Earth-moving machinery – an analysis and assessment of accident statistics
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Project:
An analysis and assessment of earth-moving machinery for the building materials industry taking particular account of employment protection law

Client:
StBG
Steinbruchs-Berufsgenossenschaft

Authors:
Prof. Dr.-Ing. habil H. Tudeski
Dipl.-Ing. Matthias Könnecke

Clausthal, June 2005
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1 Motivation for the project and its objectives

The operation of mobile equipment such as loaders or dump trucks is a source of danger in the building materials industry. The risks arising from the use of mobile equipment can be direct or indirect. All types of accidents represent direct risks. The operator of the equipment themselves can be affected, for example when their equipment is involved in an accident or fall, as well as uninvolved third parties who are hit or run over by vehicles. Repair and maintenance work on vehicles is also a constant source of risk for personnel. Indirect risks are presented by illnesses which can be caused by constant and un-ergonomic loads.

In the year 2002, 8078 notifiable accidents were reported to the German quarrymen's employers' liability insurance association (Steinbruchs-Berufsgenossenschaft - StBG). This corresponds to 54.39 accidents per 1000 employees. In the same year there were 21 fatal accidents. These figures do not include any information on the type of accident, but it is known that a considerable number of these accidents were associated with the use of mobile equipment. Although both the overall number of accidents and the number of fatal accidents could be reduced in recent years, the numbers are still too high. Accidents do not only endanger lives, they also prevent jobs from being completed, they burden the company and result in increased costs. Apart from accidents at work, material damage must also be considered, which does not involve injuries but can result in significant damage to company assets. When considering the design of earth-moving machines, it is striking how the manufacturers, for example in the design of loaders, always retain the original basic design and how fundamental changes e.g. in the access steps, have not taken place.

Within the scope of this project, we will thus investigate mobile equipment, in current use from various manufacturers, for weak-points concerning the risk of accidents and ergonomic problems. The areas where accidents occur will be pointed out and analysed. In addition, ergonomic weaknesses in the equipment should be revealed, which can lead to permanent injury to the vehicle driver. These analyses can then be used to help develop an improved basic concept for mobile equipment. The objective here is then, if possible, to completely remove all risks to the driver and third parties. In a further step this new concept could be implemented, making use of “Industrial design” principles, so that vehicles can be designed which are ideally suited to their purpose as well as providing a safe and healthy working environment.
2 Research into German and international accident prevention rules and regulations for the use and design for safety of earth-moving machines

Within the scope of this research, guidelines and accident prevention regulations (if available) from the following countries were investigated and compared:

- Germany
- Austria
- Switzerland
- Great Britain
- Luxembourg
- European Union
- Canada
- USA

In summary, the following EU directives should be mentioned for European countries, in the implementation specific to each country:

- Directive 98/37/EC from the European parliament and council from 22. June 1998 to align the member states' laws and administrative regulations for machines (the machinery directive)

The machinery directive defines the most important points for the safe operation and design of mobile equipment. For this reason, in the following, only the machinery directive is compared with the regulations from Canada and the USA.

In the proper sense, there are only accident prevention regulations in Germany. Luxembourg has adopted these with only minor changes. In all other EU states and non-European countries there are no comparably detailed regulations for the safe use of earth-moving machinery.

The following regulations were investigated from outside of Europe:

Canada:
2.1 Comparison of the European Machinery Directive 98/37 with Title 30 of the Code of Federal Regulation (COFR) (USA) and the Canadian Occupational Health and Safety Regulations (OHS) (SOR/86-304)

A comparison of appendices 1 and 3 of the European machinery directive with the OHS rules in Canada and with the safety standards in the USA shows that the structure of the American rules is very different from the EU directive. Several points are not included in the American rules; others are much more detailed and are thus more like accident prevention regulations than a directive. In the following, the important differences are analysed and summarised. The comparison only shows those regulations in the Canadian and American sets of rules which are in addition to the EU directive. The regulations missing from these rules will not be mentioned again. A detailed comparison of the regulations can be seen in table form in appendix 1.

2.1.1 Brakes

Under the point “Braking”, the EU directive requires that the machines must meet all requirements with regard to slowing down, braking, stopping and immobilisation for all of the normal operating conditions specified by the manufacturer for safe operation. The driver must be able to slow down and stop self-propelled machinery by means of a main device. The COFR also describes in detail the procedure to test the brakes on
mobile equipment. For this, the equipment must be reliably brought to a stop within a defined, level distance, depending on the weight and speed. In Canada, these tests are required for half of all equipment with a weight in excess of 45 t. Each of these pieces of equipment must be tested at least once, within a period of 3 years.

2.1.2 Tyre repairs

Under § 56.14104 the American guidelines specify the procedure for repairing tyres: Before removal, the tyre must be deflated. To inflate the tyre after fitting, either a protective cage has to be used, which will contain the tyre fragments if it bursts, or an inflation system must be used which can be operated from a position outside of the danger zone. The passage in the Canadian guidelines is similar. There is no corresponding rule in the EU directive.

2.1.3 R.O.P.S. - roll over protective structures

Roll over protection is specified in the European directive for the following machines, with a motor power in excess of 15 kW:

- Loaders or bulldozers
- Backhoe loaders
- Wheeled or caterpillar tractors
- Scrapers
- Bulldozers and dump trucks with articulated steering

This structure must be designed so that, if the vehicle rolls over, the driver is protected by an appropriate deflection limiting volume (DLV). The structure must be tested by the manufacturer. The Canadian SOR 86-304 requires that all equipment with a ride-on driver, who would be at risk if the vehicle falls or rolls over, must be equipped with roll-over protection. According to American safety guidelines, the equipment mentioned in the European guidelines must be equipped with roll-over protection from a weight of 7000 kg (in Canada from a weight of 700 kg). This protection is also required for graders, scrapers, rollers, drilling trucks and side-tilting loaders and must conform to the SAE standard. In Canada it can also be required that ROPS have to be fitted to equipment not previously mentioned, if it is necessary due to the design or the conditions of use of the equipment. Safety belts must be worn if there is a danger of
falling over or if the equipment is in motion. For operation when stationary, the belt may be undone. After an unusual stress, the ROPS may only be used again after an expert has checked that it is safe to do so. Repairs or other alterations may only be made with the agreement of the manufacturer or of an authorised expert. These details are not included in the European machinery directive.

2.1.4 Seat belts in specialised trucks

The American guidelines require seat belts to be installed and to be worn in specialised trucks. Seat belts have to be used when this enables safer working. According to the Canadian and European guidelines/directive, the installation and wearing of a seat belt is only required in equipment with ROPS.

2.1.5 Warning systems

According to the American guidelines, mobile equipment must be equipped with one of the following if the driver's rear view is not sufficient:

- Automatic reversing warning system
- An alarm bell mounted on the wheels which sounds at least once per foot of movement, when the machine is reversing, or
- Someone outside the vehicle has to give instructions

The volume of the warning signal must exceed the ambient noise level. Alternatively, at night a visual warning system (flashing light) can be used.

If necessary, before moving mobile equipment, the driver has to use a signal to warn people in the vicinity.

The EU directive requires that mobile equipment must be equipped with warning systems if this is necessary to protect the health of the people at risk. The equipment must have an audible warning system. Machines with a ride-on driver must also have a light warning system suitable for the conditions of use. Machines, whose own movements and those of its working systems present a special risk, must bear a sign prohibiting any approach to the machine whilst it is operating. This must be legible at an adequate distance, where the safety of persons is guaranteed who need to work close to the machine.
2.1.6 Parking and leaving the vehicle without supervision

According to COFR, when leaving the vehicle unsupervised on a sloping surface, apart from the parking brake, either wheel chocks must be used or the steering must be turned to point to the kerb. The Canadian guidelines require that when the vehicle is left, unintended movement must be prevented by applying the parking brake and by engaging the gear specified by the manufacturer for that purpose. If necessary, additional chocks must be used.

In addition, the equipment must be fitted with warning lights, if the parked vehicle presents a danger for persons in other mobile equipment (e.g. on roads at night, COFR).

The EU directive specifies that, if required for safety, it must be possible to immobilise the machine with a mechanical immobilisation system. The use of wheel chocks or setting the steering is not required.

