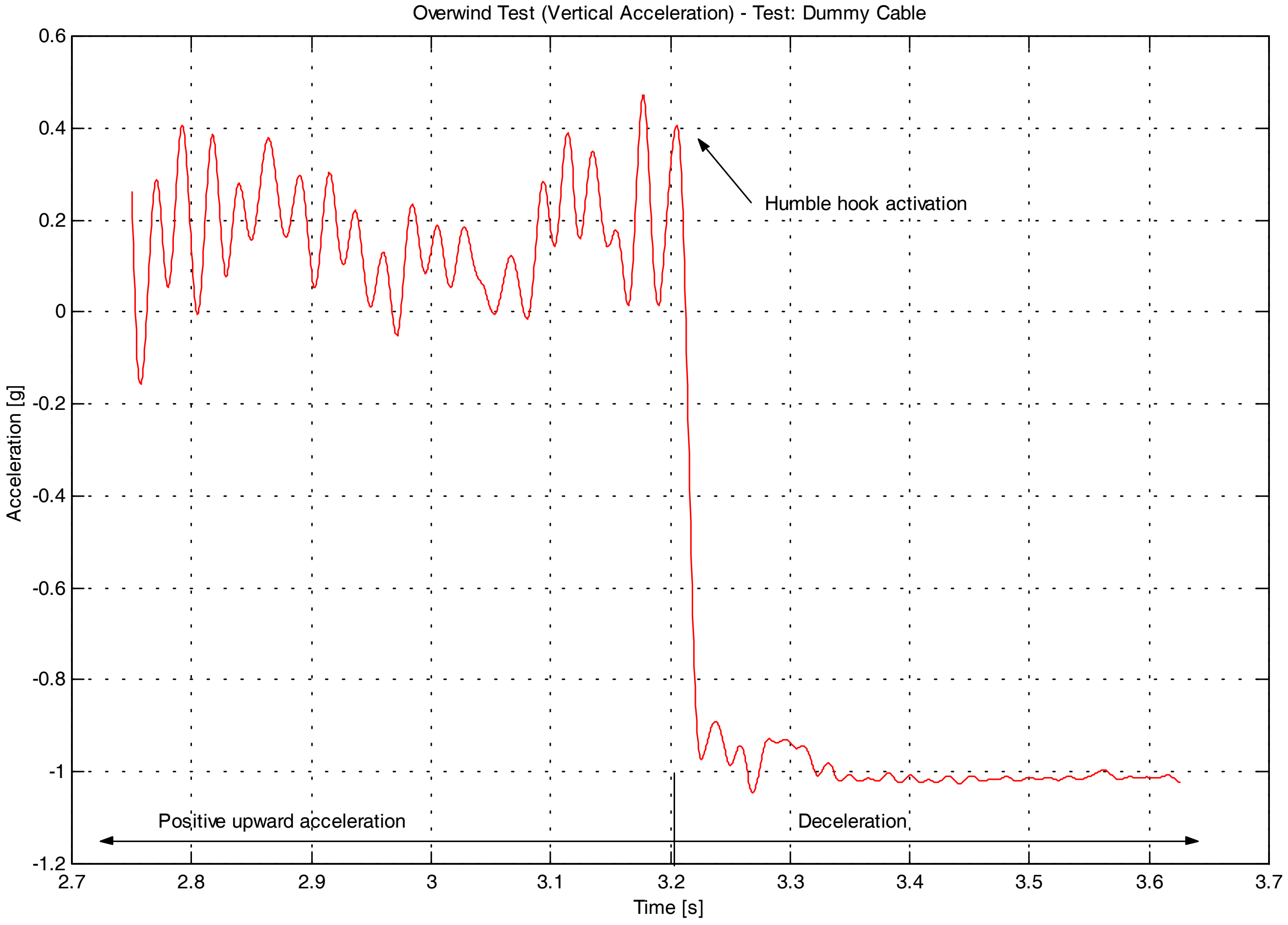

1
2
3
4
5
6
7
8
A
B
C
D
120.0
210.0
3 HOLES φ 50.0
120.0
210.0
210.0
φ50.0 END MILL
680.0
450.0
25 PLATE
NOTE:
1) MAT: 300W - 25 PLATE
2) QTY. MANUFACTURED: 4
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE SIDE PLATE
DRAWING NO. SMDL 03 01 10
SCALE 1 : 5
PROJECTION
MPV
30/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK

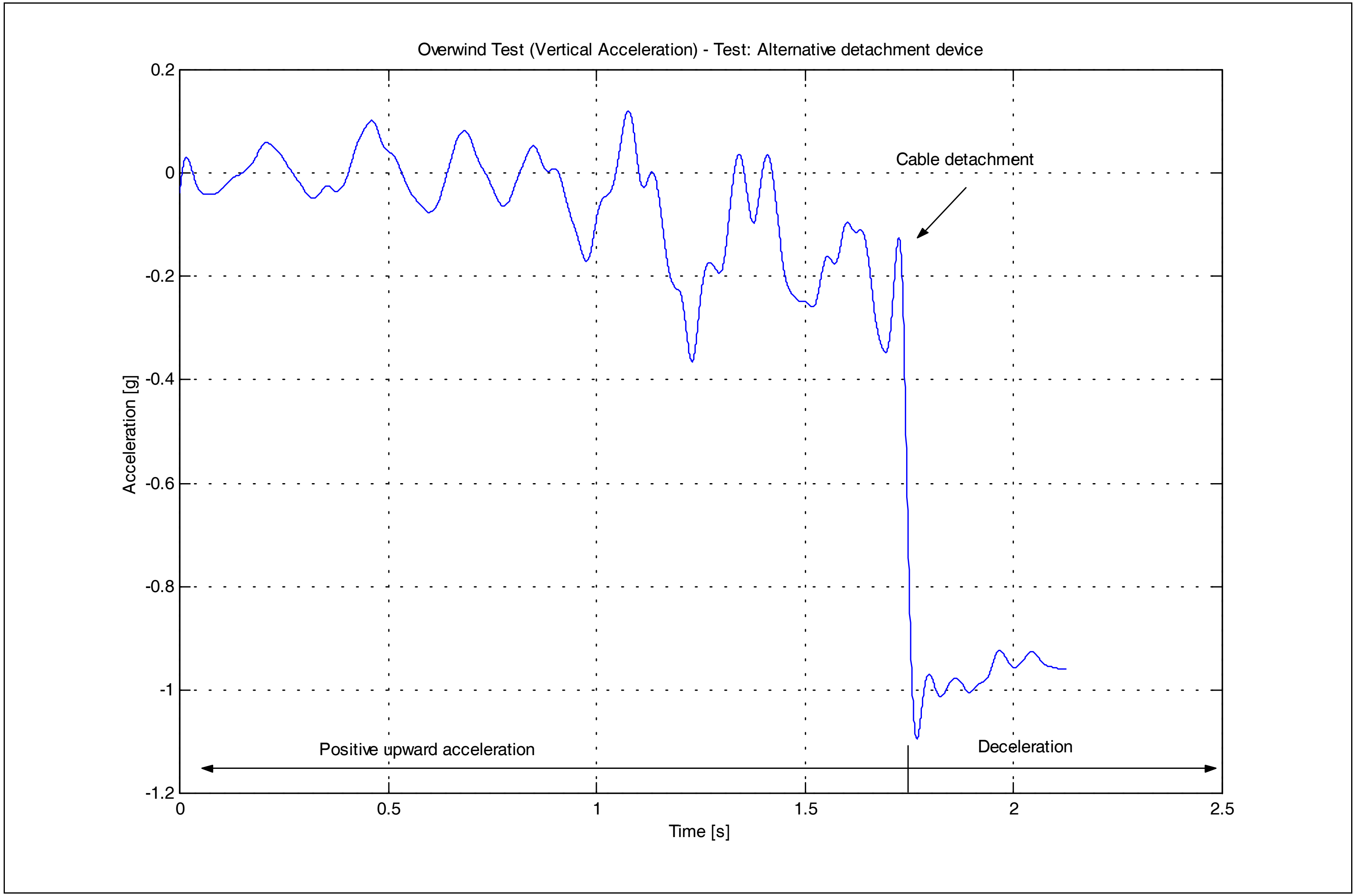
Appendix D: Test results: Overwind System


