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Development of Door Sill Assembly Test System

Metropolia University of Applied Sciences

Bachelor of Engineering

Mechanical Engineering and Production Technology

Bachelor’s Thesis

3 June 2013

Metropolia

Author Title Number of Pages Date	Mikko Nordund Development of Door Sill Assembly Test System 61 pages + 3 appendices 3 June 2013
Degree	Bachelor of Engineering
Degree Program	Mechanical Engineering and Production Technology
Specialisation option	Production Technology
Instructor	Jyrki Kullaa, Senior Lecturer

This study was done to a product development unit of a Finnish elevator technology company and it was focused on one of the components of the whole elevator, the door sill assembly. The study had two goals, the main goal was to introduce and to further develop a test system created for testing door sill assemblies, and the secondary goal was to create a technical documentation about the door sill assembly for training purpose.

The main issue with the sill assembly is that one of the main components of the whole assembly, the sill profile, does not have duty ranges. The sill profile is the visual part of the whole sill assembly and it guides the movement of elevator doors. Always when something is introduced to the elevator car, it goes over the sill profiles. There are different kinds of sill profiles available for different kind of use, but at the moment the main issue is that it is not known how much wear each profile can take. This often leads to a situation where wrong kinds of sill profiles are delivered with the elevator. A typical example is that too weak sill profiles are delivered with an elevator expecting heavy use, and eventually the sill profiles breaks down.

The test system for testing door sill assemblies was already created before this study was started, but it had to be introduced and validated. The test system was built in such a way that virtual mass was used to simulate actual mass, but when the validation of the test system was started, it was noticed that it was not working as it should and it did not give reliable results, and had to be further developed. A few different ways were tried to simulate actual mass, but the validation showed that those were not in fact simulating actual mass and could not be used.

Finally the test system was developed to be used with actual mass, but it is yet to be validated. Unfortunately it was not possible in the time frame of the present study. After the final version is validated, it is going to be used to create the duty ranges for sill profiles. The technical documentation for training purpose about the door sill assembly was created successfully.

Keywords	elevator, door, sill, test system

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Tekijä Otsikko Sivumäärä Aika	Mikko Nordlund Kynnystetijärjestelmän kehittäminen 61 sivua + 3 liitettä 3.6.2013
Tutkinto	Insinööri (AMK)
Koulutusohjelma	Kone- ja tuotantotekniikka
Suuntautumisvaihtoehto	Tuotantotekniikka
Ohjaaja	Yliopettaja Jyrki Kullaa

Tämä opinnäytetyö tehtiin suomalaisen hissiteollisuuteen keskittyvän yrityksen tuotekehitysosastolle, ja työssä keskityttiin yhteen hissin komponenttiin: hissin oven kynnykseen. Työn päätavoitteena oli ottaa käyttöön testijärjestelmä, joka oli rakennettu kynnysten testaamista varten, ja jatkokehittää sitä. Toisena tavoitteena oli luoda koulutusmateriaalia kynnyksistä.

Tällä hetkellä suurin hissin oven kynnyksiä koskeva ongelma on se, että yhdellä kynnyksen pääkomponenteista, kynnysprofiililla, ei ole kuormausluokkia. Profiili on hissin oven kynnyksen näkyvä osa, joka ohjaa hissin ovien aukenemista ja sulkeutumista. Aina kun hissiin astutaan, kuljetaan kynnysprofiilien yli. Kun kuormausluokkia ei ole, ei tarkalleen tiedetä, kuinka paljon mikäkin profiili kestää käyttöä. Tämä johtaa helposti tilanteeseen, jossa hissiin toimitetaan käyttötarkoitukseen sopimattomat kynnysprofiilit. Yleensä profiilit eivät tällöin ole tarpeeksi kestäviä ja rikkoutuvat sen johdosta.

Testijärjestelmä kynnysten testaamista varten oli jo luotu, ennen kuin tämä tutkimus aloitettiin, mutta se piti vielä ottaa käyttöön ja validoida. Testijärjestelmä oli kehitetty niin, että siihen ei tarvittu oikeaa massaa ollenkaan, vaan massaa simuloitiin hydraulisen sylinterin avulla. Testijärjestelmän validointi kuitenkin osoitti, että kyseinen rakennelma ei anna luotettavia tuloksia, ja niin testijärjestelmää jouduttiin jatkokehittämään. Oikeaa massaa yritettiin tämän jälkeen vielä simuloida erilaisin keinoin, mutta tuloksetta.

Kun massan simulointi osoittautui liian haastavaksi, kehitettiin testijärjestelmä käyttämään oikeaa massaa. Valitettavasti tämän tutkimuksen puitteissa testijärjestelmän viimeisen version validointia ei ehditty toteuttamaan. Kun lopullinen järjestelmä on validoitu, tullaan sen avulla luomaan kuormausluokat kynnysprofiileille. Myös koulutusmateriaalia kynnyksistä saatiin luotua.

Avainsanat	hissi, ovi, kynnys, testijärjestelmä

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Abbreviations

R&D	Research & Development
COP	Car Operating Panel
AMD	Advanced Modular Door
CEN	European Committee for Standardization
MAP	Maintenance Access Panel
VFD	Variable-Frequency-Drive
HALT	Highly Accelerated Life Testing
EVA	Elevator Vibration Analysis –system

1 Introduction

This Bachelor's Thesis was done to a Finnish Technology Company in elevator business. More closely it was done to the Research & Development (R&D) unit and from a product development perspective. Because of the fact the study concentrates on elevators, this chapter begins by introducing the elevator in general. After that, the background of the study is explained, answering to the question why the study was done, followed by the objectives of the study. The final part of this chapter introduces the frames of the study.

The theoretical framework of the study is largely based on previous working experience in the company and know-how gained during that period. Also several discussions in the company's R&D department were most useful and provided crucial information.

1.1 Elevator Technology

An elevator is built from different modules. These modules may be manufactured in different factories, but all the modules combined form a complete elevator. Figure 1 below represents a basic concept of an elevator.

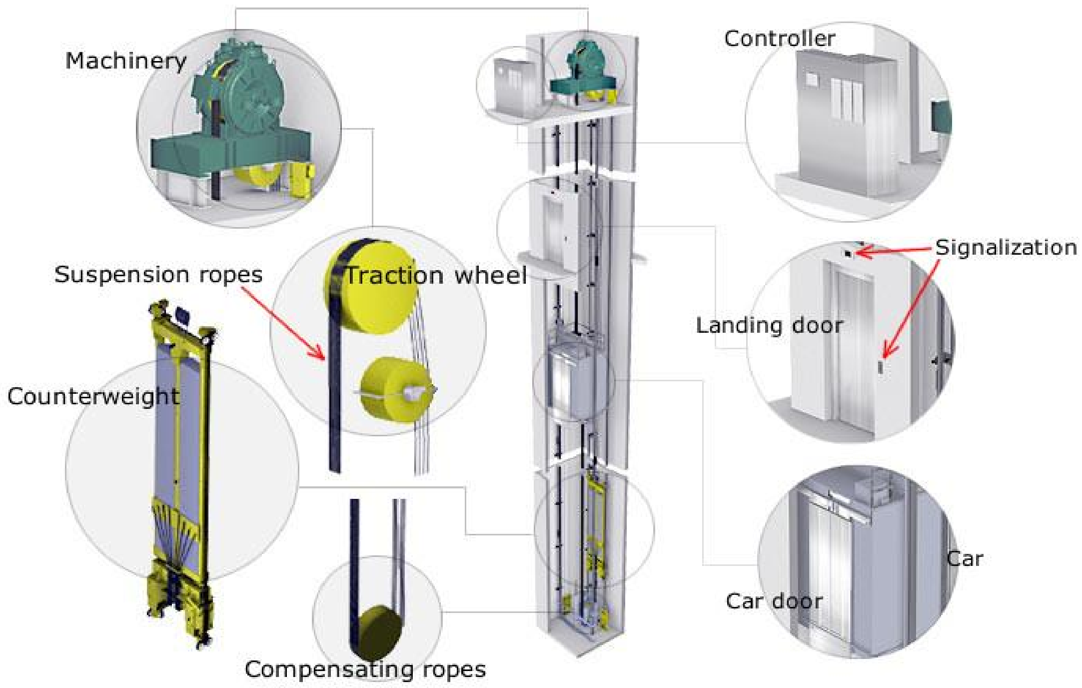

Figure 1. Basic concept of an elevator (Introduction to elevator technology, page 13).

The elevator in Figure 1 is a standard elevator where machinery is in a separate machine room. Nowadays there are also elevators where the machinery is installed inside the elevator shaft and a separate machine room is no longer needed. All of the main components in Figure 1 are explained more closely below

Machinery

Machinery takes care of the actual physical lifting of the elevator (Introduction to elevator technology, page 13). The size of the machinery varies, depending on the height of the building and size of the elevator car. The machinery also contains the brakes. (Introduction to elevator technology, page 17.) Traction wheel is a wheel inside the machinery that transmits the power from the machinery to the suspension ropes (Term bank).

Controller

The controller contains the central operating logic of the elevator. It is connected to every part of the elevator. The controller monitors the elevator car and landing calls and allocates priorities to them. The main tasks of the controller are:

- Receive calls from pushbuttons located in car and on landings
- Determine where the car is located
- Define the suitable direction of travel
- Give start command to the drive
- Give stop command when the car is at the appropriate landing. (Introduction to elevator technology, page 29.)

Drive unit

Drive unit is located inside the controller. It controls the elevator machinery and feeds the power to the machinery. The drive gets its commands from the controller. (Introduction to elevator technology, page 30.)

Elevator car

The elevator car is the main unit of the elevator. It is the part of the elevator which carries the passengers and other loads from one floor to another. The elevator car keeps passengers isolated from the equipment inside the shaft. It also muffles noise and vibrations, and provides comfortable surroundings during the trip. (Introduction to elevator technology, page 21.)

Counterweight

A counterweight is built from two main components: counterweight frame and filler bits. Fillers bits are metal or concrete components of predetermined size and weight which are stacked on top of each other inside the counterweight frame and this forms a complete counterweight assembly. Counterweight is used to ensure the traction between the traction wheel and suspension ropes. (Term bank.) Figure 2 shows a counterweight assembly.

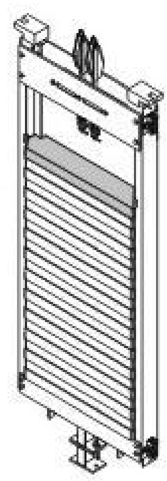

Figure 2. The counterweight assembly (Term bank).

Suspension ropes

The main ropes inside the elevator shaft are suspension ropes. Suspension ropes go over the traction wheel and one end is attached to the elevator car and the other to the counterweight. Because there is a heavy mass hanging on both ends, the ropes do not slide on the traction wheel. Traction wheel transmits the power from the machinery to the suspension ropes and when the traction wheel is rotating, the elevator car and the counterweight moves (Introduction to elevator technology, page 18.)

Compensating ropes

Compensating ropes are used to counterbalance the weight of the suspension ropes. When the travel of the elevator is long (over 40 meters), the weight of the suspension ropes affects to the machinery's workload. One end of the compensating ropes is attached to the bottom of the elevator car and the other end to the counterweight. Together with the suspension ropes, they create a loop of rope with balanced weight on the both sides of the traction wheel. (Introduction to elevator technology, page 20.) Figure 3 below shows the connection of the compensating ropes.

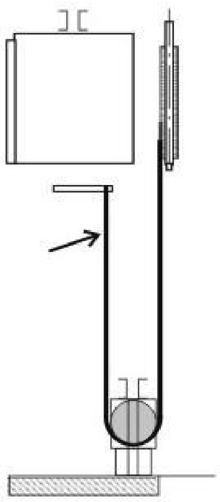

Figure 3. Connection of the compensating ropes (Term bank).

Signalization

Signalization includes all the components the elevator system uses to communicate with passengers (Introduction to elevator technology, page 33). This includes landing call pushbuttons in every landing, optional hall lantern displays and car operating panel (COP). Landing call pushbuttons are used to order the elevator to desired floor, and these are always located in every landing. Hall lantern displays are used to indicate to passengers in the hallway that at what floor the elevator is at the moment and to which direction it is moving. These are optional and often used only at the main entrance. COP is the users interface for passenger inside the elevator car (Term bank). It is used mainly to give the elevator the command to go to the desired floor.

Doors

This study concentrates on elevator doors and more closely one of the main components of the door, the door sill assembly. These components are described more closely in Chapters 2 and 3.

Shaft and guide rails

The whole elevator is build inside the elevator shaft. The car and the counterweight travels inside the shaft and guide rails guide the movement (Term bank). The idea of the guide rails is represented in Figure 4 below.

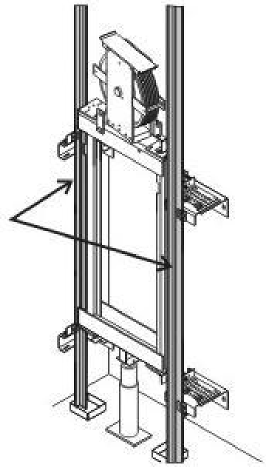

Figure 4. The counterweight and counterweight guide rails (Term bank).

In Figure 4 the counterweight is inside its guide rails. The guide rails are marked with arrows, and as it can be seen, the guide rails guides the vertical movement of the counterweight. This same idea is used with the elevator car and its guide rails.

There are also lots of other smaller components inside the elevator technology, but these are the main modules that form a complete elevator.

1.2 Background

As mentioned in the previous chapter, the door is one of the main units of the complete elevator. The door is also built from different components, and one of the main components is the door sill assembly. The door sill assembly is one of the most expensive components of the whole door, and the main problem with it is that sill profiles, one of the main components of the whole sill assembly, do not have duty ranges. The whole sill assembly is described more closely in Chapter 3, but the sill profile is the visual part which can be seen in the floor when entering to the elevator. It guides the horizontal movement of the door panels. The situation where sill profiles do not have duty ranges can lead to a situation where too expensive sill profiles are used in a place where those are not needed and too weak when stronger sill profiles would be needed. When too weak sill profiles are used, it can cause them to break. Break downs increases the claims received from the customers and this way it increases the costs. It also gives a poor reputation to the company.

Another problem with the sill assembly is that the customer service, who is taking care of the actual orders, does not know the sill assembly well enough. This leads to a situation where the personnel handling orders and tenders might not know what kind of sill assembly should be used and a wrong type of sill assembly could be delivered.

1.3 Objectives

The goals are of course very closely related to the background of the study. In the beginning of the study it had three main goals:

- To introduce the test system created for testing door sill assemblies, apply necessary changes if needed and to validate the test system
- To create reliable test procedure for testing the sill assemblies with the test system.
- To create training material of the door sill assembly for the use of the customer service to train the personnel.

When the study began it was soon realized that the test system is not ready and would not give reliable results if used as such and it would take a lot of time to make all the necessary changes and validate the whole test system. That is why the second goal was left out of the scope of this study in the very early stage and it was decided that the main goal was to introduce and to further develop the test system. Also the creation of the training material remained as a secondary goal.

1.4 Frames

There are different kinds of elevator doors for different kind of use. For different doors there are also different kinds of sill assemblies. It was decided that this study would concentrate only on the high volume doors and sill assembly delivered with these high volume doors. The difference between different kind of doors and door sill assemblies is described more closely in Chapters 2 and 3, but the sill assembly delivered with high volume doors is called heavy sill assembly. The first framing then was that the training material of the door sill assembly is only going to be created about the heavy sill assembly. The second framing was that the test system for testing sill assemblies is going to be used for testing only sill profiles. This comes from the fact that the complete sill assemblies already have duty ranges but sill profiles do not. The idea is that at some point the test system is going to be used to test complete sill assemblies, but in this study it is concentrating only on the sill profiles.

2 Advanced Modular Door (AMD)

This chapter focuses on elevator doors. As mentioned in Introduction, the elevator door is one of the main units of the complete elevator. This chapter begins by giving a general explanation of the elevator door and explaining all the main modules needed to build an AMD entrance. After this, main functions of elevator doors are described followed by an explanation of different AMD door opening types. The final part of this chapter concentrates on different kind of door offering for different kind of use.

2.1 AMD Door in General

Advanced Modular Door is one of the main modules of the complete elevator. Modularity means that it can be built with different combinations of the main components. The main components of the AMD door are drive, railing, frame, door panels and sill. Figure 5 below represents the AMD car and landing doors with main components.

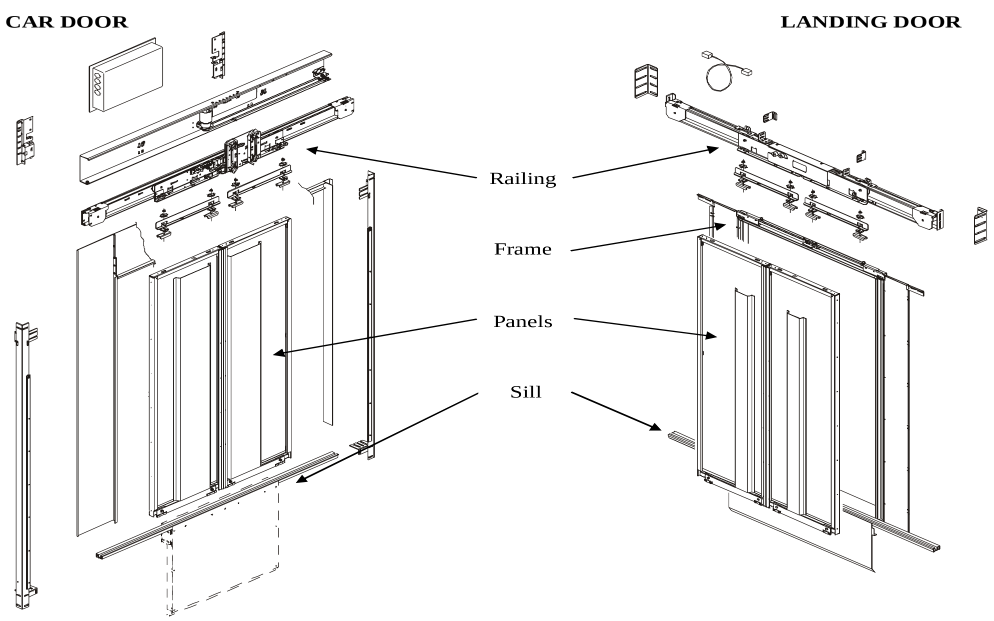

Figure 5. Main components of the AMD door (Anttila 2006).

There are few differences between car and landing doors. Landing doors do not have a drive unit at all as lading doors uses car door’s drive unit, and the sill assembly is very different in car doors than it is in landing doors. These differences and all the main components are explained more closely below.

Drive

Drive module is always located on the car side. The technical function of the module is to operate the movement of the door panels. When an elevator stops to a landing, the drive unit gives a command to both car- and landing door railing to open the door panels. (Anttila 2006.)

Railing

Railing is one of the two units which are used to guide the horizontal movement of the door panels. The other unit is the door sill assembly; this is described more closely in Chapter 3. Currently there are two different kinds of railing types available, and these are represented in Figure 6 below.

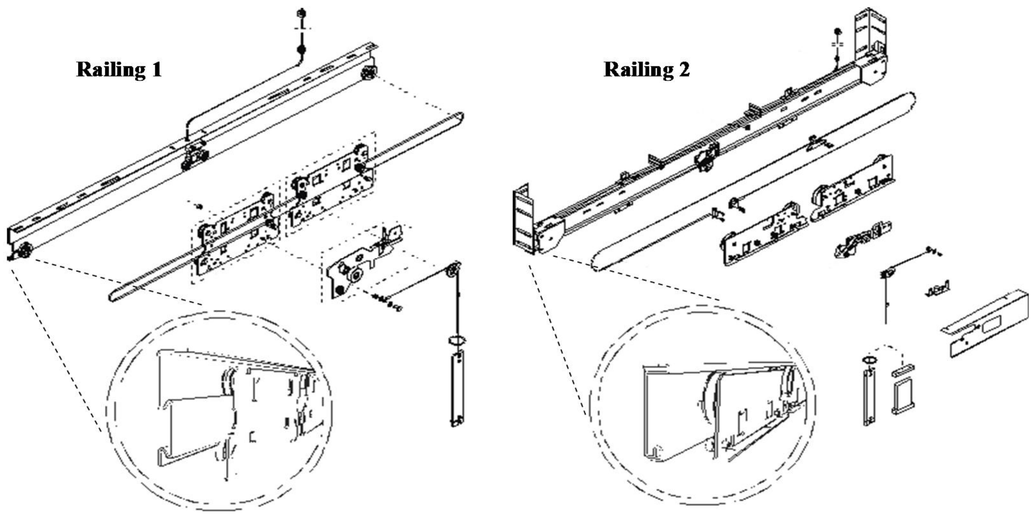

Figure 6. Constructions of railing types 1 and 2 (Anttila 2006).

Railing 1 on the left side of the figure is called a base duty railing and it is designed to perform up to 200 000 cycles per year. Railing 2 on the right side is called a high duty railing and it is designed to perform up to 800 000 cycles per year. Always when it is expected that the door is used more than 200 000 cycles per year, railing 2 is chosen.

Frame

Frame is the construction around landing door panels that covers the hole between entrance hall and shaft. There are currently three different kinds of frame types available with AMD doors:

- Narrow frame
- Frame
- Front

Figure 7 below represents these different frame types.