2.1.7 Lights

According to the EU directive, lighting must be available which is suitable for use at unlit locations. The Canadian guidelines specify that, for use at night or at locations with light levels below 10 Lux, the equipment must be fitted with warning lights at the front and at the rear, which can be seen at a distance of at least 100 m. It must also have enough lights to enable safe use of the equipment. In the American guidelines, the lighting systems must be switched on when the equipment can not be reliably recognised at a distance of 150 m. Also, the display in the driver's cabin must be illuminated and the front and rear spotlights must correspond to the SAE specification.

2.1.8 Fire extinguisher

According to the machinery directive, depending on the dangers anticipated by the manufacturer when the machine is used, the following must be provided:

- an option of fitting an easily accessible fire extinguisher or
- fitting a fire extinguishing system which is integrated into the machine.
The Health and Safety Code for Mines in British Columbia, Canada requires mobile equipment to be fitted with at least one fire extinguisher of an adequate size. According to COFR, every piece of diesel-powered equipment must have a fire extinguisher with an adequate minimum size, fitted in a position which is easily accessible by the driver and which at the same time is protected from damage. In SOR 86/304 nothing is specified about fire extinguishers.

2.2 Summary of the comparison of the legal requirements

The comparison of the legal requirements shows that the European machinery directive is more general than the American and Canadian guidelines. This can be explained by the fact that the machinery directive applies for all types of machine and that the appendices 1 and 3 relevant for the comparison relate to mobile machinery. In contrast to that, the selected North American guidelines were designed explicitly for mining and rather take account of the specific characteristics of earth-moving machinery. This means that general rules such as the dangers from extreme temperatures, non-electrical energy and incorrect installation are missing. Details in other areas are however specified much more precisely, even occasionally intruding into the running of the operation. Examples here are, for instance, maintenance instructions and dealing with faulty equipment parts as well as the testing regulations for brakes on heavy mobile equipment. The regulations on leaving parked vehicles unattended as well as the transport of material with specialised trucks must be mentioned (Boulders and large pieces of rock must be crushed before loading if they would present a danger to persons or if the stability of the vehicle would be negatively affected).

We can summarise, saying that more details are specified in the North American guidelines than in the European instruments, but comparable accident prevention regulations are missing.

In the USA and Canada the monitoring of safe operation of the equipment is done by national organisations, representing a mixture between an employers’ liability insurance association and a technical monitoring association like the German TÜV. They are responsible for checks and testing of equipment and personnel and, on the other hand, they work out safety instructions and best practice strategies and make these available to the companies involved.
2.3 Investigation of the standards regarding safety at work with earth-moving machines

The most important aspects for the safe design and construction of earth moving machines are contained in the international standards listed below:

- EN 474 The safety of earth-moving machinery, with the sub-sections:
  - 474-1 General requirements
  - 474-2 Tractor-dozers
  - 474-3 Loaders
  - 474-4 Backhoe loaders
  - 474-5 Hydraulic excavators
  - 474-6 Dumpers
  - 474-7 Scrapers
  - 474-8 Graders

- ISO 2867 Earth-moving machinery - Access systems
- ISO 5006 Earth-moving machinery - Operators field of view

The European standards EN 474-1 to EN 474-8 contain the requirements on earth moving machinery which are relevant for safety. EN 474-1 contains safety requirements which are applicable for all earth-moving machinery. In parts 2 to 8 of EN 474, special safety benchmarks are specified which only apply for the particular type of machine specified. These standards only contain supplements, deviations and specifications on the base standard 474-1.

We will explain the contents of these standards as necessary whilst evaluating the accident statistics, within the scope of the necessary design changes and suggested improvements.

At present three of the named standards are being modified. In the following, we occasionally make use of the draft new versions.
3 Evaluation of the accident statistics

The basis for evaluating the accident statistics is provided by a total of 1125 accidents with earth-moving machinery, which were reported to the German quarrymen's employers' liability insurance association (Steinbruchs-Berufsgenossenschaft) in the years 2001 to 2003. For reasons of clarity, the individual machines are summarised into the following types of equipment:

- Excavators: also contains mini-excavators
- Loaders: loaders, caterpillar tractors, backhoe loaders
- Graders: caterpillars, graders, scrapers
- Specialised trucks: dumper trucks
- Other: other accidents which could not be clearly assigned to one of the above categories

3.1 The evaluation procedure

For the evaluation, first of all the accidents were assessed by equipment type. Then the accidents were sorted into the categories “design related” and “operational” as far as was possible from the description of each accident. Within the categories, subcategories were formed to be able to structure the areas of operation and design more exactly.

The following Illustration 1 shows the evaluation procedure.

For each of the core accident areas which crystallise out of the statistics, a more exact evaluation follows later on.
3.2 Statistical evaluation of accidents at work with earth-moving machinery

The following graph shows the course of accident statistics with earth-moving machinery for the years 2001 to 2003 and the development of the number of those insured by the quarrymen's employers' liability insurance association. Over the three years investigated a decrease in the number of accidents can be seen at the same time as the number of those insured also reduces. The number of accidents went down by 21% from 418 in 2001 to 332 in 2003. Over the same period a reduction of 12% in the number of those insured could be seen.
3.3 Sorting the accidents by type of equipment

The following table shows the accidents over the period of observation divided into the various types of equipment.

Illustration 2: Accidents with earth-moving machinery depending on the number of those insured

Illustration 3: Accident numbers by equipment type
The largest decrease, with a reduction of 26 % of accidents can be seen with the hydraulic excavators.

The following diagram shows the distribution of accidents by equipment type for the period 2001 to 2003. 50 % of the accidents were with loaders and 32 % were with excavators. The other 18 % of accidents split up into 11 % on specialised trucks, 4 % on graders and 3 % on other equipment. Illustration 4 clearly shows the need for action on the working safety of loaders and hydraulic excavators.

Illustration 4: The distribution of accidents for the period 2001 to 2003

3.4 Distribution of the accidents into the two main groups

In the following evaluation, two different main groups of reasons for accidents were investigated:

- Accidents related to the design
- Accidents related to the type of operation
In total 1125 accidents occurred in the period under investigation. Of those 650 could be assigned the characteristic “design” and 368 “operation”. The following diagram shows the distribution of the accidents into design-related and operation-related accidents. For 107 accidents a clear classification is not possible as the description of the accident was insufficient.

Illustration 5: Overall distribution of the accidents

3.4.1 Design-related accidents

The design-related accidents are due to the way the individual machine components are used such as the cabin or climbing up the earth-moving equipment. The next diagram shows the equipment distribution of this type of accident related to design faults.
Illustration 6: Distribution of accidents between the individual types of equipment related to design

Viewed as a percentage, with over 53% more than half of the design related accidents occurred with loaders. The share for excavators was 30.3%, specialised trucks 11.2%, graders 4%. Other equipment had a share of 1.4% and will not be considered any further.

The following diagram shows the percentage frequency of accidents for the overall period of investigation, independently from the type of equipment, sorted by design characteristics.
Illustration 7: Accident numbers depending on the components causing the accident

At 79 %, the high proportion of accidents associated with the use of the steps to get into the driver's cabin is striking. Doors take a share of 6 %, all other design characteristics take a share of between 2 and 3 % of the accidents. The most frequent causes of accidents for each of the design characteristics considered are listed below:

- **Steps**: slipping from the steps is one of the main causes of accidents. The reasons for this are either slipperiness or an un-ergonomic arrangement / design (e.g. handholds, step spacing etc.).
- **Cabin**: the main cause of accidents is when the driver hits the cabin due to the vehicles motion or some shock.
- **Windows**, flaps: during maintenance work, an employee is injured when the flap slams shut.
- **Tyres, wheels**: the greatest risk of accidents here is when tyres are fitted to loaders and dump trucks. The reason for this is usually related to the high weight of the tyres (falling over, trapping, crushing).
• **Controls:** accidents mainly occur when hands hit the controls due to vehicle motion and shocks caused by uneven ground or by accidental contact when entering or leaving the equipment.