Overwind Test (Vertical Acceleration) - Test: Dummy Cable
Acceleration [g]
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
Time [s]
Humble hook activation
Positive upward acceleration
Deceleration

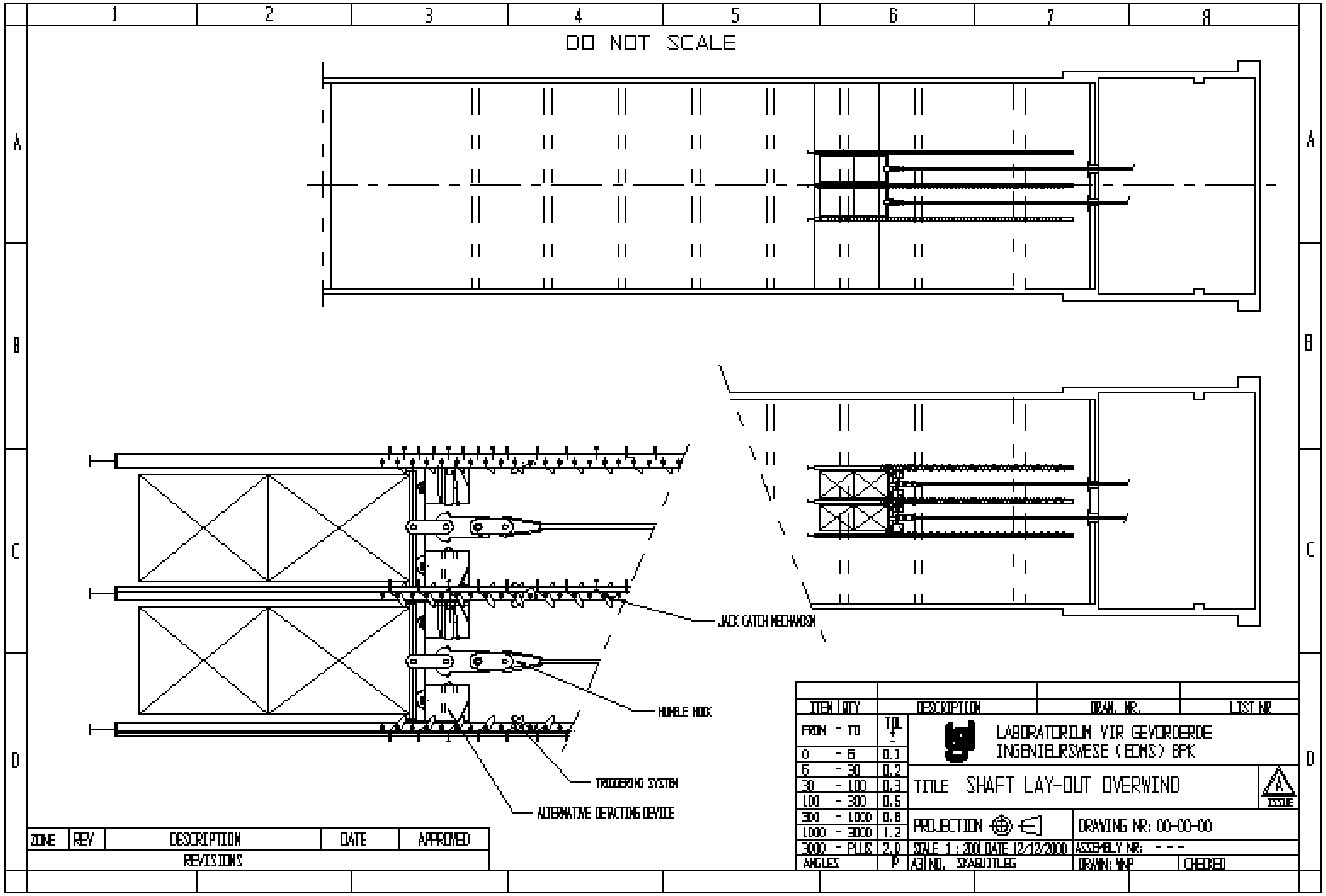

Overwind Test (Vertical Acceleration) - Test: Dummy Cable
Acceleration [g]
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
4.4
4.5
4.6
4.7
4.8
4.9
5
5.1
5.2
5.3
5.4
Time [s]
Humble hook activation
Positive upward acceleraion
Deceleration