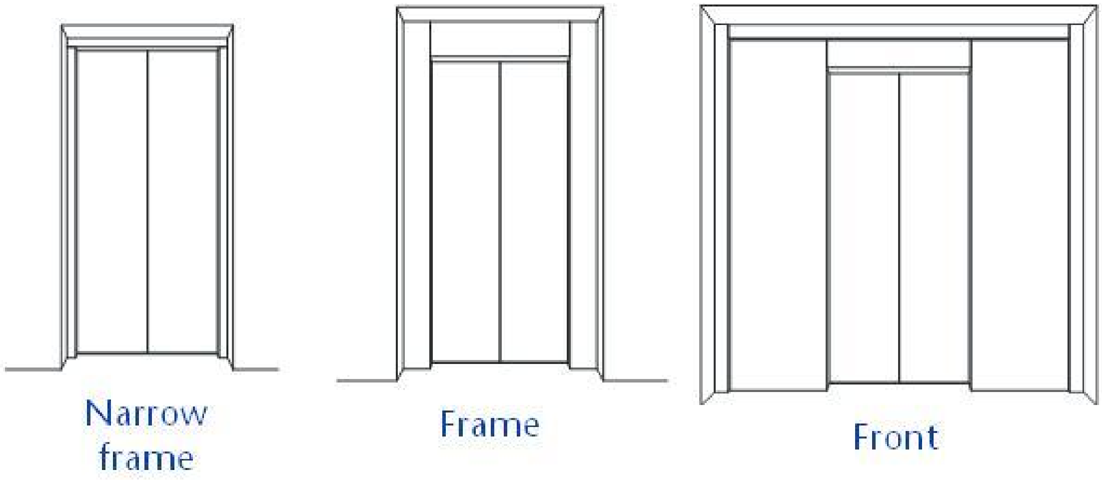

Figure 7. Frame types for the AMD door (Anttila 2006).

The basic difference between the different kinds of frames is the size of the frames, i.e. how large the hole on the wall is that the frame has to cover. The size of the hole depends on the door type used. For example door type 1 has only two door panels so a narrow frame is big enough to cover the hole, but the door type 3 has four panels so it needs at least frame for covering the hole. (Anttila.) The different door types are described more closely in Chapter 2.3.

Door panels

Door panels are the main modules to fulfill the general function of an elevator door. Different standards set different mechanical requirements for door panels and also the fire resistance of the door panels varies. There are currently four different kinds of door panel solution available, and these are represented in Figure 8 below.

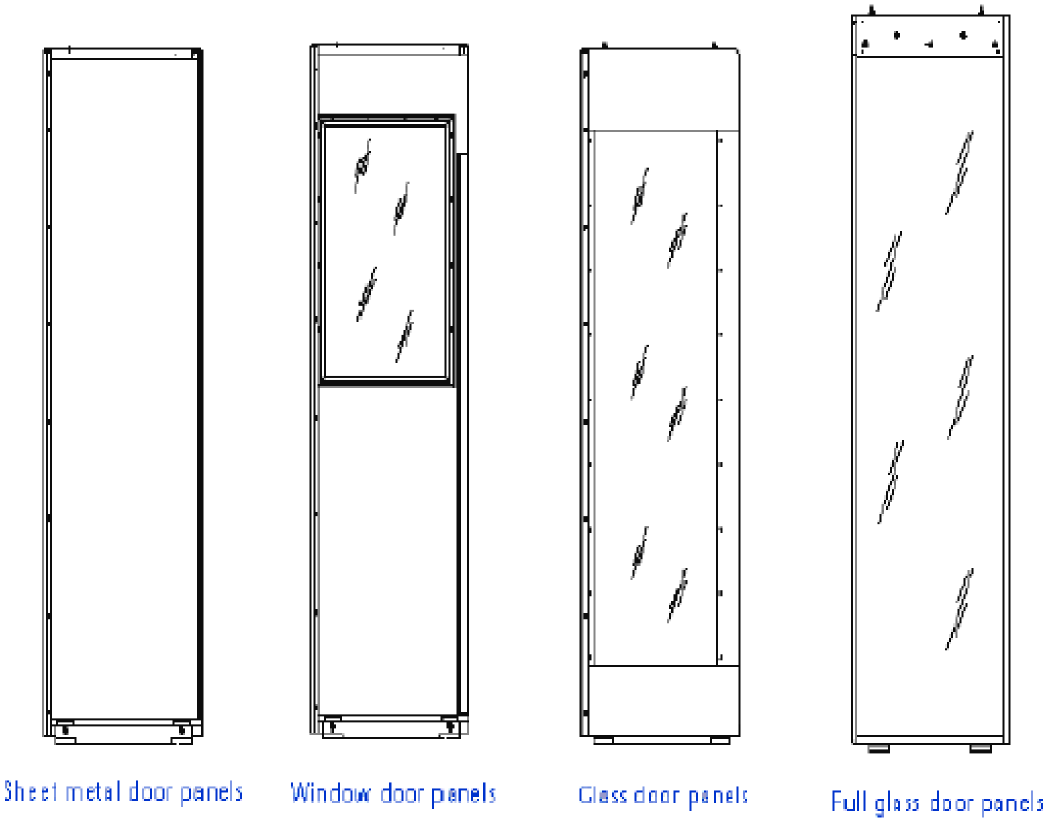

Figure 8. Different kinds of door panel options for the AMD door (Anttila 2006).

Sheet metal door panel is the standard panel type and by far most used. All the others are available to give more visual look for the elevator. For each of these there are numerous different materials available**.**

Sill

This study concentrates on the door sill assembly and it is described separately in Chapter 3.

2.2 Main functions

The doors in every entrance are called landing doors and the doors in the car are called car doors. The landing door is the construction that covers the hole on the wall that separates shaft from other part of the building and the car door is the construction that covers the entrance hole (or two holes if through type car) of the elevator car. Nowadays all the new elevators have to have doors both in the car and in every landing entrance. (Anttila.) In the past the car door was not always mandatory and actually there are still quite a few elevators also in Finland in use without a car door. However, safety regulations have changed, and now also car door is always mandatory.

The landing door has three main functions: It is a mechanical barrier between the entrance hall of the building and the shaft of the elevator, and this way it prevents people or anything else from falling down to the pit. The landing doors also give elevator car a clear and safe path to travel inside the shaft. The last significant function for the landing door is to prevent possible fire from expanding in the building through the shaft. This function does not apply in all situations. There are different kinds of fire ratings in landing doors depending on the regulations. The main difference between different fire ratings is the time the door has to resist the fire before it is allowed to melt.

The car door is installed on the front wall of the car and its main purpose is to be a mechanical barrier between the car and the shaft. It also provides safety for passenger travelling inside the elevator while the car is moving. The car doors are never fire rated.

Figure 9 below represents the main functions of the elevator doors.

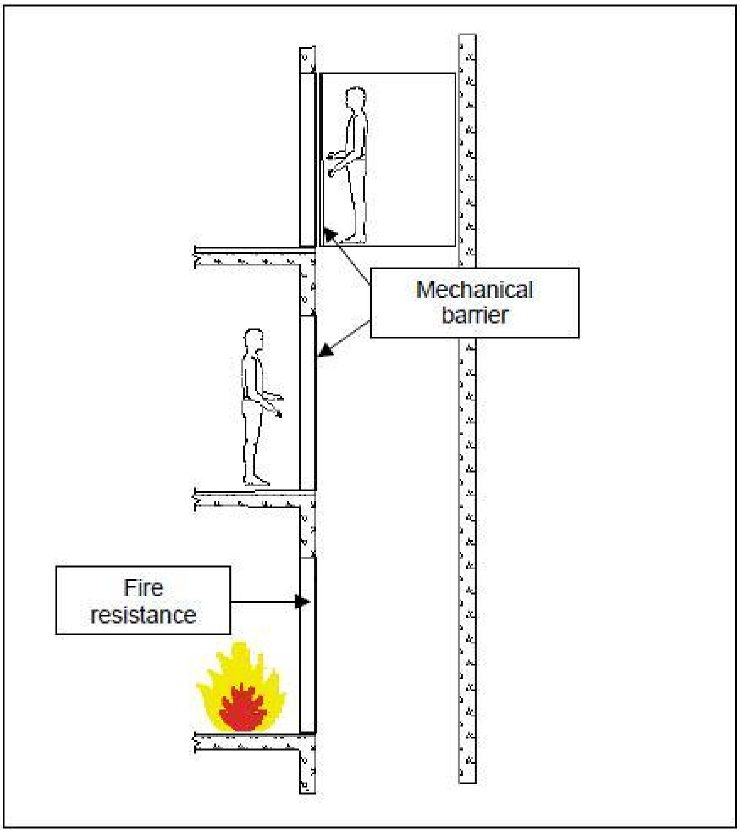

Figure 9. Main functions of elevator doors (Anttila 2006).

2.3 AMD Door Opening Types

There are six different opening types with AMD doors available. One of the reasons to use different opening types is the width of the elevator entrance, but mostly it has to do only with customer preferences. Figure 10 below represents all the different door opening types.

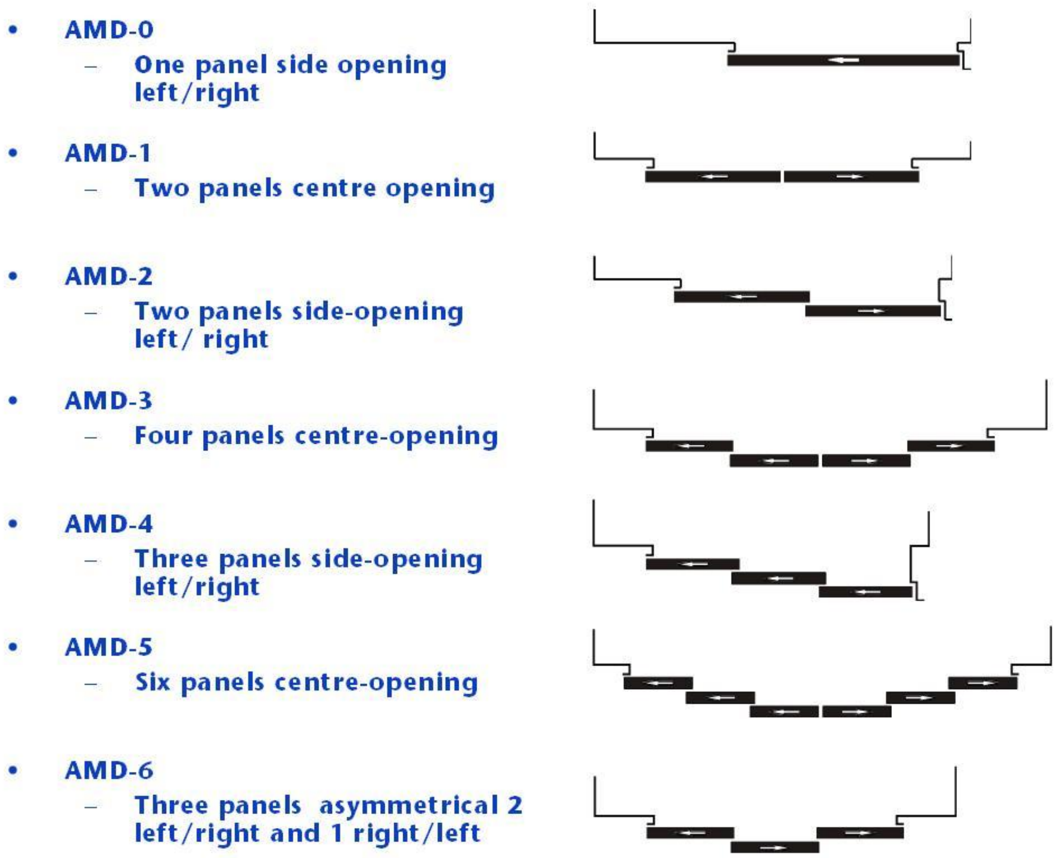

Figure 10. AMD Door opening types (Anttila 2006).

The number of panels means how many door panels is used with the specific door type and the opening type is telling is the door opening from the side of the door, when all the panels move to the same direction, or from the center of the door, when the panels move to the opposite directions.

2.4 AMD Duty Ranges

AMD doors are divided into three categories according to the estimated use of the door on a yearly level. These different categories are called duty ranges. Currently the AMD doors are divided into three different duty ranges:

- AMD 201 = base duty door (up to 200 000 cycles per year)
- AMD 600 = mid duty door (up to 600 000 cycles per year)
- AMD 800 = high duty door (up to 800 000 cycles per year). (Anttila 2006.)

Figure 11 below shows the current landing door offering based on the duty ranges.

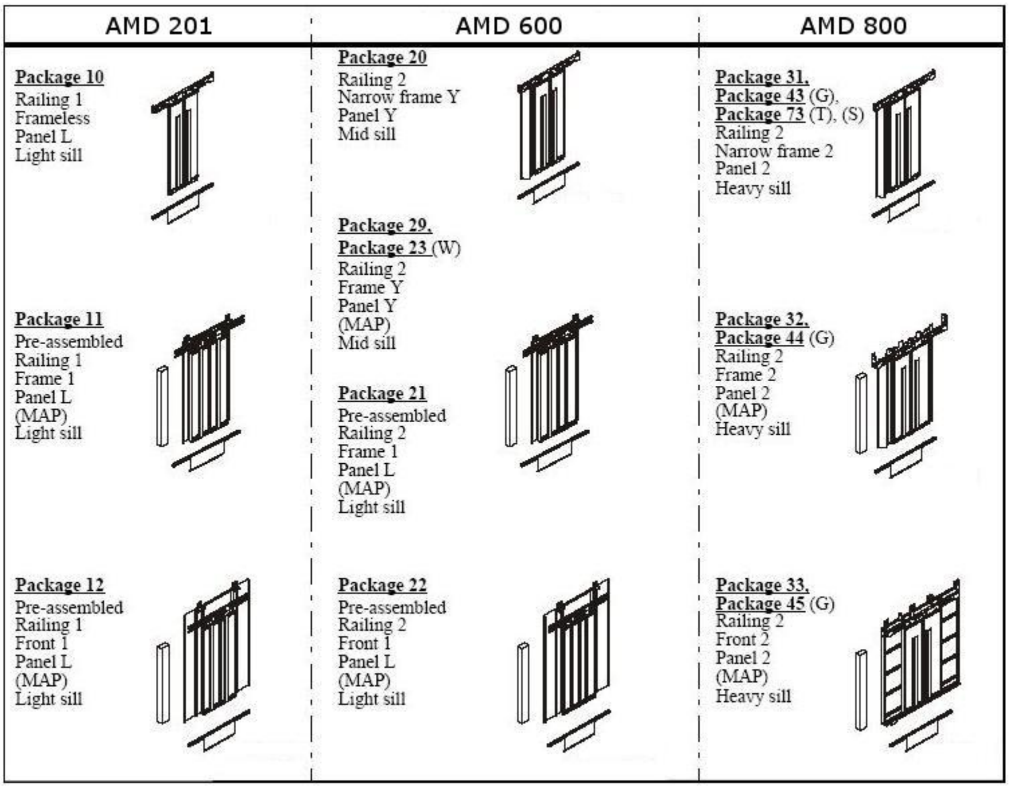

Figure 11. AMD Landing door offering (Anttila 2006)

In the figure it can be seen that for example railing 2 is always the only option when more than 200 000 cycles per year is expected. Modularity of the AMD doors gives the option to use different kind of AMD doors in the same building. For example more highly used main entrance could use high duty AMD 800 door and some other entrance with less use could use only base duty AMD 201 door. This way it is possible to save in costs.

3 Door Sill Assembly

This chapter focuses on the secondary goal of the study, which was to create training material of the door sill assembly. As explained in Chapter 2.4, there are different kinds of elevator doors available for different elevators, mainly depending on the usage of the elevator. For different doors, there are also different kinds of sill assemblies. These can be divided into three categories:

- Light sill
- Mid sill
- Heavy sill

As this study only concentrates on heavy sill assembly, light sill and mid sill are left out from this chapter. The chapter begins by explaining the components used in heavy sill assembly and after that all the different heavy sill types are explained followed by an explanation of the different heavy sill profiles. Chapters 3.4, 3.5 and 3.6 introduce sill assembly in general and therefore also light and mid sill assemblies are included into these chapters. First there are the main functions of the door sill assembly, and after that safety and reliability. The final part of this chapter concentrates on the technical requirements of the sill assembly.

3.1 Heavy Sill Assembly

The car door sill is basically just a sill profile fixed on the car floor but the landing door sill is much more complex. It is the basis for landing door frame installation and it always contains the following components:

- Sill profile
- Sill body
- Toe guard
- Wall fixing brackets
- Sill fixing brackets.

Depending on the sill type, also the following components may be present:

- Grout guard
- Carpet list. (Module 9: Door.)

All these components that form a complete landing door sill assembly are represented in Figure 12 below.

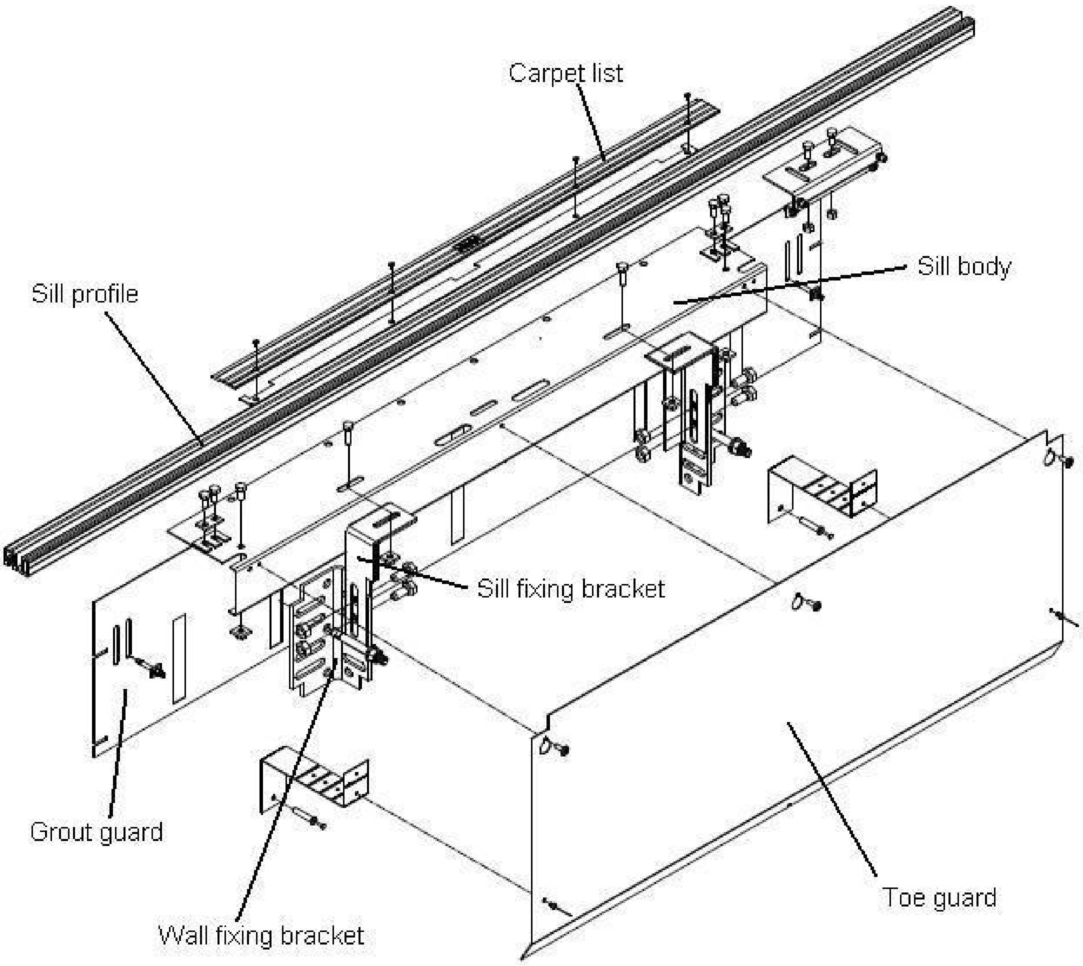

Figure 12. Landing door sill assembly (KES800, AMDL1C, N1).

These different components are explained more closely below. In addition, some nuts and bolts are needed for the installation.

Sill body

The sill body is a basis for landing door sill assembly and all the other components are built around it (Anttila).

Sill profile

As mentioned already in Chapter 2.1, the sill profile guides the horizontal movement of the door panels together with the railing. The sill profile always contains sill grooves which guide this movement. The different door types require different amount of sill grooves. There can be either one, two or three grooves, and each groove guides one or two door panel(s), depending on the door type. With side opening doors one panel uses one groove as panels are moving to the same direction, but with center opening doors one groove is used by two panels as panels move to opposite directions. The difference between the numbers of grooves is represented in Figure 13 below.

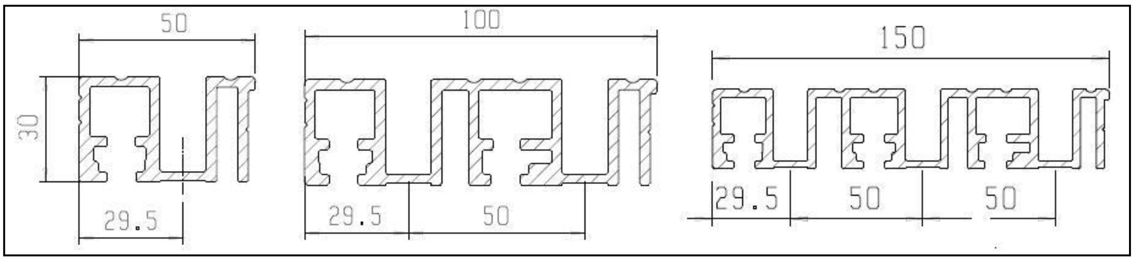

Figure 13. Cross-section –view of one, two and three grooved sill profiles (Sill profile drawings 731388, 722851 and 754672 1998).

