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INTERNATIONAL SAFETY PANEL

RESEARCH PAPER #16

Crane Driver Ergonomics

by

Daan Potters

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ABOUT THE AUTHOR

Daan Potters is a 45-year-old engineer, living in the Woudrichem region of Rotterdam in The Netherlands. He graduated as a structural engineer in 1986. He then worked for almost 3 years as a consultant, project manager and structural engineer. After this period he started working for Merford Noise Control and Merford Cabins, studied acoustics, climate control and vibration technology and became responsible for Research and Development through the complete Merford Group. Because of increasing complaint of crane drivers, Merford decided in 1996 to invest in a 3 year research project with regards to crane driver ergonomics, managed by Daan. Technical Universities, scientific institutes, ergonomists, customers and suppliers were involved in this project. The complexity of the crane drivers working environment in combination with cultural differences was extremely challenging and Daan decided to move to Merford Cabins for a full time job. He had the opportunity to increase his science network and to spread his collected knowledge about noise-, climate- and vibration control, physical- and mental ergonomics in combination with industrial solutions. Parallel to the port industry Merford Cabins became well known for operator related solutions in the steel, aluminium, paper, wood, marine and offshore industry. Special solutions with regards to blast, radiation, gas and dust protection are developed.

Together with industrial designers at Merford Cabins, many high quality products are launched, all focussed on the operators working environment. Besides supplying physical products Merford Cabins nowadays does task analyses, concept designing, project management and provides operator and maintenance instructions.

Daan is a member of ICHCA's ISP panel, the US AIST (Association of Iron and Steel Technology) crane committee and the AIST H&S committee.

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CRANE DRIVER ERGONOMICS

1. Introduction

1.1 Merford Cabins has been a cabin supplier for 40 years. Together with crane drivers, management of container ports and scientific institutes Merford is continuously studying the working circumstances of crane drivers to develop better solutions. This research paper shows the results of different practical studies and biomechanical analyses of crane driver postures done by Merford and TNO Work & Employment as a scientific institute.

2. The Problem

2.1 Many people around the world are sitting many hours a day without proper instructions and tools. Because of this, many of them suffer from back or neck problems. This is especially the case for crane drivers working in container cranes. Continuously looking downwards and sitting in a moving environment increases these problems. It is clear this results in fatigue, physical complaints, loss of efficiency and even sometimes damage and dangerous situations.

- A study of Zondervan (1989) mentioned that 64% of the crane drivers were suffering from back complaints and 42% of them from neck complaints, while Burdorf *et al*. (1993) found a prevalence of back problems over the past year among crane drivers of 50%

- A study of HSE (2002) mentioned that 44-77% of the crane drivers suffered from neck complaints and 67-86% from lower back complaints.

- Prolonged bending of the neck and prolonged bending of the trunk are known as risk factors for the development of neck pain (Ariens 2001) and back pain (Hoogendoorn 2000).

- In 2002 the stevedoring company Hesse – Noord Natie (HNN), based in Antwerp, Belgium, was confronted with a serious shortage of container crane drivers due to a very high level of absenteeism. The main reasons for this absenteeism were physical neck and back conditions of the drivers. Due to all the medical conditions, HNN was confronted with a serious problem of demotivation. The sitting position while working in cranes was considered to be the root cause of the crane drivers' neck and back conditions. The project was established in cooperation with HNN's Service for Industrial Medicine, "Medimar" (see Research Paper #10 Back Pain).

3. Development of Solutions

3.1 Since 1998 we have believed that an upper body support for container crane drivers should decrease the loads on their lower back considerably. At that time we designed and launched the Ergoseat. Thamesport (UK) recognised the added value of this concept and started replacing their cabs and seats by operator cabins, called the Ergocab 2000 with Ergoseat. Unfortunately the crane drivers didn't accept the total concept, bringing about no improvement with regards to low back loads.

3.2 However, during interviews with the crane drivers, so many improvements were mentioned that the desire for further investigation increased.

4. Specific Crane Characteristics

4.1 Both ship to shore (STS) and rubber tyred gantry (RTG) crane drivers have to look downwards almost continuously. In addition, each type of container crane has its own specific characteristics.

4.2 STS Cranes

4.2.1 STS crane cabins (figure 1) accelerate and decelerate when both moving forwards / backwards. Passing the boom junctions creates low frequency shocks. Because of the height and speeds the crane driver needs to be highly concentrated. The viewing angle downward is relatively small because of the height.

Figure 1 – STS crane showing driver's cabin

4.3 RTG Cranes

4.3.1 The RTG crane driver (figure 2) has a different field of vision. Because the spreader is relatively close to the cabin, the viewing angle is wider. Because of that, the crane-drivers legs are often an obstruction. Looking around while driving the machine and looking sideways under beams while searching for trucks leads to difficult postures. Movements sideways, in combination with the RTG's rubber tyres, create a swinging motion to the machine and the driver when starting and stopping.

Figure 2 – RTG crane

5. Crane Drivers' Body Posture – Practical Studies

5.1 Looking downward front side

5.1.1 The driver cabin of both STS and RTG cranes is fixed on a certain horizontal distance from the centre line of the hoist. Because of the height of STS cranes the vision of the spreader is always through the bottom window. The height of RTG cranes is limited. Because of this and the maximum size of the driver's cabin, the crane driver's view of the spreader is through the front and side windows of the cabin. The quality of glass, reflections, condensation, safety bars, foot-grills, composition and structure of the cabin will influence the vision of the driver. These aspects are considerable, but form no part of this report.

5.2 Viewing angle / Head inclination

5.2.1 Depending on the height of the load, the viewing angle downward is between 80° and 85° (figure 3). Crane drivers wearing glasses showed a head inclination of 80° and crane drivers without glasses a head inclination of 65-70°. Based on personal preferences and complaints of the crane driver or based on the field of vision, the head inclination of the driver is realized by neck flexion, back inclination or a combination both.