• **Bucket teeth:** the most frequent cause of accidents here is changing teeth on excavators and loaders. The problem here is when attempts are made to hit a tooth free with a hammer, sharp-edged metal splinters can be produced which then lead to injuries.

• **Field of view:** the vast majority of accidents relating to the field of view result from vehicle movement with an inadequate field of view. This can result in crashes with obstructions, impacts with other vehicles or driving over embankments and steep edges as well as in injuries to third parties.

• **Hydraulic hoses:** when dismantling, hot hydraulic oil escapes at high pressure and damages the worker's eyes or face.

• **Batteries:** accidents with batteries are largely the result of improper use. Short circuits or unwiring after trying to start the motor lead to the battery exploding from escaping oxyhydrogen. This leads to battery acid escaping which in particular can cause eye injuries.

### 3.4.2 Accidents depending on the type of operation

Accidents depending on the type of operation are caused by the individual's use of the machine. These are classified independently of the type of equipment, using the descriptions of the accident. Reasons for accidents include:

• **Driving:** inappropriate speed, collision with obstructions.

• **Loading:** overloading the bucket or piles of excessively large pieces of debris frequently leads to accidents with loaders. The consequence is that, when lifting the debris, the rear wheels of the equipment lift off of the ground or stone fragments falling out of the bucket lead to powerful shocks to the equipment.

• **Maintenance:** due to the use of tools, a variety of injuries frequently occur.

• **Cleaning:** when cleaning the equipment, employees slipping and falling are the main reasons for accidents.

• **Transporting the equipment:** the high weight of the machinery and accessories presents the main danger when loading, transporting and
unloading the equipment. This is particularly true when they suddenly move during the lashing down process or when safety fittings, such as railings, have been removed for transport.

- **Stability**: soft ground leads to the equipment tilting and then falling over.
- **Fuelling**: slipping is the main cause of accidents here.
- **Presence in the danger area**: third parties who are either not directly involved in the work or who are assisting the driver are struck by the equipment when in the danger area.
- **Lifting gear**: the lifted load falls or turns on lifting and hits the employee.

The distribution of accidents with mobile equipment depending on the type of operation can be illustrated graphically as shown below.

Illustration 8: The percentage distribution of accidents by the type of operation

From the evaluation it can be seen that 51% of accidents occur during maintenance of the equipment. Next come accidents which have actually got something to do with operational use such as driving (13%) or loading (10%). It is also worth noting that, with a share of 7%, presence in the danger area only plays a subordinate role. Accidents whilst cleaning the equipment also take a share of 7%. Stability-related accidents take a share of 5%. For completeness sake, accidents using lifting gear
(3 %), fuelling (2 %) and transport (2 %) are mentioned here but they also have a subordinate role.

3.4.3 Causes of accidents not directly influenced by the design or type of operation

The following evaluation shows further causes for some of the accidents, which are not exclusively related to the design or the type of operation. Reasons for accidents include:

- Slipping when entering or leaving the equipment
- When leaving the equipment, stepping onto an obstruction
- Twisting an ankle when leaving the equipment, or immediately afterwards
- Injury with a tool (spanner, etc.)
- Driving error such as excessive speed
- Insured person hit by flying stone
- Walking into or bumping into stationary equipment
- Slipping due to ice or rain when entering or leaving the equipment
- Wind
- Driving over loose ground or over an edge resulting in the equipment falling over or slipping away
- Technical fault such as handhold pulling off
- Slippage of material pile
- Jumping from the equipment
- Crushing hand or fingers between material and equipment e.g. when loading the bucket
- Misbehaviour
- Slippery surface on the equipment (ice, dew, oil, grease, other soiling)
- Driver not wearing seat belt

It is worth remarking on the high number of accidents caused by slipping (on steps), stepping on an obstruction and accidents caused by twisting an ankle when leaving the equipment. In the following section, these accidents will be specially considered in relation to the design of the steps.
In the following diagrams, the distribution of the above-mentioned reasons for accidents is shown both in absolute numbers (Illustration 9) and in percentage terms (Illustration 10) for all accidents over the period in question.

**Illustration 9: Absolute distribution of the most frequent causes of all accidents**

At 13% the accident types “trodden on obstruction” and “twisted ankle” present a significant fraction of the causes of accidents which can not be directly classified as being due to the design or the type of operation. Accidents resulting from the use of a tool take a share of 3%. These mostly occur when maintaining the equipment. Driving errors make a contribution of 2% to accidents in this group. The other reasons for accidents, with a share of ≤ 1% are of lesser significance. “Seat belt not worn” is not listed here as a cause of accidents, as it is not explicitly recorded in the accident reports and is only occasionally mentioned in the descriptions of the accident circumstances. In this case one should presume a higher rate of occurrence.
3.4.4 Climbing the steps as a cause of accidents

In the following diagram, the reasons for a total of 521 accidents are analysed more closely, which occurred when using the steps. Here it is particularly noticeable that, in about one half (48%) of all accidents, slipping from the steps led to the accident. Other causes of accidents, with an average fraction of 15%, are obstructions on the floor which are trodden on when leaving the equipment. Twisting an ankle is at a similar level (with an average of 12%) when coming down from the equipment onto the floor. The other causes such as jumping down, slippery surfaces due to water or ice, ice on the equipment or a technical fault as well as soiling only play a subordinate role. For the remaining 15%, the reason can not be established precisely, due to inadequate information.
Illustration 11: Causes of accidents when using the steps
4 Suggested solutions for a safer design

In the following chapter, approaches to improve the safety of mobile equipment & their components will be formulated. In this the important, most accident-prone design characteristics will be examined.

4.1 Steps

4.1.1 Accident analysis

It can be presumed that earth-moving machines, which are put into circulation in Germany, comply with the applicable standards. However, the accident statistics show that almost half of all accidents with earth-moving machines occur during the period of entering and leaving the equipment. Loaders present particular risks which, in contrast to hydraulic excavators, are not used when immobile, as the steps can be damaged by soiling or by bumping into obstructions. This sort of damage is rarely or not properly repaired by the operator and thus leads to risk for the driver. An additional problem is that other means of access are used than those intended. This includes stepping on tyres, wheel hubs and or mudguards. Occasionally, jumping from the equipment leads to accidents; in other words, not using the intended assistance to get in/out.

4.1.2 Basic requirements

When using the steps, it must be possible for the driver to hold on to two different handholds and to stand on the step with both feet at the same time. The last point is necessary if, for example, the door to the cabin is opened or if tools are to be transported on the vehicle. The positions of the handholds must be adapted to the way a human moves.

When designing the equipment, the inspection and filling openings for the operating liquids must be arranged so that they are accessible from the floor. Otherwise, suitable, adequately secure access paths onto and over the machine must be constructed.
Parts of the construction can only take over the function of a step, if they meet the same requirements in relation to dimensions and non-slip surfaces as apply to the steps themselves.

### 4.1.3 Suggested solutions for the design of the steps

One important design characteristic is the spacing from the floor up to the first step. There is no accepted, common international standard. The following table shows the different maximum permissible step heights of various German and international safety regulations and standards.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Maximum Step Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2867: 1994 Earth-moving machinery - Access systems</td>
<td>700 mm</td>
</tr>
<tr>
<td>VBG 40 - Accident prevention regulations for earth-moving machines (UVV Erdbaumaschinen) (1997)</td>
<td>650 mm</td>
</tr>
<tr>
<td>BGV D29 - Accident prevention regulations for vehicles (UVV Fahrzeuge) (1997)</td>
<td>650 mm</td>
</tr>
</tbody>
</table>

Table 1: Overview of maximum permissible step heights

From an ergonomic point of view, the height up from the floor to the first step should not be more than 550 mm, whereby a step height of maximum 400 mm is viewed as particularly safe.

To reduce the risk of accidents when leaving the vehicle, the following improvements to the design are necessary:

- For all earth-moving machines the height from the floor to the first step should not exceed 550 mm.
- The lowest step should be flexibly joined to the ladder with fabric straps, to avoid it being ripped off when an obstruction is bumped into. At the same time, the step should only be able to move sideways. In the vertical direction, the construction must be so stiff that the step can not swing back and lead to injuries to the driver's shin. Only the lowest of the ladder of steps can be flexibly fixed.
- The step should be at least 60 mm deep with a non-slip surface. The ladder should be protected from excessive soiling which can be caused by the motion
of the equipment, by suitable construction of the mudguard. Cylindrical steps are unsafe and thus not permitted.