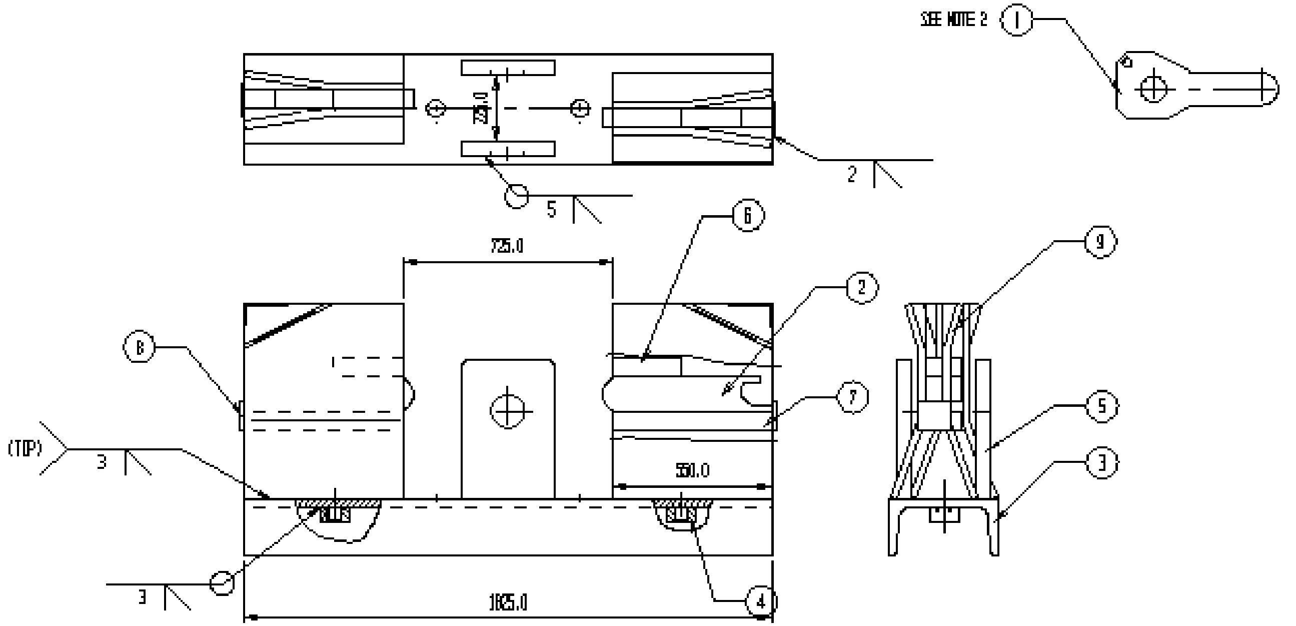

Overwind Test (Vertical Acceleration) - Test: Dummy Cable
Acceleration [g]
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
3.2
3.4
3.6
3.8
4
4.2
4.4
4.6
Time [s]
Humble hook activation
Positive upward acceleration
Deceleration


Overwind Test (Vertical Acceleration) - Test: Dummy Cable
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
Acceleration [g]
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
Time [s]
Humble hook activation
Positive upward acceleration
Deceleration


Overwind Test (Vertical Acceleration) - Test: Alternative detachment device
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
Acceleration [g]
0
0.5
1
1.5
2
2.5
Time [s]
Cable detachment
Positive upward acceleration
Deceleration

Appendix E: Drawings of full-scale overwind system


DO NOT SCALE
1
2
3
4
5
6
7
8
A
B
C
D
JACK CATCH MECHANISM
HUMBLE HOOK
TRIGGERING SYSTEM
ALTERNATIVE DETACHING DEVICE
ZONE
REV
DESCRIPTION
DATE
APPROVED
REVISIONS
ITEM
QTY
DESCRIPTION
DRAW. NR.
LIST NR
FROM - TO
TOL ±
0 - 6 0.1
6 - 30 0.2
30 - 100 0.3
100 - 300 0.5
300 - 1000 0.8
1000 - 3000 1.2
3000 - PLUS 2.0
ANGLES
LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK
TITLE SHAFT LAY-OUT OVERWIND
A
ISSUE
PROJECTION
DRAWING NR: 00-00-00
SCALE 1 : 200
DATE 12/12/2000
ASSEMBLY NR: - - -
A3
NO. SKAGUITLEG
DRAWN: WMP
CHECKED



NOTE:
1) QTY. MANUFACTURED: 1
2) ITEM 1 TO BE INSTALLED
IN FRAMEWORK OF RIG

ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR
9	4	SIDE PLATE	SMDL 02 01 10	DNBEAM123A
8	2	STOPPER	SMDL 02 01 09	DNBEAM122A
7	2	SPACER 2	SMDL 02 01 08	DNBEAM121A
6	2	SPACER 1	SMDL 02 01 07	DNBEAM120A
5	2	LUG	SMDL 02 01 06	DNBEAM119A
4	2	NUT	SMDL 02 01 05	DNBEAM118A
3	1	BASE	SMDL 02 01 04	DNBEAM117A
2	2	CATCH PLATE 2	SMDL 02 01 02	DNBEAM115A
1	2	CATCH PLATE 1	SMDL 02 01 01	DNBEAM114A

OVER - TO	TOL ±
0 - 6	0.1
6 - 30	0.2
30 - 120	0.3
120 - 400	0.5
400 - 1000	0.8
1000 - 2000	1.2
2000 - PLUS	2.0
ANGLES	± ½°