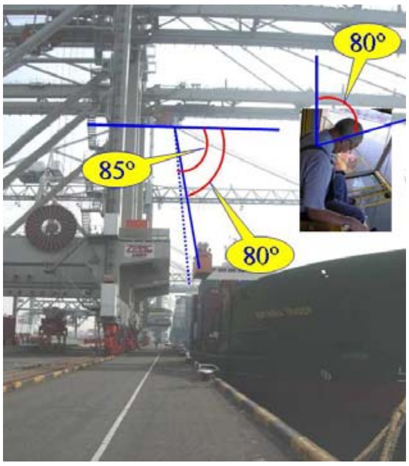

Figure 3 – Viewing Lines

5.3 Back Inclination

5.3.1 Because of accelerations and decelerations, 50-60% of all crane drivers stretch their legs (figure 4) forward to fixate their lower body in the seat arrangements (Practical study by TNO Work and Employment, performed at Thamesport (UK) 2003).

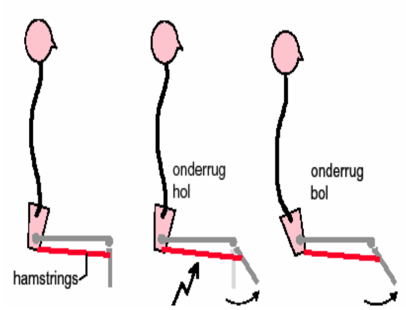

Figure 4 – Leg Stretching

5.3.2 In order to do this, only the lowest part of the backrest can be used and, via the hamstrings, these stretched legs create tilted hips. The result of these tilted hips is a curved lower back, showing a slumped posture. The back inclination varies from 35°-60°. During this slumped posture the neck flexion is limited at 20°-30° (figure 5). Looking downward, in a few instances the crane drivers were not able to spread their legs because they were limited by the consoles of the seat arrangement. The vision downward was blocked by their legs, resulting in an extreme inclination of the back forward to look over their knees. Especially in RTG's, the obstruction of vision because of the specific viewing angles

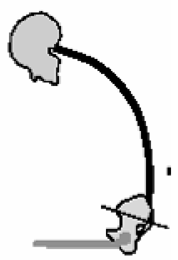

Figure 5 – Slumped Posture

and the position of the crane driver's legs often forces the crane driver in extreme postures. Many crane drivers are misusing the master controllers to stabilise and support their upper body. The low back is under significant stress since the back muscles need to generate muscle forces to counteract the remaining forward torque of the upper body.

5.4 Neck Flexion

5.4.1 40-50% of the crane drivers are sitting almost straight up, meaning a back inclination of 10-15° (Practical study by TNO Work and Employment, performed at Thamesport (UK) 2003). This is induced because of practical problems, eg viewing angles during landing a container on a truck, or because the crane driver wishes to relieve the strain on his lower back. This posture results is a neck flexion of 50-70° (figure 6).

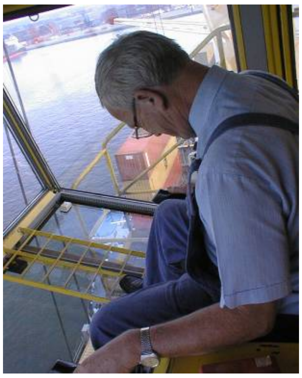

Figure 6 – Neck

5.5 Extreme situations

5.5.1 For short periods of time one can even see extreme variants of this posture. This can occur when the crane driver wants to look over a container, and does not have a stevedore to help him handle a container out of sight or when he wants to see what is below and behind him while moving from ship to shore. He then sometimes even leans with a hand on the floor, depending on the maximum viewing angle the cab allows.

5.6 Looking downward sideways / backward;

5.6.1 STS crane drivers, driving backward the drive has to look on shore to recognize equipment and people working in this area many times. Several systems are available to support the crane driver like mirrors or a camera system. During our investigation, drivers mainly spoke out in preference of a direct view of the area. Different lay-outs of cabins and seat arrangement are available. More than 90% of the cabins are provided with extra floor windows next to the seat arrangement.

5.6.2 Consoles

Often, the operator consoles are blocking the vision side-downward. Looking through the extra bottom windows requires an undesirable lateral bending of the crane driver's upper body because of the width and position of the consoles (figure 7). A greater than acceptable bending of the lower vertebras and a rotated-bended neck often takes place.

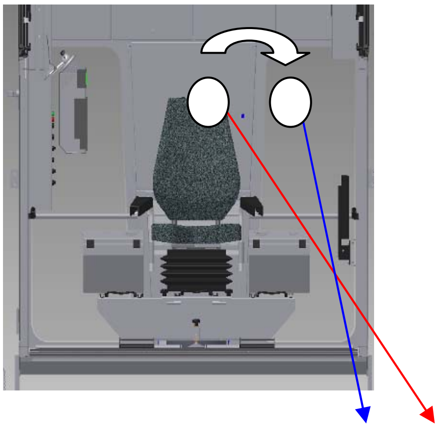

Figure 7 – Position of Consoles

5.7 Bottom windows

5.7.1 The position of the bottom window, possible safety-bars underneath, pollution of the glass and the structure around the windows many times limits the vision.

5.8 Results

To avoid uncomfortable postures or a bad vision, most crane drivers are using the main bottom window to look down-backward. The result is an extreme trunk inclination. The exposure time however is limited.

5.9 Accelerations / decelerations

5.9.1 Trolley-travelling, X direction:

Cranes are getting bigger and faster with trolley speeds up to 240 metre / min and accelerations and decelerations increased up to 1 m/ s² nowadays. A 54 minutes measurement (done by the Großhandels- und Lagerei Berufsgenossenschaft in cooperation with HHHL) at a brand new STS crane in Antwerp showed 29 times an acceleration / deceleration of the trolley above 1 m/s² because of short movement when the driver was positioning / repositioning the spreader / container. Five times the level exceeded 1.25 m/ s² with a peak level of 1.6 m/ s² (figure 8). Because of the direct connection of the trolley to the crane cabin and the lack of possibilities to absorb the accelerations and decelerations in the cabin or seat, these forces have to be absorbed by the crane driver's body itself. `