- The sides of the steps must be enclosed by an approximately 5 cm high strip or similar construction to prevent feet from slipping off sideways.

- If possible, the steps should be designed so that the steps are not arranged vertically over one another rather offset at an angle to the side of the vehicle. The resulting slope of the steps should not exceed 75°. This means that the driver can see all of the steps and does not have to “feel their way”.

- Handholds should have a diameter in the range of 25 - 30 mm. The previous standard presumed a basic value of 25 mm and a minimum diameter of 16 mm.

- The clearance for a hand is currently set at at least 75 mm. This value can be reduced to 50 mm, as has already happened in the draft version of ISO 2867:2003. This eases the arrangement of the handholds.

- Handholds for steps should be arranged vertically if possible and provided continuously so that it is not necessary, for instance, to let go for cross-braces. The surface should provide a good grip as slipping on the handholds occurs frequently, particularly when wet.

- Placing handholds for the steps on doors or other moving parts should be avoided.

Anneliese Zementwerke AG have developed an exemplary design for loader steps. This is vertical when the vehicle is in motion and can be folded out for use. This results in steps inclined at approx. 75° and the spacing of the lowest step to the floor is approx. 30 cm. This design was rewarded with a special prize Work - Safety - Health 1997 by the quarrymen’s employers' liability insurance association.

Surfaces to step on the equipment, needed for daily maintenance and cleaning, must be safely accessible, sufficiently large and non-slip. In the design of the machine, the glazing must be safely reachable from outside for cleaning work and the corresponding necessary safe standing surfaces must also be provided. It is when doing this work that drivers frequently slip from the equipment. If the surface is at a height of more than 2 m above the floor, railings must be fitted. The standard only requires railing at a height of 3 m, which can not be accepted. Some companies have already retrofitted railings to their equipment (Suggested award for quarrymen's
employers’ liability insurance association: protection from railings on the superstructure).

The following Illustration 12 shows a state of the art, frequently found ladder, with offset steps and railings. Illustration 13 shows an especially safe set of steps for loaders in the shape of steps with a railing on both sides, where the lower four steps can be folded down almost to floor level.

![Illustration 12: Loader steps with offset, non-slip steps and railings](image)
4.2 Cabin

4.2.1 Accident analysis

The accident statistics show that the proportion of design-related accidents associated with the cabin lies between 2 % for hydraulic excavators and 8 % for graders (caterpillars). The proportion of accidents for loaders is 1 %, for dump trucks 4 %.

The injuries are mainly caused by heads bumping into parts of the cabin due to the motion of the machine. It is thus not surprising that the proportion of these accidents is least with the hydraulic excavators as this equipment is mostly used without driving the machine along. Reasons for heavy shocks to the machine include obstructions on the floor, which are driven into when pushing or grading, uneven roads as well as lifting excessively heavy objects or materials. A further cause is cabins which are too small, which can lead to the driver bumping into things in the cabin, when entering or whilst driving.
4.2.2 Basic requirements

When designing the cabin, the least favourable size of driver should be presumed. Thus, when dimensioning the cabin, the largest possible machine operator should be presumed, but for all parts necessary to operate the machine, they should be within reach of very small people.

The requirements on the design of the cabin should not be set depending on the power of the motor for the earth-moving machine. Common rules are necessary here such as a division into compact earth-moving machines and other machines. This has already been included in the draft for EN 474:2001.

For roll over protection a single standard is desirable as in North America. In Canadian and American regulations on safety in mobile equipment there is no restriction on power (this could be deleted in EN 474 as, in principle, all equipment has a motor power in excess of the required 15 kW). For lower weight limits, in the Canadian OHSR 700 kg is specified, in title 30 of the COFR 7000 kg is specified. Apart from that, according to these regulations ROPS should be fitted to tractors, water trucks, bottom emptying and skid-steer loaders or on all vehicles with ride on drivers where there is a risk of roll over.

Wearing seat belts should be made compulsory by technical means in machines which are equipped with ROPS, for example by locking the gears when the belt is not worn or by sounding an alarm signal. In this way injuries from bumping into the cabin can be prevented, at least in the direction of motion.

4.2.3 Suggested solutions for the design of the cabin

All earth-moving machines should, if possible, be fitted with a restraining belt for the driver. In the Canadian guidelines, the use of a safety belt is specified if this contributes to improving the safety of the equipment operator.

The current minimum dimensions for driver's cabins which depend on the motor power should be enlarged and fixed to a common size. The following table shows the current relevant body dimensions for a large machine operator (95. percentile).
<table>
<thead>
<tr>
<th>Country</th>
<th>Seat height from SIP</th>
<th>Elbow width</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 474</td>
<td>920 - 1050</td>
<td>450 - 550</td>
</tr>
<tr>
<td>USA</td>
<td>990</td>
<td>500</td>
</tr>
</tbody>
</table>

The cabin should be at least 920 mm, for compact machines a reduction to 650 mm is permissible.

The 650 mm mentioned above for compact machines does not take account of an adequate safety distance to the cabin wall. The width necessary for that is 750 mm, comprising an average elbow width of 500 mm, 20 mm thickness of clothing and a safety distance of 115 mm on both sides.

In the design of cabins for earth-moving machines the following changes are necessary:

The internal height of the cabin must be at least 1 m, measured from the Seat Index reference Point (SIP according to ISO 3411). This dimension must also be maintained if, as is usual for smaller machines, the front or rear windscreen can be folded up underneath the roof of the cabin.

The internal width of the cabin for compact machines should be at least 750 mm, for all others it should be at least 920 mm.

### 4.3 Doors, windows, flaps

Doors, windows and flaps are all moveable elements which serve to close openings in the equipment.

According to EN 474 or VBG 40, the safety requirements on these elements are only as follows:

“The doors and windows must be held in the open and closed positions by a suitable fitting. Safety glass must be used for the glazing.”

Nothing is said about flaps. In the standards there are still specifications formulated on separating protective fittings and covers, from which you can deduce that opening and closing must be easy and safe. When open, the parts must also be safely locked in place for wind speeds up to 8 m/s (wind force 4). The draft for EN 474 specifies that the positive locking must be used. Locks relying on friction are no longer permitted.
4.3.1 Risk analysis

Over the period investigated, there was a total of 36 accidents with doors. They can be distributed as follows between the individual groups of equipment:

loaders 7 % (15 accidents), hydraulic excavators 4 % (13 accidents), dump trucks 11 % (8 accidents), caterpillars and other 0 %.

Viewing the accident statistics per equipment type shows that most door-related accidents occur with loaders despite only presenting 7 % of design-related accidents. This mostly concerns injuries to hands or fingers caused by slamming the door closed. The reasons for this include the driving around of this type of equipment and also, owing to the working procedure, the need to have to more frequently leave the vehicle. Other reasons include inadequate locking of the door when open, particularly when there is a wind, which is often to be encountered at speeds over 8 m/s in open-cast mining.

A further source of danger from the cabin door is the door frame and the direction of opening in connection with the steps. With some equipment, the door swings directly towards the driver, who then, standing on the access ladder and hanging on to a handhold with one hand, has to bend backwards to be able to open the door. Other equipment has a sufficiently large standing area next to the cabin door so as to be able to safely open it from there. When closing the cabin door it is also possible for dust and sand from the step in front of the cabin to be blown into the driver's eyes.

There was a total of 16 accidents with windows or flaps. The percentage share of design-related accidents was in the range of 1 % (for loaders) to 8 % (for graders) (excavators 4 %, specialised trucks 5 %).

The main cause of accidents with flaps is inadequate locking when open. This means that they can close by themselves resulting in the flap injuring the employee. In the area of windows there were only 2 accidents over the entire period. Here, employees have trapped their fingers closing the window.

4.3.2 Suggested solutions for the design of doors, windows and flaps

It must be possible to lock the doors when opened; positively locking them against backplates, and it must not be possible for them to open themselves (mechanical locking system).
Handholds which are used with the steps, should not be on doors or other moveable parts.