As it can be seen in Figure 13, the basic difference between sill profiles with a different number of grooves is the width of the sill profile. The height of the sill profile is always 30 mm.

One of the biggest problems with sill assemblies is that the sill profile does not last passage of loads introduced into the elevator car. Usually in this case the sill groove(s) gets too narrow and this causes doors to jam. The idea is that this could be reduced by creating proper duty ranges for different sill profiles with the test system after it is ready to be used.

Toe guard

The toe guard is a metal panel installed below the landing door sill to reduce the shearing action from the edge of the sill (Term bank).

Wall fixing brackets

Wall fixing brackets are used to fix the sill assembly into its position either in the shaft or on the wall (Term bank).

Sill fixing brackets

Sill fixing brackets are used to support and fix the sill into the landing of the elevator (Term bank).

Grout guard

The grout guard is a plate that prevents after cast concrete from flowing into the elevator shaft (Term bank). The grout guard is used only and always when after cast is needed and used.

Carpet list

The carpet list is a profile that covers the gap between the entrance hall and the sill and it is delivered only when needed, usually only if there is a wall-to-wall carpet in the hallway of the building or if for some reason there is a small gap between the floor of the building and the door sill assembly.

3.2 Heavy Sill Types

There are many different landing door sill types depending on the type of the building and the usage of the elevator. In some buildings the landing door sill assembly is fixed in the shaft and in some buildings on the floor of the building. Different rated load of an elevator means that in some cases the sill assembly must withstand more loads than in others and for this there are also different sill types available. Also extra wall fixing brackets are used to make the same sill assembly to last more. A full list of different heavy sill types is shown in Table 1.

Table 1. Different heavy sill types.

Sill type	Mounting type	Flooring (mm)	Carpet list (mm)	Max. load (kg)
N1	In the shaft	35-135	NO	1000
N1E	In the shaft	35-135	NO	2000
N2	In the shaft	35-55	NO	1000
N2E	In the shaft	35-55	NO	2000
N3	On the floor	60-110	NO	4000
N4	On the floor	35-105	NO	2000
N5	On the floor	125-325	NO	1000
C1	In the shaft	35-135	48	1000
C2	In the shaft	35-55	48	1000
C3	On the floor	60-110	48	1000
C4	On the floor	35-105	48	1000
C5	On the floor	125-325	48	1000
L1	In the shaft	0	92	1000
L2	In the shaft	0	92	1000

There are basically seven different door sill types available: N1, N2, N3, N4, N5, L1 and L2. N1E and N2E are the same sill types than N1 and N2 but with extra wall fixing brackets to get the sill assembly to withstand more loads. C1…C5 are the same sill types that N1…N5 but with 48 mm long carpet lists. The seven different sill types are explained on a more detailed level below.

Sill type N1

The sill type N1 is a sill mounted in the shaft with adjustment margin from 35 to 135 mm. This means that the minimum flooring thickness is 35mm and maximum 135mm. This sill type is called the standard sill and it is by far the most used heavy sill type as over 50 % of high duty doors are delivered with N1 sill. (AMD 800 Statistics.) The usage of the different heavy landing door sill types is explained more closely in Chapter 3.2.1.

Sill type N2

The sill type N2 is the same sill as the N1 but with shorter wall fixing brackets, so the adjustment margin is smaller. Flooring thickness from 35 to 55mm can be used. Shorter wall fixing brackets gives the advantage to use the sill in buildings where the floor to floor distance is small and therefore installation area is limited (Anttila).

Figure 14 below represents cross-section-views of the sill types N1 and N2.

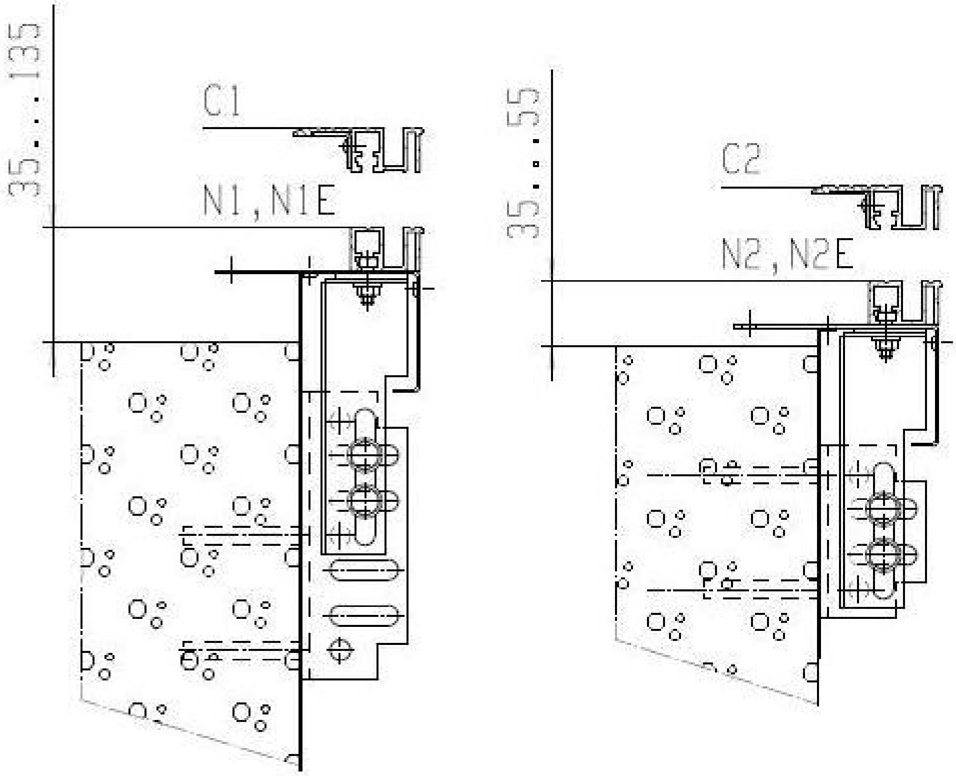

Figure 14. Sill types N1, N1E, C1, N2, N2E and C2 (Sill type drawing 733804 1998).

As it can be seen, both of the sill types are mounted in the shaft and the basic difference of these two is only the length of the wall fixing brackets. For this reason the adjustment margin of the sill type N2 is smaller than with the sill type N1.

Sill type N3

The sill type N3 is a sill mounted on the floor. This sill type is the basic to be used in goods elevators as the sill type can last more loads when it is mounted on the floor (Anttila 2012). The flooring thickness with this sill type is from 60 to 110mm.

Sill type N4

The sill type N4 is basically like N3 so sill that is mounted on the floor. Only difference with these two is that N4 does not necessary require any space from the shaft which makes it a very good solution for buildings with limited space and therefore with small shaft. Flooring thickness with N4 is from 90 to 130 mm.

Figure 15 below represents cross-section-views of the sill types N3 and N4.

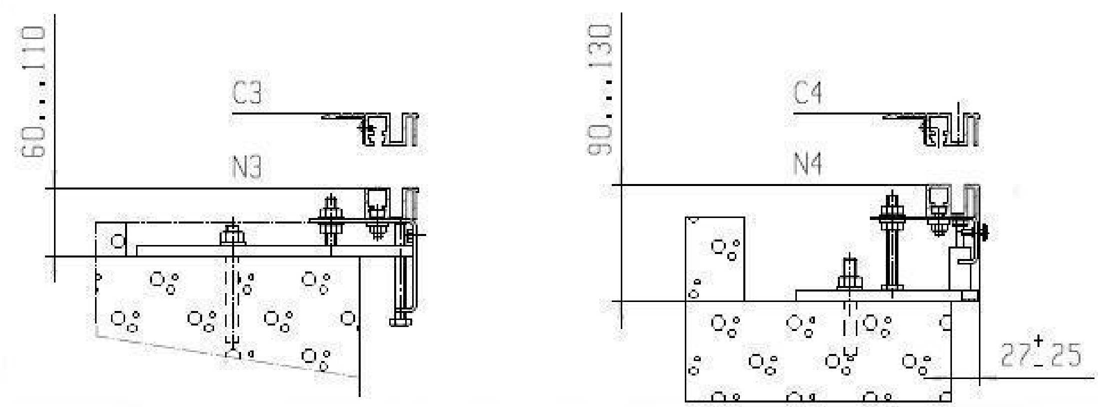

Figure 15. Sill types N3, C3, N4 and C4 (Sill type drawing 733804 1998).

As it can be seen, both of these sill types are mounted on the floor and the basic difference is that the sill type N4 does not require nearly any space from the shaft. The construction has the disadvantage that it does not last as much loads as the sill type N3 and this makes the sill type N3 more popular in goods elevator use.

Sill type N5

The sill type N5 is also a sill mounted on the floor but with big adjustment margin (130–330 mm). It is to be used in a place where very thick floor is required and therefore big flooring thickness is needed. Figure 16 below represents cross-section-vies of the sill type N5.

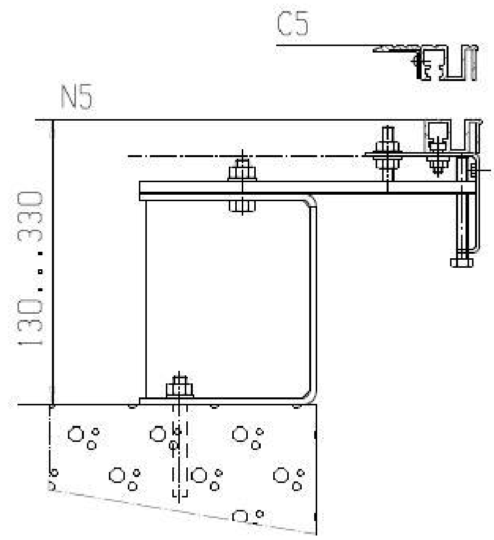

Figure 16. Sill types N5 and C5 (Sill type drawing 733804 1998).

As it can be seen, a very big adjustment margin is available. The disadvantage of this construction is that it last loads introduced to the elevator car even less than the sill type N4.

Sill type L1

The sill type L1 is so called 0-flooring sill. With sill types N1-N5 after cast is always needed but the sill type L1 is installed directly to same level with the floor of the building and there is no need for the after cast and therefore flooring thickness is always 0 mm.

Sill type L2

The sill type L2 is also 0-flooring sill and it is like the sill type L1 but with shorter wall fixing brackets so it can fit to buildings with smaller floor to floor distance.

Figure 17 below represents cross-section view of the sill types L1 and L2.

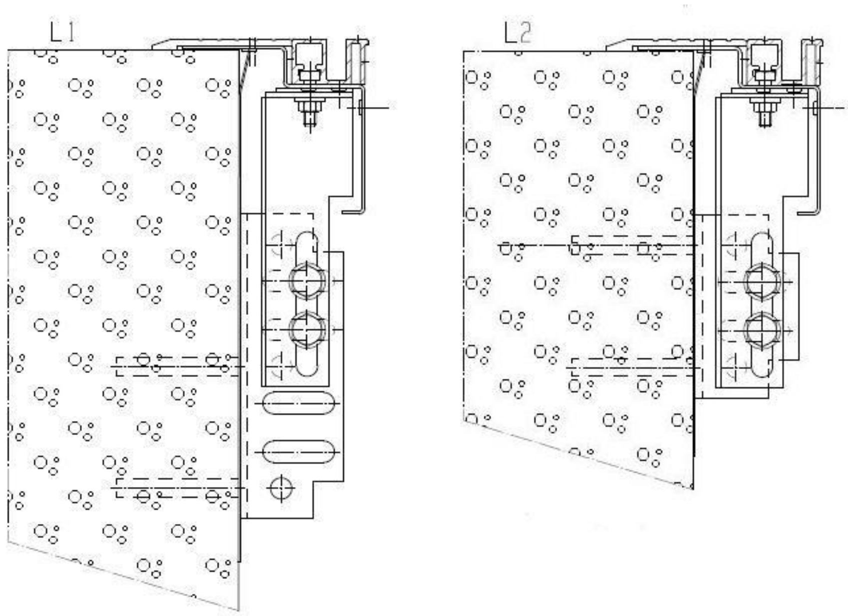

Figure 17. Sill types L1 and L2 (Sill type drawing 733804 1998).

As it can be seen, these sill types are mounted in the shaft and no adjustment margin is available.

3.2.1 Usage of Heavy Sill Types

The usage of different heavy sill types is represented in Figure 18 below.

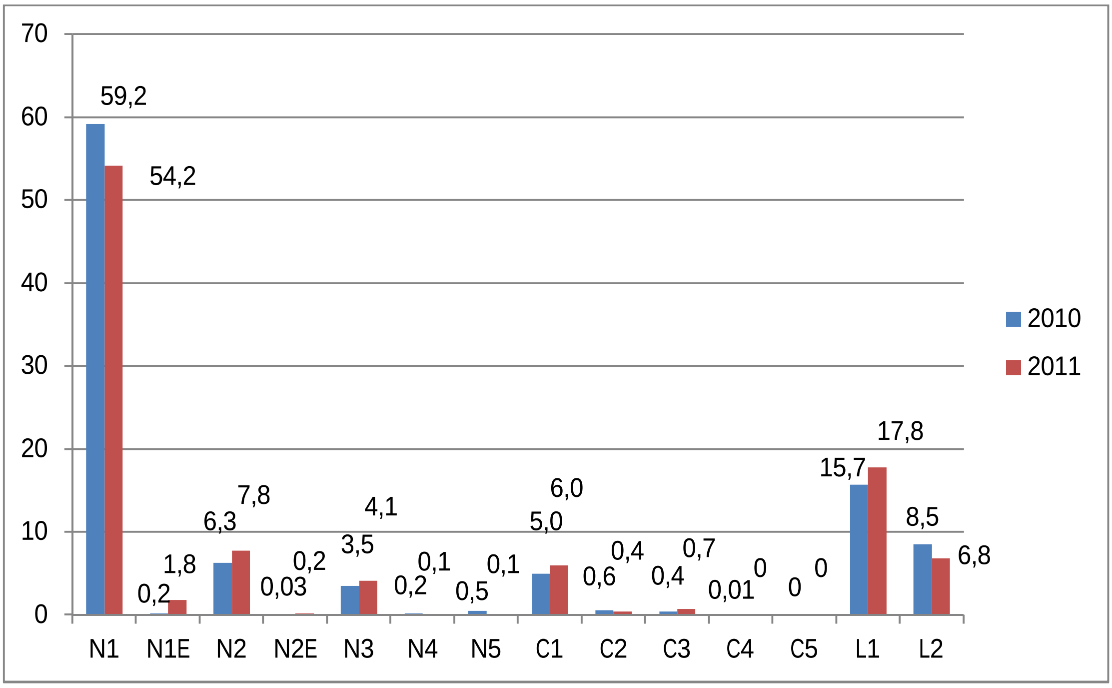

Figure 18. The usage of different heavy sill types (AMD 800 Statistics).

Figure 18 represents statistics of the sill type usage in years 2010 and 2011. As it can be seen, the standard sill type N1 is by far the most popular sill type. Also 0-flooring sills L1 and L2 are very popular. It can also be seen that sill types with carpet lists (C1…C5) are approximately ten times less popular than the same sill types without carpet list (N1…N5). Also sill types with wall fixing brackets (N1E and N2E) were already in 2011 ten times more used than in 2010.

3.3 Heavy Sill Profiles

As mentioned in the previous chapter, there are different kinds of sill profiles available depending on the usage of the elevator. One critical factor is the elevator’s rated load but there are also other differences between different sill profiles. Some of the profiles are produced from aluminum and some from stainless steel. Some are solid profiles allowing the sill profile to withstand more loads. Also one brass profile is available. A full list of different sill profiles available for the heavy sill assembly is given in Table 2 below.

Table 2. Heavy sill profiles

Sill profile	Material	Description	Limitations
A	Aluminum	Standard	None
B	Aluminum	Anodized	None
L	Brass	Visual	Only with sill types N & L
S	Stainless steel	Folded	Only for passanger elevators
F	Stainless steel	Solid	Only with sill types N & L
G	Aluminum	Solid	None

All these profiles are explained more closely below.

Extruded aluminum (A)

The extruded aluminum is the standard sill profile and it is meant to be used mainly in passenger elevators (Anttila 2012). It is by far the most used sill profile with high duty doors as over 70 % of heavy sill assemblies are delivered with this sill profile (AMD 800 Statistics). The usage of different sill profiles is described more closely in Chapter 3.3.1.

Brass (B)

The Brass profile is the same as extruded aluminum (A) but it is made from brass to give it a nice visual look.

Anodized aluminum (L)

The Anodized aluminum –profile is also the same profile than extruded aluminum (A) but it is surface treated to make it last more corrosion and to give it a longer age of use.

Figure 19 below represents cross-section-view of the sill profiles A, B and L.

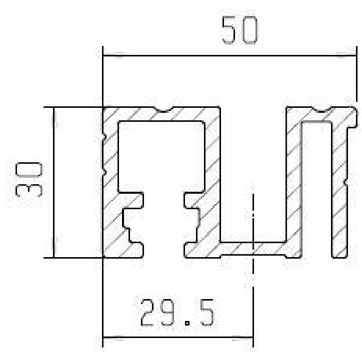

Figure 19. Sill profiles A, B and L (Sill profile drawing 733851 1998).

As it can be seen in, sill profiles A, B and L are basically the one and the same. Only the material and the surface treatment method vary.

Stainless steel folded (S)

The stainless steel folded is designed to be used only in passenger elevators. Originally it was designed to be used also in goods elevators but shortly it was realized that it scratches easily and does not last much anything and it became to be used only as a visual sill profile. (Anttila.) Figure 20 below represents cross-section-view of the sill profile S.

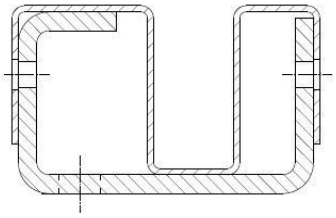

Figure 20. Sill profile S (Sill profile drawing 838587 2004).

The basic dimensions between different sill profiles are always the same, meaning that the height of this profile is also 30 mm, and in case of one grooved sill profile the width is 50 mm.

Solid stainless steel (F)

The Solid stainless steel –profile is meant to be used only in goods elevators under heavy use, so for example if the elevator is loaded by using a forklift. This profile is very expensive as it is solid stainless steel and the manufacturing method is grinding, which is very expensive. One solid stainless steel –profile can easily cost as much as the whole door assembly with standard sill profile. (Anttila.) Figure 21 below represents cross-section-view of the sill profile F.

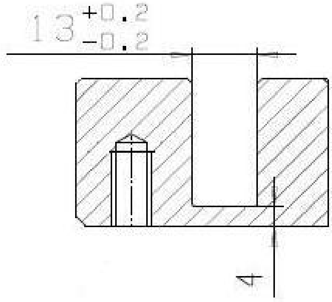

Figure 21. Cross-section-view of the one grooved sill profile F (Sill profile drawing 776838).

As it can be seen, the sill profile is solid. The dimensions of the sill groove are also given. These apply for all different sill profiles and for all different number of grooves. As mentioned earlier, the height of the sill profile is always 30 mm. The minimum depth of the sill groove is 25 mm; this is described more closely in Chapter 3.5.

Solid aluminum (G)

The solid aluminum sill profile (G) was presented in 2011 and this makes it the newest member for the sill profile family. It is designed to be used in good elevators and the main reason it was brought to the market is the fact that the solid stainless steel -profile is too expensive and the stainless steel folded (S) failed to be used in goods elevators (Anttila). Solid aluminum is not as solid as solid stainless steel but it is still expected to last loads up to 4000 kg. This is going to be verified with the test system after the test system is ready to be used. Figure 22 below represents cross-section-view of the sill profile G.

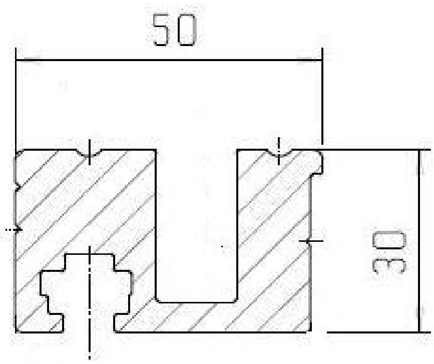

Figure 22. Sill profile G (Sill profile drawing 997123 2010).

As it can be seen, it is basically the same profile than the solid stainless steel (F), but it is made from aluminum and it is a cheaper choice for goods elevator, which are not under so heavy loads. The idea is that with the test system under work, it will be tested if this sill profile could replace more expensive solid stainless steel (F) also in elevators under heavy use.

At the moment the only duty range related limitation in sill profiles is that the stainless steel folded (S) should not be used in goods elevators (Anttila 2012). Proper duty ranges for different sill profiles are to be created with the test system after it is ready to be used.

3.3.1 Usage of Heavy Sill profiles

The usage of different heavy sill profiles is represented in Figure 23 below.