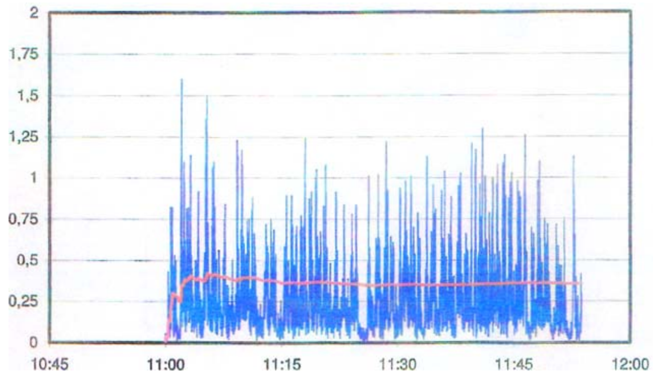

Figure 8 – Acceleration/deceleration of Trolley

5.9.2 Crane-travelling, Y direction:

The speeds, accelerations and decelerations during crane travelling of an STS crane are minor and of no importance with regards to this report. Also for RTG's the speed, accelerations and decelerations sideways are minor, however because of the rubber tyres in combination with the stability, the movements up in the cabin sideways during stop or start driving do have a certain influence on the crane driver.

5.9.3 Lower body part;

As mentioned in 5.3 "back inclination", the crane driver eases these forces in the lower part of the body by stretching his legs and pushing the lower part of the back against the back rest. The results are mentioned in that chapter. Another striking fact was observed. Because of the stretched legs an unacceptable pressure of the front part of the seat cushion on the upper legs takes place. To solve this problem the seat cushion is tilted up to 15° forward with an uncomfortable oppression in the crotch because of the trousers.

5.9.4 Upper body part;

Figure 9 - Joystick

The upper part of the body however is “free in the air”. Some ports are providing their driver seats with a 4 points safety belt. We found no drivers using this device to support their upper body in forward direction during normal crane operation for a long time. During our study we found many drivers “leaning” on the joy-stick or the structure around it (figure 9). The need for heavy duty joy-sticks is explained because of this. The ergonomic use is limited because of the location, arrangement and size of these joy-sticks; however this is not a part of this report. Besides the static loads on the low back, looking downward as described in 5.3 “back inclination”, the dynamic part of the STS crane driver’s job is enlarging the need to generate muscle forces to counteract the forward torque of the upper body. Because of the limited trolley speeds and travelling distance for RTG’s, this dynamic aspect in forward / backward direction is minor. For RTG’s, the movements sideways create a lateral load on the lower back. This aspect needs to be avoided in combination with a forward bended trunk.

5.10 Shocks and Vibrations

5.10.1 High frequency vibrations

High frequency vibrations are found in cabins, not provided with anti-vibration mounts or provided with poor quality anti-vibration mounts. These vibrations caused by wheel to rail contact or caused by hoist or travel motors mainly bring about uncomfortable noise levels inside the cabin. However, the levels are negligible with regards to the subject of this report. Well designed anti-vibration mounts (figure 10) are capable to reduce high frequency vibrations considerably.

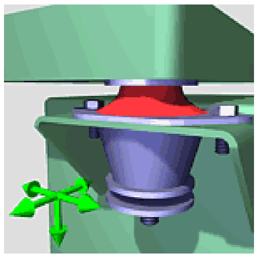

Figure 10 – Anti Vibration Mounts

5.10.2 Lower frequency vibrations (shocks)

Low frequency vibrations (shocks) in vertical (Z) direction are caused by wheels passing the rail junction (STS cranes) or landing / lifting heavy loaded containers (both STS and RTG cranes). The boom-junction shocks are decisive. No cabin suspension systems were found that were absorbing these low frequency shocks. Because of this, all these shocks penetrate up to the base structure of the seat arrangements. The 54 minutes measurement at the STS crane in Antwerp in the Ergoseat, however, showed an average level of 0,17 m/s^2, far below the daily (8 hour) exposure limit - 1.15 m/s^2 and the daily (8 hour) action value - 0.5 m/s^2 (ISO 2631-1 Mechanical Vibration and Shock – Evaluation of human exposure to whole body vibration, figure 11). The 'vibration transmission rate' characterises the quality of the seat to reduce or deteriorate vibrations.

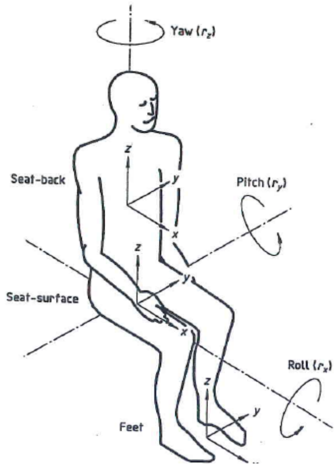

Figure 11 – Whole body vibration

5.10.3 Vertical movements upper body;

However during the 54 minutes the crane moved 21 containers and passed the boom joints 42 times. Maximum peak levels of 1.47 m/s^2 were measured when the trolley passed the boom joints (figure 12). There is no proven relationship of these shocks with regards to lower back or neck pain, but these shocks create a vertical movement of the forward bended upper body, creating a torque in the lower back. This fact makes it quite likely these shocks contribute to lower back problems.

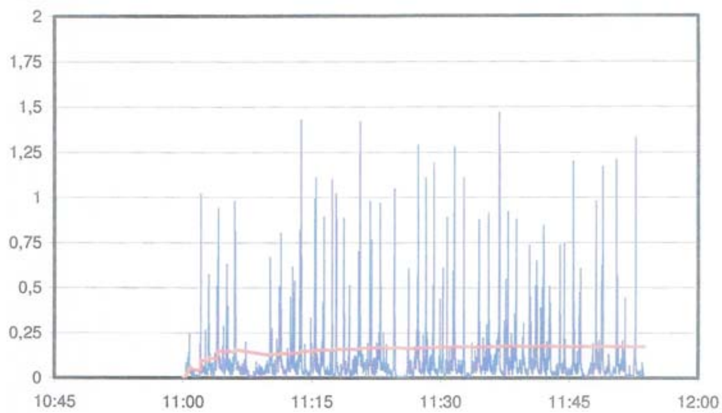

Figure 12 – Vibration when passing boom joints

5.11 Suspension systems of seat arrangements

5.11.1 Suspension system only under the seat

More than 85% of all investigated seat arrangements were provided with a mechanical and / or pneumatic suspension system under the seat itself. The remaining seat arrangements were provided with a suspension system under both the seat and consoles.