TITLE HUMBLE HOOK
CARRIER ASSY

DRAWING NO. SMDL 02 01 00

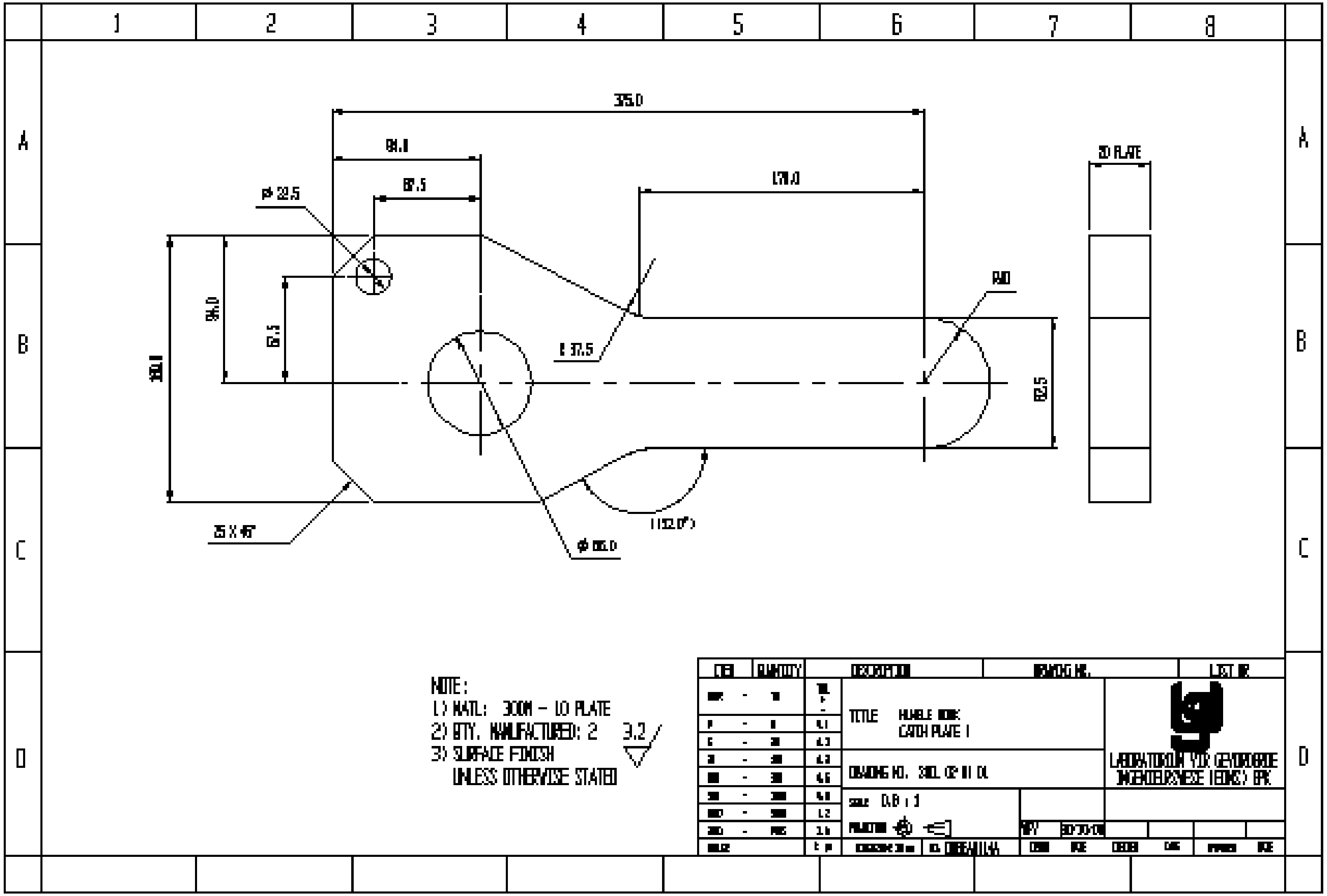
SCALE 1 : 3

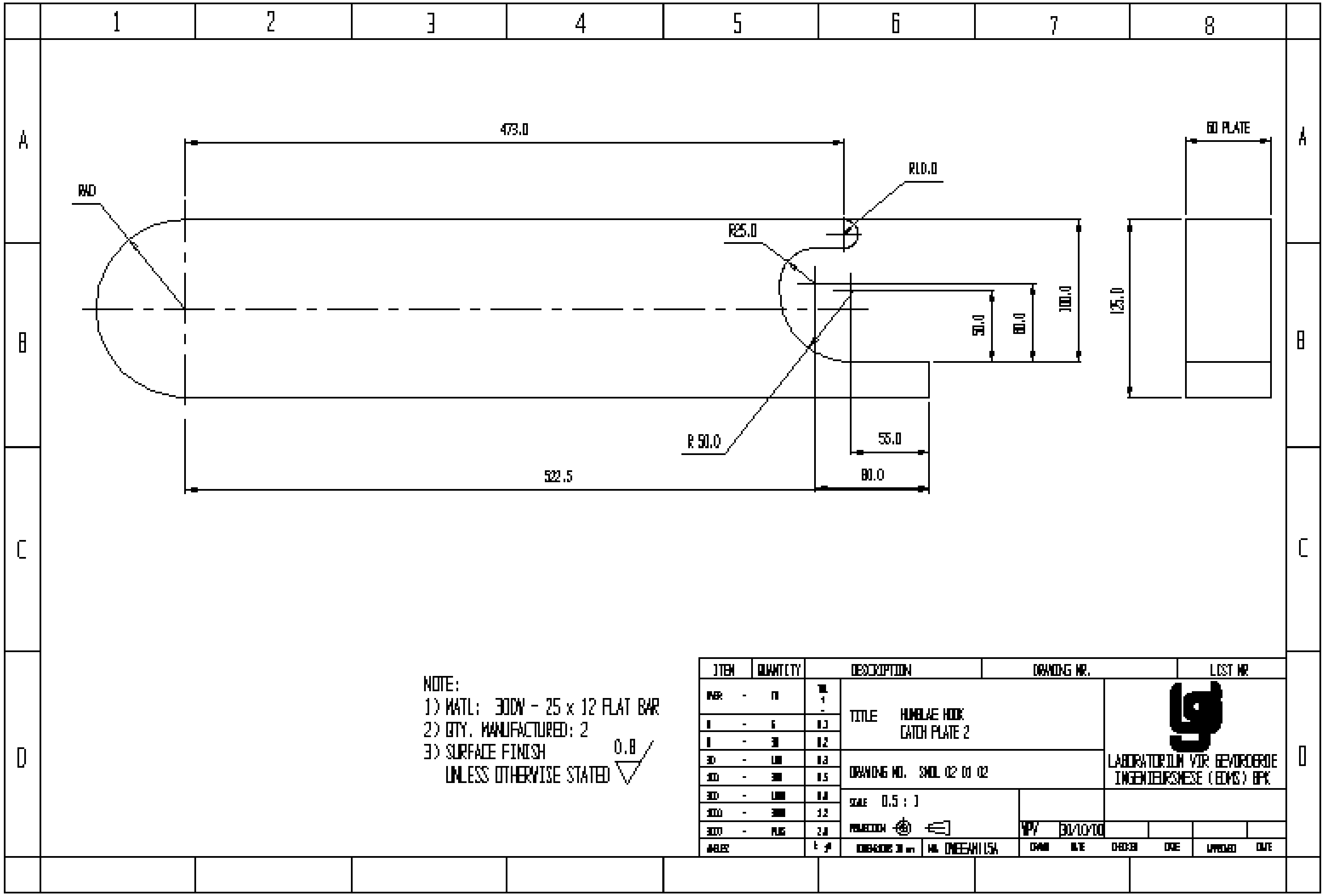
PROJECTION

DIMENSIONS IN mm
FILE OVERYINDASSY

LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK

DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
WPV	31/10/00				


1
2
3
4
5
6
7
8
A
B
C
D
375.0
94.0
67.5
ϕ 22.5
170.0
20 PLATE
R40
100.0
94.0
67.5
R 37.5
82.5
(152.0°)
25 X 45°
ϕ 65.0
NOTE:
1) MATL: 300M - LO PLATE
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NO.
LIST NO.
TITLE
CATCH PLATE 1
DRAWING NO.
SCALE 0.8 : 1
PROJECTION
REV
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK