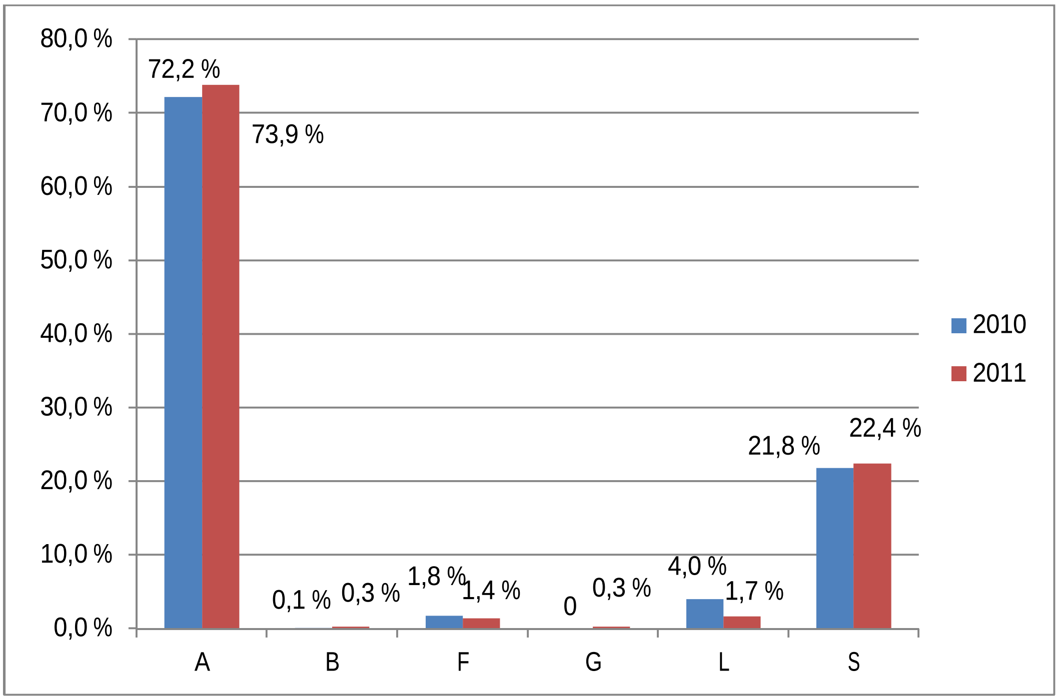

Figure 23. The usage of different sill profiles (AMD 800 Statistics).

Figure 23 shows the statistics of the sill profile usage in years 2010 and 2011. As it can be seen, the extruded aluminum profile (A) is by far the most popular sill profile. Solid aluminum profile (G) was not in the offering yet in 2010 but in 2011 it was already taken some of the share from solid stainless steel (F). For the folded sill profile (S) statistics are not reliable as the same code is still used also for ordering old goods elevator sill profile, which is not in the standard offering anymore.

3.4 Main Functions

The car door sill has basically only one main function and it is to guide the bottom parts of the car door panels in the horizontal direction. This function applies also for landing door sill, but it has other main functions as well. As mentioned before, the landing door sill is a basis for landing door frame installation and that is why it must be installed with-in 0.5 mm accuracy. In addition, tall buildings are not always straight, so adjustability is needed to balance this. (Anttila.)

3.5 Safety and Reliability

The sill groove's main function is to guide the door panels, but it has also safety related functions. It has to keep the door panels in place in case of something hits the door panels. This prevents the door panels from slipping away from their position and keeps people (or anything else) from falling down to the shaft. Because of this the regulations say that the depth of the sill groove has to be at least 25 mm. (Anttila.)

In the case of a fire in the building the landing door sill assembly must keep its rigidity so it is not allowed to melt. This ensures that the landing doors and frames stay in place and fire does not escape through the shaft to the other parts of the building. With all different fire rated landing doors there is always the same sill assembly so basically there is no fire rating in sills. (Anttila.)

The basic reliability rated regulation is that the sill profile has to be strong enough to withstand the passage of loads introduced into the car and the sill grooves original 13 mm width should not be changed. This prevents door panels from jamming. In some countries trash holes are also needed in sill profiles to prevent sand or anything else to get stuck in the sill groove(s). For example Scandinavian countries usually use trash holes. (Anttila.)

3.6 Technical Requirements

European Standard EN81 gives rules and regulations for the construction and installation of elevators. This standard has been approved by CEN, European Committee for Standardization, and all manufactured elevators must obey all these regulations.

The main, and basically only, regulation for landing door sill is that every landing entrance has to incorporate a sill of sufficient strength to withstand the passage of loads being introduced into the elevator car (SFS EN81-1, page 71). The maximum passage of loads depends on the duty range of an elevator. Duty ranges are divided into three categories:

- Passenger elevators with rated load less than 2500kg in private premises, office buildings, hotels, hospitals, etc.
- Passenger elevators with rated load of 2500kg or more and A-process goods elevators
- C-process goods elevators with rated load more than 2500kg. For example elevators that are used with forklift loading. (SFS EN81-1, page 261.)

A-process means that the elevator is manufactured with standard components and standard procedure and C-process means that something special has to be agreed between the company and the customer. In this case it is the duty range category.

Elevators in the first category can take a maximum of 40 % of the car rated load into the elevator at once, second category elevators can take 60 % and the third category elevators can take up to 85 % of the car rated load (SFS EN81-1, page 261). For example if the elevator is in the first category and its rated load is 2000kg, then maximum 800kg can be introduced into the car at once (0,4x2000kg). So in this case the door sill assembly does not have to withstand 2000kg of load but only 800kg.

4 Product Reliability Testing

This study concentrates on creating the test system for testing components of a complete product and therefore the theory of product reliability testing is also described. The chapter begins with the introduction of the product testing, followed by the purpose of product reliability testing. The final part of this chapter concentrates on the reliability testing techniques.

4.1 Introduction

In product development, there might be a lot of different kinds of products under study, i.e. is the risk worth taking compared to the possible profit that the product might make. Once the major ‘go’ decision with some specific product is taken, the actual product will be developed. Based on information collected, such as customer preferences, cost analyses and the company’s own desire, the team begins to work on making the product. Once the first prototype version of the new product is achieved, it is essential to test whether it works in the way intended or not. This means that it must undergo thorough testing to ensure that all the attributes within the product work the way they are supposed to. For example new drugs must be proven that they have the desired effect without harmful side effects or a new engine developed for better fuel efficiency must be shown to deliver a higher number of kilometers with one liter of petrol. (Baker & Hart 2007, page 330.)

Reliability testing is often performed at several levels. Possible levels are for example component, assembly, subsystem or system level. Performing tests at lower levels catch problems before they cause failures at higher levels. (Reliability Testing.) For example when running tests in elevator industry, each main component of an elevator is tested separately, and in addition many of the components inside these main components are also tested. A good example is the main subject of this study, the sill profile. The sill profile is one of the components inside the door sill assembly, which is one of the main modules of the AMD door.

4.2 Purpose

It takes a long time for a company to build up a good reputation, but only a very short time to be branded as “unreliable” if delivering unreliable products (Engineering Statistics Handbook). For this reason the main purpose of product testing is to ensure that the new developed product works as it should, and this way decrease the early failure rate of the product. If the failure rate is high early in the product's life, it gives a bad reputation for the product, and this way affects to the possible success of the product. (Anttila.)

Another reason for product testing is to give the company more information about the product. For example if a company is offering different kind of elevator door sill profiles for different kind of use, and at the moment only the most expensive ones are delivered for elevators expecting heavy use, doing additional tests for the sill profiles might reveal that some of the cheaper sill profiles could also be used in elevators under heavy use. This way it is possible for the company to save in costs. (Anttila.)

4.3 Highly Accelerated Life Testing (HALT)

In a typical life data analysis, the data is analyzed from the products directly under normal usage conditions. This type of analysis allows quantifying the life characteristics of all the products in the population. For many reasons, for example when a new industrial product is being developed, engineers running the tests may wish to obtain reliability results for the product more quickly than they can when the data is obtained under normal operating conditions. (Quantitate Accelerated Life Testing Data Analysis.) For this there is a methodology called Highly Accelerated Life Testing (HALT). HALT is a methodology for systematically improving the hardware reliability of manufactured products and products under development. A key for this is to apply the techniques to a product as early in its life as possible and then to do corrective actions to fix the problems found. (Anthony Chan & Englert 2001, page 3.)

HALT tests are used primarily to reveal probable failure modes for the product so that the engineers can improve the product design. In this kind of testing, one or more stress types, which cause the failures during normal operation in the field, are increased. (Anthony Chan & Englert 2001, page 3.) The stress types can be for example time, temperature, load, humidity, and so on. The easiest stress type is time, this can be used for products which are not used continuously and expected total usage cycles in the lifetime of the product are not too high. A good example is a microwave, if it is expected to be used 5000 times in the whole lifetime the HALT test is then operated with a much higher pace. This way it is possible to reach to 5000 cycles in a couple of days. Data from this kind of tests can be analyzed the same way that it would be analyzed as if the test was run under normal usage conditions (Quantitate Accelerated Life Testing Data Analysis).

When testing products which are expected to be used continuously, for example high duty elevator doors or their components, where expected cycles per year are approximately 800 000 and the lifetime of the product is decades, time cannot be used as an increased stress level. For this kind of products some other stress level must be implemented. For example if a sill profile is expected to be used under a load of 800 kg, then higher loads are used to get the product to show its weaknesses more quickly. In this case the accelerated loads could be for example 1000, 1200, 1400 and 1600 kg. For analyzing the results gained, a mathematical model with life-stress relationship is needed to estimate the products life in normal use conditions (Quantitate Accelerated Life Testing Data Analysis).

The observed failure rate of many new products or components introduced to the market is often the form of a bathtub curve. This is shown in Figure 24 below.

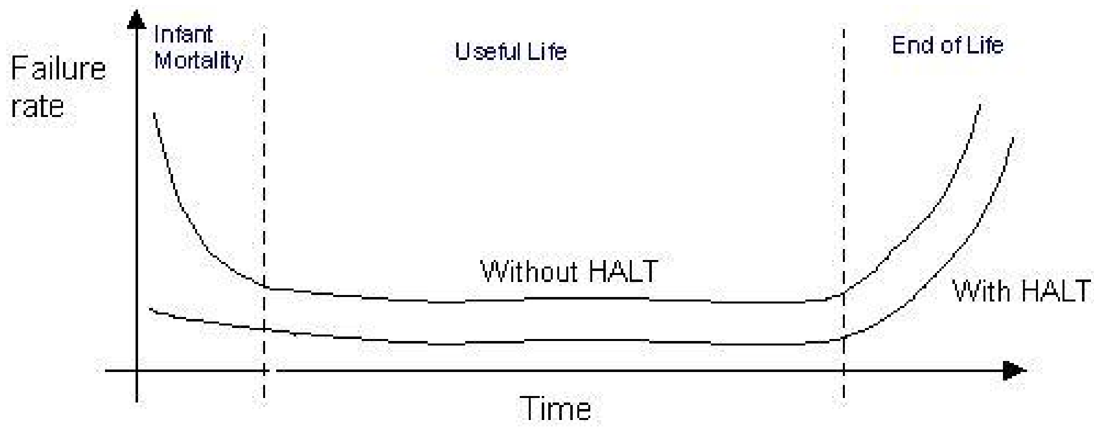

Figure 24. Bathtub curve (Anthony Chan & Englert 2001, page 14).

Figure 24 shows a classical lifetime of any product. As it can be seen, HALT is mainly used to decrease the failure rate early in the lifetime of the product. (Anthony Chan & Englert 2001, page 14.) The types of hardware failures during a products lifetime can be attributed to the following causes:

- Design failures
- Infant mortality
- Random failures
- Wear-out. (Reliability and Availability Basics.)

Design failures take place due to inherent design flaws in the system, and infant mortality includes failures in newly manufactured product. (Reliability and Availability Basics.) These two can be dramatically decreased by applying correct HALT techniques to the product. The reason for the failure rate to decrease even without HALT techniques being introduced is due to fact that the product is then improved based on the customer claims.

Random failures can occur during the entire lifetime of the product and for various different reasons; these will often be visible with or without HALT techniques and for this reason zero failure rate level is in most cases impossible to achieve. At the end of the product’s life, the failure rate is often anyway high, in most of the cases this is due to some type of wear out mechanism. (Anthony Chan & Englert 2001, pages 14-15.)

Even though HALT techniques are mainly meant to be used early in the lifetime of a product or component, the same techniques can still be used when testing a product already in the market, for example when creating duty ranges for door sill profiles.

5 Door Sill Assembly Test System

This chapter concentrates on the main goal of the study; to introduce and to further develop the test system created for testing door sill assemblies. The chapter starts by introducing the test system as it was, when the study was started. After that the implementation of the original test system and faults found during that implementation are described. Chapter 5.3 discusses developing the test system and implementing the changes made followed by the validation of the developed version. The final part of this chapter concentrates on the creation of the final version of the test system.

5.1 Introduction

After it was clear that the test system had to be further developed, a simplified 3D-model of the test system was built to support the development. This 3D-model is used through this whole chapter to introduce the test system and to show the changes done during the development of the test system. Figure 25 below shows the original test system in real life.

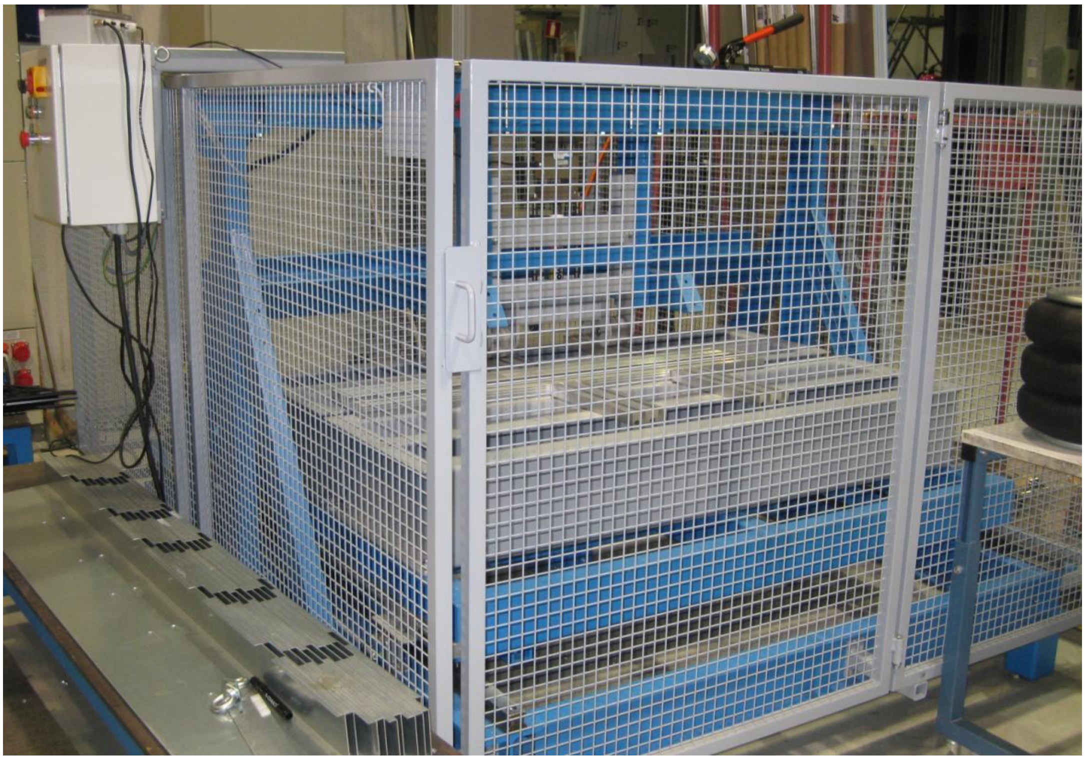

Figure 25. The original test system.

As it can be seen in Figure 25, the safety net around the test system makes it almost impossible to show it clearly with actual pictures and therefore from now on the 3D-model is used to represent the test system more closely. Figure 26 below shows the complete 3D-model of the original test system.

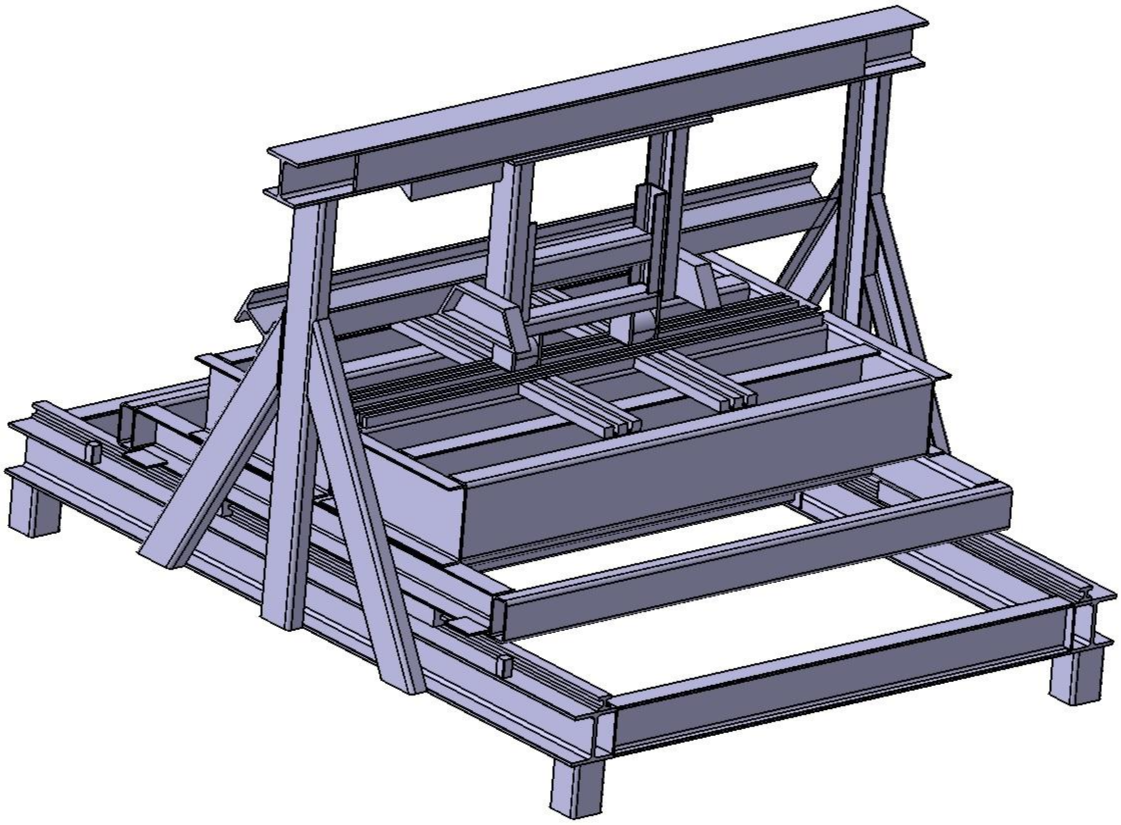

Figure 26. The 3D-model of the original test system.

The test system was created to simulate a pallet jack. It was created so that there was no need for actual mass because the system was created in such a way that it simulated actual mass with virtual mass. Another key point is the fact that the wheels are not moving in horizontal direction as the bed below the wheels is the moving part. This and all the other main points about the test system are explained below. The introduction starts from the base of the test system, which is shown in Figure 27.

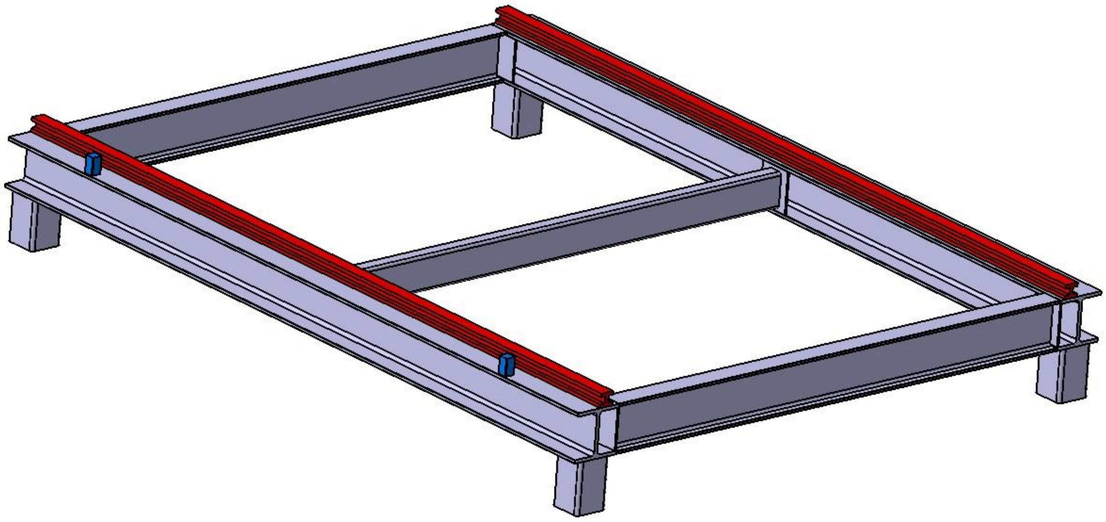

Figure 27. The base of the test system.

This is the unit which is holding the whole test system together. Main components are highlighted with different colors in the figure. Guide rails are showed with red color; these guide the movement of the test system. Another critical component in the base of the test system is the limit switch; this is highlighted with blue color. Limit switch is an electric switch, which is operated by a power-driven machine and which alters or controls the electric circuit associated with the machine (The Free Dictionary). In this case, it is used to change the direction of the test system. When it detects metal, it gives a command to the machine to change the rotation direction of the machine. This gets the test system to change the moving direction. The metal plates used together with the limit switches are shown in Figure 28 below.