5.11.2 The seat arrangements provided with a suspension system only under the seat are experienced as the most solid units. However, low frequency shocks in these units permeate into the consoles and joy-sticks. Crane-drivers supporting their upper body via the master-controllers / consoles absorb the shocks via their arms.

5.11.3 A flexible suspension system under the seat creates movement / height differences (up to 65 mm) of the upper body compared to the consoles. This difference is compensated by the upper arm / shoulders and decreases the feeling on the joy-sticks and crane control. Many crane-drivers adjust the suspension to reduce these movements which decreases the shock absorption.

5.11.4 Suspension system under both the seat and consoles

Seat arrangements provided with a suspension system under both the seat and consoles doesn’t show these differences in vertical movements. Unfortunately these units are showing more than acceptable space and or wear mainly because of the horizontal dynamic loads on the suspension systems during the time. This space and or wear create unwanted movement mainly forward / backward. Instability can be the cause of extra dynamic loads on the operator’s body and can influence the exactness of operating the master controllers.

5.12 Adjustments for seat and control components

5.12.1 Because the number of seat arrangements produced for container cranes are quite small, they have been mainly derived from other industries in the past. The seat itself has been produced many times for the truck industry. Many kinds of control stations are also available in the market. However the typical circumstances in container cranes require specific qualities and adjustments.

5.12.2 It is accepted world wide that the sizes and adjustments at least have to meet the 5th-95th percentile for males and females in the area of use. Because of use of control stations world-wide, suppliers have to consider the size and adjustments that are appropriate in specific areas or world-wide. World wide equipment requires large adjustments with the risk of reduction of quality and, for some, fixed size compromises have to be accepted.

5.12.3 Anthropometry;

Today, anthropometry plays an important role in industrial design and ergonomics. Statistical data about the distribution of body dimensions in the population are used to optimize products (figure 13 shows an example).

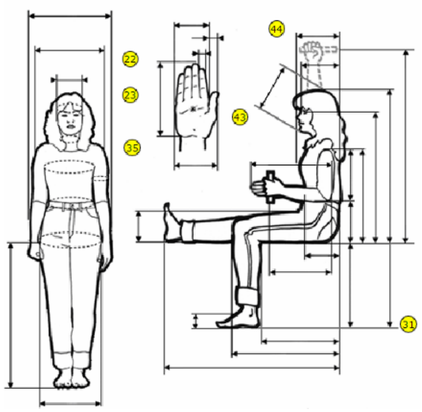

Figure 13 – Study of Body Dimensions

5.12.4 DINED Data, example sitting height;

Using the DINED data of the University of Delft , the average popliteal height (height of sitting cushion to the floor without shoes) for male in Central Europe is 465 mm with a standard deviation of 24 mm (figure 14). The P5 percentile shows 426 mm. The P95 percentile shows 505 mm. A height difference of 79 mm is required.

For South East Asia, the average popliteal height for female is 385 mm with a standard deviation of 12 mm, P5 is 365. The P95 percentile shows 405 mm. A height difference of 40 mm should be sufficient. Combining both sets of data, a height adjustment of 140 mm should be required to fit for both Central European male and South Asian female. This shows that a world wide useful seat arrangement needs a high quality specific design or a specific seat arrangement for different areas has to be provided.

Data						
label	name	male MEAN	male SD	female MEAN	female SD	unit
body measures						
2	stature	1710	58	1660	61	mm
14	popliteal height	465	24	425	21	mm
16	eye height sitting	800	33	750	33	mm
17	sitting height	940	30	880	33	mm
22	shoulder breadth (bi-deltoid)	460	21	420	27	mm
23	head breadth	155	5	150	5	mm
24	hip breadth	350	20	360	29	mm
25	hip breadth sitting	365	24	400	33	mm
28	head depth	190	6	180	6	mm
31	elbow-grip length	360	18	325	21	mm
33	buttock-knee depth	610	33	580	30	mm
34	buttock foot length	1070	50	1000	46	mm
35	head circumference	570	18	550	15	mm
41	foot length	265	14	240	12	mm
43	hand length	190	9	175	9	mm
44	hand breadth without thumb	90	5	75	5	mm
51	reach depth finger tip	850	27	800	30	mm
other						
	biacromion	400	20	365	20	mm
	knee height	550	30	500	24	mm
label	name	male MEAN	male SD	female MEAN	female SD	unit

Figure 14 – Average Popliteal Height

5.13 Practical requirements;

5.13.1 It is not in the scope of this report to work out all details of required sizes and adjustments of control stations - however a few practical issues are worth mentioning.

5.13.2 Height of sitting cushion

Besides anthropometrical data, the height of the sitting surface of the crane driver is influenced by:

- The suspension system of the seat and the weight of the crane driver
- To what extend the tilting mechanism of the seat is used.
- The lifetime of the seat in combination with the hardness of the cushion.
- The forward position of the seat compared to the tilted foot-rests in the cabin. More far forward to the front of the cabin, the foot-rests are mostly in a higher position.
- The required posture of crane driver with regards to vision and the position of their legs.

5.13.3 Length, position and shape of sitting cushion

Looking downward in combination with the specific posture of the crane driver influences the requirements of the sitting cushion -

- Because of the length of the upper legs, and the need to push the lower back to the lower part of the back rest, the length of the sitting cushion needs to be adjustable.
- To create vision downward, the cushion needs a V-cut.
- Because of the spread legs, the cushion needs to be extended side-ways at the front.
- The position of the V-cut needs to be in front of the base frame to makes it useful for looking downward.
- The front edges of the cushion need to be flexible to reduce local pressure on the lower legs.

5.13.4 Height of consoles

To operate the master controllers in an ergonomic way and to reduce the shoulder load the height of the consoles is important.

- Because the height of the seat is adjustable and because of anthropometrical data the height of the consoles needs to be adjustable compared to the seat.
- The different postures of crane drivers also require height adjustable consoles.