NOTE:
1) MATL: 300W - 25 x 12 FLAT BAR
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH 0.8
UNLESS OTHERWISE STATED

TITLE HUMBLAE HOOK
CATCH PLATE 2

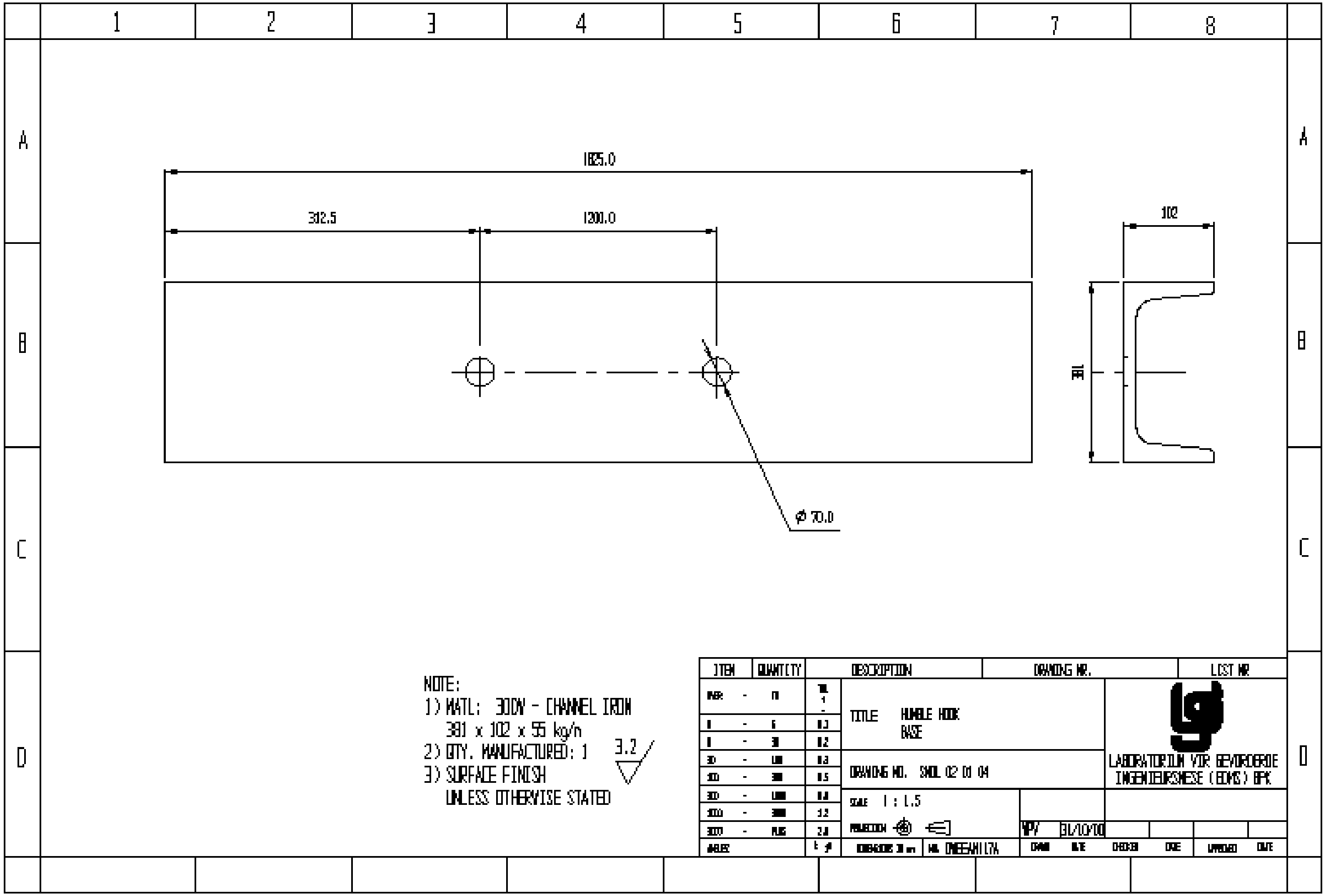
DRAWING NO. SMDL 02 01 02

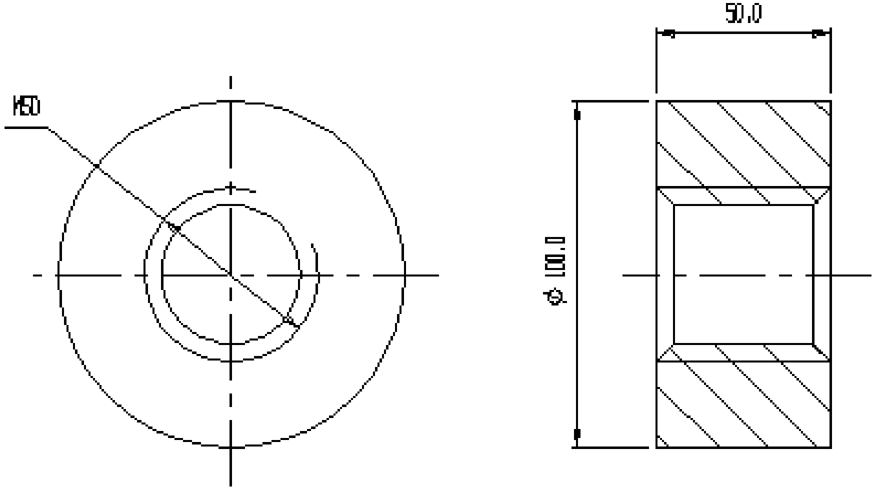
SCALE 0.5 : 1

MAT. ONEEAM115A

YPV 30/10/00

LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK

1
2
3
4
5
6
7
8
A
B
C
D
1825.0
312.5
1200.0
102
381
Ø 70.0
NOTE:
1) MATL: 300W - CHANNEL IRON
381 x 102 x 55 kg/m
2) QTY. MANUFACTURED: 1
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE HUMBLE HOOK
BASE
DRAWING NO. SHDL 02 01 04
SCALE 1 : 1.5
PROJECTION
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK
31/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE



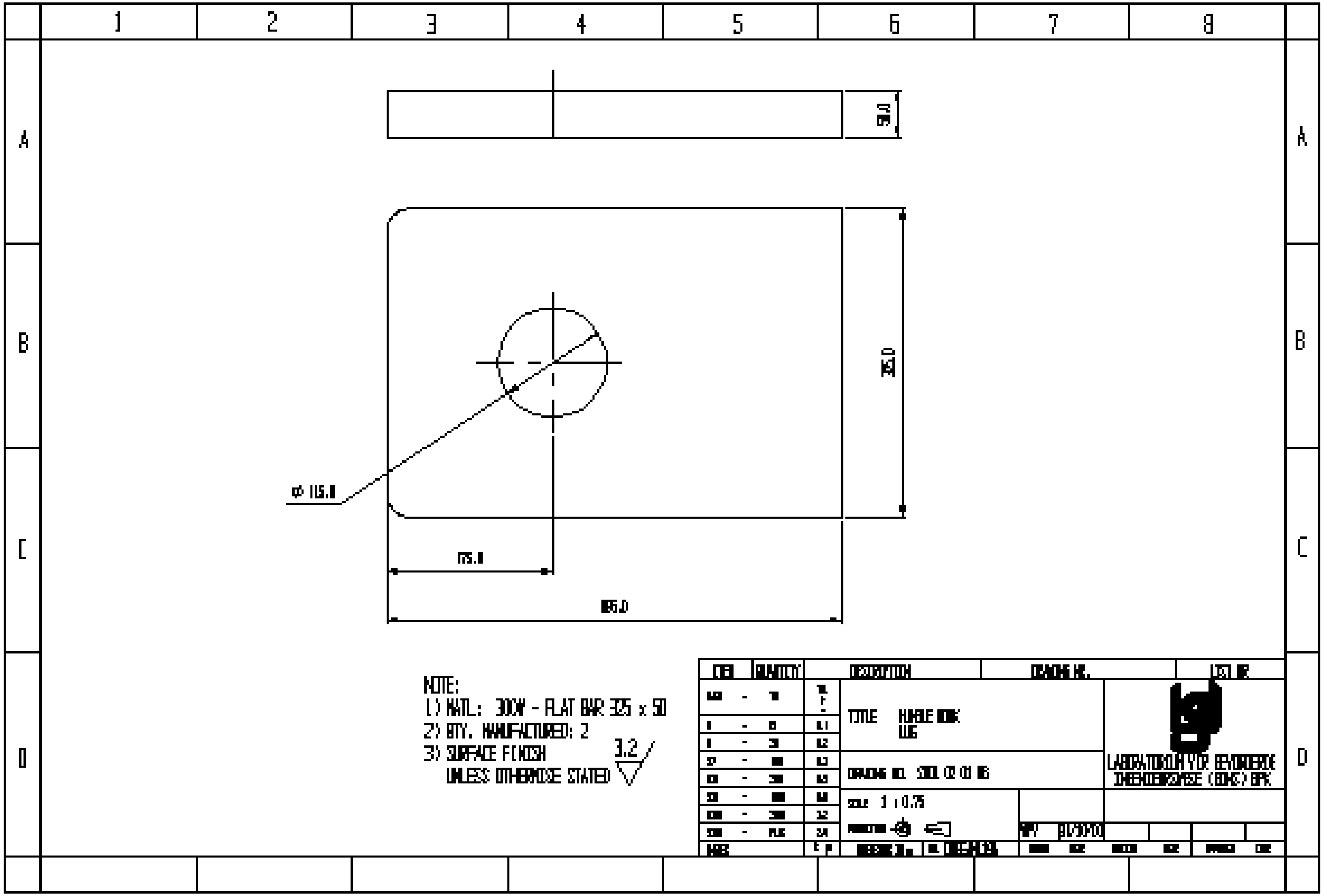
NOTE:
1) MATL: ROUND BAR - 100 DIA
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED 3.2 ▽

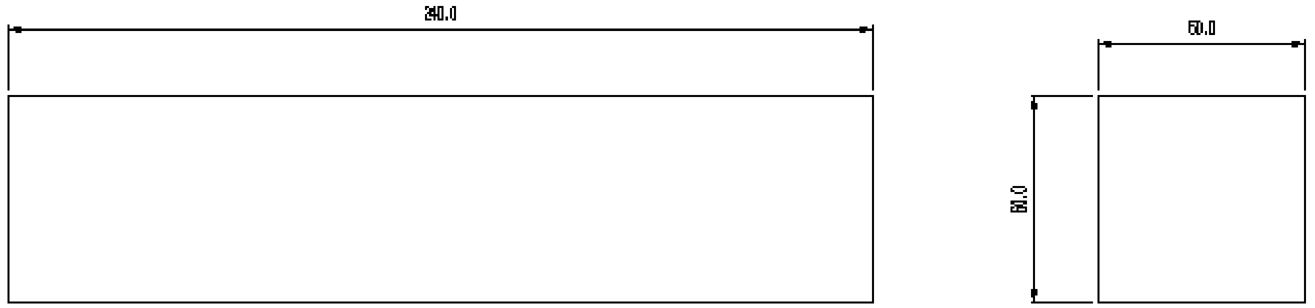
ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR

[illegible] - [illegible]	TOL. ±	TITLE HUMBLE HOOK NUT
[illegible] - [illegible]	0.1	
[illegible] - [illegible]	0.2	DRAWING NO. SMDL 02 01 05
[illegible] - [illegible]	0.3	
[illegible] - [illegible]	0.5	
[illegible] - [illegible]	0.8	SCALE 1 : 0.25
[illegible] - [illegible]	1.2	
[illegible] - PLUS	2.0	PROJECTION ⊕ ⊏
ANGLES	± 1°	DIMENSIONS IN mm · NO. DWBEAM118A

LABORATORIUM VIR GEMOTORIEERDE
INGENIEURSWESE (EDMS) BPK

MPY	31/10/00				
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE

1
2
3
4
5
6
7
8
A
B
C
D
50.0
Ø 115.0
175.0
NOTE:
1) MATL.: 300W - FLAT BAR 325 x 50
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NO.
TITLE
SCALE 1 : 0.75



NOTE:
1) MATL: 300W - SQUARE BAR 60 x 60
SHAFTING - 20 DIA
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH 3.2
UNLESS OTHERWISE STATED

ITEM	QUANTITY	DESCRIPTION	DRAWING NR.	LIST NR

OVER - TO	TOL ±
0 - 6	0.1
6 - 30	0.2
30 - [illegible]	0.3
[illegible] - [illegible]	0.5
[illegible] - [illegible]	0.8
1000 - [illegible]	1.2
2000 - [illegible]	2.0
ANGLES	± ½°