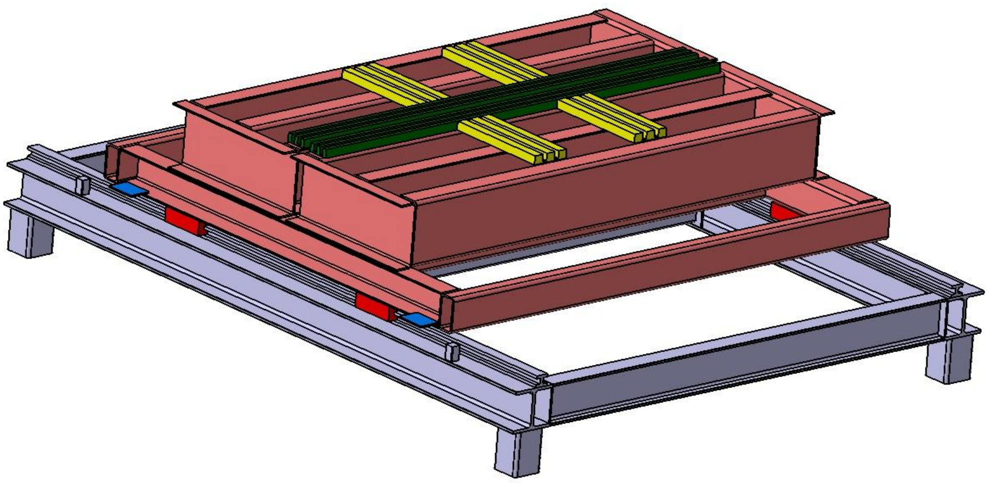

Figure 28. The base and the bed of the test system (the bed highlighted with brown color).

On top of the base is the actual moving part of the test system that is called the bed of the test system. This is highlighted with brown color in Figure 28. The guiding shoes are highlighted with red color; they guide the movement of the system in the guide rails. The metal plates used together with the limit switches are highlighted with blue color. The location of these plates can be adjusted and this way it is possible to change the length of travel the test system goes in one round. The limit switch together with the metal plate is shown more closely in Figure 29 below. The parts highlighted with yellow color are there for the wheels. These are built from parts of two grooved solid stainless steel sill profiles. The parts highlighted with green color are highlighting the sill profiles which are under testing in the test system. These are always removed and replaced with the sill profiles which are going to be tested. The track for the wheels (yellow parts) can be adjusted, meaning that all different sill profiles (one, two or three grooved) can be tested with the test system.

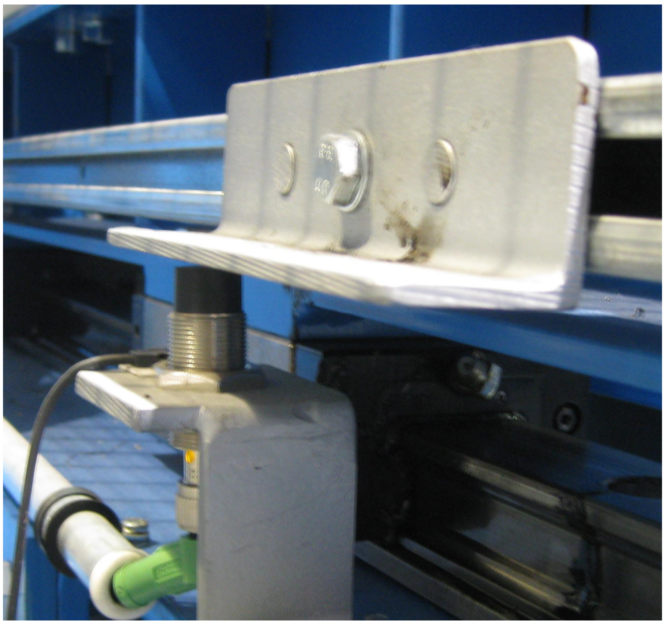

Figure 29. Limit switch assembly.

Limit switch is the little black circle and the metal plate is above it in Figure 29. When the limit switch detects this metal, it gives a command to the machine to change the direction.

Figure 30 shows the final part of the test system built around the base and the bed.

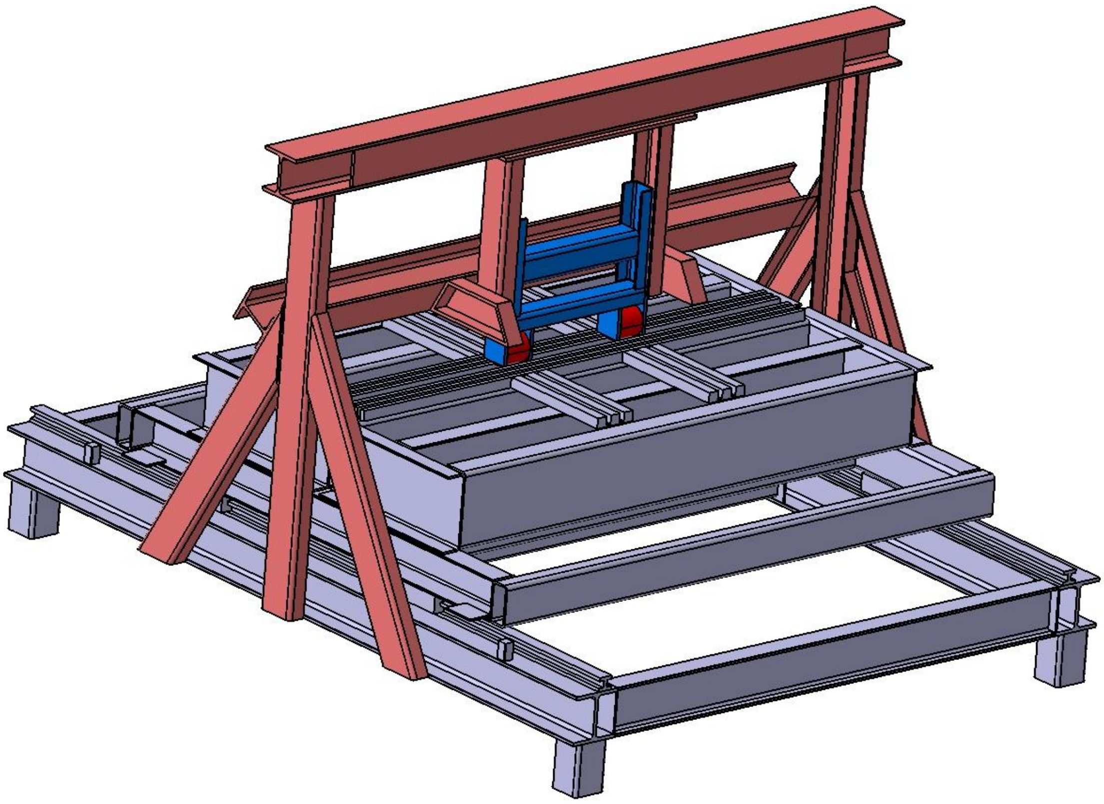

Figure 30. The complete 3D-model of the original test system

The final part of the test system is the part which simulates the pallet jack. The blue part can move freely in a vertical direction and the red parts are highlighting the pallet jack wheels. The brown part around this system is there to support the construction. When the bed is moving back and forth the wheels are simulating a pallet jack the same way as a pallet jack would be introduced to an elevator car. The force to simulate the actual mass is done with hydraulic cylinder and load cell. These are represented more closely in Figure 31 below.

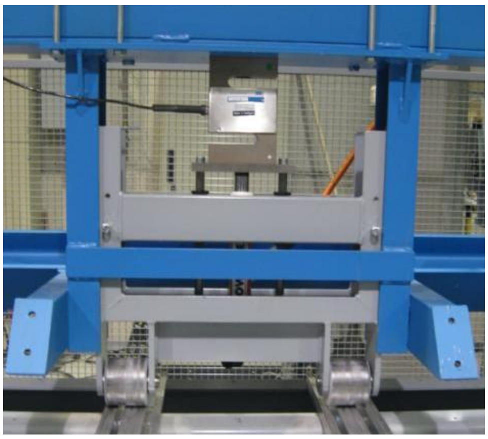

Figure 31. The wheels, the hydraulic cylinder and the load cell of the test system.

Load cell is the device shaped like the letter S, and the hydraulic cylinder is located under the load cell. When the pressure to the cylinder is added, it squeezes the load cell, and this construction is simulating the real mass. The more pressure is added to the cylinder, the more the load cell squeezes and this way it is simulating bigger real mass. The pressure to the cylinder is inserted with hand pump, which is located on top of the test system. This is shown in Figure 32 below.

Figure 32. Hand pump for the hydraulic cylinder.

There is a meter on the hand pump which shows the current pressure inserted to the cylinder, but there is no need to use that because there is a device inserted to the load cell which shows the pressure immediately in kilograms. This way it is not needed to calculate the pressure to kilograms as it can be directly seen. The device can be seen in Figure 33 below.

Figure 33. The device connected to the load cell.

The pressure that was inserted to the test system when this photo was taken was simulating real mass of 2876 kilograms.

The whole test system is run with a motor that is located under the test system. The motor is controlled from the control panel, which is located outside the test system. The control panel is shown in Figure 34 below.

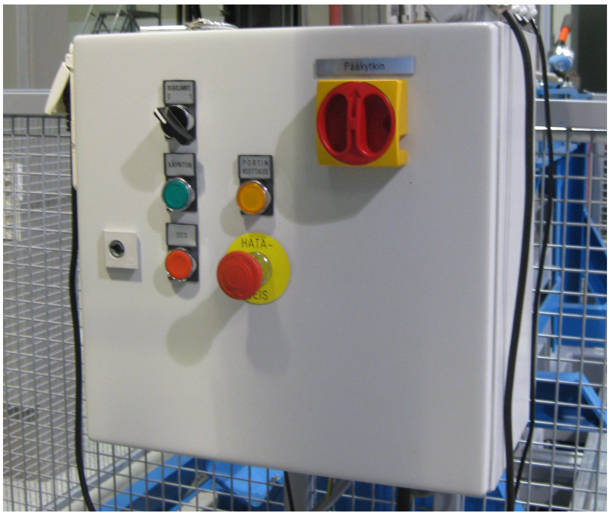

Figure 34. The control panel of the test system.

Basically in the control panel there is only the main power on/off –switch, start and stop-switches and the emergency stop.

Assembly drawing with main dimensions of the complete original test system can be found in Appendix 1.

5.2 Implementation

The implementation of the test system was started with the idea that the test system would be ready to be used and the development of the test procedure could start. This means that when the first tests with the test system were run, the test procedure was already under work. The test procedure means how the sill profiles should be tested with the test system: amount of repetition needed, what kind of mass to use, how to measure the results and so on. But as mentioned already in Introduction, it was soon realized that the test system was not working properly and it would not give reliable results if used as such. There were three main problems spotted:

- Speed of the test system seemed to be quite slow.
- Elevator's leveling accuracy was not taken into account.
- Hydraulic cylinder could not maintain the pressure adjusted in the beginning of each test.

These issues and solutions are described more closely in the next chapter.

5.3 Development

This chapter explains the problems found in the test system and solutions found for those issues.

Speed

When the test system was running for the first time, the speed of the test system seemed quite slow. As it is known, the speed plays a major role when it comes to impacts, and when the wheels of the test system hits the sill profiles, a part of that kinetic energy is transferred from the wheels to the sill profiles. The equation for kinetic energy is: $E_k = \frac{1}{2}mv^2$, where m is the mass of the moving object and v is the speed (Mäkelä, Soininen, Tuomola & Öistämö 2005, page 92). As it can be seen, the speed has a major role for the amount of kinetic energy that is stored inside the test system when it is moving.

The speed was measured with EVA-625, Elevator Vibration Analysis -system, which is used as a measurement tool in the elevator industry to measure elevator's ride quality, vibration and sound (Ride Quality Measurement & Analysis for the Elevator/Escalator Industry). EVA was attached to the side of the test system's bed, and when the test system was run, it measured the speed. The results can be seen in Figure 34 below.

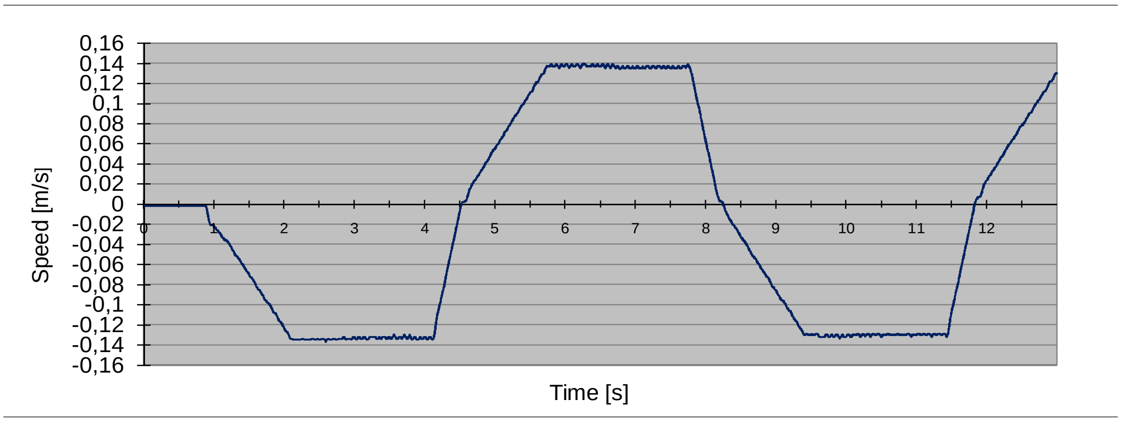

Figure 35. The speed of the original test system.

In Figure 35 above, the vertical axis shows the speed and the horizontal axis the time. First the test system accelerates to its maximum speed, then it is going with this speed until it hits the limit switch, which makes it decelerating the speed and to change the direction. After that the test system accelerates again but this time to the opposite direction. As it can be seen, the maximum speed of the test system was about 0.14 m/s.

Inside the control panel, there is a variable-frequency-drive (VFD), where the rotation speed of the motor can be changed. This way the speed of the test system is adjustable. Now it just had to be figured out to what level the speed should be adjusted. For this a test was arranged. The EVA was attached to the side of a real pallet jack and a load of 1000 kg was inserted to the pallet jack. After this the pallet jack was pushed inside to an elevator and back. The results from this can be seen in Figure 36.

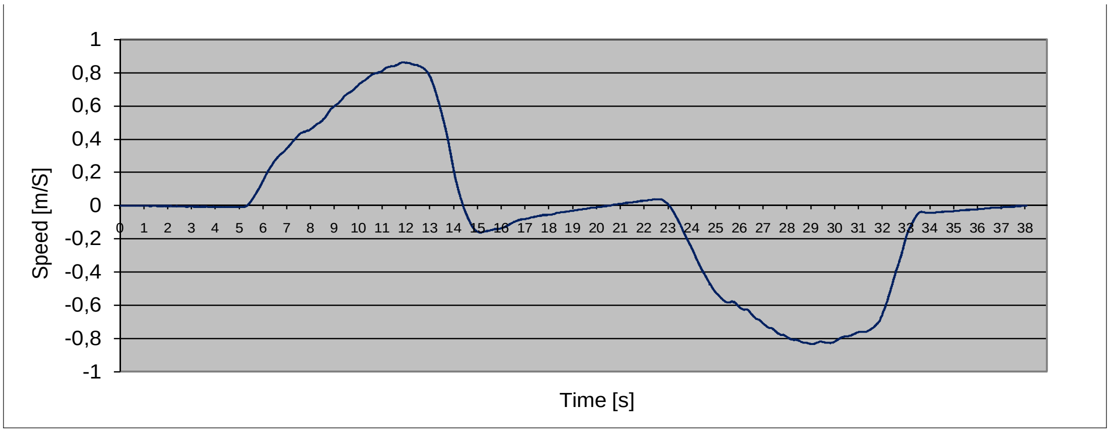

Figure 36. The speed of the pallet jack with 1000 kg load.

As it can be seen, the speed is much more than the speed of the test system, over 0.8 m/s. The speed of the test system cannot be adjusted this high as the motor hits its limit, but it is adjusted as high as possible and from now on the test system is going about 0.4 m/s. When the actual tests are run with the test system, it is informed in the report of the test that the sill profiles are tested with the speed of 0.4 m/s.

Leveling accuracy

The test system was built so that the both sill profiles were leveled to the exact same level. But it is impossible to build an elevator that would always get the car to stop at the exact same level than the landing of the building. The amount of force transferred from the wheels of the test system to the sill profiles under test is depending on the acceleration of gravity; $F=mg$, where the m is the mass of the object and g is the acceleration of gravity (Mäkelä, Soininen, Tuomola & Öistämö 2005, page 91). For this reason the leveling accuracy must be taken into account.

According to the regulations, the leveling accuracy of any elevator should be within +/- 10 mm (SFS EN81-1 1998, page 135), but because the company can promise that the leveling accuracy of any new elevator delivered is within +/- 5 mm (Transys, page 5), this is chosen. The other side of the bed is raised 5 millimeters and from now on the sill profiles are automatically simulating the leveling accuracy of an elevator. This is shown in Figure 37 below.

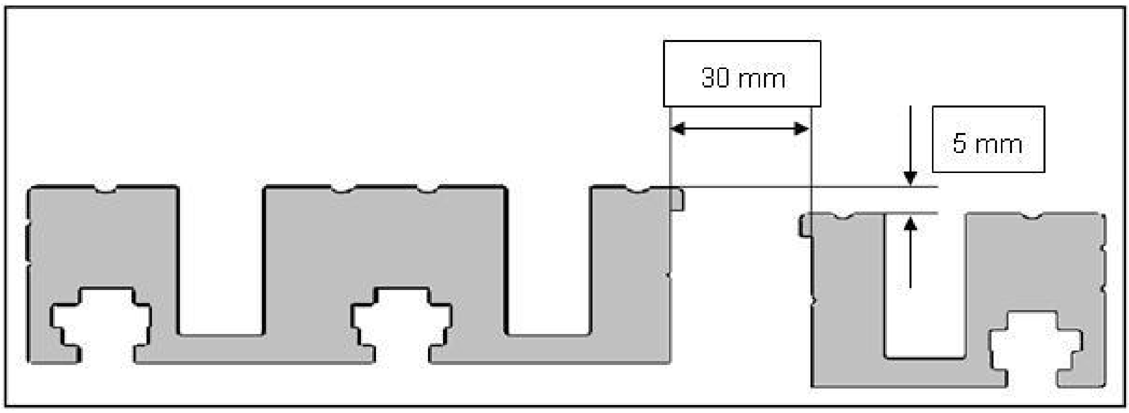

Figure 37. One and two grooved solid sill profiles showing how the profiles are fixed into the test system after the update

Figure 37 shows how the sill profiles are fixed into the test system after the update. The 30 mm groove between the car door sill and the landing door sill was taken into account already in the original test system, but the leveling accuracy was not.

The problem with the hydraulic cylinder

When the first tests with the test system were run, it looked like the pressure of the cylinder was changing a little. For this a test was done. A pressure of 1500 kilograms was set to the test system, then the test system was run for two minutes and then the pressure was checked again. This was repeated five times and results can be seen in Table 3 below.

Table 3. The pressure maintaining test

Time (min)	Pressure (kg)
0	1502
2	1430
4	1351
6	1278
8	1213
10	1143

As it can be seen in Table 3, the hydraulic cylinder could not keep the pressure adjusted for it. This was investigated as at first it was thought that the test system is too harsh for the cylinder, and that is why the pressure is decreasing. Investigations anyway revealed, that the cylinder is broken and had to be changed. The same pressure test was done again with the new cylinder and results can be seen in Table 4 below.

Table 4. The pressure maintaining test for the new cylinder

Time (min)	Pressure (kg)
0	1498
2	1499
4	1498
6	1497
8	1498
10	1499

As it can be seen, the pressure was not decreasing anymore and the problem seemed to be solved by changing the cylinder. But when this was fixed, another problem popped up. When the 5 mm leveling accuracy was taken into account, the cylinder could not maintain the same pressure on the both sides of the bed. This can be seen in Figure 38.

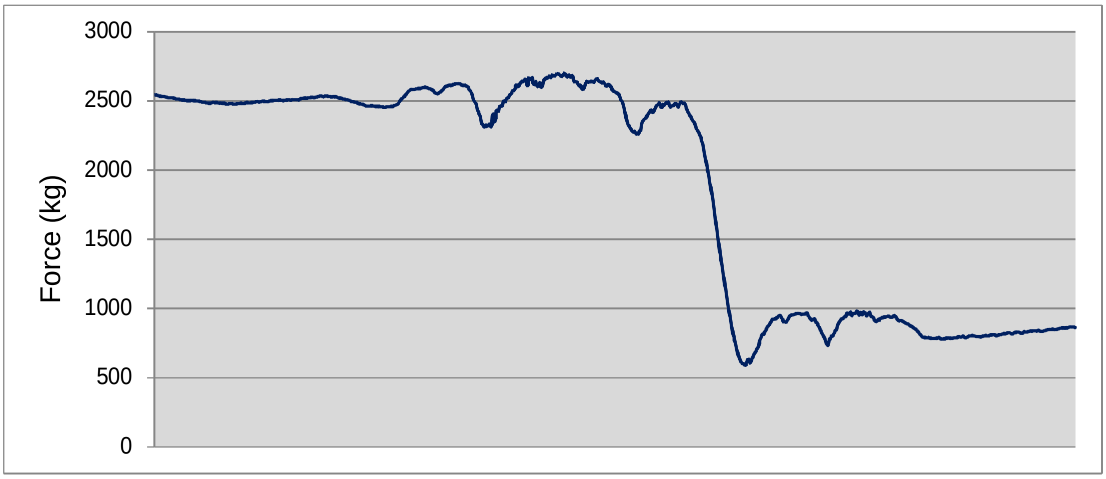

Figure 38. The pressure problem with 5 mm step between the sill profiles.