5.13.5 Position of master controllers

Because of different forward – backward positions and the anthropometrical data of crane drivers the forward – backward position also needs to be adjustable.

5.13.6 Forced to work in the same position

It’s highly unwanted to work continuously in the same position. However the lack of adjustments in seats and consoles and the difficulties crane drivers are facing during their job, often force them to work for longer times in the same position.

5.14 Composition of cabin structure;

5.14.1The composition of the cabin structure and the position of the cabin compared to the centre of the spreader is very important with regards to the ergonomics of the crane driver. As mentioned before, crane drivers sometimes work for short times in extreme postures because of required vision. As an example we found a driver standing straight up, his chest supported by the horizontal beam of the front wall of the cabin, looking downward through the upper front hinged window and his arms stretched to the rear to operate the joy-sticks.

5.14.2 A few items are worth mentioning comparing body posture to cabin lay-out.

- The length of the main bottom window is limited in many cases. In this case, the crane driver's view will be blocked by the front lower bar in case he adjusts his seat in a more forward position.
- Often the main bottom windows are divided in 2 or 3 parts. A bottom window in 2 parts has a bar in the centreline of the cabin, blocking the vision at the centre corner castings in case of twin lift. The 2 bars in length direction in case of a window in 3 parts can block the vision of the outside corner castings of both 20 ft as 40 ft containers depending on the height of the lift.
- Many seats are not revolving. To protect the main bottom window from scratching by walking on it, this window is many times fully covered by protection grills. In particular bars from left to the right obstruct the vision because of the parallel position of both the crane driver's eyes.
- Reflections in the bottom window create blind spots in the field of vision of the crane driver, resulting in unwanted crane-driver postures. The reflections can be created by in-falling light from floodlights or sunlight, internal lights or internal reflecting surfaces. Even high visibility clothing can be quite annoying.
- Especially for RTG cranes, reflections in the side windows are undesirable because of the bigger viewing angle.
- Because of the base frame many seats are positioned far backward compared to the bottom window. Unwanted leaning forward is the only way to overcome this problem.
- Extra bottom windows are often useful in a limited way because of the location, the size, safety bars, pollution, and a cumbersome structure around the window in combination with the viewing angle and because of the position of the consoles.

5.15 Instruction, Knowledge and Consciousness-raising.

5.15.1 Interviewing crane drivers in general it can be said that the knowledge about ergonomic and anatomical principles is poor. Looking at the results as described in International Safety Panel Research Paper #10, Back Pain by Steven Vereecke and based on personal experiences, the consciousness-raising will increase after explanation of anatomical principles, body conditions and instructions about seat adjustments.

6 Bio-Mechanical Analysis

6.1 Since 1998 it is our believe that an upper body support for container crane drivers should decrease the loads on their lower back considerably. Based on experiences, anthropometrical data and lab-tests (figure 15, 16, 17) we designed and launched the Ergoseat, a ceiling suspended control station with extreme adjustable armrests to support the upper body via the arms of the crane-driver. Lab tests with 10 test persons (all West Europeans) learned to find the most comfortable position of the crane driver's arms and joy-sticks looking downward (figure 15, 16 and17). Based on this information the range P5-P95 male and female worldwide is determined.

Figure 15 – Study Arm and Joy-stick Position

6.2 Thamesport (UK) recognised the added value of this concept and started replacing their cabs and seats by operator cabins, called the Ergocab 2000 with Ergoseat. Unfortunately the crane drivers held on to their existing large and stiff joy-sticks. These joy-sticks forced the drivers to lift up their arms to operate the crane, bringing about no improvement with regards to low back loads. Interviewing the crane drivers (done by TNO working employment), the desire for further investigation increased because so many improvements because of the Ergoseat were mentioned.

Figure 16 – Study Arm and Joy-stick Position

6.3 In particular the large adjustments, the possibility to spread the legs underneath the consoles, the large height adjustment and the shock absorption in both the seat and consoles were appreciated.

6.4 It was decided to investigate:

- The performance working with smaller joy-sticks
- The difference of the physical loads working with and without upper body support via the arms.

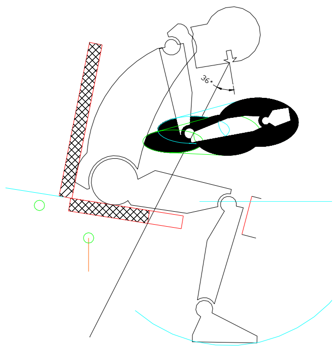

Figure 17 – Result Arm and Joy-stick Position

6.5 Computer task – joysticks

6.5.1 TNO created a static lab-test facility (figure 18, 19) to test different kind of joy-sticks by means of a computer task. The field of vision was created as a copy of the working circumstances of container crane drivers.

Figure 18 – Lab Test (1)

Figure 19 – Lab Test (2)

6.5.2 Ten male test persons carried out 4 kinds of computer tasks;

1) Ergoseat, joystick with large lever
2) Ergoseat, joystick with small lever
3) Conventional crane seat, joystick with large lever
4) Conventional crane seat, joystick with small lever

All test persons had to move as many boxes as possible in a certain time. Besides the number of moves, the numbers of collisions were registered.

6.5.3 Before the real tests, every test person practised 10 times 1 minute to realize a stable test.
The final test results showed -

- A significant improvement with regards to the number of movements working with smaller joy-sticks, especially in combination with the Ergoseat (figure 20)
- An improvement with regards to the number of collisions working with smaller joy-sticks. However, only in combination with the Ergoseat figure 21).

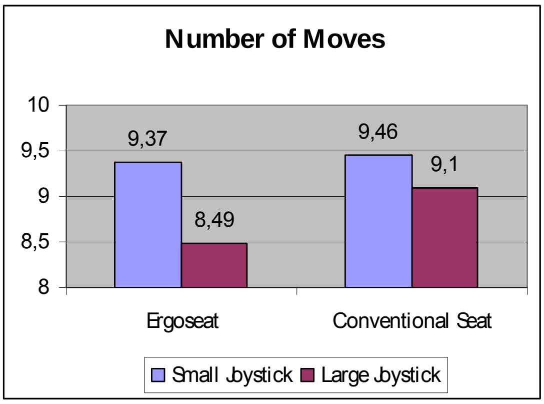

Figure 20 – Number of Movements

6.5.4 It is plausible that this effect will be stronger during dynamic crane operation.

6.5.5 Though not tested, it is very likely that the armrests in combination with the seat's ceiling mounted suspension, also reduce the influence of shocks and vibrations on the stability of control. This is different from most traditional seats in which only the seat is suspended and the controls are not.