TITLE HUMBLE HOOK
SPACER 1

DRAWING NO. SMDL 02 01 07

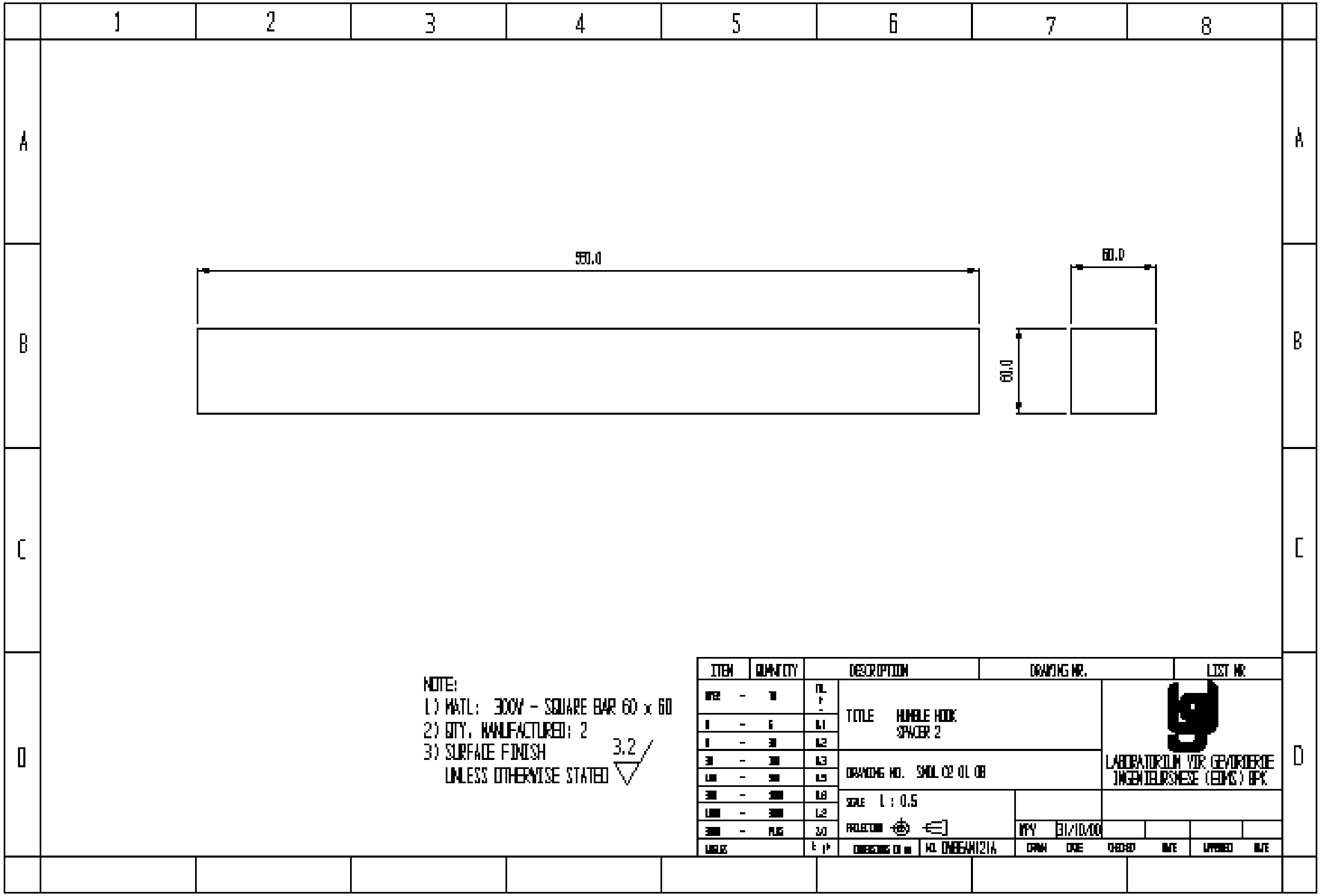
SCALE 1 : 0.75

PROJECTION

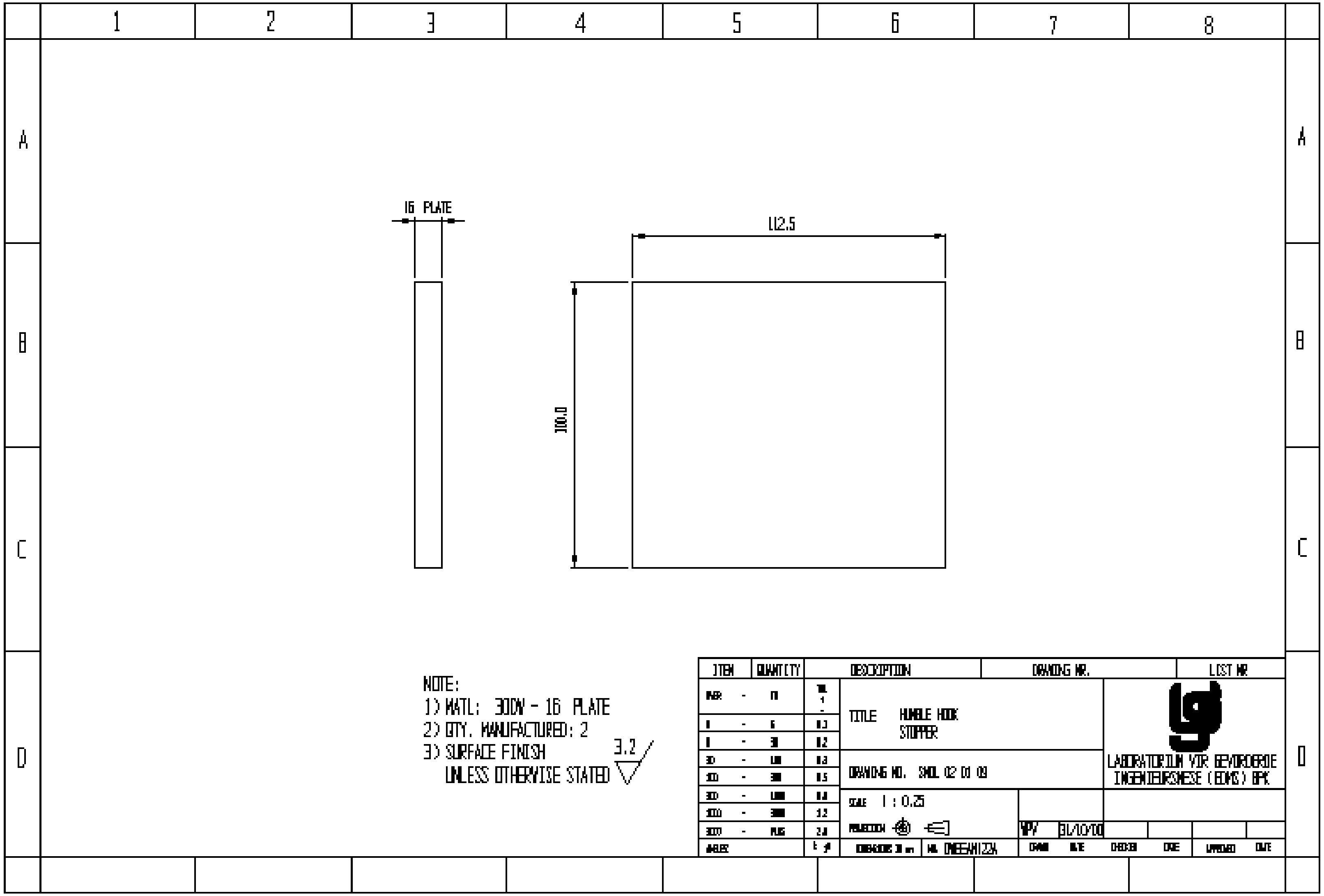
DIMENSIONS IN mm | MAT. [illegible]