Figure 38 shows the change in the force when the bed of the test system is moving and the wheels move relatively from the other side of the bed to another. The test system is started from the side where the sill profile is 5 mm higher, and when the wheels drop to the lower side of the test system the force is changing from 2500 kg to less than 1000 kg. This is due to the fact that when the wheels drop the 5 mm, the distance from the bottom of the cylinder to the load cell grows the same amount, and this causes the pressure to drop inside the cylinder. This is a big problem and cannot be accepted. At this point it was decided that the hydraulic cylinder cannot be used as simulating actual mass.

After this big decision was taken, a few experts from the company's reliability laboratory gave their opinion on how the actual mass could be simulated. The idea of using actual mass was also brought to discussion, but still there was the desire to make the test system as easy to use as possible and somehow it should be able to simulate actual mass. Finally the idea of using an air spring instead of hydraulic cylinder was brought into the discussion and it seemed like a very good idea. The air spring is shown in Figure 39 below.

Figure 39. One layered air spring (Safeware Components)

Air springs are used to balance the pressure differences and it should be perfect to this test system where there is 5 mm vertical difference and it is decided that it should be tested if it works or not. The air spring was installed between the load cell and the test system. This can be seen in Figure 40.

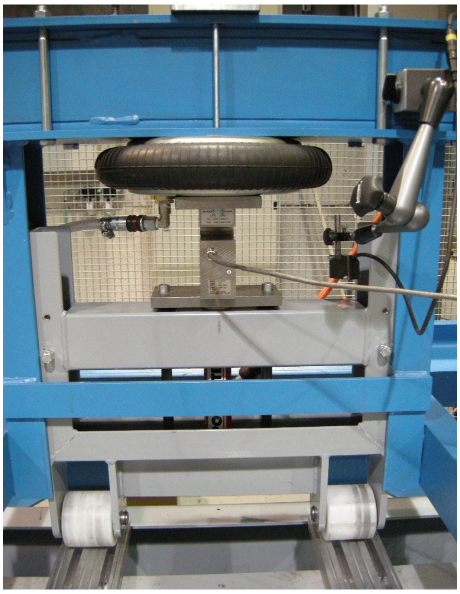

Figure 40. The air spring installed to the test system

The hydraulic cylinder is still under the load cell but it is not in use. The simulation of actual mass with the air spring is executed basically the same way than with the hydraulic cylinder. The air spring is filled with air and the more air it is introduced to the air spring, the more it squeezes the load cell and this way the pressure grows. The pressure can be read from the device attached to the load cell in kilograms the same way that with the hydraulic cylinder. The maintaining of pressure was tested the same way that it was with the hydraulic cylinder and the result can be seen in Figure 41.

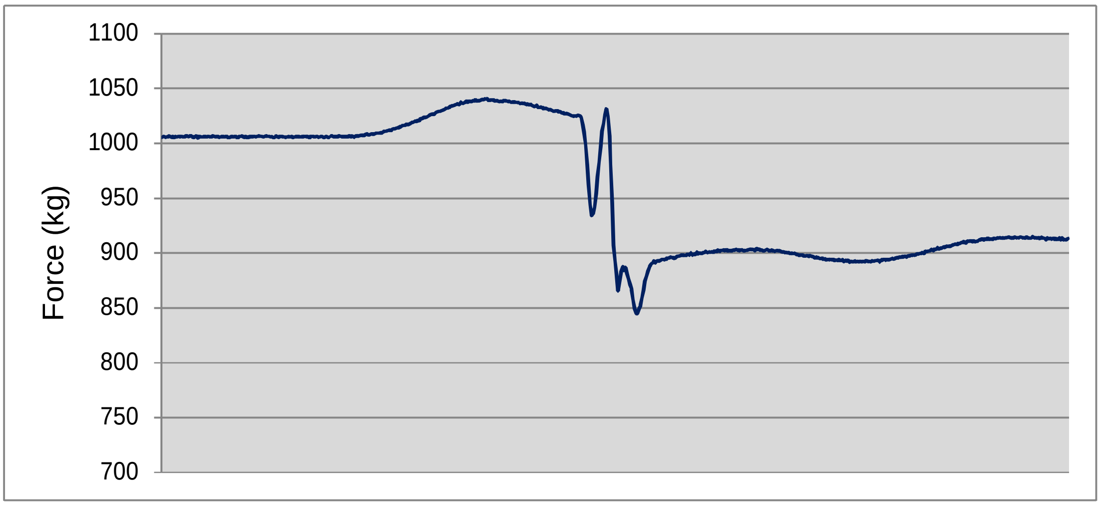

Figure 41. The pressure maintaining test with the air spring.

There is still some difference when the wheels drop the 5 mm to the lower level but the change is much smaller than with the hydraulic cylinder and it is decided that this is acceptable. This would also be reported on the sill profile test reports the same way than the speed of the test system is going to be.

5.4 Validation

After the test system was further developed, it was necessary to validate it. Validation was done to give evidence that the test system would give reliable results and could be used to simulate a pallet jack. The biggest validation point was the simulation of actual mass. The validation was decided to be done by comparing results that the test system is giving with the air spring to results when the test system is run with actual mass. It just had to be figured out how the actual mass is going to be fixed to the test system and how big amount of mass is needed.

It was decided that the results would be compared by using the same amount of actual mass to mass simulated with the air spring. Comparison would then be done by measuring the permanent deformation that the force is doing to the sill profiles. There was only one problem: none of the sill profiles is so weak that it would be possible to build a stand for that amount of actual mass that would make a permanent deformation to the sill profiles. It was then decided that hollow aluminum profiles would be used to simulate the sill profiles as it is possible to get permanent deformation for hollow aluminum much easier than to any of the actual sill profiles. It was then tested that a force of 400 kilograms already makes a permanent deformation to the aluminum profiles and therefore a stand with maximum load of 500 kilograms had to be built. Figure 42 below shows how the hollow aluminum profiles were fixed to the test system instead of sill profiles.

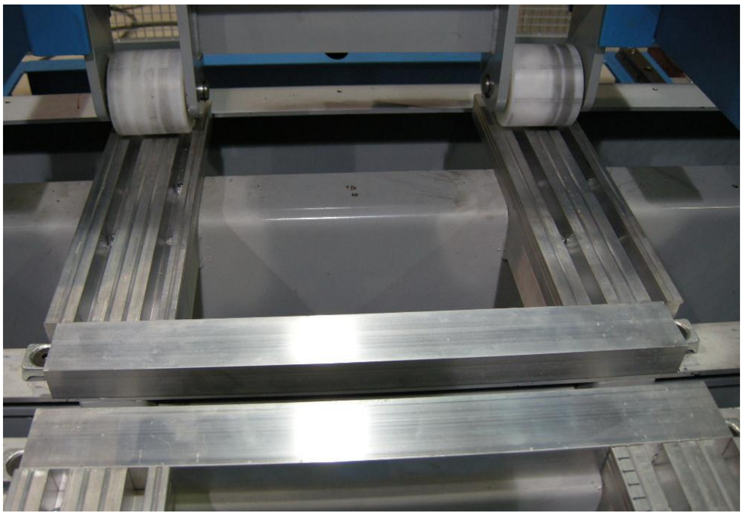

Figure 42. The hollow aluminum profiles fixed to the test system.

As it can be seen, hollow aluminum profiles were fixed to the test system like the sill profiles would be fixed. The aluminum profiles simulated one grooved sill profiles and the dimensions were exactly the same. The idea was that the test system is run once back and forth with actual mass, then the profiles are changed to new ones and the same amount of force is set for the air spring and then the test system is run once back and forth. After that the permanent deformation from both cases is measured with 3D measuring table and the results are compared to each other. It was decided that this would be done with five different mass: 250, 350, 400, 450 and 500 kilograms, but before the test could be performed, the stand for the actual mass has to be designed and built.

The idea for the stand was that the same filler bits that are used in counterweights are used to create the actual mass. One filler bit weights 25 kg and therefore it is easy to adjust the amount of weight that is installed to the stand. The stand for filler bits was designed and the final result can be seen in Figure 43.

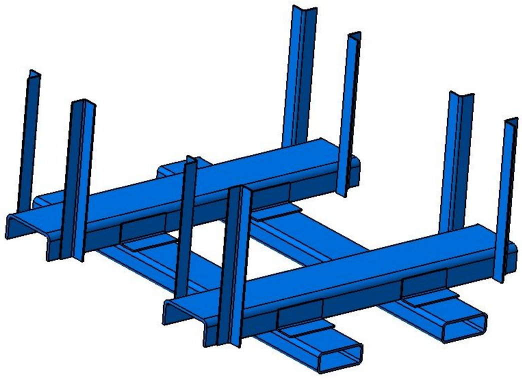

Figure 43. The developed stand for real mass.

The stand was designed to be installed on top of the wheels of the test system and for each side of the stand it is possible to load ten filler bits, each 25 kilograms. This makes it possible to load maximum 500 kilograms on top of the stand, but the stand itself weights approximately 100 kg and therefore it is possible to get a maximum load of 600 kg. For this reason the test loads were adjusted and the test was going to be run with five different weights: 350, 450, 500, 550 and 600 kilograms. This adjustment was done to get more easily measurable permanent deformations visible to the aluminum profiles. The stand fixed on top of the test system can be seen in Figure 44.

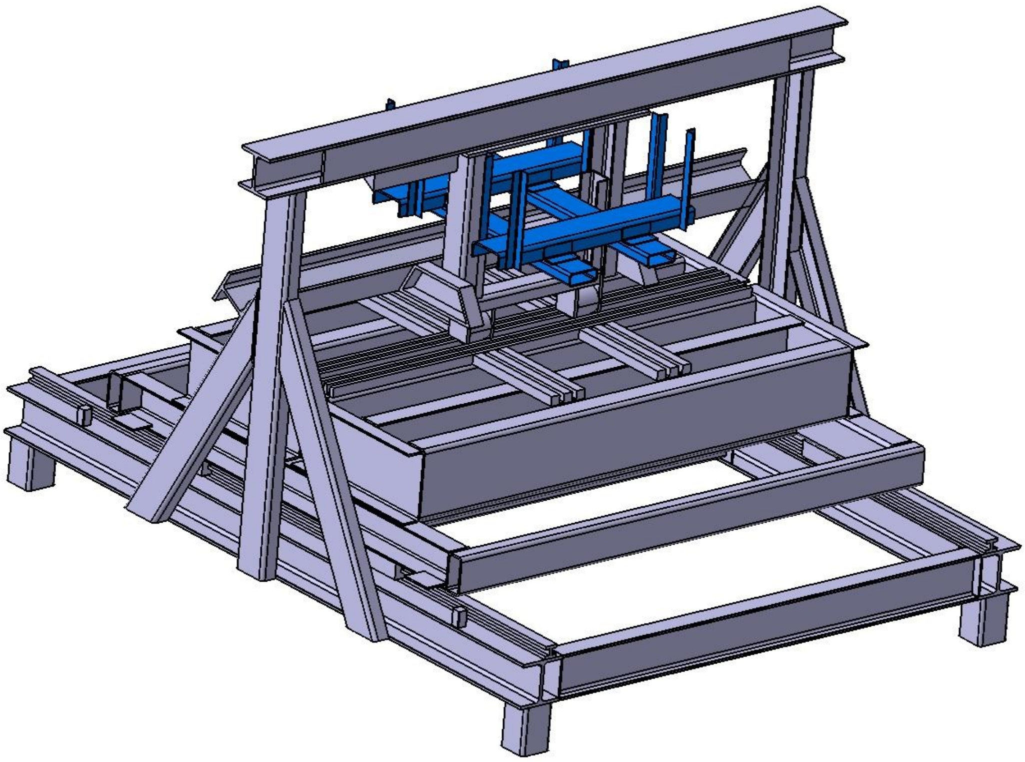

Figure 44. The test system with the developed stand for real mass.

As it can be seen, the air spring had to be taken off every time when the stand for actual mass was fixed to the test system, and for this reason it was decided that all tests with the actual mass are going to be done first, and after that the same tests are repeated with the virtual mass of air spring. More detailed drawing of the stand can be found in Appendix 2.

Just before the test was going to be started, a meeting was held with one of the employee from the company's reliability laboratory. His opinion was that measuring permanent deformation is not very reliable and suggested that the instant deformation when the wheels are on top of the aluminum profiles should be measured instead. As this possibility was brought into discussion, it was decided that instantaneous deformation was going to be measured and test arrangements were started.

The same stand created for the actual mass and the hollow aluminum profiles were going to be used, but also some other equipment were needed in order to measure the instant deformation. High speed -camera was installed to take video of the wheels when they relatively go over the aluminum profiles. In this way it was possible to see afterwards on slow motion how the wheels and the mass were affecting to the aluminum profiles. The camera can be seen in Figure 45.

Figure 45. The high speed –camera.

As it can be seen, a small hole had to be made on the side of the safety net. This was not seen as a safety risk and therefore it could be done.

In addition to the high speed camera, also a measurement tool for measuring the instant deformation of the aluminum profiles had to be fixed into the test system. The measurement was done by laser-distance-meter Omron ZX-LD40, and it was fixed on the system as shown in Figure 46.

Figure 46. The Omron ZX-LD40 laser-distance-meter fixed into the test system.

The laser-distance-meter measured the distance between the stand of the wheels and the equipment itself. When the test system was moving, the distance between the equipment and the stand for the wheels was changing in a vertical direction. When the test was run, the laser-distance-meter fed the results immediately to a computer used in the validation, which is represented in Figure 47 below.

Figure 47. The computer used for analyzing the results of the validation.

The validation test was started by running the test system with actual mass of 350 kg. Figure 48 shows the stand for actual mass fixed into the test system with load of 350 kg.

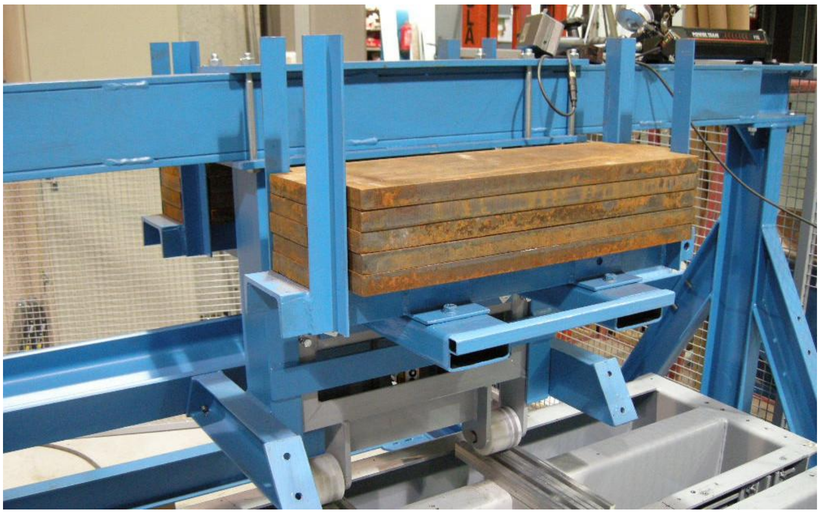

Figure 48. The stand for actual mass fixed into the test system with load of 350 kg.

Then a new pair of aluminum sill profiles was fixed into the test system and then it was run once back and forth. This was then repeated with loads of 450, 500, 550 and 600 kilograms and every time brand new pair of hollow aluminum sill profiles was fixed into the test system. Figure 49 shows the results when a mass of 500 kilograms was fixed on top of the stand.

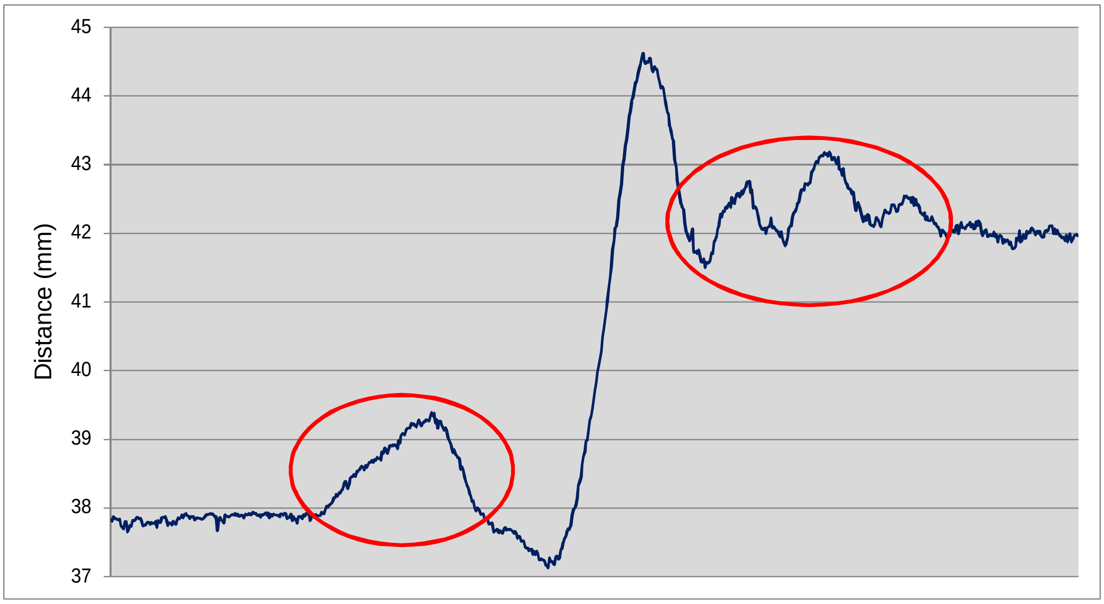

Figure 49. Validation results with an actual mass of 500 kg.

The instant deformations of hollow aluminum profiles can be seen (marked with red circles) in the graph above. The test system was started from the side where the wheels were on the upper level. When the wheels were moving in vertical direction, the distance between the laser-distance-meter and the stand for wheels changed. First, when the wheels were on the upper level, the distance was about 38 mm and the mass of 500 kg caused an instant deformation of over 1 mm for the hollow sill profile fixed to the upper level of the test system. After that the big change in distance, from 37 to 44 mm, was caused when the wheels dropped from the upper level to the sill groove between the two profiles. Then the wheels climbed from the sill groove to on top of the hollow aluminum sill profile fixed on the lower level of the test system and after that the instant deformations when the wheels were on top of the profile can be seen. As it can be seen, the actual mass made the wheels to vibrate after the drop from the upper level to the lover one and it caused the deformation to happen many times. This is the direct cause from the fact that the leveling accuracy of 5 mm is taken into account.

The same tests with the same amount of virtual masses were then run with the actual test system where the air spring is used to simulate the actual mass. Results when a virtual mass of 500 kilograms was fixed into the system can be seen in Figure 50 below.

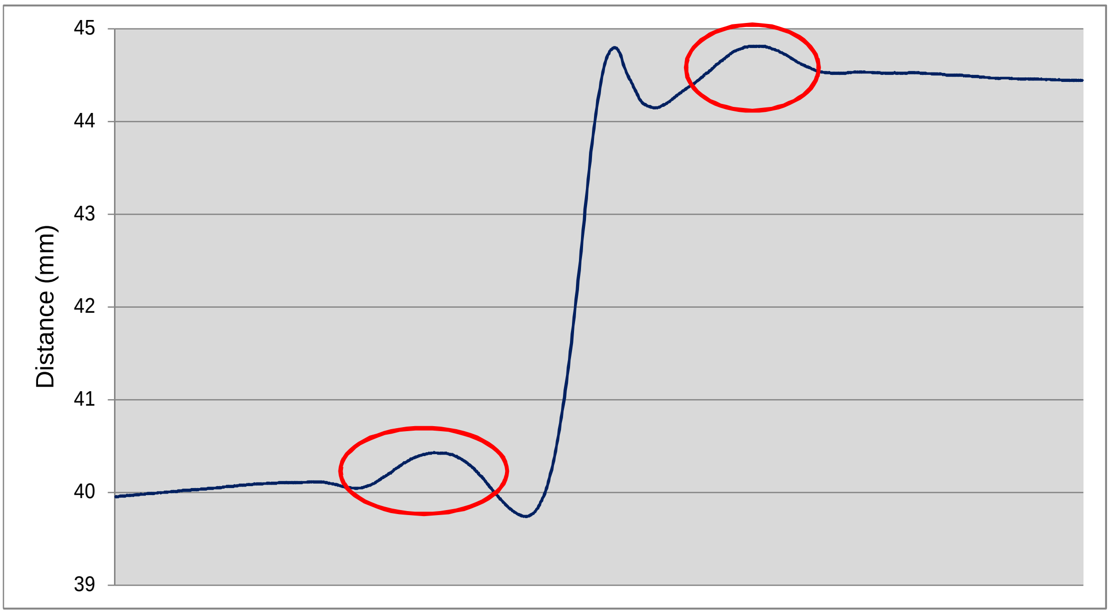

Figure 50. Validation results with a virtual mass of 500 kg.

The instant deformations of the hollow aluminum profiles are marked again with red circles. When comparing the results from the virtual mass to actual mass, few notifications can be made:

- The instant deformation is much bigger with the actual mass. For example the first deformation when the wheels were on top of the first hollow aluminum profile is approximately 1.3 mm with actual mass and only 0.4 mm with virtual mass.
- The actual mass gives an initiation to the wheels and gets the wheels to bounce and this way there are many instant deformations on top of the other profile. The air spring did not do this at all.

The first issue could be probably solved just by testing that what amount of virtual mass gives the same amount of deformation than 500 kilograms of actual mass and this way to create a usage instruction to the test system that for example if a mass of 500 kg wanted to be tested then virtual mass of 1300 kg is needed and so on. The other issue on the other hand is much bigger and cannot be solved. The air spring is used to balance the pressure differences, and even though it works when the same amount of pressure is wanted on different levels, it does not simulate the actual mass. The only possible solution was that the leveling accuracy should be removed and the sill profiles to be tested without taking the leveling accuracy into account. This was also tested but even the sill groove between the two sill profiles was enough to cause the actual mass to jump just like it did with the 5 mm step and it is not a solution either. And the leveling accuracy also wanted to be kept.