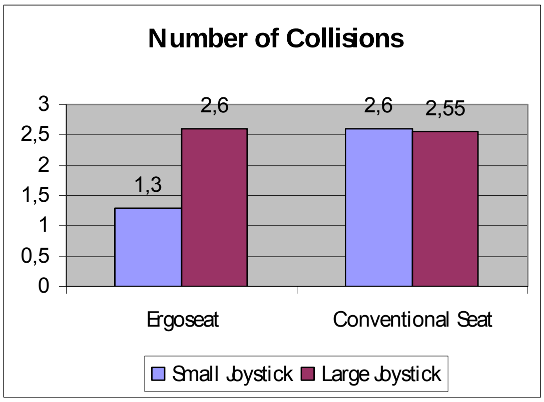

Figure 21 – Number of collisions

6.6 Biomechanical analyses

6.6.1 In the above mentioned lab-test situation the data with regards to the posture of all test-persons was recorded both working in a traditional seat arrangement and working in an Ergoseat with upper body support via the arms.

6.6.2 The data is used as input for the biomechanical analysis. To make it possible to do the calculations, the anatomic data of the test persons is also recorded (missing data was filled up with data from ADULTDATA) and the loads on both the cushion and armrests are measured during the computer task.

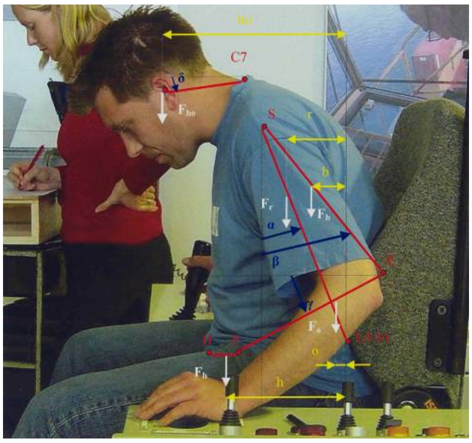

Figure 22 –Traditional Posture

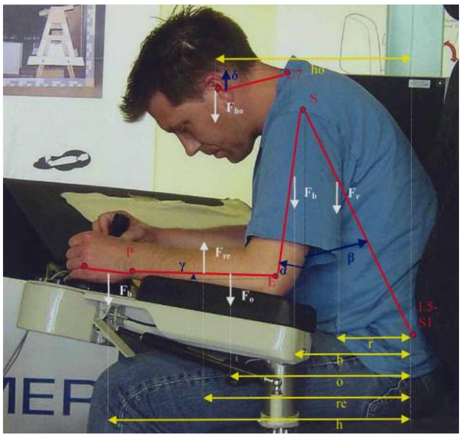

Figure 23 – New Posture

6.6.3 The figures above illustrate the bio-mechanical context of the traditional working posture (figure 22) of a crane driver and the new posture (figure 23) that he can adopt in the Ergoseat. The figure shows that differences in neck and trunk posture between the Ergoseat and a conventional seat are only minor. In the traditional seat the low back is under significant stress since the back muscles need to generate muscle forces to counteract the forward torque of the upper body. However, in the Ergoseat, a significant part of the weight of the trunk, head, arms and hands is carried at the armrests. The mechanical loading on the low back is thereby reduced.

6.6.4 On the basis of the total body mass of the operators, the body segment lengths, the orientation of the body segments and the measured pressure at the armrests, TNO quantified this reduction. It appeared that the Ergoseat is capable of reducing the loading on the low back by more than 50%, compared to the traditional situation. The further forward the operator leans, the more this reduction may be.

6.6.5 With regard to the neck, they did not find any significant difference between the two types of sitting. Regarding the shoulder load, the differences between seats were not clear. In the Ergoseat with arm support, the stabilizing forces at shoulder level would be lower (e.g. Attebrant et al. 1997). However, this decrease in internal shoulder load might be counterbalanced by the muscle activity that is required at shoulder level when leaning on the armrests with 30-40 N per side as measured.

6.6.6 Nevertheless, a clear advantage of the Ergoseat, is the potential variation in shoulder load over the day: the crane operators may vary the load on their shoulders (and low back) by varying the extent to which they lean on the arm support (ranging from total support to none). Hence, internal structures in the back and shoulder can recover during work. Fatigue can be postponed.

6.6.7 In contrast, in the traditional situation the loading on shoulder and low back level while operating the crane is constant and continuous.

6.6.8 Though not tested, it is very likely that the armrests reduce the influence of extra loads on the lower back because of accelerations and shocks in the dynamic working environment of a container crane.

7. Ergonomics – Evaluation of Static Working

7.1 International Standard ISO 11226 (Ergonomics – Evaluation of static working postures) establishes ergonomic recommendations for different work tasks. This standard provides information to those involved in design, or redesign, of work, jobs and products that are familiar with the basic concepts of ergonomics in general, and working postures in particular.

7.2 It specifies recommended limits for **static** working postures without any or only with minimal external force exertion, while taking into account body angles and time aspects.

7.3 It is designed to provide guidance on the assessment of several task variables, allowing the health risks for the working population to be evaluated.

7.4 It applies to the adult working population. The recommendations will give reasonable protection for nearly all healthy adults. The recommendations concerning health risks and protection are mainly based on experimental studies regarding the musculoskeletal load, discomfort/pain, and endurance/fatigue related to static working postures.

7.5 For detailed information and more useful information about upper arm elevation, extreme joint positions, recovery time etc. we would like to refer to the standard itself.

7.6 Recommendations from this standard with regards to trunk inclination and head posture in combination with the above mentioned practical studies confirm the need for specific equipment for crane drivers. In this report we give a short overview about these recommendations.