LABORATORIUM VIR GEVORDERDE INGENIEURSWESE (EDMS) BPK

DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
MPV	31/10/00				



NOTE:
1) MATL: 300W - SQUARE BAR 60 x 60
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH 3.2
UNLESS OTHERWISE STATED



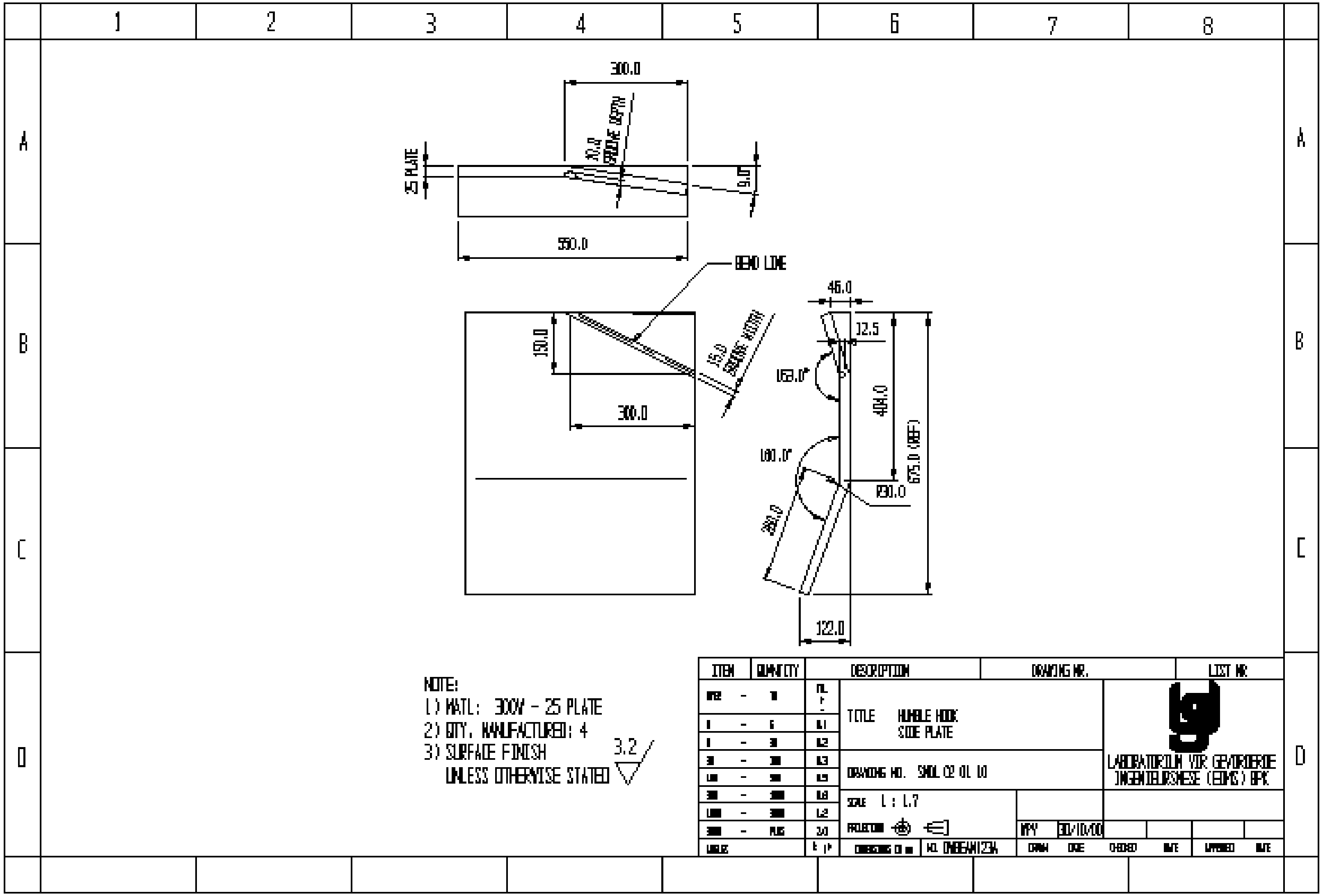
NOTE:
1) MATL: 300W - 16 PLATE
2) QTY. MANUFACTURED: 2
3) SURFACE FINISH
UNLESS OTHERWISE STATED 3.2

TITLE HUMBLE HOOK
STOPPER

DRAWING NO. SMDL 02 01 09

SCALE 1 : 0.25

WPV 31/10/00


1
2
3
4
5
6
7
8
A
B
C
D
300.0
10.0
GROOVE DEPTH
25 PLATE
9.0°
550.0
BEND LINE
150.0
15.0
GROOVE WIDTH
300.0
46.0
12.5
163.0°
404.0
675.0 (REF)
180.0°
R30.0
280.0
122.0
NOTE:
1) MATL: 300W - 25 PLATE
2) QTY. MANUFACTURED: 4
3) SURFACE FINISH
UNLESS OTHERWISE STATED
3.2
ITEM
QUANTITY
DESCRIPTION
DRAWING NR.
LIST NR
TITLE HUMBLE HOOK
SIDE PLATE
DRAWING NO. SMDL C2 01 10
SCALE 1 : 1.7
PROJECTION
LABORATORIUM VIR GEVORDERDE
INGENIEURSWESE (EDMS) BPK
MPY
30/10/00
DRAWN
DATE
CHECKED
DATE
APPROVED
DATE