Doors must be fitted on the equipment so that they do not impede employees standing on the steps when they are opened. The employee must be able to stand safely on the steps whilst the door is opened or must be able to stand on a platform next to the cabin.

### 4.4 Field of view

According to EN 474, the driver's cabin must be designed so that the driver has an adequate field of view over the driving and working area of the machine. This states that the driver must be able to see all important procedures in the working area, such as when individuals are in the danger area or the approach of other vehicles. This requirement is vital for the use of the equipment but does lead to problems, particularly for larger machines as, for example, ROPS protection of the cabin or the larger dimensions of the machine create areas around the machine which are out of sight.

#### 4.4.1 Risk analysis

18 accidents occurred in total over the period investigated which can be classified as being caused by “Restricted field of view”. With 7 accidents (2 %), loaders are responsible for the largest number of field of view related accidents, excavators make up 3 % (6 accidents), specialised trucks make up 5 % (4 accidents) and graders make up 4 % with just one accident.

In the following diagram the percentage share of accidents per type of equipment is shown, sorted into three groups:

- Accidents where the driver was injured (blue)
- Accidents where other people were injured (yellow)
- Accidents where other people were fatally injured (red)

The calculated percentages show the proportion of equipment involved in accidents with inadequate field of view. The total of the values in the diagram is thus 100 % and is not shown, as above, depending on all accidents with that type of equipment.
Accidents with loaders mainly concerned reversing with an inadequate field of view. During this, persons were hit or there were collisions with objects or vehicles.

With the excavators the accidents were caused in equal parts by the following movements:

- Reversing
- Swivelling the superstructure
- Operating the lifting gear

The main causes of accidents with specialised trucks was driving over embankments and steep edges as well as collisions with other vehicles. These accidents happened exclusively when the specialised trucks were reversing.
4.4.2 Suggested solutions

For loaders the driver's reverse field of view can be improved by equipping the vehicle with a video camera on the rear side. Particularly for machines in the upper power class, the size of the area behind the equipment which is out of the field of view is larger, caused by the longer motor. Camera systems are now available from 500 Euros, and are so small that it is possible to install the monitor (flat-panel display) in the driver's cabin without needing lots of space. In addition, earth-moving machines can be equipped with ultrasonic systems, as included as standard today in many cars, to detect objects in the reversing area. The disadvantage of this equipment is that it is not a replacement for the driver being able to see, it is just something additional. The systems can be affected by the weather and can also not discriminate between a person and an object behind the vehicle. The driver must then come down from the vehicle to take a look for themselves. The warning sounds can also distract the driver when the machine is working in a tight space for operational reasons. The system can also fail fairly quickly due to soiling.

To prevent specialised trucks from falling over when tipping their payload backwards, protective barriers should be mandatory for all tipping sites. In the Canadian and US American guidelines to prevent accidents there are already rules like this. In Germany, their use is only required for fixed location tipping sites. A protective barrier which can be used very flexibly has been developed by Rheinischen Kalksteinwerke and has won an award from the quarrymen's employers' liability insurance association.

Design changes to improve the field of view include sloping the motor cover and cladding which leads to a reduction of the areas around the machine which are out of the driver's field of view.

To prevent accidents with people in the reversing area of the equipment, it is sensible to equip the machines with a reversing warning system. This can be either a visual or an audible system. In Canada, a warning system is required for every earth-moving machine with rubber tyres, with a permissible maximum speed of more than 8 km/h and an operating weight of more than 7 t.

To avoid traffic accidents in open-cast mining, North America requirements ask that every transport vehicle is either equipped with a whip aerial with lights and a flag or carries a flashing light on the roof. This requirement would only make sense in European operations where large specialised trucks are used, as for smaller vehicles, the driver does not sit so high over the road and still has an adequate field of view to be able to recognize vehicles in front of or next to the truck.
4.5 Controls

The controls on earth-moving machines are steering wheel, levers, pedals and switches. These items are used to control the equipment.

4.5.1 Risk analysis

In the period under investigation there were a total of 20 accidents with controls. This corresponds to 3% of the design-related accidents. The equipment-related fractions were divided as follows:

- Excavators 2% (3 accidents)
- Loaders 4% (13 accidents)
- Specialised trucks 5% (4 accidents)

For excavators the main causes of accidents were: accidental activation of the controls, malfunctioning of the controls and injuries from the controls themselves owing to powerful shocks to the equipment.

The most frequent reasons for accidents with loaders are: accidental operation of the controls, getting caught on controls and impact with controls.

For the group of specialised trucks, reasons for accidents include the steering wheel jumping back after driving over obstructions and hitting the steering wheel as a result of heavy braking.

4.5.2 Basic requirements

The following are important for the design:

- The controls must be ergonomically arranged and designed for safety.

- They must be arranged in such a way that when operating levers and switches the upper arm does not have to be moved and, when operating the pedals, the upper part of the leg does not have to be moved.

- The direction of motion of the levers must obviously match the movement of the equipment (or its parts) that it triggers.

- Levers should be arranged so that they can not be accidentally operated when entering and leaving the equipment.

- It must be possible to lock the controls with a safety lever so that the vehicle can not be moved when the driver is not present.
4.5.3 Suggested solutions

The evaluation shows that the greatest need to act is in the area of preventing unintended operation of the controls. For more than 10 years excavators have been built with safety levers which cover the area to enter and leave the cabin (Illustration 15). If the lever is lifted, all machine movements are disabled. This solution has proven its worth in practice. Loaders are not equipped with this so far; only some skid loaders have this fitted. In place of the safety lever, a door contact could also be used although this would lead to problems as the drivers do not always keep the door closed whilst working.

Another solution that has been suggested is to arrange the controls so that accidental activation, or their use as handholds when entering/leaving the cabin, is almost impossible.

Illustration 15: Safety lever on a hydraulic excavator
5 Operation of earth-moving machines

In this section all accidents related to operation and behaviour are assessed and analysed.

The following activities, which often result in accidents, are examined:

- Driving
- Loading
- Presence in the danger area
- Cleaning
- Maintenance
- Fuelling
- Transport
- Lifting gear
- Stability

5.1 Driving

An analysis of the statistics for driving accidents produces the following values. The sum of the accident percentages put down to “operation” per type of equipment is 100 %, but not per category from the “operation” area.

- Excavators: 1 % (2 accidents)
- Loaders: 20 % (32 accidents)
- Graders 29 % (7 accidents)
- Specialised trucks: 29 % (11 accidents)

The low share taken by excavators can be explained by the way this equipment is used. Excavators mostly work at a fixed location and are rarely driven. With all other machines, a considerable part of their use consists of driving the machine. This sometimes occurs as high speeds, particularly with loaders and specialised trucks. External circumstances can increase the risk of accidents when using the equipment; circumstances such as the condition of the ground or the visibility. The following criteria can be identified as factors which can result in accidents:

- Inappropriate speed
- Driving on soft road shoulders which cannot support the weight of the vehicle
- Driving over embankments or steep edges
• Collision with obstructions as a result of inattention
• Driving over large stones
• Driving in ruts
• Driving without seat belt
• Travelling as a passenger on the equipment without a proper seat (e.g. on steps)

5.1.1 Suggested solutions

For driving accidents, the factors causing the accidents mostly indicate human error. This problem is partially dealt with in standard 474 and in the machinery directive, however a large part has been dealt with by sample operating instructions for each type of equipment produced by the quarrymen's employers' liability insurance association.

Some of the accidents can be avoided by improved training and ongoing training of the equipment operators. During driver safety training, the drivers can be made more aware of the sources of risk when using the equipment.

5.2 Loading

For loading accidents the analysis of the statistics results in the following distribution around the types of equipment:

• Excavators: 14 % (19 accidents)
• Loaders: 9 % (14 accidents)
• Graders 0 % (0 accidents)
• Specialised trucks: 8 % (3 accidents)

These results are to be understood like this: that 14 % of all operationally-related accidents with excavators occurred whilst loading.