7.7 Trunk Posture

7.7.1 Trunk Posture α (figure 24);

- Acceptable:
  Trunk inclination α 0° - 20°
  Trunk inclination α 20° to 60° **with** full trunk support.
- Not Recommended:
  Trunk inclination α > 60°
- Take into account the holding time (see 7.7.2):
  Trunk inclination α 20° to 60° **without** full trunk support.

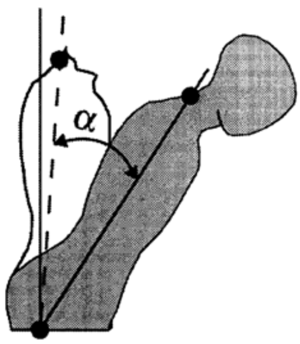

Figure 24 – Trunk Posture

7.7.2 Holding Time (figure 25);

Axes 1 shows the time in minutes, axes 6 shows the trunk inclination in degrees.

- Acceptable:
  - o Zone 3, trunk inclination α 0° - 20°
  - o Zone 4, for example trunk inclination α 60° for 1 minute max.
- Not Recommended:
  - o Zone 2, for example trunk inclination α 60° > 1 minute.
  - o Zone 3, trunk inclination α > 60°

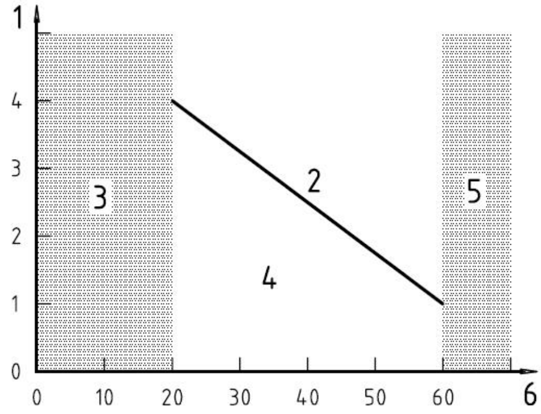

Figure 25 – Holding Time

7.8 Head Posture

7.8.1 Head Inclination ß (figure 26):

- Acceptable:
  Head Inclination ß 0° - 25°
- Not recommended:
  Head Inclination ß > 85°
- Take into account the Holding time:
  Head Inclination ß 25° to 85° **with** full trunk support.
- Take into account the Neck Flexion:
  Head Inclination ß 25° to 85° **without** full trunk support.

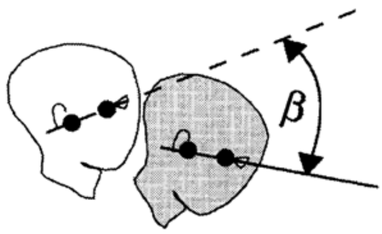

Figure 26 – Head Inclination

7.8.2 Holding Time (figure 27);

Axes 1 shows the time in minutes, axes 6 shows the trunk inclination in degrees.

- Acceptable:
  - o Zone 3 and 4
- Not recommended:
  - o Zone 2 and 5

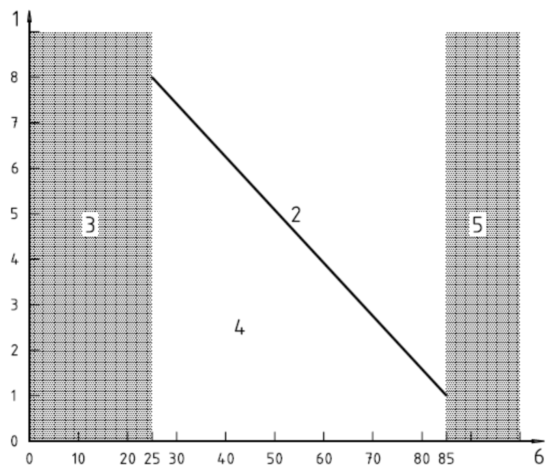

Figure 27 – Holding Time vs Inclination

7.8.3 Neck Flexion ß-α (figure 28, 29);

- Acceptable:
  0° - 25°
- Not recommended:
  > 25°

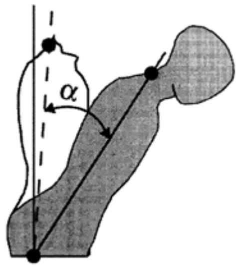

Figure 28 – Neck (1)

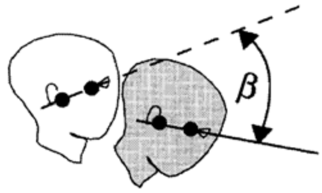

Figure 29 – Neck (2)

7.9 Convex lumbar spine posture (figure 30)**:**

7.9.1 This is not recommended for sitting

7.9.2 A straight lumbar spine posture is recommended by using a backrest support.

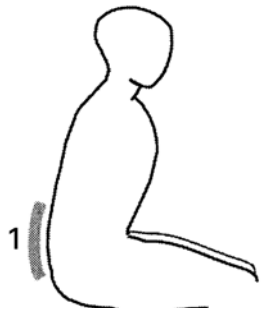

Figure 30 – Lumbar Spine

8 Conclusion

8.1 Time to exposure

The limitation of the time of exposure to vibrations and the bent forward position are very important details to reduce physical complaints of crane operators.

8.2 Specific Equipment

By summarizing practical analyses, lab-tests and standards, the physical complaints of crane drivers are clarified. The working situation of crane drivers can be improved considerable by providing specific control stations in combination with a well designed cabin. The main requirements for a container crane control station are a well fitting full trunk support, good shock absorption and the possibility to vary position. The Ergoseat (figure 31) is an example of such a control station.

Figure 31 – The Ergoseat

8.3 Education / Instruction

8.3.1 The explanation of anatomical principles (figure 32, 33) and body conditions will increase consciousness-raising and decrease physical complaints.