The result from the validation then was that the air spring was not working as it should and it does not simulate actual mass and could not be used if reliable results wanted to be achieved.

5.5 Creation of Final Version

When it was discovered that the air spring could not be used to simulate actual mass, the decision was made that the test system was going to be created with actual mass. For this a few different ideas were brought into discussion and models created based on those ideas can be seen in figures below.

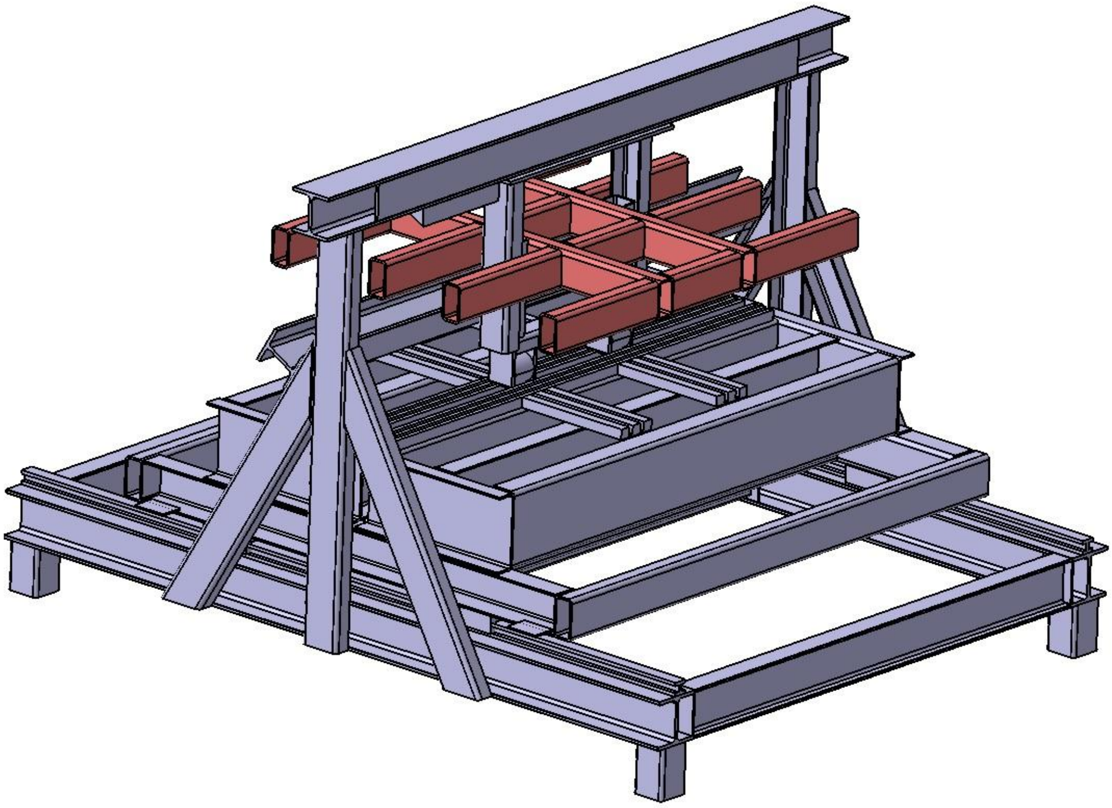

Figure 51. First suggestion for actual mass.

The first suggestion was that the test system would be kept as it was and similar kind of stand for actual mass would be created as it was created for the validation. This can be seen in Figure 51 above. The stand created for validation cannot be used as the maximum amount of mass is not big enough.

The maximum amount of mass for pallet jack using wheels like these is 2300 kilograms. If the pallet jack is allowed to carry more loads a different kind of wheels are used which are less stressful for the sill profiles. From the 2300 kilograms typically 70 percent of the load is on top of the front wheels, which the wheels on the test system are simulating. 30 percent is on top of the rear wheels. This way the maximum load needed is 2300 x 0.7 = 1610 kg. (Mielonen.)

The first suggestion was made with the idea that the hydraulic cylinder still inside the test system wanted to be kept for statistic pressure testing for sill profiles. It was anyway decided that loading and unloading a stand like this is too heavy and the first suggestion was turned down. If statistic pressure testing is going to be done in the future, a separate test system for that will be built.

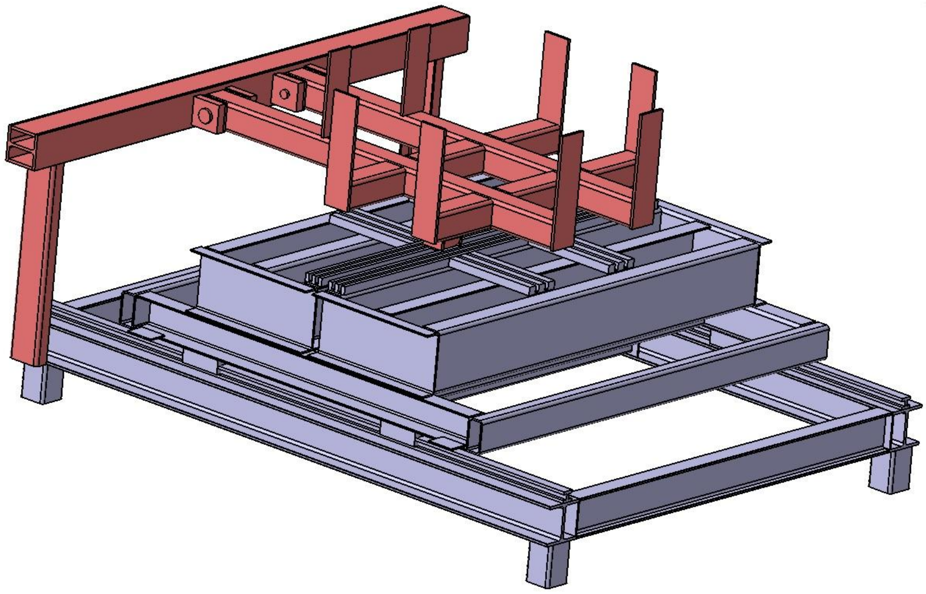

Figure 52. Second suggestion for actual mass.

The second suggestion was made with the idea that the bed of the test system and the stand for the test system were going to be kept as they originally were, because there was nothing wrong with their functionality. The stand for hydraulic cylinder/ air spring was going to be removed and a new stand for real mass was going to be built. The idea is shown in Figure 52 above. This suggestion was approved but with small changes. The final version based on the suggestion 2 can be seen in Figure 53 below.

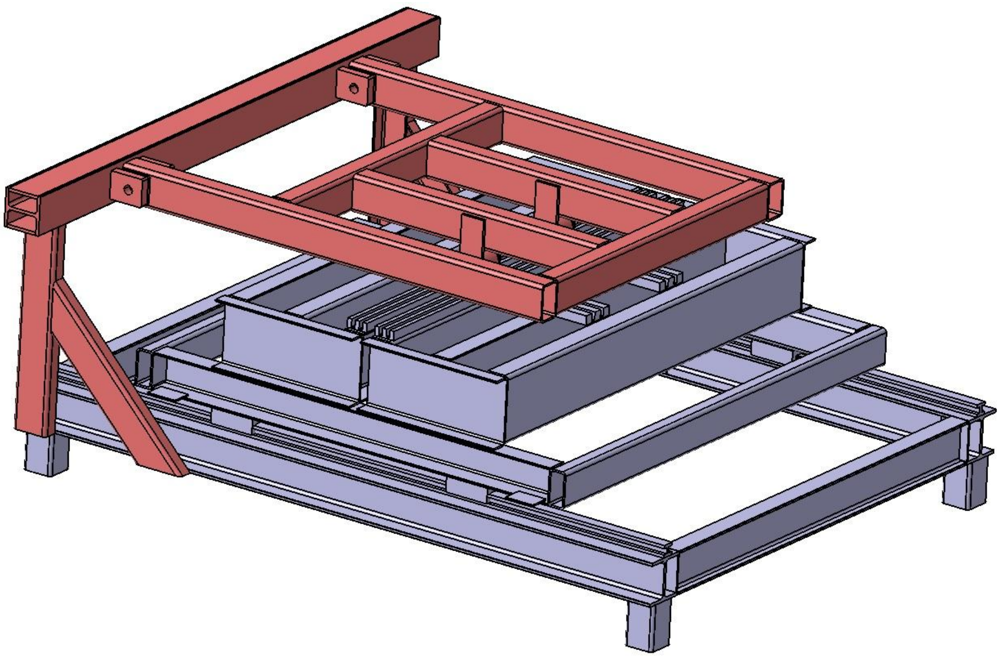

Figure 53. The final version of the test system.

The change compared to suggestion 2 was that the stand for actual mass is going to be built in such a way that the loading can be done by using a fork lift. This way it is very easy to load and unload the actual mass to the test system. The desired mass is going to be loaded on top of a pallet, and that is then going to be lifted into the test system by using a forklift. More detailed drawings of the final version can be seen in Appendix 3.

6 Discussion and Conclusions

The study had two goals. The main goal was to introduce, validate and if needed, to further develop the test system created for testing door sill assemblies. When the introduction of the test system was started, it soon became visible that the test system was not giving reliable results and had to be further developed. The test system was created with the idea that no real mass is needed but it is simulated with a hydraulic cylinder. Anyway the simulation with the hydraulic cylinder was not possible and something else had to be invented. The test system was then further developed and the hydraulic cylinder was replaced with an air spring. The air spring was chosen because of the fact that it balances the pressure changes and it withstands the stress much more than the hydraulic cylinder.

After the test system was developed to be used with the air spring, it had to be validated. The validation was done by comparing results with the air spring to results with actual mass. The validation showed that the air spring was not an option either, if reliable results wanted to be achieved. At this point it was decided that the simulation of mass would be forgotten and the test system would be created in such a way that it uses actual mass. After that the test system was modified to be used with actual mass. Unfortunately it was not possible to validate the final version of the test system within the time frame of this study.

The main issue with the study was the time needed from the other employees of the company. When a change was needed for the test system, a help from others was always needed. For example when the broken hydraulic cylinder had to be replaced with a new one, it took several weeks before the broken cylinder was replaced. The same was when the validation stand for actual mass was designed, it took several weeks before the stand was built and ready to be used after it was designed. All the employees who were involved in the study were very helpful, but the fact that they had their own work to be done caused this situation.

The next step with the test system is to actually build the final version and then to validate it. After the validation is complete, the test procedure how the sill profiles should be tested have to be created, and only after that the test system is ready to be used. Then the test system is going to be used for creating proper duty ranges for different sill profiles.

The secondary goal of the study was to create a proper training material of the door sill assembly, and with the help of one of the employee, this was done without any big issues. The next step with this is to arrange proper training sessions for the employees handling orders and tenders, and to use this training material to improve their knowledge about the door sill assembly. This way it is possible to improve the correctness of sill assembly deliveries.

Overall the goals of the study were achieved. The test system was introduced and further developed, and the training material of sill assemblies was created.

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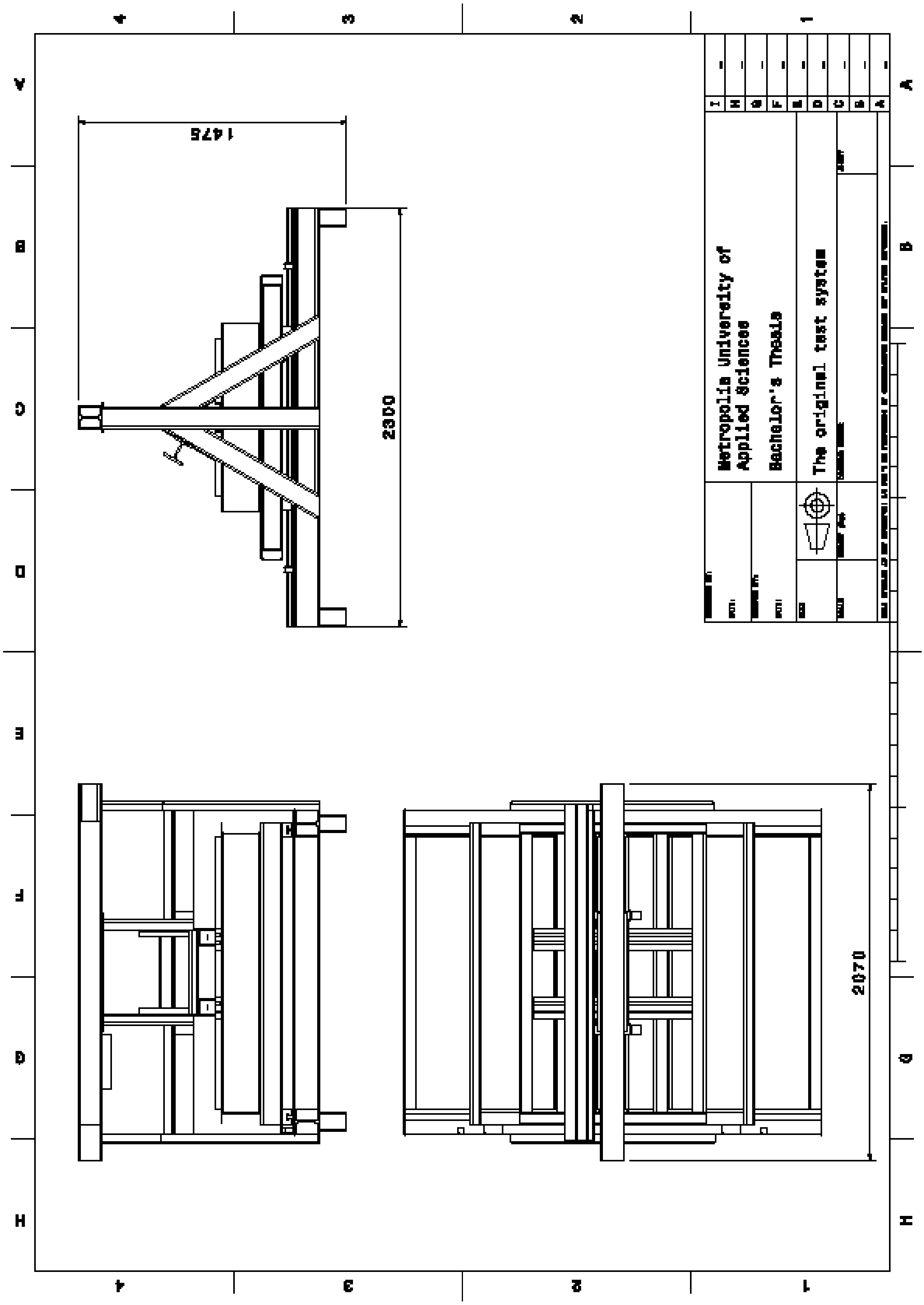
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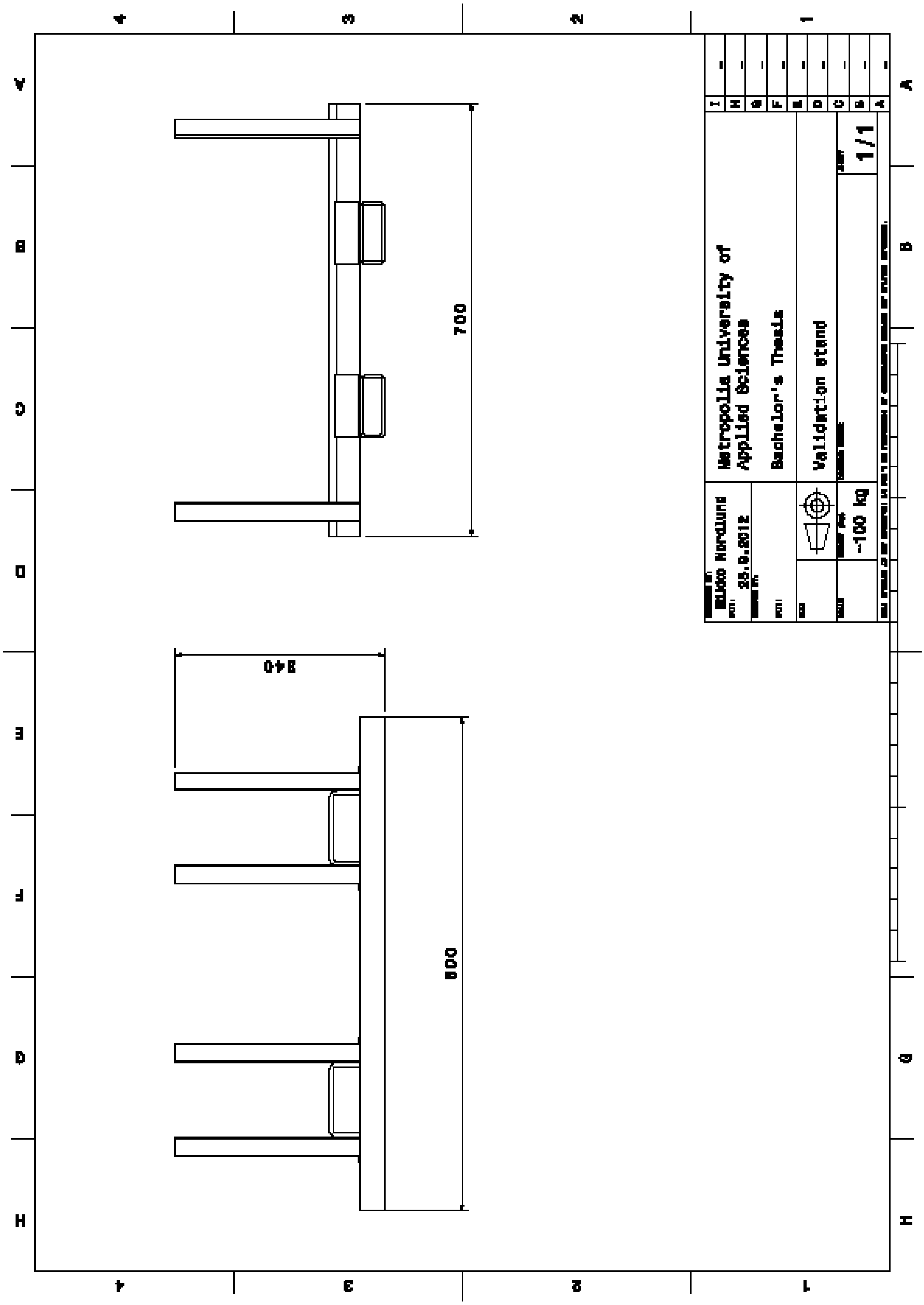
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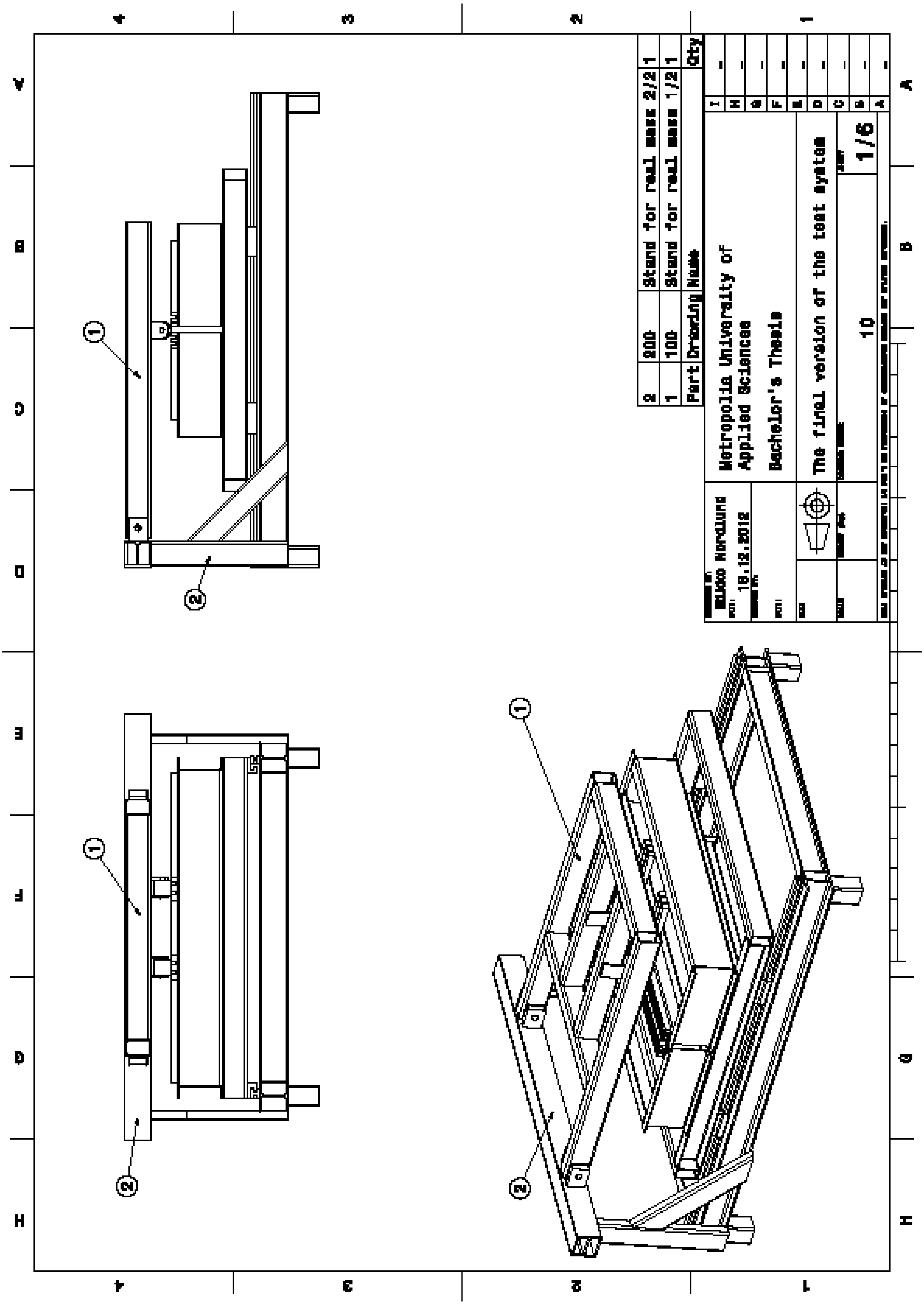
Validation stand
Mikko Nordlund
25.9.2012
~100 kg
1/1
700
840
800