Inevitably, most accidents occurred with the actual loading equipment i.e. excavators and loaders. With specialised trucks, the accidents occurred whilst loading the equipment. The factors which most frequently caused accidents were:

• Material falling out of the embankment
- Material falling out of the bucket
- Flying stones from crushing or loading work
- Equipment suddenly lurching when loading caused by hitting edges or obstructions under the pile being loaded
- The bucket slipping off when attempting to pick up large objects resulting in a heavy shock to the equipment

### 5.2.1 Suggested solutions

For loading accidents, the suggestions already mentioned under point 5.1.1 apply. The frequency of accidents due to the equipment suddenly stopping and the resulting shock in particular can be reduced by making the wearing of seat belts obligatory. Better suspension for the cabin and the driver's seat can also help to reduce the effects of shocks on the driver.

### 5.3 Presence in the danger area

A total of 24 accidents could be classified as “presence in the danger area”. They were distributed around the equipment types as follows:

- Excavators: 8 % (11 accidents)
- Loaders: 8 % (12 accidents)
- Graders: 4 % (1 accident)
- Specialised trucks: 0 % (0 accidents)

The accidents with excavators were mostly due to the following reasons:
- Movements of the superstructure or the bucket led to injuries to third parties.
- Outside assistants struck when the vehicle moved.
- Falling load or rolling stones on embankments injure the driver or third parties.

Accidents were caused with loaders due to the following reasons:
- Third parties hit by the vehicle when it moves.
- Lowering the bucket to the floor catches body parts of third parties.
When transporting or lifting bulky objects, these move suddenly and hit third parties.

Only one accident was reported for graders, where a third party stood behind the caterpillar during grading work and was caught by the caterpillar track.

5.3.1 Suggested solutions

It can be necessary for someone to be in the danger area, particularly when assisting the driver in tight spaces. For this job it is important that the assistant can always be seen directly by the equipment operator. This would at least avoid accidents from vehicles hitting or running over persons. Third parties must not be allowed to be in the danger area and must be made aware of this by suitable information from the employer or by attending a training course. In some cases the use of a radio link between the driver and the assistant may make sense, if there is no direct visual contact.

5.4 Cleaning

Accidents occurred whilst cleaning the equipment in 24 cases. The accidents were distributed around the equipment-types as follows:

- Excavators: 3 % (4 accidents)
- Loaders: 8 % (12 accidents)
- Graders: 8 % (2 accidents)
- Specialised trucks: 11 % (4 accidents)
- Other: 29 % (2 accidents)

The accidents were mostly caused by:

- Slipping or falling from the equipment during cleaning work
- Stumbling, twisting an ankle or bumping into the equipment
- Injury from the cleaning equipment

High-pressure cleaners are often used to clean the machines. Owing to the high water pressure, this equipment often “kicks back”. It is thus necessary to hold the nozzle with both hands. Drivers frequently have no access to suitable ladders or
platforms for cleaning and, for convenience, climb directly onto the wet machine and slip as the non-slip surfaces of the platforms aren't good enough, or there aren't enough of them.

5.4.1 Suggested solutions
The platforms on the equipment which are used for cleaning can relatively cheaply be fitted with non-slip sheets, to reduce the risk of slipping. The use of sheets in these areas is not a problem as they are not part of the actual access steps and are thus subject to less wear. When designing the equipment, manufacturers should consider the cleaning, particularly of the front and rear windscreens, and should provide suitable access and platforms on the equipment. There is also the option of fitting permanent ladders and platforms around a cleaning bay from which the vehicles can be safely cleaned.

5.5 Maintenance
In the maintenance area, most accidents occur for the characteristic “operation”. A total of 190 accidents occurred corresponding to a percentage of 51 %. The accidents were distributed around the equipment-types as follows:

- Excavators: 59 % (83 accidents)
- Loaders: 49 % (78 accidents)
- Graders 46 % (11 accidents)
- Specialised trucks: 39 % (15 accidents)

The high accident rate can be explained, amongst other reasons, by the use of tools (18 % of all accidents). The most frequent causes of accidents are:

- Injured with the tool
- Slipped off of the equipment
- Body parts crushed when during assembly/disassembly work
- Bumping into machine, falling, hitting
- Injury due to high weight of individual parts
- Metal splinters breaking off
Accidents in the area of maintenance are relatively hard to prevent through design measures. Equipment should be designed so that it is easy to maintain, so that it is possible to get access to parts subject to wear and to inspection points without having to remove lots of other components. Heavy components should be designed with hooks or eyes so that chains or belts can be safely attached. Reducing the maintenance intervals would lead to a reduction in the maintenance work, owing to components having a longer life, and could also contribute to a reduction in the accident statistics.

5.6 Fuelling

The distribution of fuelling accidents around the types of equipment is:

- Excavators: 3 % (4 accidents)
- Loaders: 1 % (2 accidents)
- Graders: 4 % (1 accident)
- Specialised trucks: 3 % (1 accident)

Accidents happened exclusively by slipping from the equipment or slipping whilst fuelling. With many machines it is necessary to use the access steps to reach the fuel-tank filling point. With a fuel nozzle in one hand, there is an additional danger as the driver can no longer hold on with both hands.

5.6.1 Suggested solutions

The equipment should be constructed so that the fuel-tank opening, and other openings for daily maintenance, can be reached from ground level. Alternatively, for larger vehicles, suitable access steps should be fitted which are wide enough, non-slip and, depending on the height, have railings.

For older equipment, the risk of accidents can be reduced by using stable ladders or by fuelling from a loading platform.

5.7 Transport

7 accidents occurred whilst equipment was being transported, which can be distributed around the groups of equipment types as follows:
• Excavators: 3 % (4 accidents)
• Loaders: 1 % (1 accident)
• Graders 0 % (0 accidents)
• Specialised trucks: 3 % (1 accident)
• Other: 14 % (1 accident)

The main danger-points are when loading or unloading the machine from the transporting vehicle as well as heavy parts to be built on to the machine, which shift on the transporter by themselves or when being lashed down. Other sources of risk are missing safety fittings such as railings, which have been removed for the transport of the machine.

5.7.1 Suggested solutions
Transporting the equipment is a special operation and does not usually occur very frequently. For this reason, when loading/unloading the equipment, work should be done very carefully.
The manufacturer can help to make the transport safer by providing enough fixing points for transport restraints such as chains or belts.

5.8 Lifting gear
10 accidents involved operations with lifting gear, 6 with excavators (4 %) and 4 with loaders (3 %).
The accidents largely occurred through movements of the lifted parts. This resulted in persons being struck and injured. A further cause is sudden movements of the bucket when digging in or pulling out as well as crushing extremities whilst transporting the load.
No solutions were suggested for operations with lifting gear as this mode of operation rarely occurs in mining and the frequency of accidents does not justify further analysis.
5.9 Stability

17 accidents were due to inadequate stability. The largest number here was for excavators:

- Excavators: 5 % (7 accidents)
- Loaders: 3 % (4 accidents)
- Graders 8 % (2 accidents)
- Specialised trucks: 8 % (3 accidents)
- Other: 14 % (1 accident)

From these accidents, four main causes for the accidents could be identified:

- Lifting excessively heavy objects lead to one side of the equipment lifting off of the ground and even to it falling over
- Soft or slippery ground (e.g. steep edges where tipping is done)
- Coming off of the road when reversing
- Driver error

5.9.1 Suggested solutions

Excavators should be equipped with an overload warning system, which warns the driver when the permissible load is exceeded thus preventing accidents by the superstructure swinging around and the equipment then tipping over. To date, this system is only required for equipment used in lifting. On overload, only a warning should be produced for the driver. Switching off and locking the entire control system is not sensible as the driver would then not even have the option of putting the load back down on the ground.