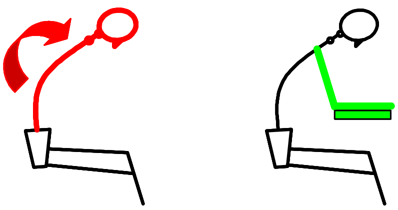

Figure 32 – Improved body conditions

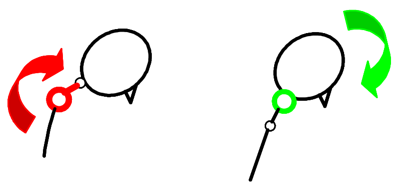

Figure 33 – Improved neck position

8.3.2 Specific instructions about seat adjustments should be given. As an example the instructions for the Ergoseat are shown (figure 34)

Ergoseat Instruction

MERFORD
OPERATOR CABINS

Tilt Seat	1	Seat cushion horizontal
Suspension Softer, Switch Forward / Tougher, Switch Backward	2	Weight and Comfort
Height Down, Switch Forward / Up, Switch Backward	3	Knees and Ankles in Neutral Position
Seat Forward / Backward Handle Up	4	Depending on Viewline and Lenght of Crane operator
Seat Cushion Forward / Backward 2 Handles Up	5	Hand Between Front seat and Calf
Backrest Inclination Handle Up	6	Personal Preference
Backrest Height Release Handle	7	Support in Back Cavity
Backrest Lumbarsupport Turn Knob Tight - Loose	8	Tighten Perceptible
Headrest Height Up- Down by Hand	9	Top Headrest Equals Top Drivers Head
Console Tilt Pull Up Console to get Tilt Up	10	Slightly Sloped Up
Console Tilt Pull Up Console and Release Handle to get Tilt Down	11	Slightly Sloped Up
Arm Cushion Frontside Push Aside Front of Cushion In / Out	12	Wrist Straight, Hands Beside Joy-Sticks
Arm Cushion Backside Push Aside Back of Cushion Forward- Out, Backside Zigzag	13	Outside, Depending on Shoulder-Width
Console Individually Sideways Release Handle, Turn the Console	14	Field of vision, Personal preference
Console Individually Up- Down Release Handle, Push with Elbow=>Move Down, No Load ->Move Up	15	Round 4 cm Below Elbow while Sitting Straight
Consoles together Forward Release both Handles, Move Consoles	16	Elbows before Shoulders, Limit the Angle of the Neck

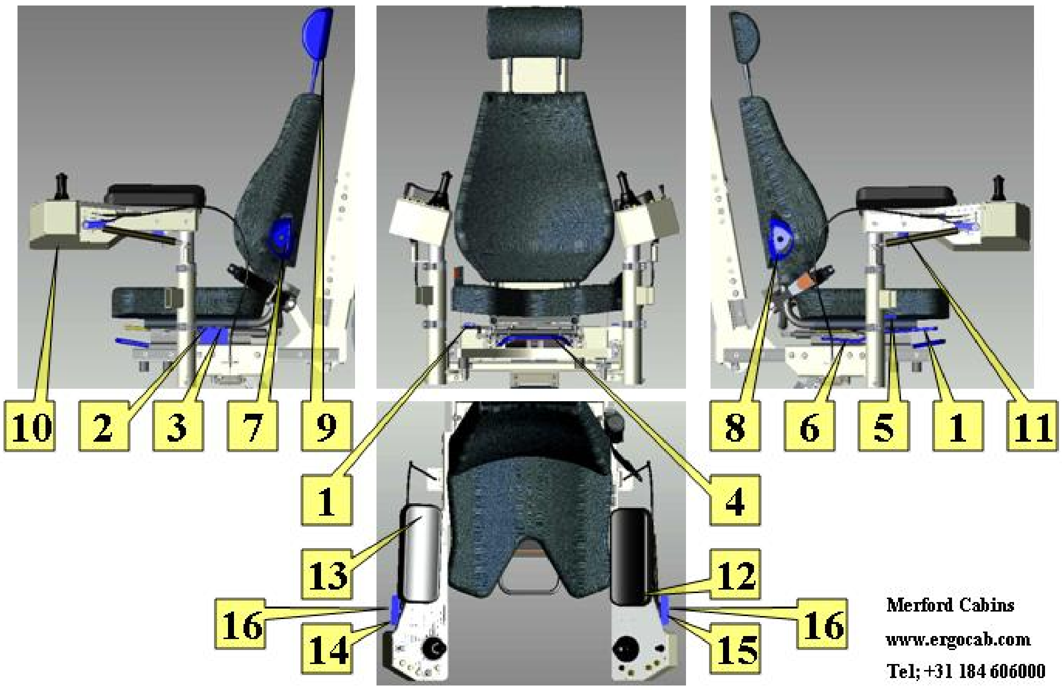

Figure 34 – Instructions for Ergoseat

9. References

Health and Safety Executive, Docks unit / Services sector, Musculoskeletal issues for crane drivers in the docks industry, Version 1, 2002.

Ariëns GAM, Mechelen W van, Bongers PM, Bouter LM. Physical risk factors for neck pain. Scandinavian. Journal for Work, Environment and Health 2000;26:7-19.

Attebrant M, Winkel J, Mathiassen SE, Kjellberg A. Shoulder-arm muscle load and performance during control operation in forestry machines. Applied Ergonomics 1997;28:85-97.

Burdorf A, Zondervan H. An epidemiological study of low-back pain in crane operators. Ergonomics 1990; 33(8):981-987.

Hoogendoorn WE. Work-related risk factors for low back pain. Amsterdam: Vrije Universiteit, 2001. PhD thesis.

Huysmans MA, Looze MP de, Hoozemans MJM, Beek AJ van der, Dieën JH van. The effect of type of joystick, gain and precision demands on performance and physical load in the work of crane operators. Amsterdam: Vrije Universiteit, 2004. Report. Will be submitted to scientific journal.

Zondervan H, Burdorf A, Wingerden S van, Duuren L van. Aandoeningen van het bewegingsapparaat bij kraanmachinisten. Tijdschrift voor toegepaste Arbowetenschap 1989;2(2):17-22. In Dutch.

International Standard ISO 11226, First Edition 2000-12-15, Ergonomics – Evaluation of static Work Postures.

International Standard ISO 2631-1, Second Edition 1997-05-01, Mechanical vibration and shock evaluation of human exposure to whole body vibration.

ICHCA International –
Research Paper RP#10 Back Pain (2006)
Research Paper RP#12 Whole Body Vibration (2006)