2 200 Stand for real mass 2/2 1
1 100 Stand for real mass 1/2 1
Part Drawing Name Qty
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The final version of the test system
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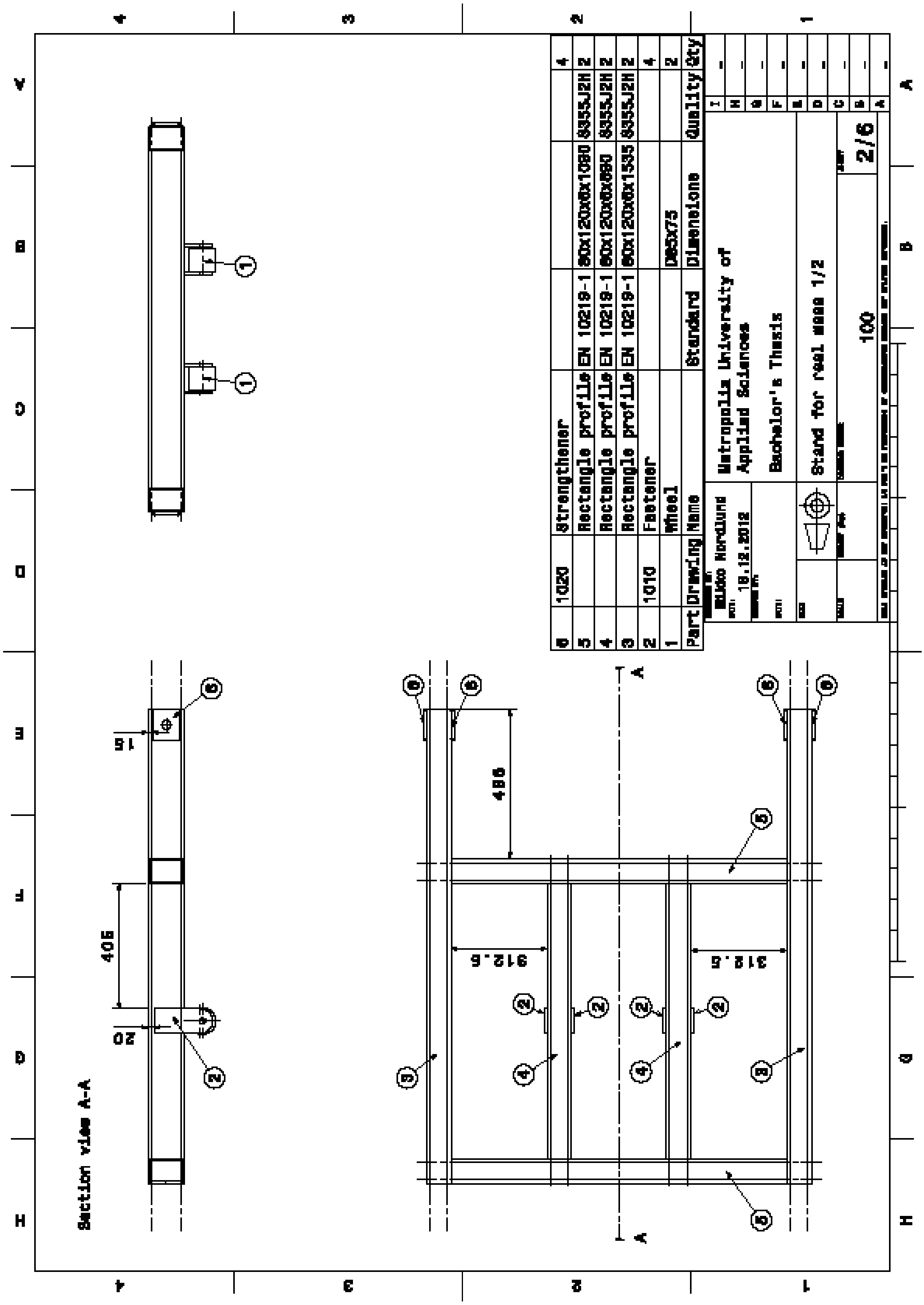
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5 | | Rectangle profile | EN 10219-1 | 80x120x8x1080 | S355J2H | 2
4 | | Rectangle profile | EN 10219-1 | 80x120x8x880 | S355J2H | 2
3 | | Rectangle profile | EN 10219-1 | 80x120x8x1535 | S355J2H | 2
2 | 1010 | Fastener | | | | 4
1 | | Wheel | | D85x75 | | 2
Part | Drawing | Name | Standard | Dimensions | Quality | Qty
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Metropolia University of Applied Sciences
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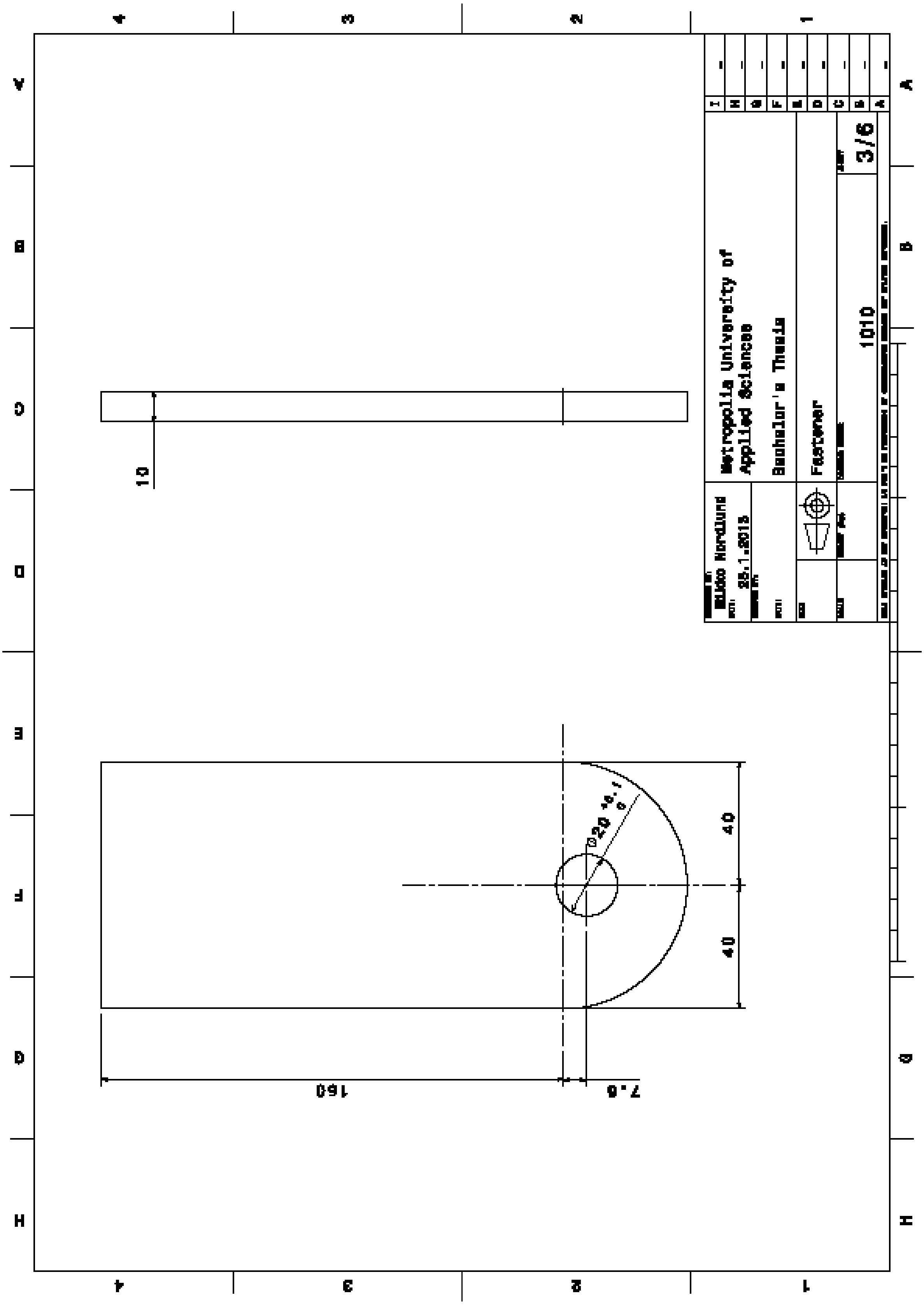
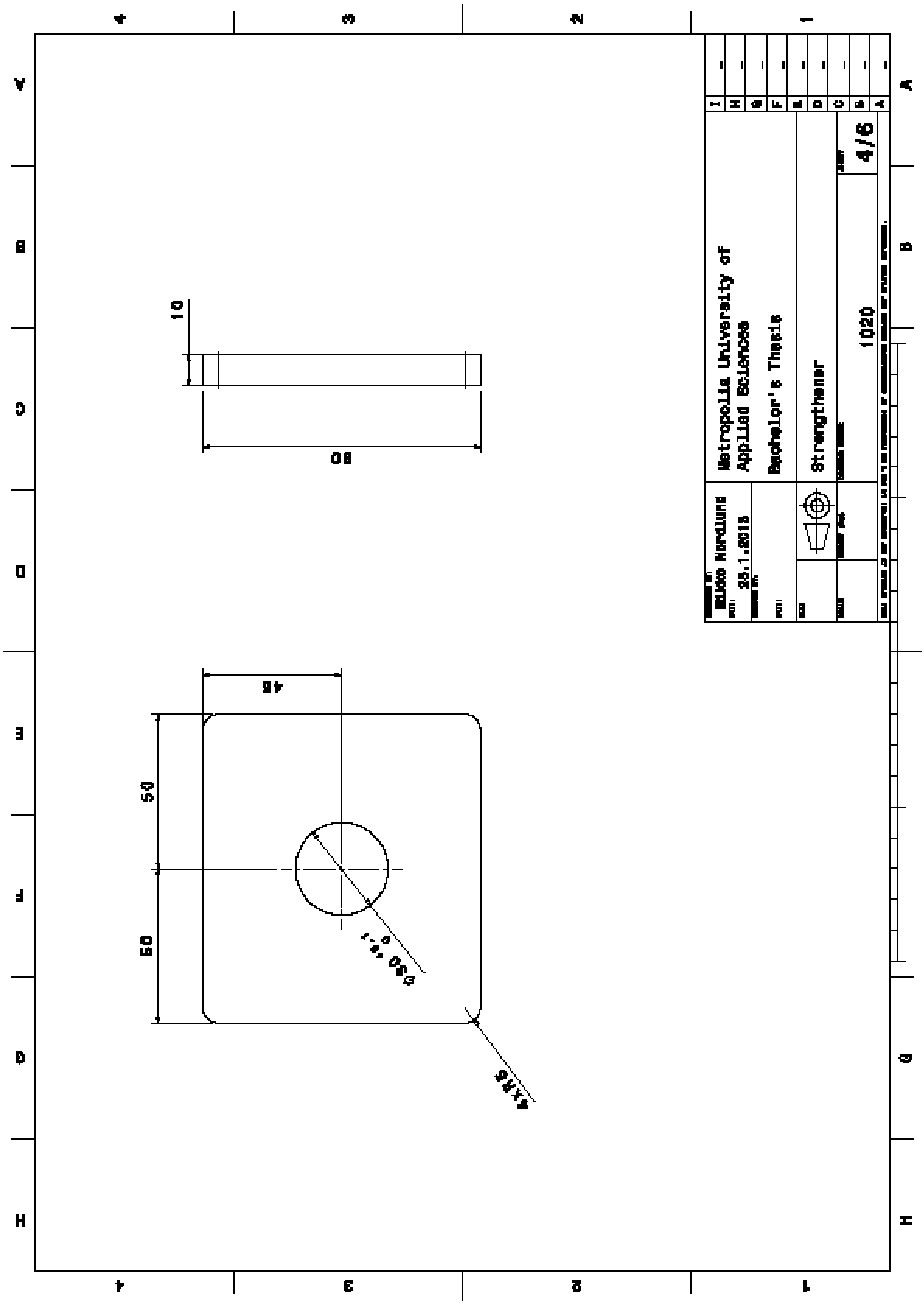
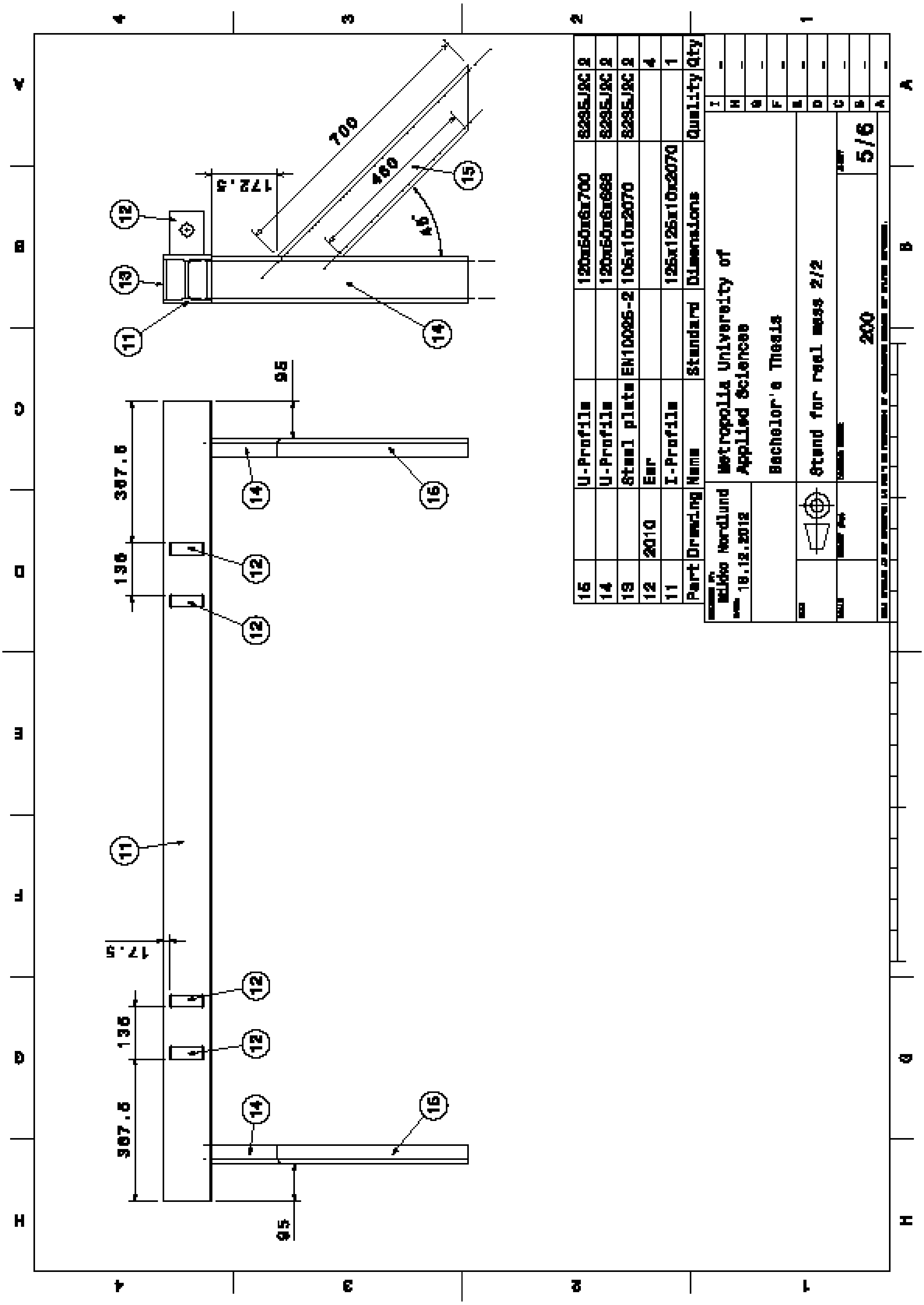
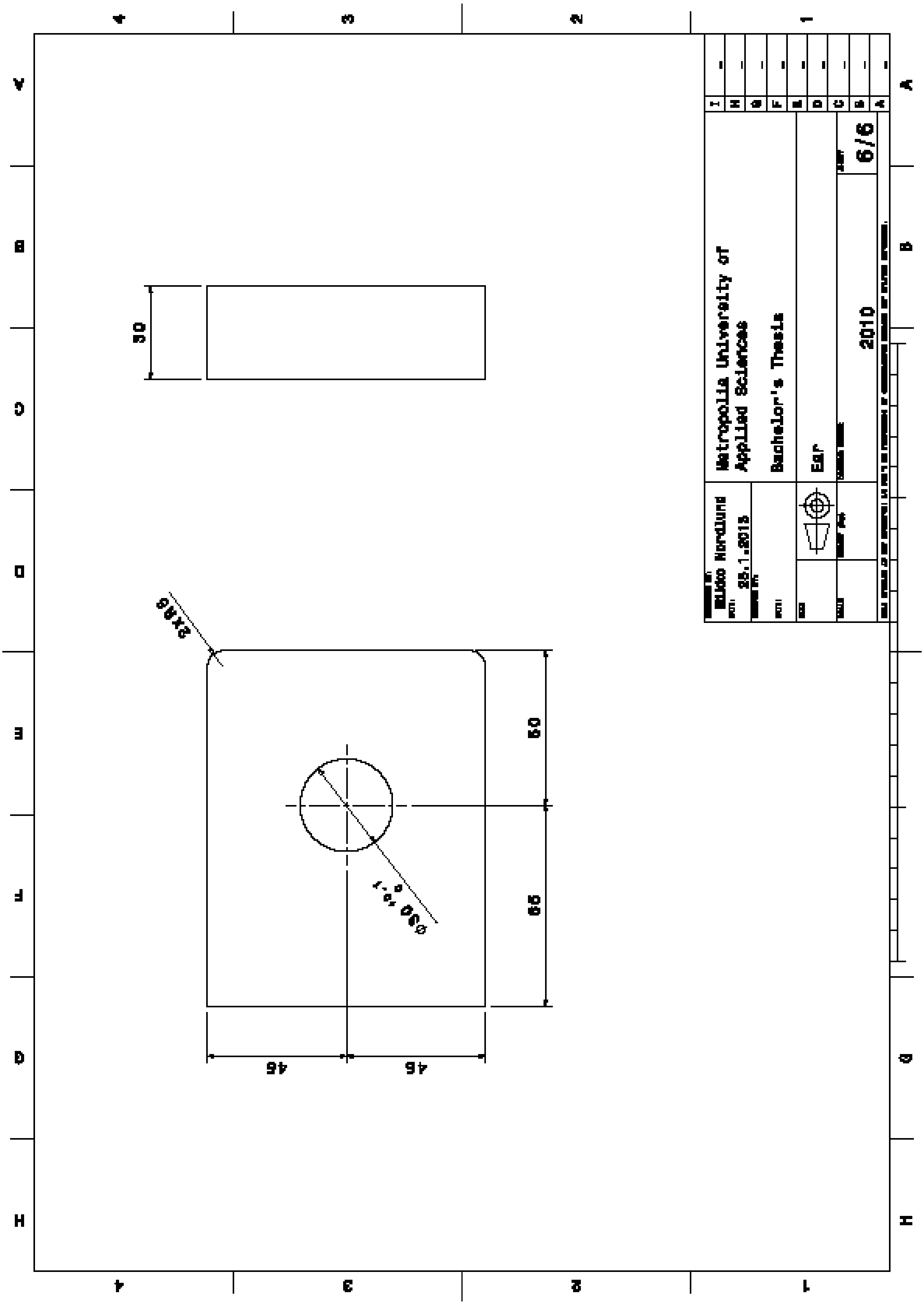
Stand for reel mass 1/2
100
2/6
Section view A-A
486
912.5
312.5
405
20
15


Metropolia University of Applied Sciences
Bachelor's Thesis
Fastener
Nordlund
1010
3/6
10
40
40
160
7.5


Metropolia University of Applied Sciences
Bachelor's Thesis
Strengthener
Mikko Nordlund
1020
4/6
10
80
45
50
50


700
460
172.5
45°
95
387.5
136
17.5
15 U-Profile 120x50x6x700 S235JRC 2
14 U-Profile 120x50x6x668 S235JRC 2
13 Steel plate EN10095-2 105x10x2070 S235JRC 2
12 2010 Ear 4
11 I-Profile 125x125x10x2070 1
Part Drawing Name Standard Dimensions Quality Qty
Mikko Nordlund
18.12.2012
Metropolia University of Applied Sciences
Bachelor's Thesis
Stand for reel mass 2/2
200
5/6


Metropolia University of
Applied Sciences
Bachelor's Thesis
Ear
2010
6/6
Mikko Nordlund
25.1.2013
30
2xR5
60
65
45
45