Injuries caused by the equipment falling over can be prevented by the use of ROPS for all excavators. To date, ROPS and a seat belt for the driver are only required for excavators with an operating weight below 6000 kg. In the USA, ROPS is required for all vehicles with a ride on driver where there is a danger of tipping over, whatever the operating weight (see 4.2.2). This would result is a requirement for seat belts in almost all machines used in the stone and earth industries.
Many loaders are already equipped with weighing systems. It should thus be technically possible, depending on the equipment, to programme a maximum permissible load into the weighing systems so that these warn the driver on overload. In Canada it must be possible for the driver to clearly recognise the maximum load with which the vehicle can safely be moved. Driving errors can be avoided by better staff training. Inappropriate speed or misjudging the situation leads to impairment of the stability and thus to accidents.
6 Production and evaluation of a questionnaire on the safety of earth-moving machines

In parallel to the evaluation of the accident statistics, a questionnaire was developed to gather further information about the use of earth-moving machines. A main objective in designing the questionnaire was to get information about “close calls”, accidents that almost happened, as well as design faults, in addition to the accidents. To gather this information from as wide a base as possible, two different questionnaires were developed and were sent to a total of 2800 member companies in the quarrymen's employers' liability insurance association. One questionnaire is intended for management, the second is intended for staff in the workshop or drivers.

6.1 The management questionnaire

This questionnaire dealt mostly with suggested improvements. First the type of machine has to be selected from the 5 categories excavators, loaders, caterpillars, specialised trucks and dumpers for which the questionnaire is to be completed. Subsequently, the manufacturer, the type of equipment and the year of construction have to be specified. The following three questions asked which improvements are necessary for the selected machine, whether the maker of the machine has already been presented with them and, if yes, how they reacted. Then details were requested whether employees had been unable to work as a result of accidents with earth-moving machines in the last 5 years and, if yes, how many days were affected. Question 5 asked about recommendations to optimise working safety when using earth-moving machines. Recommendations could be made both on the subject of design and for behaviour. The last question was associated with the awards made by the quarrymen's employers' liability insurance association. In total, four prizes are to be awarded in the area of earth-moving machines, for which a question was asked as to whether these are known about and whether they are implemented in the company. The awards specified are:

- Flexible protective barrier for tipping points
- Safer boarding of loader cabins
- Wheel changing equipment for construction machines
- Requirement for seat belts for drivers of loaders / specialised trucks
See the appendix for the original questionnaire.

### 6.2 Questionnaire for workshop staff / equipment operators

This questionnaire is aimed at staff who use earth-moving machines on a daily basis or staff in the workshop who are responsible for the maintenance and repair of this equipment.

First the employee has to state whether they work as a driver or a mechanic. They are then asked whether they have personal experience in the use of earth-moving machines. Finally, the type of machine, the manufacturer and product type have to be entered. The next questions cover possible employee accidents. The questions differentiate between the following:

- Close calls (near accidents)
- Injured on the equipment
- Accident without losing a day's work
- Accident losing a day's work

For the types of accidents mentioned, more details can then be supplied on the cause of the accident by selecting from a list. This is then divided between the following design characteristics and activities:

- Steps
- Cabin
- Controls
- Bucket
- Tyres
- Field of view
- Driving
- Loading
- Swivelling, lifting and lowering the bucket
- Cleaning
- Maintenance, repair
Should it not be possible to classify the accident / close call into one of the categories specified above, then another cause for the accident can be entered as text in a field. Then the employee is asked what they particularly dislike on the equipment specified and whether they would like to suggest improvements to the previous options.

6.3 Evaluation of the questionnaire

By the end of 2005, 958 completed questionnaires had been returned and evaluated in the following. The completed questionnaires can be divided up as follows:

Management
- Total number returned: 311
- The number of those completely/correctly completed: 247
- The number which were incomplete, incorrect or not filled out at all: 64

Employees not involved in accident / close call
- Total number returned: 429
- The number of those completely/correctly completed: 391
- The number which were incomplete, incorrect or not filled out at all: 38

Employees involved in accident / close call
- Total number returned: 223
- The number involved in close calls: 182
- The number involved in accidents without losing a day's work: 196
- The number injured but without losing a day's work: 93
- The number with at least one day's work lost: 27
- The specified number of days work lost: 528
The returns comprised 68% employee questionnaires and 32% management questionnaires.
From the employee questionnaires, the evaluation showed that 66% of the questionnaires were completed by employees who had not been involved in an accident. The share involved in accidents or close calls is 34%.

6.4 Analysis of the accidents

The analysis of the accidents from the questionnaires was done in a similar way to that used in chapter 3.

6.4.1 Distribution of accidents by type of equipment

The distribution of accidents by type of equipment shows parallels to the quarrymen's employers' liability insurance association accident statistics investigated. Loaders are the most frequently mentioned type of equipment with a share of 56%. Illustration 16 below shows the percentage distribution by type of equipment. In addition, it is also clear that the bulk of the accidents (80%) are associated with loading equipment (loaders, excavators). Caterpillars, dumper trucks and specialised trucks with shares of 9%, 6% and 5% play a subordinate role.
6.4.2 Working days lost by employees due to accidents with mobile equipment

The evaluation of working time lost by employees also shows a high share in the use of loading equipment. However, the analysis shows that, despite the high numbers of accidents with loaders, the relative number of days lost is less than for the excavators. Viewed absolutely, the time lost due to accidents with loaders and excavators can be divided into approximately equal shares. The overall share of loading equipment comprises 72% (Illustration 17). The other times lost are due to transport equipment, specialised trucks and dumper trucks. Within the scope of the survey, no time lost could be determined for caterpillars.
Illustration 17: Working time lost by staff depending on the type of equipment

### 6.4.3 Distribution of the accidents

For the following evaluation, a division is made into design-related and operation-related accidents. The design-related accidents can be divided into the categories:

- Steps
- Bucket
- Cabin
- Field of view
- Controls
- Door

Overall 160 accidents can be assigned to the “design” area.

The operation-related accidents are then divided into the categories:

- Driving without an adequate field of view
- Maintenance
63 accidents were assigned to the “operation-related” area. The evaluation of the questionnaires showed that, in a similar way to the quarrymen’s employers’ liability insurance association accident statistics, the design related accidents occur twice as frequently as the operation-related accidents.

Illustration 23 shows that the employee questionnaire also results in steps, with a share of 58 %, being the most frequent cause of accidents in the area of design. The most frequently mentioned causes of accidents for the design feature “steps” are:

- Slipped off of the steps (64 %)
- Twisted ankle when coming down (18 %)

Accidents associated with the driver’s cabin still take a share of 18 %. The reasons for these accidents are:

- Bumped into parts of the cabin when entering/leaving (79 %)
- Bumped into parts of the cabin as a result of sudden stops or heavy shocks to the machine (21 %)

Accidents categorised to the design feature “field of view” occur almost exclusively when reversing. This mostly concerned collisions with objects. Accidents resulting in injuries to persons are rare.
Illustration 18: Distribution of design-related accidents

The following diagram shows the distribution of working time lost as a result of accidents in the area of “design”. One can clearly see that the accident black spot “steps”, with a share of 87 % is responsible for the most working days lost. Together with the distribution of the accident frequency this leads to the conclusion that accidents on the steps often lead to high numbers of working days being lost.
The analysis of the operation-related accidents does not permit any clear accident black spot to be identified. The most frequent accidents are those related to inadequate field of view. Cleaning the equipment and loading each take up about a quarter of the accidents. At 16 %, the accidents during maintenance only play a subordinate role (Illustration 20). The most frequently mentioned reasons for accidents are:

**Driving without an adequate field of view**: collision with objects

**Loading**: material falling down from the embankment or bucket

**Cleaning**: slipped off of the equipment

**Maintenance**: injured with tool
Illustration 20: Distribution of operation-related accidents

The working time lost by operation-related accidents can be divided into two-thirds for “driving with inadequate field of view” and one-third for maintenance. One can thus conclude that field of view accidents result in a higher average number of working days lost than the other operation-related accidents (Illustration 21).
Illustration 21: Distribution of the numbers of working days lost due to operation-related accidents

6.4.4 Evaluation of the suggested improvements

Within the scope of the survey, improvements could also be suggested for the selected equipment. Overall 258 improvements were suggested, which are distributed as follows:

- Employees not involved in an accident: 56
- Employees involved in accident / close call: 39
- Management: 163

The following diagram shows the percentage distribution in each of the categories of respondents. It is noticeable that management made an above average number of suggestions. It can also be seen that the employees who had been involved in an accident made more suggestions than their colleagues who had not.
Illustration 22: Distribution of the suggestions in the questionnaires

The analysis of the suggestions showed that, with a share of 64%, the most suggestions were made for loaders. The share for excavators was around 20%. This distribution can be explained by the distribution of equipment used in the companies and also with the way that loaders are used. Almost every company has at least one loader, which, in contrast to excavators, does not work at a fixed location but is frequently moved.
The evaluation of how frequently suggestions were made results in a differing picture between employees and management. The most frequent answers from employees are more in the area of ergonomics and comfort, whilst the answers from management concentrate more on safety.

**Overview of the most frequent subjects mentioned:**

<table>
<thead>
<tr>
<th>Management</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Steps</td>
<td>Steps</td>
</tr>
<tr>
<td>2. Cabin</td>
<td>Cabin</td>
</tr>
<tr>
<td>3. Reversing camera</td>
<td>Field of view</td>
</tr>
<tr>
<td>4. Field of view</td>
<td>Accessibility (maintenance, cleaning)</td>
</tr>
<tr>
<td>5. Cabin door</td>
<td>Driver's seat</td>
</tr>
<tr>
<td>6. Reversing warning system</td>
<td>Lights</td>
</tr>
</tbody>
</table>

In addition to the suggested improvements, the employees were asked what they disliked most on the selected equipment. The evaluation here shows a clear emphasis in the area of ergonomics and comfort. There are clear differences between employees who have been involved in an accident and those who had not.
Employees who had been involved in an accident mentioned the design features steps, door, access, lights and field of view much more frequently than the other employees. On the other hand, they mentioned the cabin and the driver's seat less often. From this distribution, conclusions can be drawn about the origins of design-related accidents as some design features were mentioned more frequently by the employees who had been involved in an accident than those who had not. Illustration 24 shows the detail of the analysis.

Illustration 24: Evaluation of employees who were particularly unhappy with a design feature

6.4.5 Awards made by the quarrymen's employers' liability insurance association

Within the scope of the survey in the companies, management was asked to provide information about awards. They were asked whether they knew about these awards and which had been implemented in their company.

The result of this survey showed that about 50 % of the improvements suggested were known within the companies but that their implementation had occurred much more rarely, with a share of between 5 and 15 %. The most frequent successes were the introduction of a requirement to wear a seat belt for specialised trucks and loaders.
as well as the flexible protective barrier for tipping sites. For “safe steps to loader cabins” it can not be presumed that all companies who claimed to have implemented this have actually retrofitted the design produced by “Anneliese Zement” to their loaders.

The diagram below shows the detailed results of the evaluation.

![Diagram showing evaluation results](image)

**Illustration 25: Evaluation of familiarity with and implementation of the quarrymen's employers' liability insurance association award**

### 6.5 Summary of the evaluation of the questionnaires

The evaluation of the questionnaire confirms the results of the analysis of accidents in chapter 3. Here too the steps are identified as the accident black spot. This is particularly true for loaders and excavators. This means that there is urgent need for action in the design of steps. Important parameters for modifications to the steps are:

- Reduction of the step height to below 550 mm with corresponding changes to the “access systems” standard. The slope of the steps should not exceed 75°.

An even better design of the steps is shown in Illustration 13. Also, the transition from the steps to the cabin should be designed so that the equipment operator has an adequately large and safe platform available to stand on when opening and closing
the cabin door. The evaluation of the questionnaire shows that many of the equipment operators complained about the door frame as well as opening and closing the cabin door from a standing position on the steps.

The evaluation also showed that the field of view, especially for loaders, is inadequate, particularly when reversing. The survey resulted in a repeated request for reversing cameras as standard as well as for larger mirrors e.g. on the sun screen.

Cleaning the equipment has turned out to be a problem owing to a shortage of suitably sized, safe platforms. Here, the equipment operators not only complained about the sometimes poor access to front and rear windscreens but also about faulty mudguards which do not adequately catch the dirt thrown up by the tyres, thus contributing to the soiling of the glazing and of the steps. Complaints were also made that some equipment did not have a rain gutter on the cabin, which leads to dirty water running over the cabin roof and down the front windscreen, impairing vision even more when it rains. On some equipment the windscreen wipers are also too small.

The evaluation also revealed that the cabin dimensions for lower and medium power classes are frequently seen to be too small. This results in additional sources of accidents in connection with the absence of a requirement to wear seat belts in loaders. It is particularly in these vehicles that the driver bumps into parts of the cabin as a result of shock, caused by driving motion and / or loading. Another disadvantage of small cabins is that the equipment operator bumps into things when entering and leaving the cabin and in some equipment there is also a problem with ventilation resulting in condensation on the windscreen in winter or when the weather is cold and wet.
6.6 Summary

The operation of mobile equipment such as loaders or dump trucks is a source of danger in the building materials industry. The risks arising from the use of mobile equipment can be direct or indirect. All types of accidents represent direct risks. The operator of the equipment themselves can be affected, for example when their equipment is involved in an accident or fall, as well as uninvolved third parties who are hit or run over by vehicles. Repair and maintenance work on vehicles is also a constant source of risk for personnel. Indirect risks are presented by illnesses which can be caused by constant and un-ergonomic loads. Although both the overall number of accidents and the number of fatal accidents could be reduced in recent years, the numbers are still too high. Accidents do not only endanger lives, they also prevent jobs from being completed, they burden the company and result in increased costs.

When considering the design of earth-moving machines, it is striking how the manufacturers, for example in the design of loaders, always retain the original basic design and how fundamental changes e.g. in the access steps, have not taken place. Within the scope of this project, we have thus investigated mobile equipment, in current use from various manufacturers, for weak-points concerning the risk of accidents and ergonomic problems. In addition an analysis and comparison was made of the currently valid German and international guidelines, accident prevention regulations and standards, when considering the design for safety of earth-moving machines. It became apparent that the European machinery directive is very different from the corresponding North American guidelines. These last-mentioned guidelines contain more detailed regulations and thus have more of the character of accident prevention regulations. It should also be noted that none of the countries investigated had accident prevention regulations which are comparable to those in Germany or Luxembourg. The analysis of the standards investigated for the safe design of earth-moving machines showed that the technical requirements are in part quite dated (e.g. for illumination) or no longer correspond to present day requirements for a safe and ergonomically correct design of the equipment. Accident statistics from the quarrymen's employers' liability insurance association were then evaluated and two different questionnaires were produced to verify the results and distributed to companies in the stone and earth industry.

In summary it can be said that the results of the evaluation and analysis of the accidents and the results from the questionnaires sent to the companies show the same basic tendency.
Design-related accidents occur in both evaluations more frequently than for operation-related accidents; in the first analysis about 70% more frequently, in the survey almost three times as frequently. Overall, about 80% of all accidents are related to loaders. The serious accidents occurred mostly with this type of equipment too. Over half of all accidents are due to the use of loaders. The analysis of design-related accidents showed that most accidents were in connection with entering or leaving the vehicle. For the accidents related to operations, it can be seen that most of the accidents happened during maintenance measures. The share of accidents for “driving without adequate field of view” must be mentioned, particularly from the survey results with more than a quarter of the operation-related accidents.

The analysis of the suggested improvements showed that most suggestions were made for loading equipment. Loaders took a share of 64% of the types of equipment. In summary it can be stated that the design of loading equipment, above all in the areas of steps, field of view and cabin dimensions must be optimised.

The evaluation showed that conforming to standards is not sufficient to design the equipment safely enough for the areas mentioned. The manufacturers must be asked here to do better than the values (e.g. the maximum permissible step height) specified in the standards, if this means that the safety of the equipment can be increased.

It is thus important to shift the acceptance and responsibility towards the manufacturers and not towards the operating companies as is currently the case. There is urgent need to act in including and integrating the equipment manufacturers in the process of optimisation. In this, account must be taken of the experiences gathered and introduced into the process, with the objective of optimising the equipment by working together.
Earth-moving machinery – an analysis and assessment of accident statistics

Steinbruchs-Berufsgenossenschaft
Germany

Theodor-Heuss-Straße 160
D-30853 Langenhagen
Phone: +49 511 72 57-0
Fax: +49 511 72 57-7 90
Internet: www.stbg.de
e-mail: info@stbg.de